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Development of a Maturity Model for assessing the Industry 4.0 Maturity of Industrial Enterprises

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Ich habe zur Kenntnis genommen, dass ich zur Drucklegung meiner Arbeit unter der Bezeichnung

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Wien, im September 2015

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Andreas Schumacher

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Abstract

After the water- and steam empowered mechanization of manufacturing, the introduction of mass production based on electrical energy, and the first digitalization of industrial productions in the 1970s, currently a 4th industrial revolution is propagated – commonly referred to as "Industry 4.0". Based on Cyber-Physical Systems (CPS) and enhanced by modern Information and Communication Technology (ICT), Industry 4.0 should enable an entirely new approach to industrial manufacturing and serves as a means to strengthen Europe's and especially Germany's production industry (Acatech 2013).

Although highly supported by political initiatives and increasingly acknowledged by scholars, the implementation of Industry 4.0's "smart factories", "smart products" and "smart networks" fails to keep up pace with its political popularity. Current surveys indicate that – beside high investment costs – the high topic-complexity resulting in uncertainty is one core issue decelerating the realization. Consequently to the company's uncertainty, they fail to assess their own capabilities and maturity within the field of Industry 4.0, which disables from taking any coordinated measures towards successful realization.

Tackling the outlined problems, within this work the so called "Industry 4.0 Maturity Model (I40MM)" is developed – a model that allows companies to self-asses their capabilities in Industry 4.0 and, consequently reduces uncertainty which results in target-aimed development of road-maps in Industry 4.0.

The I40MM is developed using a multi methodological approach including a systematic literature research and qualitative and quantitative survey research. The model is scientifically based on Hevner's design science approach (Hevner et al. 2004) as well as Becker's procedure model for the development of maturity models (Becker at al. 2009).

In a first step, interviews were carried out with Industry 4.0-experts to highlight the practical need of the maturity model, capture the state of Industry 4.0 in real life and to support the domain-specific population of the I40MM. Simultaneously, a systematic literature review on "maturity models" resulted in more than 3400 findings and the consideration of 72 publications for inclusion into the model's development. Also, no published maturity model applicable to the domain of Industry 4.0 has been found during the literature research, which supports the model's academic relevance. Afterwards, the model's practical relevance was validated by expert-ratings of the maturing items' practical importance (attributes) – resulting in 23 responds with an average importance rating of 3,2 (1 – not important, 4 – very important). Their rating was used for the weighted calculation of the 9 company dimension's Industry 4.0-maturity. The attribute's maturity-measurement within the company is surveyed using a newly developed questionnaire consisting of 62 questions (one question per maturing attribute) in 9 company-dimensions. To ensure good practical usability, the I40MM is transformed to a Maturity Report consisting of 11 pages, whereby the 1st page (Maturity Dashboard) summarizes the companies Industry 4.0 maturity at-a-glance.

Finally, the I40MM has been pilot tested in cooperation within two companies. Feedback regarding usability and representability is positive throughout, which validates the model for real-life application.

Kurzfassung

Nach der dampf- und wasserkraftbasierten Mechanisierung der Produktion, der Einführung der arbeitsteiligen Massenproduktion mithilfe elektrischer Energie, sowie der Digitalisierung der Industrie in den 1970ern, wird derzeit eine vierte industrielle Revolution ausgerufen – die sogenannte „Industrie 4.0“. Basierend auf der Einführung von Cyber-Physikalischen Systemen (CPS) und mit Hilfe moderner Informations- und Kommunikationstechnologie (IKT) soll Industrie 4.0 völlig neue Wege der industriellen Produktion ermöglichen, und somit die europäische, und im Speziellen die deutsche Wirtschaft stärken (Acatech 2013).

Trotz zahlreicher politischer Initiativen bestehen weitreichende Probleme bei der Realisierung der Industrie 4.0-Vision. Aktuelle Studien machen, neben den nötigen Investitionen für moderne Technologien, vor allem die hohe Themenkomplexität für die schleppende Umsetzung verantwortlich. Hohe Komplexität lässt Unternehmen bei der Einschätzung der eigenen Fähigkeit in der Industrie 4.0 – der sogenannten „Industrie 4.0-Reife“ – meist scheitern und lässt somit keine Entwicklungsmaßnahmen zu.

Um die bestehende Unsicherheit bzgl. der Unternehmensreife in der Industrie 4.0 zu reduzieren und so die Entwicklung von zielgerichteten Road-Maps zu ermöglichen, wird in dieser Arbeit das sogenannte „Industrie 4.0 Reifgradmodell – I40MM“ entwickelt. Dieses erlaubt Unternehmen durch „self-assessment“ die eigene Industrie 4.0-Reife zu bestimmen. Das Modell basiert auf Hevner’s Design Science Approach (Hevner et al. 2004), sowie Becker’s Leitfaden zur Entwicklung von Reifegradmodellen (Becker et al. 2009).

Hevner’s Entwicklungsrichtlinien folgend wurden in einem ersten Schritt Experteninterviews durchgeführt, um den eigentlichen Bedarf an einem Industrie 4.0-Reifegradmodell zu ermitteln, sowie die domänenspezifischen Anforderungen zu erheben. In einem zweiten Schritt wurde eine umfangreiche, systematische Literaturrecherche zum Thema „Reifegradmodelle“ durchgeführt, welche in mehr als 3400 Resultaten und der Berücksichtigung von 72 Publikationen für die Entwicklung endete. Auch wurde während der Recherche kein existierendes Reifegradmodell zur Ermittlung der Industrie 4.0 Reife gefunden. Die praktische Relevanz der, aus der Literatur abgeleiteten Reife-Attribute, wurde mittels Experten-Ratings bzgl. der „Wichtigkeit des Attributes für die Realisierung von Industrie 4.0“ validiert. 23 Experten bewerteten die Attribute in einem ausgesendeten Fragebogen mit einer durchschnittlichen „Wichtigkeit“ von 3,2 (1 – unwichtig bis 4 – sehr wichtig). Diese Bewertung der Attribute dient folglich für die gewichtete Berechnung der Industrie 4.0-Reife in 9 Unternehmensdimensionen. Die Messung der Reife-Attribute im Unternehmen erfolgt mit einem eigens entwickelten Fragenbogen, bestehend aus 62 Fragen (Eine Frage pro Reife-Attribut). Die Überführung des Modells in ein praktisch nutzbares Tool erfolgt durch die Überführung der Modellinhalte und Ergebnisse in einen 11-seitigen Industrie 4.0 Reifebericht als PDF-Dokument.

Das Industrie 4.0 Reifegradmodell wurde erfolgreich in zwei Unternehmen getestet, womit eine erste Validierung der praktischen Anwendbarkeit erfolgt ist.

Table of Contents

1 Introduction

1.1 The Fourth Industrial Revolution

In the last few years there has been a growing interest in the propagated fourth industrial revolution – commonly referred to as “Industry 4.0”. Considering the past industrial revolutions, manufacturing processes have changed significantly since the introduction of the steam-engine (1784), Henry Ford’s electrically driven assembly lines (1870) and the digitalization and globalization with the help of micro-controllers and information technology (1969). The term of “Industry 4.0” has been firstly brought to public in 2011 during the “Hannover Messe”, and in 2012 the German Federal Ministry of Education and Research (BMBF – Bundesministerium für Bildung und Forschung) published an action plan (“High Tech Strategie 2020)[1] which stated ten projects that aim for securing prosperity and sustainability and for strengthening Germany’s economic position in the world. One of the projects named “Industrie 4.0” – described a whole new approach to production industries based on the introduction of Cyber-Physical Systems (CPS) and enhanced by modern Information and Communication Technology (ICT) which should consequently result in the creation of “Smart Factories”. The realization of these futuristic factories enable the creation of smart grids, smart products, smart buildings, smart mobility as well as smart logistics thus, affecting the society fundamentally in their work- and private life. During the “Hannover Messe 2013” the final report titled “Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0”[2] – coming from the initiated Industry 4.0 working group consisting of representatives from research and the economy – has been handed over to the German chancellor Angela Merkel. Based on these recommendations for the realization of Industry 4.0, several initiatives (e.g. the “Plattform Industrie 4.0”)[3] were founded to foster and focus the efforts stated in the underlying high tech strategy of the German government.

Currently, high public funding is provided to enhance the realization of Industry 4.0. Until today, Germany committed to EUR 200 Million of public funding specifically for research in the field Industry 4.0[4]. Furthermore, Germany’s industry is expected to invest EUR 40 Billion annually into Industry 4.0-related solutions until 2020[5]. In Austria, the Austrian Research Promotion Agency (Forschungsförderungs-gesellschaft – FFG) provides funding of around 250 EUR Million for the promotion of new manufacturing technologies (research and industry). Besides increased attention

[1] (Bundesministerium für Bildung und Forschung (BMBF) Referat Grundsatzfragen der Innovationspolitik, 2012)
[2] (Kagermann, Wahlster, & Helbig, 2013)
[3] http://www.plattform-i40.de
[4] http://www.bmbf.de/de/9072.php (10.09.2015)
[5] (Geissbauer, Schrauf, Koch, & Kuge, 2014, S. 14)

by Governments, Industry 4.0 gains attention among scholars as well. The search-term “Industrie 4.0” inserted into the scientific search engine “google scholar”[6] results in a steadily increasing number of results since 2011 - the time when Industry 4.0 was firstly introduced to the public (see Table 1):

Table 1: Scientific publications on "Industrie 4.0" in the time 2011-2015

Year	Results
2011	54
2012	85
2013	194
2014	710
2015 (until 10th of September)	812

Although shifting into the focus of research and promoted by several public and private initiatives, several challenges and problems prevent the realization of Industry 4.0 to keep up pace with its political popularity.

1.2 The Challenge of Industry 4.0 – Problem Definition

Industry 4.0 requires industrial enterprises that are capable of managing their whole value-chain in an agile and responsive manner. Therefore, companies need both - virtual and physical structures that allow for close cooperation and rapid adaption along the whole lifecycle from innovation to production and distribution[7]. Currently, required technological and organizational pre-conditions for meeting these challenges often not exist, as indicated by previous studies.[8] [9] [10] [11] [12] They state aspects such as outdated technology, fragmented IT-Systems, inflexible and inconsistent organizational structures and processes as well as knowledge- and culture-barriers as the main challenges during the realization of Industry 4.0. Another important issue hold responsible is the high complexity of the topic, as Industry 4.0 encompasses various ideas, concepts and target areas. A current survey carried out by IBM (IBM 2015) highlights that - beside high investment costs and fragmented IT-systems - the complexity of the Industry 4.0-concepts and the resulting lack of required know-how are the main restraints for the realization. The issue of high topic-complexity is also highlighted by a survey in Germany carried out by experton

[6] www.scholar.google.at/ (10.09.2015) – German Results
[7] (Wahlster, 2013)
[8] (IDC Multi-Client-Projekt, 2014, S. 7)
[9] www.statista.com – Barrieren und Probleme des Konzeptes Industrie 4.0 in Oberösterreich im Jahr 2014
[10] (Experton group, 2014)
[11] (Wischmann, Wangler, & Botthof, 2015)
[12] (Schlaepfer, Koch, & Merkof, 2015)

(Experton Group 2014), whereby the "high topic-complexity" as well as "un-readiness for Industry 4.0" rank among the most critical issues.[13]
The results presented in these surveys are strongly supported by various research projects we carried out on the topic of Industry 4.0 in the Institute of Management Science (IMW) as well as work-shops and industrial projects carried out through the Fraunhofer Austria Research GmbH[14]. Thereby we discovered, that due to the novelty of the Industry 4.0-vision as well as the immense topic-complexity, high uncertainty about the possible outcomes and benefits (e.g. Return in Investments) as well as the company's own capabilities (e.g. Industry 4.0-maturity) exits. The issues resulting from uncertainty are enhanced by the incredibly tiny margins, under which conservative industry operates, as they prevent investments into uncertain areas such as Industry 4.0 and consequently results in inactivity in that domain.[15]

1.3 Use of Maturity Models to decrease Uncertainty in Industry 4.0 – Research Question

Tackling the issue of uncertainty about the own capabilities (uncertainty about the Industry 4.0-maturity) the concept of assessing maturity through the utilization of so called "Maturity Models" proved sufficient as previous research indicated. Maturity models aim for assessing maturity by assigning the maturing elements (persons, objects or social systems) to constructed maturity-levels, whereby the highest maturity stage represents the "state of being complete, perfect or ready". [16] Increased in popularity, maturity models allow for the situational analysis of one's capabilities, for defining a place to start, for providing guidance through the evolutionary process as well as for the creation of a benchmark for comparison.[17] [18] [19] [20]

Although previous research increasingly focused on the development of maturity models in technical areas[21], no model that addresses the issue of assessing the maturity in the domain of Industry 4.0 could be found.

Based on the maturity model approach, this work aims for the development of a maturity model that proves suitable for the assessment of the Industry 4.0-maturity of industrial enterprises – in this thesis referred to as the "Industry 4.0 Maturity Model (I40MM)". The I40MM should enable the assessment of company's Industry 4.0

[13] (Experton group, 2014)
[14] http://www.fraunhofer.at/de/pl/leistungsspektrum/industrie_4_0.html
[15] (Rüßmann u. a., 2015)
[16] (Simpson, Weiner, & Oxford University Press, 1989)
[17] (von Scheel, von Rosing, Skurzak, & Hove, 2015, S. 395)
[18] (Antunes, Carreira, & Mira da Silva, 2014, S. 806)
[19] (Mettler & Rohner, 2009)
[20] (Introna, Cesarotti, Benedetti, Biagiotti, & Rotunno, 2014, S. 109)
[21] (Wendler, 2012, S. 1329)

capabilities, thus reduce uncertainty, and finally allows companies to take coordinated measures to develop further – go get “more mature”.

Therefore, the purposes and goals of the Industry 4.0 Maturity Model can be stated as follows:

- From a scientific point of view, the model should enable to assess an organization’s maturity towards the desired end of being mature in the area of Industry 4.0, based on objective and validated measures by asking: “what attributes in what organizational dimensions should be distinct in what ways to be considered mature in Industry 4.0”.
- Beside the actual assessment of the Industry 4.0-maturity, the model and its contents offer a collection of “success-factors for realizing Industry 4.0” which have been derived from literature and validated by experts in relating fields.
- On a practical level, the model enables companies to base future activities on a clear “as-it-is”-status in Industry 4.0. Uncertainty about the own status is reduced and comparability with other companies made possible. Moreover, re-assessing the maturity at later times allows companies to detect changes in maturity and relate them to measurable changes towards realization.

Based on the outlined problems, the obvious need for a maturity model and the intended purposes of the I40MM, the research question of this thesis is developed:

What are the basic determinants of Industry 4.0 maturity and which methodologies are suitable to assess the Industry 4.0 maturity?

Details about the approach for developing the I40MM as well as included methodologies are presented in the following.

1.4 Development of the I40MM – Research Approach

Literature on maturity model development shows a variety of approaches, whereby scholars from this domain often argue, that the strong scientific basis for the model’s development is sometimes missing. Most maturity models published have been developed using practices and methods derived from projects in Industry that turned out to be successful. This approach results in a lack of theoretical foundation and methodology.[22]

Therefore, the objective of this work is to develop a maturity model to assess the Industry 4.0 maturity of industrial enterprises including strong scientific foundations and a transparent and replicable approach. The development of the Industry 4.0 Maturity Model is based on a design science approach offered by Hevner et al in

[22] (García-Mireles, Ángeles Moraga, & García, 2012, S. 282)

2004[23]. The design science paradigm has its roots in engineering and has initially been developed for problem solving by creating “artifacts”. These artifacts are innovations which are not exempt from natural laws, but on the contrary, are created through capabilities of the researchers, and are based on existing and successfully tested and applied theories.

Furthermore, two widely accepted and distributed frameworks offered by De Bruin & Rosemann (2005)[24] and Becker et al. (2009)[25] are building on Hevner’s foundations and are used for deriving the step-by-step procedure for developing the I40MM. Thereby, Becker aligns their procedure model for the development of maturity models to the seven guidelines of Hevner’s design science approach which ensures the scientific basis.

Becker’s procedure model for maturity model development shows the following order (compare with Figure 1) : Initiation → Problem definition (1) → Comparison with existing maturity models (2) → Determination of development strategy (3) → Iterative model development (4) → Concept transfer and evaluation (5) → Implementation of transfer media (6) → Real-life evaluation of the model (7). Becker aligns his approach to the seven guidelines of Hevner’s design science approach and therefore defined seven requirements for the development of a maturity model as indicated in the flow diagram with grey circles showing the “Requirements R1 – R7” (see Figure 1).

For this work Becker's procedure model has been used to derive the principal steps for arriving at a maturity model. Several scientific research methods such as systematic literature review, qualitative and quantitative survey and conceptual modeling have been applied to conduct these steps. By following Becker’s procedure model for developing the Industry 4.0 Maturity Model, the underlying requirements of Hevner’s design science approach are met as well (see grey circles – Hevner’s Requirements and blue fields – Methods used in the thesis in Figure 1).

[23] (Hevner, Salvatore, Park, & Ram, 2004)
[24] (de Bruin & Rosemann, 2005)
[25] (Becker, Knackstedt, & Pöppelbuß, 2009)

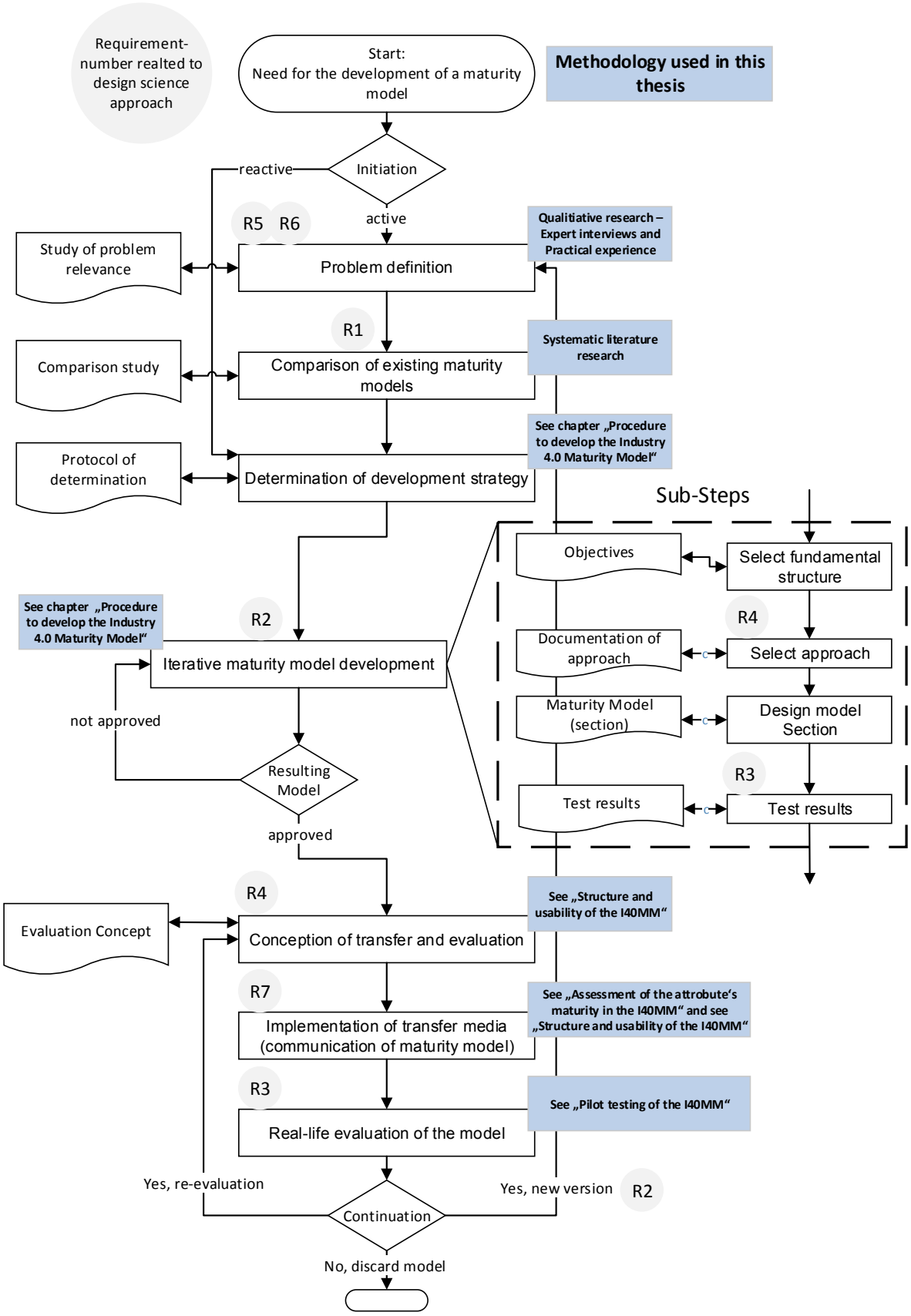


Figure 1: Procedure-model for developing maturity models based on by Becker et al.[26] (modified figure)

[26] (Becker et al., 2009, p. 218)

1.5 Work Packages of Master Thesis

The thesis is carried out in three work packages (Figure 2) whereas the content of the work packages converts from theoretically (work package 1) to practically applied (work package 3).

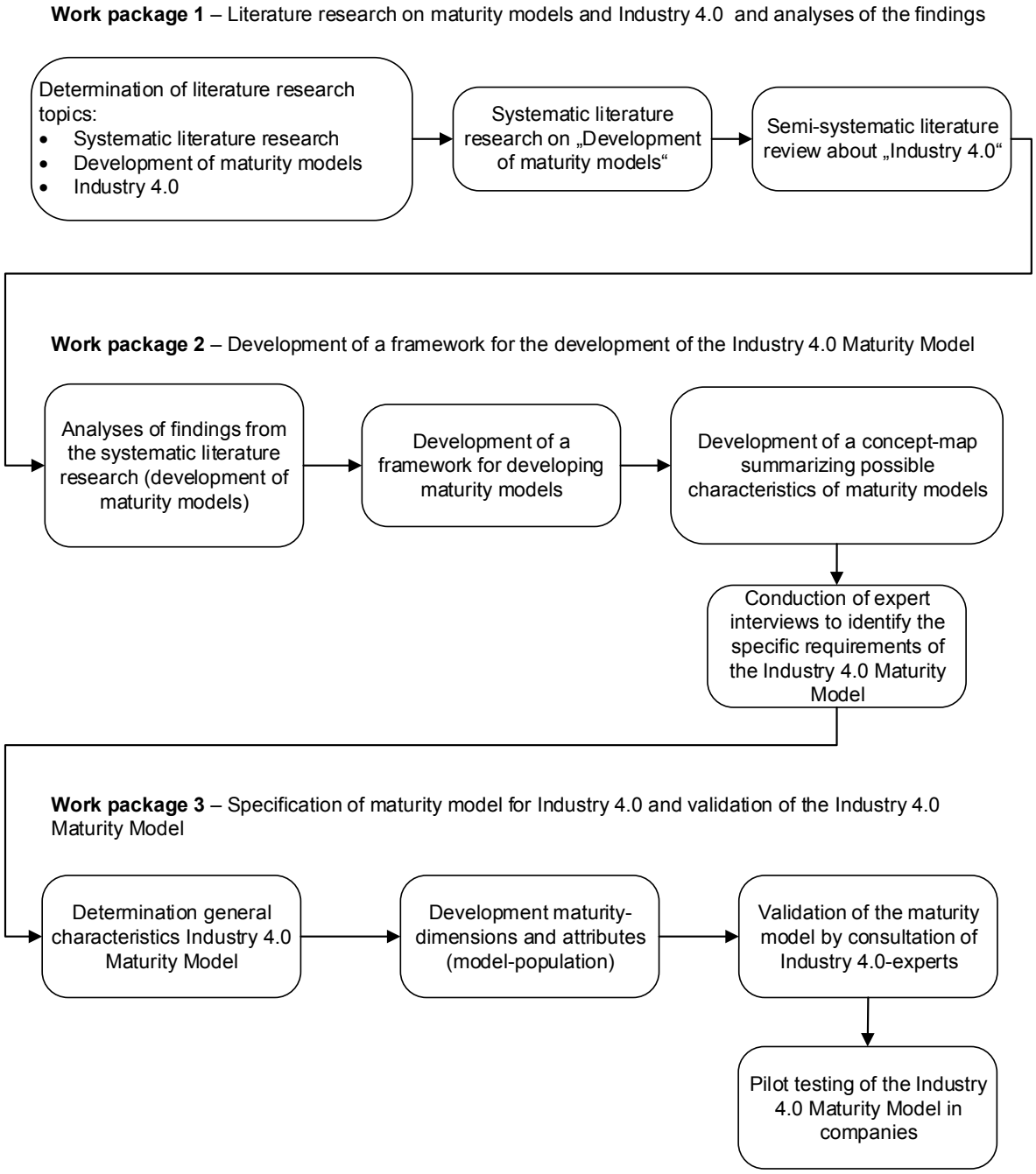


Figure 2: Overall approach of master thesis [27]

[27] All flow-diagrams in this work are created using the software Microsoft Visio (www.microsoft.com)

- **Work Package 1:** Literature Research on maturity models and Industry 4.0 and analyzes of the findings

In a first step, a systematic literature research is carried on “maturity models” to understand the concept of existing models and to derive possible characteristics of the Industry 4.0 Maturity Model. Secondly, a semi-structured literature research on “Industry 4.0” is conducted to collect the necessary input for specifying the model for the domain of Industry 4.0.

- **Work Package 2:** Development of a framework for the development of the Industry 4.0 Maturity Model

The findings of the systematic literature research are analyzed and three following sub-tasks are carried out; first, a procedure for developing maturity models is derived from literature, second, possible characteristics of maturity models are collected and summarized in a concept map and, in a third sub-task, expert interviews are conducted to determine the specific requirements of a maturity model applicable on the domain of Industry 4.0 and to validate the practical need for the Industry 4.0 Maturity Model.

- **Work package 3:** Specification of maturity model for Industry 4.0 and validation of the Industry 4.0 Maturity Model

The findings of the literature research on Industry 4.0 and the results of the expert interviews are now used to populate the maturity model (specification for Industry 4.0). The model’s practical usability is validated by pilot testing the model within companies and the feedback used for further improvements.

1.6 Structure of Master Thesis

The core of the thesis is the development of the Industry 4.0 Maturity Model which is specified for assessing the Industry 4.0 maturity of companies. Therefore, the main focus lies on the population and validation of the model:

Table 2: Focus-share and degree of completion master thesis

	Topic / Chapter	Focus-share[28] [%]	Degree of completion [%]
1	Systematic literature research about maturity models	15	15
2	Semi-structured literature research about Industry 4.0	10	25

[28] The provided focus share in per cent is based on the authors intended and perceived hours spent on the topic in this thesis – a detailed list of hours spent on the topics is not offered

3	Analyses of literature findings about maturity models (concept map)	10	35
4	Development of framework maturity model	15	50
5	Population of the Industry 4.0 Maturity Model	20	70
6	Validation of Industry 4.0 Maturity Model	20	90
7	Pilot testing of the Industry 4.0 Maturity Model	10	100

Related to the seven focus areas listed (Table 2), the thesis is structured into six main chapters[29]:

Following the 1st **chapter** (Introduction), **chapter 2** (Industry 4.0 and the Maturity Assessment of Companies) introduces the reader to the two main research areas targeted in this thesis. The background of the fourth industrial revolution (Industry 4.0) is presented by giving insights into the historical development, the main characteristics and terminology used, as well as the relevance of Industry 4.0 in this thesis. In the same chapter, the maturity assessment of companies (2.2.1 Maturity models – Introduction) is explained in detail and is based on a scientific foundation (2.2 Maturity Models and the Design Science Approach).

Chapter 3 (Methodological Approach to develop the Industry 4.0 Maturity Model – I40MM) presents the scientific background of the methods and concepts included into this thesis. Moreover, procedures derived from literature are presented which are followed to apply the methodologies. The overall concept to develop the maturity model is presented by using “Concept Mapping” as a method to present the research approach at-a-glance (3.1 Methodological Approach at a glance – Using Concept Mapping). The need for a “Systematic Literature Review” on maturity models is argued and the results and findings are presented (3.2.6 Summary findings systematic literature review). Finally, the research methods of “Qualitative and Quantitative Survey Research” included in the thesis is explained as well as the procedures followed for conducting expert interviews and for developing questionnaires to self-assess the maturity within companies (3.3 Qualitative and Quantitative Survey Research utilized in the thesis

In **chapter 4** (Model-Development and the resulting Industry 4.0 Maturity Model (I40MM)

In this chapter the scientific basis of the I40MM is presented as well as the derived procedure to develop the model.

[29] Introduction not considered

Development of the Industry 4.0 Maturity Model) the scientific frameworks and the development-procedure followed in the thesis are outlined in detail. The results of the expert interviews as well as the result of the expert-ratings to validate the practical importance of the model's content are presented and embedded into the development-procedure.

The 4.2nd **chapter** (Result: The Industry 4.0 Maturity Model – I40MM) introduces the resulting maturity model. The general characteristics, the model's scope and design, the mode of maturity assessment and representation of the results are described 4.2.6 Summary characteristics of the I40MM). Finally, the model is transformed in a practically usable tool for assessing the maturity of companies – the 11-pages maturity report (4.2.7 Representation of the results – The I40MM Maturity Report).

In order to prove practical usability and relevance, **chapter 5** (Pilot-Testing of the I40MM) presents the models testing in two companies. The resulting maturity profiles are highlighted and conclusions about the models quality and validity are derived.

Finally, the 6th **chapter** (Discussion and Outlook) aims for unveiling flaws, weaknesses and limitations of the model (6.2 Discussion of used Methodology), and, therefore contains arguments for further developments and improvements (6.3 Further Research).

2 Industry 4.0 and the Maturity Assessment of Companies

2.1 Industry 4.0

Recently, a fourth industrial revolution is propagated which is triggered by cyber-physical systems and the use of modern Communication and Information Technology (ICT)[30]. Smart factories and smart manufacturing should result in an entire new approach to the conventional production industry and based on the disruptive innovations, most areas of daily life, as well as work life will be affected. Acatech – the National Academy of Science and Engineering offers the following definition for Industry 4.0:

"The term Industry 4.0 stands for the fourth industrial revolution. Best understood as a new level of organization and control over the entire value chain of the life cycle of products, it is geared towards increasingly individualized customer requirements. This cycle begins at the product idea, covers the order placement and extends through the development and manufacturing, all the way to the product delivery for the end customer, an concludes with recycling, encompassing all resultant services"

and, states Industry 4.0 as the

"technical integration of cyber-physical systems into production and logistics as well as the application of the internet-of-the-things in industrial processes – including all resulting consequences for value creation, business models or following services and organization of labour"[31].

Based on the extensive literature review on "Industry 4.0", the expert interviews and discussion within the research team, the following own understanding of Industry 4.0 is offered:

(German)

"Industrie 4.0 beschreibt die Vereinheitlichung, Digitalisierung und Virtualisierung des Wertschöpfungsnetzwerkes durch die Nutzung moderner Technologien mit dem Ziel Kosten zu senken, sowie Nachhaltigkeit und Kundenmehrwert zu schaffen. Dabei kommt es zu einer daten- und echtzeitbasierten Synchronisierung und Integration von Prozess- Produkt- und Kundenlebenszyklen, welche die Neuausrichtung organisationaler Strukturen sowie existierenden Geschäftsmodelle erfordert"

[30] See „Vocabulary of Industry 4.0"
[31] (acatech - Deutsche Akademie der Technikwissenschaften, 2013); translated to Englisch

(Englisch)

"Industry 4.0 encompasses the coordinated digitalization and virtualization of the entire value-creation network through the implementation of modern technology with the goal of reducing costs, increasing sustainability and the creation of customer value. Thereby, process- product- and customer lifecycles are synchronized and integrated based on big data- and real-time information, which requires the alignment of organizational structures and existing business models."

2.1.1 Terminology – Industry 4.0

Consistent, clear and widely accepted definitions of Industry 4.0 rarely exist and literature offers widely divergent explanations[32]. In order to create common ground, standardization regarding wording and vocabulary is stated in this chapter. In the following, the terms and related definitions are explained that are to date commonly used in practice and academia: [33] [34] [35] [36] [37]

- **Cyber-physical System:** is a system, which connects physical objects and processes with virtual objects (which are able to process information) through open and interconnected information-networks.
- **Cyber-Physical Production System:** is a production system which utilizes cyber-physical systems to operate.
- **Smart Factory:** is a manufacturing solution that provides flexible and adaptive production processes and that assists machines and people in context-aware manners via the use of modern computing technology
- **Smart Product:** Products which are able to communicate and interact with other objects and systems (e.g. with production machines during production, with other products etc.) and which are uniquely identifiable.
- **Internet of the things:** is a dynamic global network infrastructure where physical and virtual objects have their own identities, physical attributes, and virtual personalities. These objects use intelligent interfaces, and are seamlessly integrated into the information network.
- **Embedded systems:** are computer-systems which consists of software and hardware and which are integrated in a complex, technical systems (mostly machinery).
- **Cloud Computing:** is a model for enabling on-demand network access to a shared pool of computing resources whereby no human interaction with the service provider is required

[32] (Bauernhansl, Hompel, & Vogel-Heuser, 2014, S. 2)
[33] (acatech - Deutsche Akademie der Technikwissenschaften, 2013, S. 17)
[34] (Schleipen, 2015)
[35] (Vermesan u. a., o. J., S. 10)
[36] (Siemers, 2011, S. 2)
[37] (Radziwon, Bilberg, Bogers, & Madsen, 2014)

- **Big Data:** amount of data which cannot be handled (and captured) manually but with the use of specific computer software.

2.1.2 Historical background and economic impact of Industry 4.0

Industry 4.0 follows three previous industrial revolutions (Figure 3)[38]:

- In 1750, the development of the steam engine allowed for the transition from hand production to machines, which increased productivity within production plants and, as a result, raised the standard of living consistently.
- In 1870, the introduction of electrical energy in combination with division of labor enabled mass production, which led companies to focus on economy of scale.
- In 1960, electronics triggered the later implementation of Information and Communication Technology (ICT) which built the base globalized value chains.

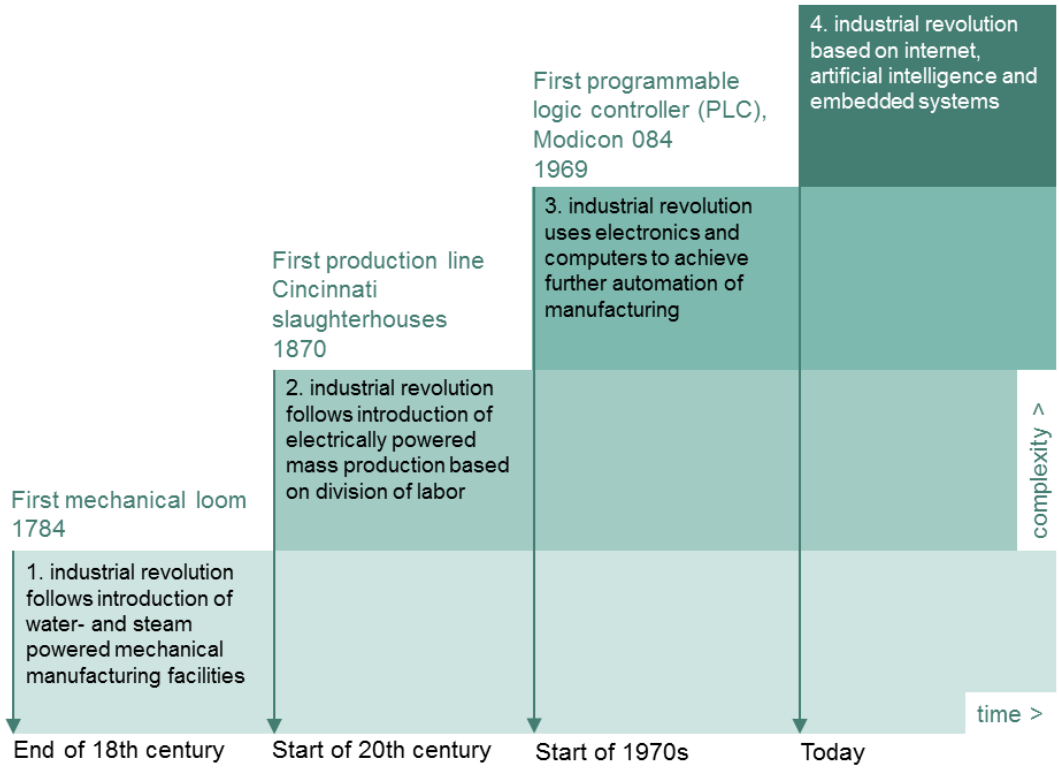


Figure 3: The four industrial revolutions based on DFKI 2011)[39]

The 3rd industrial revolution led to increasing importance of the service sector, whereas conventional production industries where expected to decrease to less than 10% of the gross value added. Although countries such as France, England or the US consistently decreased the industrial share, Germany kept the share of the

[38] (Bauernhansl u. a., 2014, S. 6)
[39] See Deutsches Forschungszentrum für künstliche Intelligenz GmbH (DFKI), 2011

machinery and plant manufacturing industry at 25% (20% during the financial crisis around 2008, 23% in 2011[40]). Germany's strong manufacturing industry is one possible explanation for its economic success and, therefore, other countries (especially emerging countries) follow this example. In order to maintain the strong position as the "number one industrial nation", and to increase innovativeness and prosperity, the German government presented the so called "Die Neue High Tech Strategie"[41]. Part of this strategy was the development of "smart factories" – self organizing and self-reliant factories based on Cyber-Physical Systems and modern Information and Communication Technology (ICT). As the consequences for production should be highly disruptive, these changes are considered the 4th industrial revolution – referred to as Industry 4.0. The first three industrial revolutions have been stated as such ex post – based on the observations these developments had on the industry and society. In contrast, the fourth industrial revolution is stated as such ex ante – triggered and promoted by the German government and several related initiatives. Industry 4.0 should help to strengthen Europe's economy and Germany's in particular. Several surveys shed light on the topic and highlight the importance for the fast realization of the Industry 4.0 vision:

- The share of worldwide manufacturing (a total of EUR 6,577bn) held by emerging countries is 40% and doubled in the last two decades. Whilst Western Europe hast lost 10% of manufacturing value added between 2001 and 2011[42]
- Traditional industrial policy will not provide enough support for reaching the goal of 20% value added by traditional industry in Europe. Therefore, a new agenda for strengthening Europe's industry has to be proposed (Industry 4.0)[43]

Prognostic surveys highlight the immense potential and movements towards Industry 4.0:

- In 2015 around 650 million Euros are being invested into Industry 4.0 related technologies and applications in Germany[44]
- By 2020 European companies will invest 140 billion Euros annually in Industrial Internet applications[45]
- Overall, an additional economic growth of around 1,7% in chosen industries in Germany between 2013 and 2025 has been estimated[46]

[40] (Blanchet, Rinn, Von Thaden, & De Thieulloy, 2014, S. 6)
[41] Translation: A new strategy based on high-technology to foster innovation in Germany; http://www.hightech-strategie.de/
[42] (Blanchet u. a., 2014, S. 19)
[43] (Blanchet u. a., 2014, S. 19)
[44] http://de.statista.com/statistik/daten/studie/372846/umfrage/investition-in-industrie-40-in-deutschland/
[45] (Geissbauer u. a., 2014, S. 12)
[46] Fraunhofer IAO/Bitkom 2014

- Moreover, Industry 4.0 might lead to an employment-increase of 6% in Germany in the next 10 Years[47]

The additional economic potential in Germany is widely divergent as a survey of the consulting company Roland Berger estimated 20 billion Euros per year (Roland Berger 2014), Bitkom 28 billion Euros per year (Bitkom 2014), PricewaterhouseCoopers 30 billion per Year (PwC 2014). The wide range of forecasts estimating the economic potential can be mainly explained with the long time horizon the surveys take (10-15 years). Moreover, the prognoses are based on the view of experts in the field of Industry 4.0, which includes an inherent optimism due to their willingness to realize Industry 4.0[48]. Although, all prognoses show a positive impact on the economy, companies currently seem unwilling to carry out the measures foreseen by the initiatives and governments. The main reason can be found in the immense investments required across all industries. A survey presented by PricewaterhouseCoopers estimates, that around 40 billion Euros of investments into Industry 4.0 are required in Germany in the next 5 years, while the added revenue should be around 30,7 billion Euros[49]. Little monetary incentives result in only 4% of the companies in Germany implementing Industry 4.0 actively in 2014 (survey in 2014 by Experton Group[50]).

2.1.3 Basic concepts and target areas of Industry 4.0

Industry 4.0 bases on the utilization of existing and newly developed elements which collaboratively should lead to the fourth industrial Revolution (Figure 4). The base-elements are embedded systems - software/hardware-systems that are integrated into a technical system to fulfill a specific purpose (e.g. board-computer in a car). Furthermore, the Internet (in this context the “Internet of the Things” – IoT or the “Internet of the Services – IoS”) allows of the broadband-interconnection of physical objects, resulting in the “Internet of Everything – IoE”. The irreversible integration of physical objects with the virtual world then leads to the creation of Cyber Physical Systems or in short CPS (e.g. assistant systems using virtual reality in manufacturing).

[47] (Rüßmann u. a., 2015, S. 7)
[48] (Wischmann u. a., 2015, S. 19)
[49] (Geissbauer u. a., 2014)
[50] (Experton group, 2014)

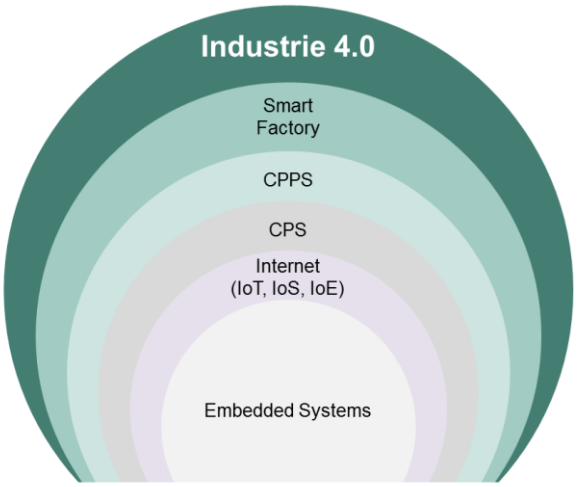


Figure 4: Basis elements leading to Industry 4.0

Consequently, the application of Cyber Physical Systems in manufacturing turns conventional production into so called Cyber Physical Production Systems. The resulting complexity of such systems can be handled by the utilization of modern Information and Communication Technology (ICT) which allows for the intelligent interconnection of humans, machines and resources – the creation of "Smart Factories". These factories are capable of managing complexity, are less prone to disruption and are able to manufacture goods more efficiently. In the following, a table which shows the major shifts from today's factories to smart factories:

Number	Smart factory production system	Traditional production line
1	**Diverse Resources.** To produce multiple types of small-lot products, more resources of different types should be able to coexist in the system.	**Limited and Predetermined Resources.** To build a fixed line for mass production of a special product type, the needed resources are carefully calculated, tailored, and configured to minimize resource redundancy.
2	**Dynamic Routing.** When switching between different types of products, the needed resources and the route to link these resources should be reconfigured automatically and on line.	**Fixed Routing.** The production line is fixed unless manually reconfigured by people with system power down.
3	**Comprehensive Connections.** The machines, products, information systems, and people are connected and interact with each other through the high speed network infrastructure.	**Shop Floor Control Network.** The field buses may be used to connect the controller with its slave stations. But communication among machines is not necessary.
4	**Deep Convergence.** The smart factory operates in a networked environment where the IWN and the cloud integrate all the physical artifacts and information systems to form the IoT and services.	**Separated Layer.** The field devices are separated from the upper information systems.
5	**Self-Organization.** The control function distributes to multiple entities. These smart entities negotiate with each other to organize themselves to cope with system dynamics.	**Independent Control.** Every machine is preprogrammed to perform the assigned functions. Any malfunction of single device will break the full line.
6	**Big Data.** The smart artifacts can produce massive data, the high bandwidth network can transfer them, and the cloud can process the big data.	**Isolated Information.** The machine may record its own process information. But this information is seldom used by others.

Figure 5: Comparison of today's factory and an Industry 4.0 factory[51]

[51] (Wang, Wan, Li, & Zhang, 2015, S. 6)

The implementation of smart factories leads to a paradigm shift in production in three areas:[52]

- **Individuals** play a crucial role, as the new way of organizing work is human-centered and self-organization and autonomy is increasing. The socio-technological approach of Industry 4.0 tends to enlarge the fields of activity of employees and increases their access to knowledge. Especially new chances for older employees are created to engage in work-life.
- Integrated **Technology** aims for the connection of customized products and processes, whereby the emerging complexity is addressed using self-organizing systems. Interfaces are constructed in ways, so that handling complex systems is made possible for humans. Smart products serve as information-carrier within the virtual information system along their entire life-cycle. The overall resource-efficiency can be planned and optimized continuously due to real-time monitoring.
- **Organization** of work is re-invented, as dynamic division of labor is based on newly structured value creation chains and the integration of products, production and services. Intercompany cooperation opens company boarders which results in new business environments and business models.

The resulting digitalization and virtualization of the entire value creation chain finally enables the propagated new approach to production industries – the Industry 4.0. Based on the described elements, Industry 4.0 should be realized through the implementation of four key concepts [53] [54] [55]. Thereby, the first three concepts are considered the three ways of integration in Industry 4.0 (Figure 6). The fourth concept of exponential technologies is seen as an enabler for the fast implementation of the latter ones.

[52] (compare: Plattform Industrie 4.0 Germany, o. J., S. 4)
[53] (acatech - Deutsche Akademie der Technikwissenschaften, 2013)
[54] (Schlaepfer u. a., 2015)
[55] (Wang u. a., 2015)

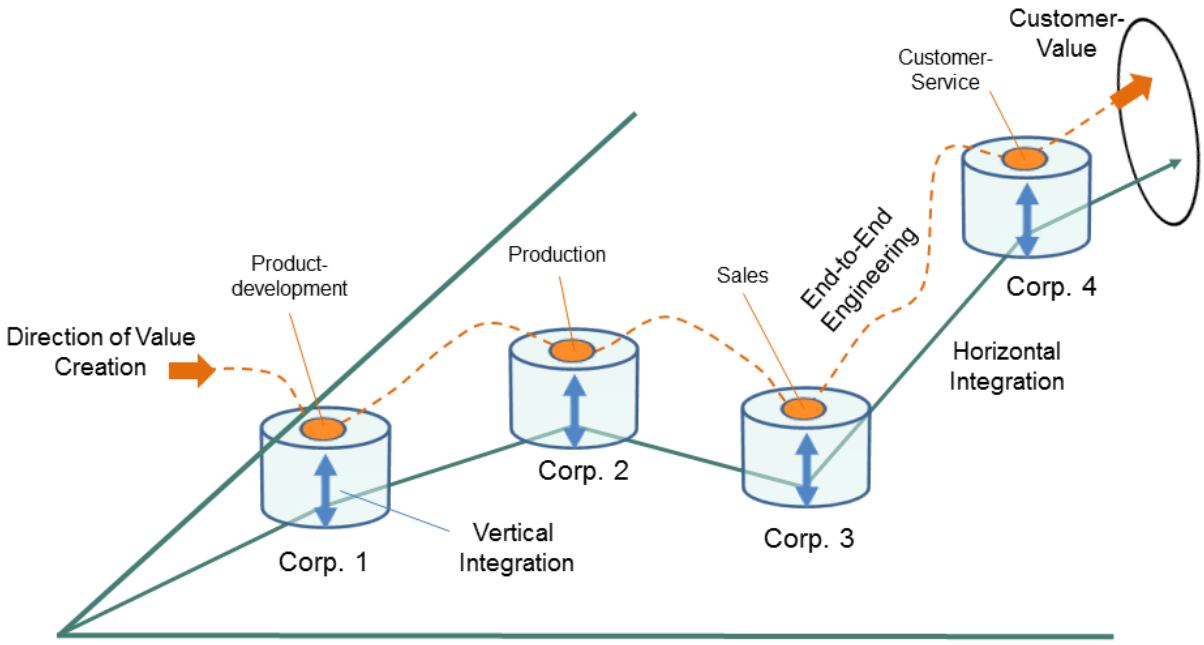


Figure 6: Three kinds of integration in Industry 4.0

1. Vertical integration and networked manufacturing systems

The existing subsystems (e.g. actuators and sensors, control systems, production management, manufacturing planning) are required to be integrated vertically, up the Enterprise resource planning-system (ERP). The vertical integration creates a flexible and reconfigurable manufacturing system which can operate in self-organizing and self-optimizing manners. The adaption of the manufacturing system to changing boundary-conditions on a corporate-level (e.g. order of different product types) is enabled through vertical transition of massive data-streams which.

2. Horizontal integration through value networks

Besides competing with other companies, strategic corporations should be entered to form an efficient eco-system. By the horizontal integration of relevant corporations a fluent exchange of information, finance and material is enabled. As a result, new value networks are created and new business models emerge. Conventional “production-silos” are eliminated and corporations add their competences in flexible production-networks to create customer value.

3. End-to-end digital integration of engineering across the entire value chain (Integration of Engineering)

Within the value creation process, the chain of activities reaches from determining the customer requirements, the product design and development, the production planning and engineering, organizing the distribution, offering after-sales services

and finally ensuring maintenance and recycling. The engineering of these activities has to be integrated and networked in digital manners to allow holistic end-to-end engineering including all disciplines and reducing interfaces.

4. Acceleration through exponential technologies

Modern technological approaches such as the “Internet of the Things”, “big-data”, “cloud computing” as well as “artificial intelligence” are enabling the concepts of Industry 4.0. The integration of powerful microprocessors and artificial intelligence technologies creates smart production machines in the sense that they possess autonomy and sociality. These smart artifacts are interconnected with each other through the Internet of the things with the help of big data and cloud computing, Besides the vertical and horizontal interconnection of machines, new business models and value networks can be created through the utilization of modern information and communication technology (e.g. real-time exchange of massive data using cloud services).

2.2 Maturity Models and the Design Science Approach

2.2.1 Maturity models – Introduction

The concept of assessing maturity and constructing levels – one building on the other was introduced by Crosby in 1979 with the Quality Management Process Maturity Grid. Maturity can be defined as „the state of being complete, perfect or ready”[56] and, therefore „maturity implies evolutionary progress in the demonstration of a specific ability or in the accomplishment of a target from an initial to a desired end stage”[57]. Most maturity models consist of discrete maturity stages (or maturity levels) – from an initial stage to the highest stage possible, which represents a conception of total maturity.[58] The stages show increasing quantitative or qualitative capability changes of a maturing element, which can be: persons, objects or social systems.[59] [60]

Maturity models can be descriptive, prescriptive or comparative in nature. A descriptive model is not aiming for improving the maturity or performance but rather captures that state-as-it-is (single point encounter). The prescriptive model relates the state-as-it-is to business performance and offers e.g. road-maps for approaching maturity improvement to create a positive business effect. Comparative business models aim for comparing maturity of practices across organizations within a certain industry whilst recognizing that similar levels of maturity do not translate directly to

[56] (Simpson u. a., 1989)
[57] (Mettler & Rohner, 2009)
[58] (Becker u. a., 2009, S. 213)
[59] (Wendler, 2012)
[60] (Kohlegger, Maier, & Thalmann, 2009, S. 54)

business performance. These three types of models can be seen as evolutionary phases of the same maturity model as the state-as-it-is is required for any statements about business performance or comparative cross-organizational conclusions.[61]

Although called “maturity models” they tend to be somewhere in between a “model” and a “method” (Figure 7). Models generally describe some aspects of the physical or social reality for the purpose of understanding and communicating. Methods are used to perform a system development project, based on a specific way of thinking, consisting of directions and rules, structured in a systematic way of development activities with corresponding development products. Maturity models show a duality as they combine descriptions (e.g. description of the characteristics of the maturity levels) and activities (e.g. activities to be carried out for reaching a higher level of maturity). [62] [63]

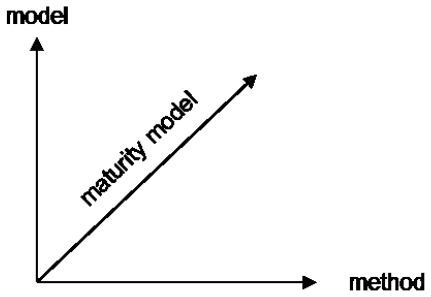


Figure 7: Maturity models in-between of models and methods (modified figure)[64]

Wendler carried out an extensive literature review in 2012 considering more than 2000 papers about maturity models for further examination, resulting in 237 publications which have been included for further analyzes (Figure 8). He found that the number of articles dealing with maturity models increased steadily since 1993 and peaked in 2009 (he indicates that the decline in 2010 does not allow stating a downward trend already).

[61] (de Bruin & Rosemann, 2005)
[62] (Mylopoulos, 1992)
[63] (Brinkkemper, 1996)
[64] (Mettler & Rohner, 2009)

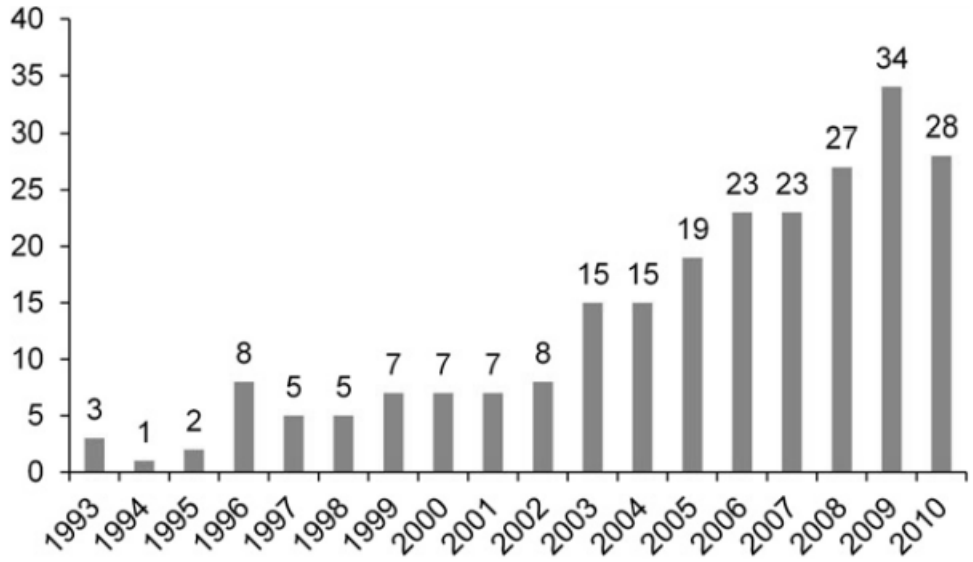


Figure 8: Timeline of publications in maturity model research (number of articles) [65]

The increasing popularity can be explained with various benefits organizations can derive from assessing their maturity:[66] [67] [68] [69]

- A situational analysis of one's capabilities
- A place to start
- A framework for prioritizing actions
- As a benchmark for comparison
- An aid to understand
- Enable continuous improvement
- Provide guidance through the evolutionary process
- Help adapting to the environment by enhancing the quality of choices
- Help understanding the needs of an organization

Wendler's analysis of existing publication on maturity models also showed, that maturity model research is taking place in more than 20 domains (Figure 9), heavily dominated by software development and software domains.

[65] (Wendler, 2012, S. 1329)
[66] (von Scheel u. a., 2015, S. 395)
[67] (Antunes u. a., 2014, S. 806)
[68] (Mettler & Rohner, 2009)
[69] (Introna u. a., 2014, S. 109)

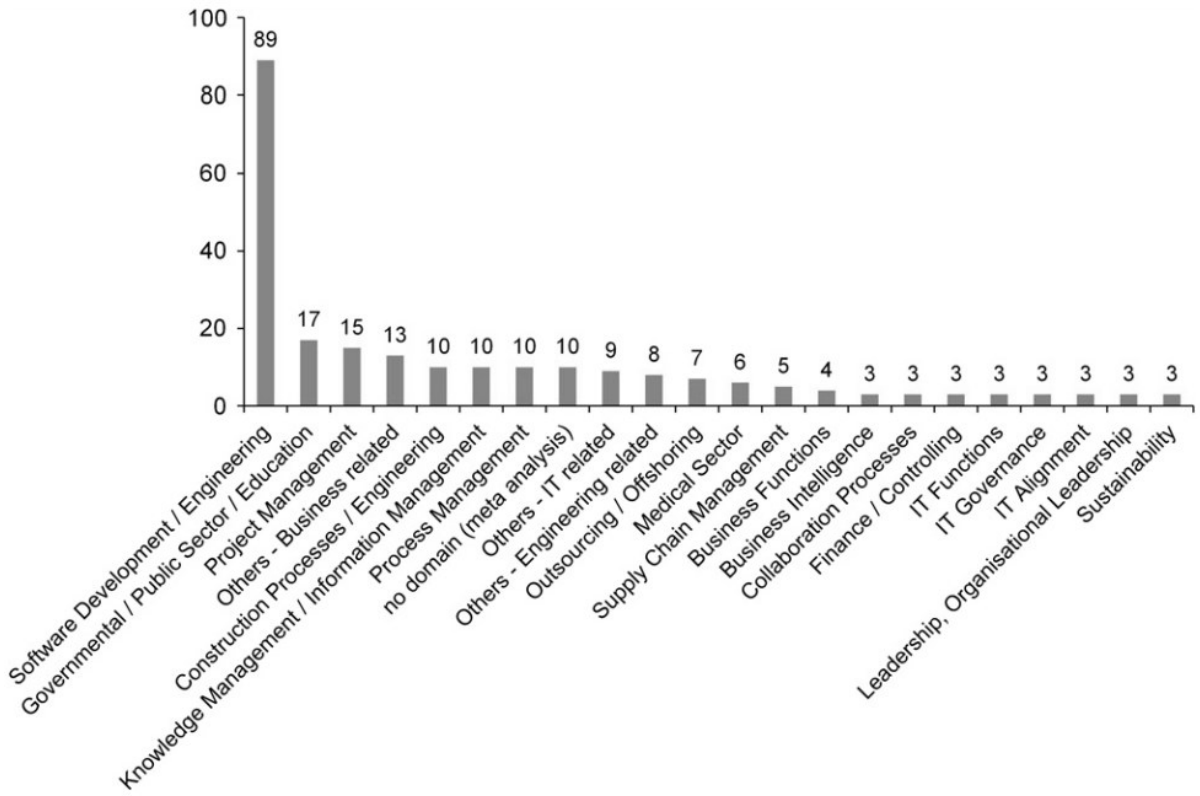


Figure 9: Application domains throughout the mapping study (number of articles)[70]

Beside the field of application, maturity models can be compared and distinguished through a number of variables such as its success, the approach taken (staged or continuous), the number of maturity levels, or the level of detail provided. Fundamentally, maturity models can be divided into four basic groups: [71]

- **Maturity Grids:** Contains textual definitions for each activity at each maturity level and are of moderate complexity.
- **Likert-like questionnaires:** questions asked are a statement of good practice and the respondent is asked to score the relative performance of the own organization form 1 to n (if n=2 the scale becomes a checklist).
- **Hybrids:** questionnaires are combined with the definitions of maturity levels (no additional description of the activities).
- **CMM[72]-like models:** process areas are organized by common features which specify a number of key practices to address a series of goals

[70] (Wendler, 2012, S. 1328)
[71] (Fraser, Moultrie, & Gregory, 2002, S. 247)
[72] CMM – Capability Maturity Model

2.2.2 Development of maturity models

Most maturity models published have been developed using practices and methods derived from real-life projects that turned out to be successful. This approach results in a lack of theoretical foundation and methodology[73]. Instead, fundamental questions have to be answered when developing a maturity model: [74]

Table 3: Guiding questions when developing a maturity model

Representative Question	Description / Example[75]
• How do elements change in time?	Knowledge elements change in nature while they advance through the knowledge maturing process
• What does “maturing” mean?	Maturing means change in formality, distribution, commitment, legitimation, understandability and teachability of the maturing subject, i.e. of socially constructed knowledge in an organization
• What is the maturing subject?	The maturing subject is a knowledge domain in the sense of knowledge about a topic in a socially distributed activity system
• How is the model designed?	The model is designed as a sequence of phases which do not necessarily build on each other. Each phase can use outputs provided by all other phases as inputs for knowledge maturing activities in this phase
• What is the model used for?	The model can be used as an analytic model to help structure the analysis of existing organizational and technical infrastructures in support of goal-directed learning on a collective level
• Who uses the model?	The model can be used by people taking on the role of guides helping to foster and reduce barriers for knowledge maturing
• Does the model complement other models?	The model does not complement another model
• Has the model a conceptual mother model?	The knowledge maturing model is not related to any other maturity model
• How do the stages build on each other?	The stages of the model are independent from each other as the upper stage cannot be traced back to the lower stage

[73] (García-Mireles u. a., 2012, S. 282)
[74] (Kohlegger u. a., 2009, S. 57)
[75] Example-answers using a knowledge maturity model

• How does the subject proceed from one level to the next?	The maturing element matures implicitly between the stages. However, there can be explicit decisions to take a knowledge domain from one phase to the next one
• What is the number of stages?	The knowledge maturing model has five stages
• What do the level descriptions include?	The level descriptions of the knowledge maturing model include conceptual descriptions of the stages
• What is the degree of detail of the trigger description?	The model has no triggers between its stages
• Is level-skipping allowed?	The model does not mention level skipping
• Are there parallel maturing processes possible for one unit?	Within one organizational unit, there might be different knowledge domains which are in different knowledge maturing stages
• What is the number of goal levels?	The model has no goals assigned to its stages
• What is the method of goal benchmarking?	The model uses a non-metric way of goal benchmarking
• Where do assessment data come from?	The model is not practically used yet, so assessment has not been specified yet
• What is the model used as?	The model is used as a conceptual model
• Is tool support available?	The model is not supported by a tool
• What is the model description based on?	The model is based on practical experience
• Is certification available?	There is no certification available for the model

Although these guiding questions (Table 3) support discussion and reflection, a scientific approach for developing maturity models has to be followed – in this thesis, the so called “Design Science Approach”.

2.2.3 Limitations of maturity models

The popularity of maturity models is triggered mainly by the field of business consulting, where maturity models are used as an assessing-tool for companies and governments. These models often lack scientific background and are derived from existing, successful models. As a result, a number of issues can be extracted from literature:

- Models, which are based on personal experience and which have not been developed in the open market (CCM has been developed based on the experience of large government contractors) are not representative[76].
- Many maturity models are developed for identifying the gap between the actual and the intended status. However, mostly these models do not describe how to close the identified gap which leaves organizations on their own.
- Maturity models can create a falsified certainty about the status of a company which can lead to setting wrong focuses and hinder from being innovative[77] .
- Maturity models tend to fail in non-stable environments and when the technology is not well understood
- If the situativity of organizations (e.g. legal restrictions) is not considered when defining the requirements of the maturity levels, companies can be stuck in one maturity level for too long[78].
- The maturity grid development process is not completely rigorous and some comprise is necessary to enhance usability[79].
- Maturity Models mostly ignore human resource and organizational aspects[80].
- Many maturity models are not successful as they are too theoretical and not applicable in practice[81].
- Maturity models using fixed maturity levels have the weakness to not allow expressing interdependencies between the processes with a capability level[82].
- Detailed documentation about the design process of existing maturity models does often not exist or is not accessibly freely (analyzes of 51 maturity models and personal talks with the model's developers by Becker et al. in 2009)[83].
- Maturity models can inherently become obsolete due to changing conditions, technological progress or environmental changes (regular evaluation of validity is necessary) [84]

Considering these issues, organizations are advised to critically reflect their maturity assessed. Blindly trusting the as-is-state resulting from one model can result in the wrong measures taken and, either slow down the maturing-process, or create immense pressure as the maturity-state is assessed higher than it is in reality.

[76] Companies such as google, Microsoft or IMB do not consider their processes more mature than level 3 on a CCM model for software development, but they are undoubtedly mature
[77] (Mettler & Rohner, 2009)
[78] Hayes and Zubrow found out that 73% of the companies assessed using the CCM-maturity level where stock in level 1 due to the fact that the requirements for the dimension project management were far to hard
[79] (Fraser u. a., 2002, S. 244)
[80] (Backlund, Chronéer, & Sundqvist, 2014, S. 841)
[81] (Backlund u. a., 2014, S. 843)
[82] (García-Mireles u. a., 2012, S. 281)
[83] (Becker u. a., 2009, S. 216)
[84] (Becker u. a., 2009, S. 219)

2.2.4 Design science approach – Introduction

The design science paradigm has its roots in engineering and has initially been developed for problem solving by creating “artifacts”. These artifacts are innovations which are not exempt from natural laws, but on the contrary, are created through capabilities of the researchers, and are based on existing and successfully tested and applied theories. The development of useful artifacts is therefore depending on the individuals experience and creativity in problem solving. Extending the human boundaries for problem solving, IT-support for the creation and implementation of the artifacts became indispensable. Hevner et al. defined seven guidelines for conducting design-science research (Table 4):[85]

Table 4: Design-Science Research Guidelines

Guideline	Description
• **Guideline 1:** Design as an Artifact	Design-science research must produce a variable artifact in the form of a construct, a model, a method or an instantiation.
• **Guideline 2:** Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
• **Guideline 3:** Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
• **Guideline 4:** Research Contribution	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
• **Guideline 5:** Research Rigor	Design-science research relies upon the application of rigorous methods on both the construction and evaluation of the design artifact.
• **Guideline 6:** Design as a Research Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
• **Guideline 7:** Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audience.

[85] (Hevner u. a., 2004, S. 83)

Maturity models can be understood as artifacts which serve the "problem of determining a company's status quo, and for deriving measures for improvement therefrom"[86]. Therefore, the basic guidelines provided for design research are applicable to the development of the maturity model which offer a scientific base for the model's development – presented in the following chapter.

2.2.5 Design science approach for developing maturity models

Hevner's design science approach can applied on the development of maturity models based on the work of Becker et. al in 2009, which aimed for developing a maturity model in the domain of IT Management.

Table 5: Application of Design Science guidelines on maturity model development[87]

Design Science Research Guideline	Applied on maturity model development
Guideline no. 1 and **Guideline no. 4**	Comparison with existing maturity models.
Guideline no. 6	Maturity models must be developed iteratively (e.g. step-by-step); All principles and premises for the development (as well as usefulness, quality and effectiveness of the artifact) must be evaluated iteratively – for the problem of delimiting the evaluation criteria.
Guideline no. 3	The evaluation of all (intermediary) results must be carried out with appropriate scientific methodology.
Guideline no. 5	A multi-methodological procedure (variety of well-founded research methods) is carried out and the research methods must be finely attuned.
Guideline no. 2	The relevance of the problem solution proposed by the maturity model must be demonstrated as well as the domain of the maturity model, intended benefits and conditions for its application.
Guideline no. 7	The presentation of results and the documentation must be targeted the needs of specific user groups as well as the condition of its application. The design process of the maturity model must be documented in detail (parties involved, applied methods and results).

[86] (Becker u. a., 2009, S. 214)
[87] (Becker u. a., 2009)

Applying the design science research guidelines (Table 5) on the development of maturity models increases the development's scientific validity and reduces the risk of "no applicability in real-life". Moreover, the guidelines are necessary to avoid maturity models becoming mere marketing tools for business consultancies. Following this procedure raises awareness for the need of well-founded methodologies for the maturity-model design.

3 Methodological Approach to develop the Industry 4.0 Maturity Model – I40MM

3.1 Methodological Approach at a glance – Using Concept Mapping

Organizing and depicting knowledge in a graphical way can be carried out using so called “concept maps”, whereby a concept can be seen as “a perceived regularity in events or objects”. The origin of concept maps lies in the field of child-education in 1972, when researches where trying to understand children’s conceptual understanding and to represent their knowledge in form of a concept map.[88]

3.1.1 Development of concept maps

A concept map consists of three basic elements – the concepts, the cross-links and the propositions. The concepts are certain perceived regularities or patterns which are related to each other. These relations are highlighted inserting cross-links between the concepts, whereby, proposition specify the relation using a word or a phrase.

Characteristics of concept maps:[89] [90]

- Map aims for answering a “focus question”[91]
- Concepts are represented in hierarchical order (general to specific)
- Hierarchical order is generally downward-branching
- Cross-links between concepts are included showing relationships
- Proposition are specifying the kind of relation the concepts have

The main advantage of concept maps can be found in the depiction of information “at a glance” which fastens the uptake of knowledge. Complex interferences can be depicted using cross-links and hierarchical order can be added through sub-concepts.

[88] (Novak & Canas, 2008, S. 3)
[89] (Novak & Canas, 2008, S. 2)
[90] (Chou, 2014)
[91] A focus question frames the map and helps to organize the map e.g. which concept are placed where in the hierarchical order

3.1.2 Procedure to create the methodological concept map in thesis

The concept map is used for presenting the conceptual relations of the research topics in the thesis (see 3.1.3 Resulting concept map of the master thesis) as well as for summarizing the findings of the systematic literature review at-a-glance (see 3.2.6 Summary findings systematic literature review). To create the concept map, a four step-procedure is followed:[92]

STEP 1 – Definition of focus question
General: The identification of the relevant segment of knowledge leads to the determination of a context in which the concepts should be organized. For practical manageability, a further specification resulting in a so called "Focus Question" is carried out. The resulting concept map now responds to the defined focus question leading to clear hierarchical orders and cross-links. **Outcome STEP 1:** Defined focus question
Application on the thesis: The focus questions of the two concept maps included are 1. "What research areas and methodologies are included into this thesis and for what purpose"? 2. "What general characteristics can be derived from the review of existing maturity models"?
STEP 2 – Identification of key concepts [93]
General: In a next step, the "key concepts" (related to the focus question) are identified. The identification of key concepts can be conducted by e.g. group-works, literature reviews or expert interviews. Key concepts are general patterns or regularities perceived while examining the field of research. **Outcome STEP 2:** Preliminary concept map including key-concepts
Application on the thesis: 1. See Figure 11: Concept map - Theoretical Background of master thesis 2. See Figure 17: Concept Map - characteristics of existing maturity models
STEP 3 – Identification of sub concepts
General: Further research leads to the definition of more specific concepts (sub-concepts) related to the key-concepts (the number of levels depends on the complexity of the topic and the degree of

[92] (Novak & Canas, 2008)
[93] Step 2 and Step 3 are carried out parallel

detail required). The concepts can be "ranked" in a number of sub-levels starting with the most general to the more specific.[94]

Outcome STEP 3: Preliminary concept map including sub-concepts

Application on the thesis:

1. See Figure 11: Concept map - Theoretical Background of master thesis
2. See Figure 17: Concept Map - characteristics of existing maturity models

STEP 4 –Definition of cross-links and finalization

General:

Taking the preliminary concept map, cross-links are inserted connecting concepts in different segments or domains of knowledge.

Outcome STEP 4: Concept map (including all concepts and cross-links)

Application on the thesis:

1. See Figure 11: Concept map - Theoretical Background of master thesis
2. See Figure 17: Concept Map - characteristics of existing maturity models

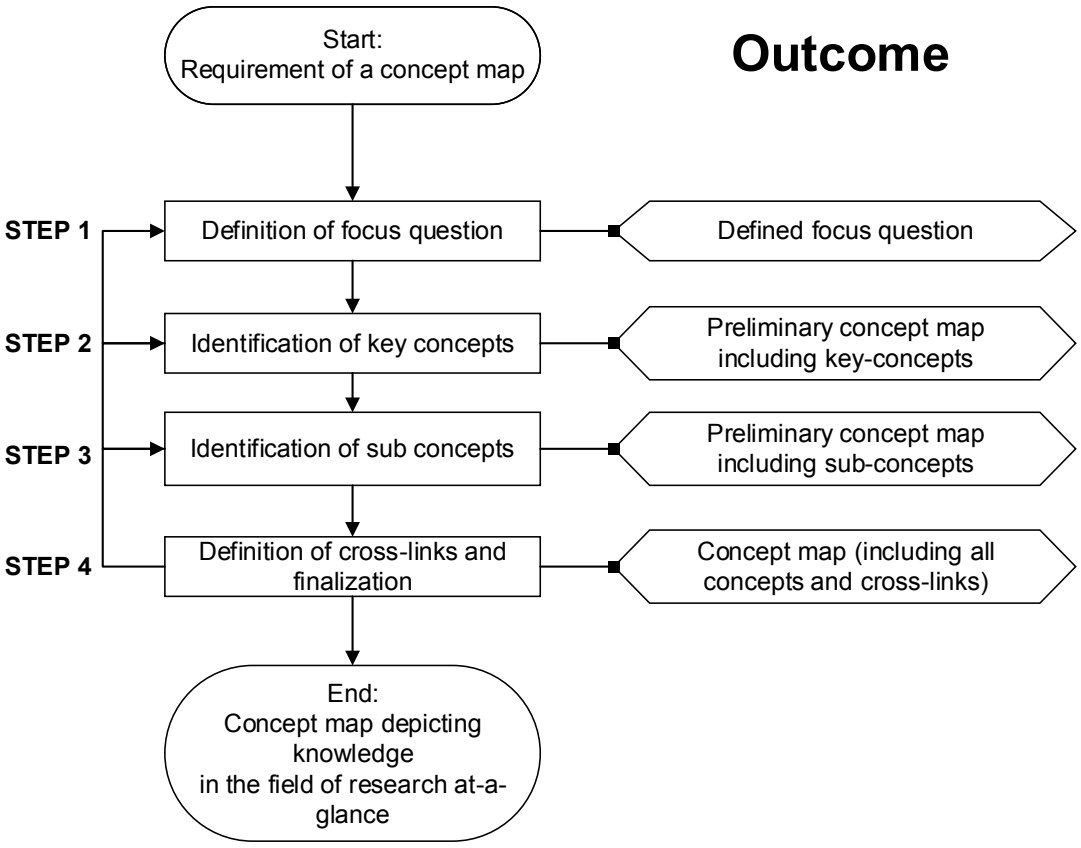


Figure 10: Step-by-step procedure concept map

[94] Concepts listed are not necessarily included into the final concept map

3.1.3 Resulting concept map of the master thesis

The concept map (Figure 11) depicts the methodologies applied in this thesis with the overall goal of developing a maturity model to assess the Industry 4.0-maturity of industrial enterprises (see right end in the concept map). In order to ensure clarity, only the main relations between the methodologies are shown, but it should be noted that all areas influence each other and are carried out in a holistic manners.

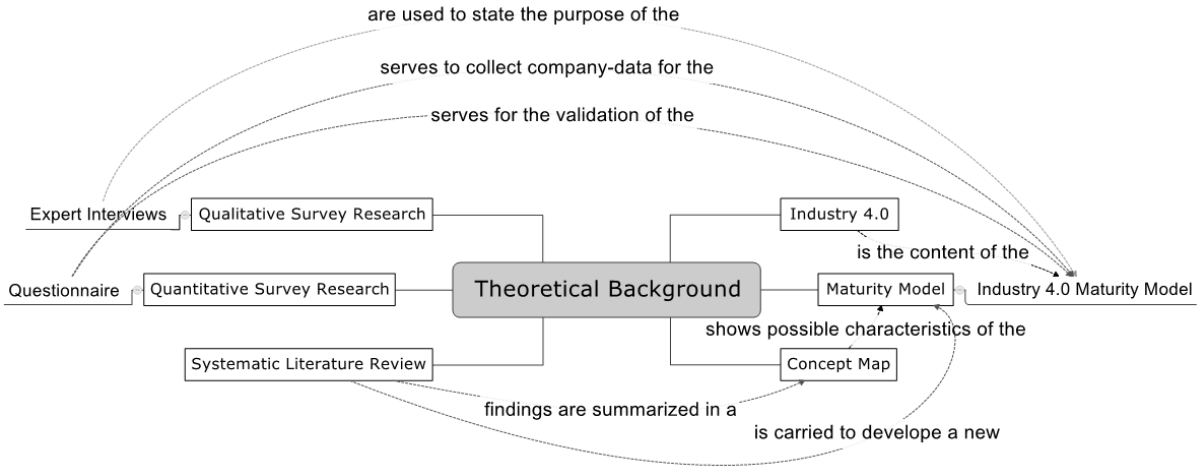


Figure 11: Concept map - Theoretical Background of master thesis[95]

Although the concept map shows one-directional relations between the methodologies, the development of the Industry 4.0 Maturity Model is carried out in iterative manners, as improvements and adaptions based on feedback and validations are conducted.

In the following, the background of the methodologies and their applications within this thesis are described in detail. Thereby, the focus lies on introductory presentations of the research topic, used methodologies as well as the relevance of the research topic in the thesis.

3.2 Systematic Literature Review on Maturity Models

The review of literature in science has various purposes such as providing theoretical background, presenting the breadth of research in a certain field or unveiling a research gap. Independent of the purpose, a literature review should always contain critical reflection of the existing scientific work in the field.

The most common reason for reviewing literature is to provide the theoretical background of the research topic and to bring the research question into focus and

[95] Created with Xmind - www.xmind.net

context. Carried out for such purposes, the literature review is part of the scientific process, but not the core of the scientific work. However, approaching literature through a "stand-alone literature review"[96] is getting increasingly popular, with the goal of reviewing all existing publications in a field. These reviews can provide great guidance to other researches as the breath of research is captured. According to Fink (Fink 2005), a stand-alone review must be systematic in following a methodological approach, explicit in explaining the procedures by which it is conducted, comprehensive in its scope of including all relevant material, and hence reproducible by others who want to follow the same approach[97].

3.2.1 The need for a systematic literature review

Traditional approaches to literature reviews are describing and appraising previous works in the field of research, but do not describe the specific methods by which literature was identified, selected and evaluated. The traditional approach leads to the consideration of popular literature, already known to the researcher. As popular and successful studies are cited frequently, the risk of pursuing with the biases of the primary studies and literature is increased.[98] The main argument for challenging the traditional, unsystematic approach can be found in the very fundamental requirement in science for replicability of scientific findings, whereas, it is rarely possible to replicate the findings of an un-systematic and un-protocolled literature review.

Beside the known disadvantages of traditional literature reviews, the explosion of publications in all fields of science requires changed methods and approaches. As the number of scientific output doubles every nine years[99], it is impossible to capture the state of art in a field of research without a systematic approach, thus, leading to works with little scientific value.

3.2.2 Features and advantages of systematic reviews

The definition of a search strategy and clear criteria for inclusion/exclusion of literature allows for distinguishing the relevant from the interesting findings. To determine, if the approach is systematic, some key-questions can be answered and reflected[100]: Are explicit and transparent methods used? Are standardized stages and steps followed? Is the approach accountable, replicable and updateable? Is the researcher actively involved to ensure the findings are relevant and useful? If the

[96] (Okoli & Schabram, 2010a, S. 1)
[97] (Fink, 2005)
[98] (see. Mallett, Hagen-Zanker, Slater, & Duvendack, 2012, S. 448)
[99] Source: http://blogs.nature.com/news/2014/05/global-scientific-output-doubles-every-nine-years.html
[100] http://eppi.ioe.ac.uk/cms/Default.aspx?tabid=67 (13.08.2015); "What is a systematic review"?

steps of a systematic approach are carried out with rigor, advantages can be found in:[101] [102] [103]

- improving the methodological transparency of the review
- reducing biases due to subjective consideration of literature
- reducing the one-sidedness of researched literature
- ensuring a complete acquisition of existing literature in the relevant field
- allowing the actual prove that the scientific contribution is targeting a research-gap
- including studies and results from beyond known subjects
- unbiased answering of uncertain research questions;

Although systematic literature reviews are offering obvious advantages, a number of practical problems have to be encountered. First of all, the access to academic databases is crucial for the acquisition of literature but can be problematic and expensive (especially) for non-academic researchers. One of the main advantages of a systematic approach to literature reviews is ensuring objectivity; however, there is an inevitable subjectivity, for example, while defining the criteria for screening potentially relevant studies.[104] Another challenge which introduces bias into the review process is institutional websites for searching literature. Differences in the websites' search functions, appearance and structure of the website and database can lead to exclusion which means that high numbers of studies are missed.[105]

3.2.3 Relevance of systematic literature reviews in thesis

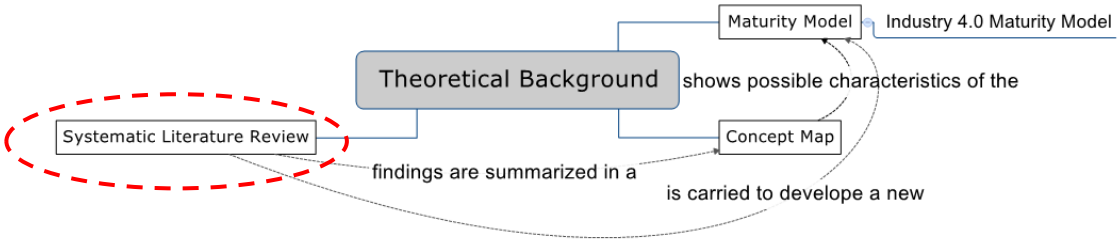


Figure 12: Relevance of a systematic literature review in the thesis-concept

The approach of a systematic literature review is used to capture the state of research in the area of „maturity model development" and allows for deriving the new model which is specified for the assessment of the Industry 4.0-maturity. No literature

[101] (Mallett u. a., 2012, S. 448)
[102] (Gough & Elbourne, 2002)
[103] (Petticrew, 2006, S. 11)
[104] The disagreement rate in terms of inclusion/exclusion can be reduced drastically (e.g. 18 per cent to under 10 per cent in a case study) by extensive discussion within the research team; (see. Mallett u. a., 2012, S. 449)
[105] Researchers tend to preferring websites and databases which show familiar structure, layout and functions

on maturity models applicable on the domain of Industry 4.0 has been found and, therefore, theoretical frameworks and existing models in other areas are used for deriving the new modelThe systematic approach included publications from various domains which ensured a comprehensive and multi-perspective view on maturity model concepts and related experiences.

In the following the procedure that was followed while carrying out the systematic literature review is presented.

3.2.4 Procedure followed to conduct a systematic literature review in thesis

As described in theory, a systematic literature review has to include the definition of a review topic and review question, detailed criteria for inclusion and exclusion and a protocol for documenting the findings. A seven-step procedure is developed based on various literature sources which ensure a systematic and practical way for conducting a literature review:[106] [107] [108] [109] [110] [111] [112] [113]

STEP 1 – Definition of the review topics
General: In a first step the review topic is defined for which relevant literature should be found. This determination of a review topic ensures that the review questions defined in a later step (STEP 3) are within the relevant research topics (framing of the research). **Outcome STEP 1:** Defined review topics
Application on the thesis: The main review topics of the systematic literature review are “Maturity Models” and “Maturity Model Development”.
STEP 2 – Stating the purpose of the literature review
General: The reviewer is required to outline to the reader the exact purpose and goal of the literature review and how the review supports answering the initial research question. **Outcome STEP 2:** Defined purpose of the literature review

[106] (Petticrew, 2006, S. 27)
[107] (Cronin, Ryan, & Coughlan, 2008, S. 38)
[108] (Ramdhani, Ramdhani, & Amin, 2014, S. 49)
[109] (Tranfield, Denyer, & Smart, 2003, S. 214)
[110] (Okoli & Schabram, 2010b)
[111] (Kitchenham, 2004)
[112] (Crossan & Apaydin, 2010, S. 1158)
[113] (Stone, 2012, S. 114)

Application on the thesis: The main purposes of the literature review are to learn about maturity models in general, to understand the development-process and to collect possible characteristics of the Industry 4.0 Maturity Model.

STEP 3 – Definition of review questions

General:

A systematic review aims for answering specific questions rather than presenting general summaries of the literature on the topic. Therefore, the third step contains the definition of specific questions, which should be answered using the literature review. Weak review questions, which are not supporting the initial research question, reduce the quality of the work significantly.[114] It might be necessary to re-phrase and improve the review questions when carrying out later steps (iterative process).

Outcome STEP 3: Specific review questions within the research topic

Application on the thesis: The following review questions (four questions assigned to four sub-topics) have been defined to structure the search and to focus the analyzes of the findings:

- **Sub-topic: Introduction to maturity models**

"What are the general aspects of maturity models (introduction)"?

"What are the fields of application of maturity models"?

"How do maturity models differ from each other"?

"What are the limitations and issues when utilizing maturity model"?

- **Sub-topic: Criteria for assessing maturity**

"How is maturity assessed (general aspects)"?

"What are the main criteria for assessing maturity"?

"How do the criteria differ between maturity models"?

"How are maturity levels are constructed and stated"?

- **Sub-topic: Development of a maturity models**

"How is a maturity model developed (general)"?

"What are approaches for developing a maturity model"?

"What tasks have to be carried out while developing a maturity model"?

"How is maturity represented to the audience"?

- **Sub-topic: Dimensions of maturity models**

"How many, and what kind of dimensions are used in existing maturity models use"?

"How are the dimensions structured in existing maturity models"?

"What parameters are considered within the dimensions"?

"How are the parameters within the dimensions evaluated"?

[114] "All-encompassing" review questions lead to unmanageable amounts of literature on the one hand and support speculative and non-scientific conclusions on the other hand

STEP 4 – Development of a review protocol

General:

After defining the specific review questions, the next step is to determine, how the search for literature should be conducted. To ensure comprehensiveness and systematic throughout the search, the following criteria need to be discussed and defined:

General criteria:

- Definition of search strategy
- Determination of databases and sources used for the search of literature

1st degree inclusion/exclusion criteria[115]:

- Time-frame of publications
- Language of publications
- Key words and search terms used
- Kind of literature to be considered
- Amount of text required (100% = full text)

2nd degree inclusion/exclusion criteria[116]:

- Relation to the research topic (Yes, No)
- Suitability for answering the review questions (Yes, No)
- Required quality of literature (Yes/No)
- Creation of additional value for answering the review question (Yes, No)

Optional: Metadata-Collection

Besides answering the review question by qualitatively analyzing the content of the literature, the collection of meta-data related to the publication can create additional insights. The kind of data which is collected has to be determined depending on the kind of review question (e.g. date of publication, domain of application, author or institution etc.).

Outcome STEP 4: Defined search strategy; List of databases and sources; List of key words; List of search terms used for research; Defined 1st degree criteria; Defined 2nd degree criteria;

Optional: List of required Metadata; Strategy for Metadata-Collection; Metadata collection

Application on the thesis:

General criteria:

- **Definition of search strategy:** web-based search using online data-bases of scientific publishers, universities or scientific search engines
- **Determination of databases and sources used for the search of literature:** database of Science direct[117], database of the University of Vienna[118], Google scholar[119]

[115] 1st degree criteria is applied when using the filter-functions in the database
[116] 2nd degree criteria is applied on the findings after the 1st degree criteria

1st degree inclusion/exclusion criteria:

- **Time-frame of publications:** 1995 – 2015
- **Language of publications:** English (main) and German (partly)
- **Key Words and search terms used:** maturity AND model, Introduction AND maturity AND model, application maturity model, limitations maturity model, review maturity model, criteria maturity model, assessment maturity model, criteria assessment maturity, development maturity model, approach maturity model, method development maturity model, step development maturity model, phase development maturity model, dimension maturity model, determination maturity model, aspects maturity model, maturity model, framework AND maturity AND model, Total Quality management readiness, Development AND maturity AND model, Maturity AND model AND review, maturity model, development AND maturity AND model, development AND maturity AND model, Entwicklung UND reifegradmodell, Reifegradmodell AND Industrie AND 4.0
- **Kind of literature to be considered:** research articles (journal or conference), technical reports, government reports, books, dissertations, thesis
- **Amount of text required (100% = full text):** Full text required

2nd degree inclusion/exclusion criteria:

- **Relation to the research topic (Yes, No):** Researcher judgement during screening
- **Suitability for answering the review questions (Yes, No):** Researcher judgement
- **Required quality of literature (Yes/No):** Researcher judgement
- **Creation of additional value (Yes, No):** Researcher judgement

STEP 5 – Running the research and first screening of the titles and abstracts

General:

Applying the general, 1st degree, 2nd degree-criteria, the search is carried out.

The findings after the applying the general and 1st degree criteria on the search are documented:

- databases used
- key words and search terms used
- number of results after general and 1st degree criteria

Interim Result 1: List of findings in the database (online)

After, the 2nd degree criterion is applied while screening only the title of the results online. A first exclusion of literature is carried out and the remaining findings are downloaded for screening the abstracts.

Interim Result 2: Downloaded findings (locally stored on computer)

[117] http://www.sciencedirect.com/
[118] http://bibliothek.univie.ac.at/
[119] https://scholar.google.at/

After further exclusion (based on the screening of the abstracts) the remaining findings are prepared for screening of the full texts (carried out in STEP 6).

Interim Result 3: Locally stored findings for screening of full text

Outcome STEP 5: Collection of full text fulfilling 1st and 2nd degree criteria

Application on the thesis: Results of the research see chapter 3.2.5 Results of the systematic literature review

STEP 6 – Second screening of findings (screening of the full-texts)

General:

The findings remaining after screening the abstracts in STEP 5 are reviewed in more detailed by screening the full text. By using a scale (e.g. 1 – very suitable, 7 – not suitable), the relevance of the publications for answering the review questions can be assigned and helps to structure the findings.

Outcome STEP 6: Relevant full-texts (optional: with rating regarding relevance)

Application on the thesis: Results of the research see chapter 3.2.5 Results of the systematic literature review

STEP 7 – Analysis of final set of literature

General:

The final set of literature is analyzed, whereby the most suitable literature for answering the review question is analyzed in greatest detail.

Outcome STEP 7: Answers to the defined review questions

Application on the thesis: the findings (characteristics of maturity models) are depicted in Figure 17: Concept Map - characteristics of existing maturity models

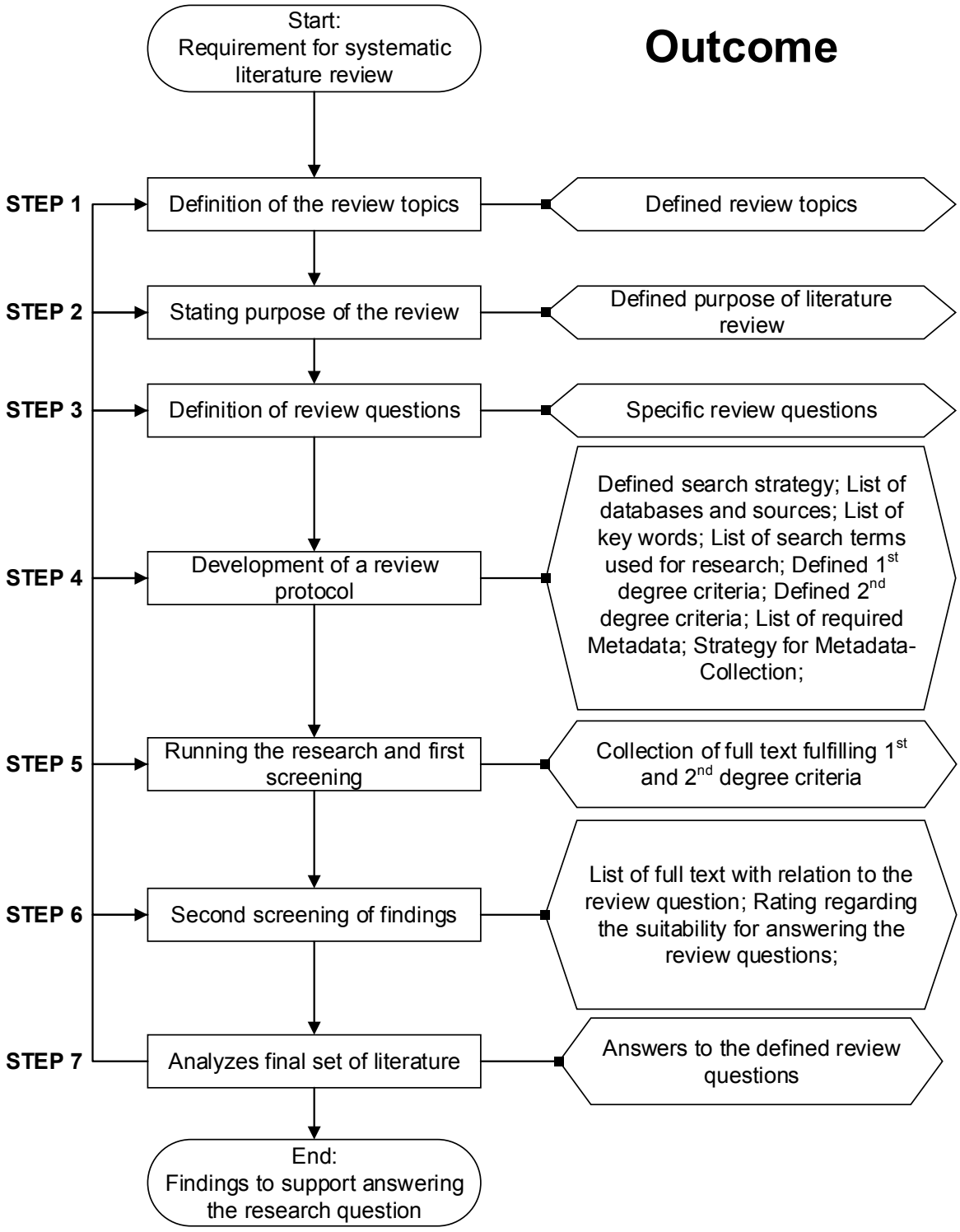


Figure 13: Step-by-step approach for systematic literature review

3.2.5 Results of the systematic literature review

The systematic literature review has been conducted through two web-based databases and one scientific search engine as these are known to contain a big number of scientific publications in relevant research areas. First, Science Direct is a database offered by a private scientific publisher, the library-database of the University of

Vienna is a public data-base and Google Scholar is an online search engine encompassing all available publications. Findings that showed up as results of more than one data-base are only considered once (removal of duplicates). The following tables (Table 6 - Table 8) are summarizing the results after applying the 1st and 2nd inclusion/exclusion-criteria. Furthermore, the exact words and phrases entered into the search-engine of the database are listed. The other criteria (e.g. year of publication, language etc.) has been applied as described in the procedure for conducting the systematic literature review (see chapter 3.2.4).

- **Search-result data-base "Science Direct":**

Table 6: Search Results - Database of Science Direct

Search Term (as entered)	Results after 1st degree criteria	Results after 2nd degree criteria and after filtering non accessible results (=downloaded results)
maturity AND model	110	18
Introduction AND maturity AND model	0	0
application maturity model	5	1
limitations maturity model	0	0
review maturity model	2	0
criteria maturity model	0	0
assessment maturity model	4	0
criteria assessment maturity	1	0
development maturity model	3	1
approach maturity model	1	0
method development maturity model	147	3
step development maturity model	23	1
phase development maturity model	66	2
dimension maturity model	57	1
determination maturity model	86	0
aspects maturity model	97	0

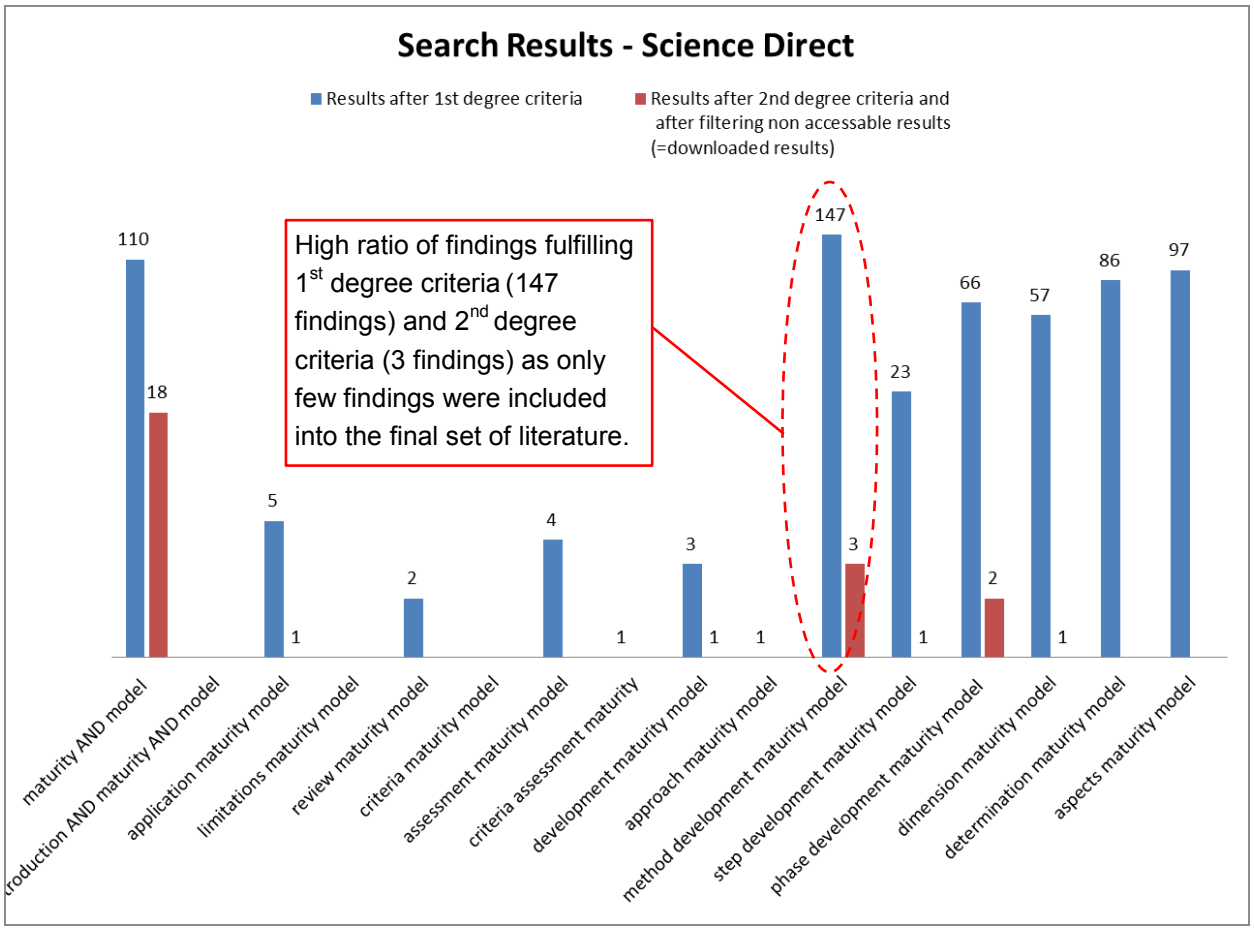


Figure 14: Search results after 1st and 2nd criteria - Science Direct (log-scale)

- **Search-result data-base of the University of Vienna:**

Table 7: Search Results - Database of the University of Vienna

Search Term (as entered)	Results after 1st degree criteria	Results after 2nd degree criteria and after filtering non accessible results (=downloaded results)
"maturity model"	966	15
framework AND maturity AND model	52	0
Total Quality Management Readiness	17	2
Development AND maturity AND model	140	3
Maturity AND model AND review	28	2

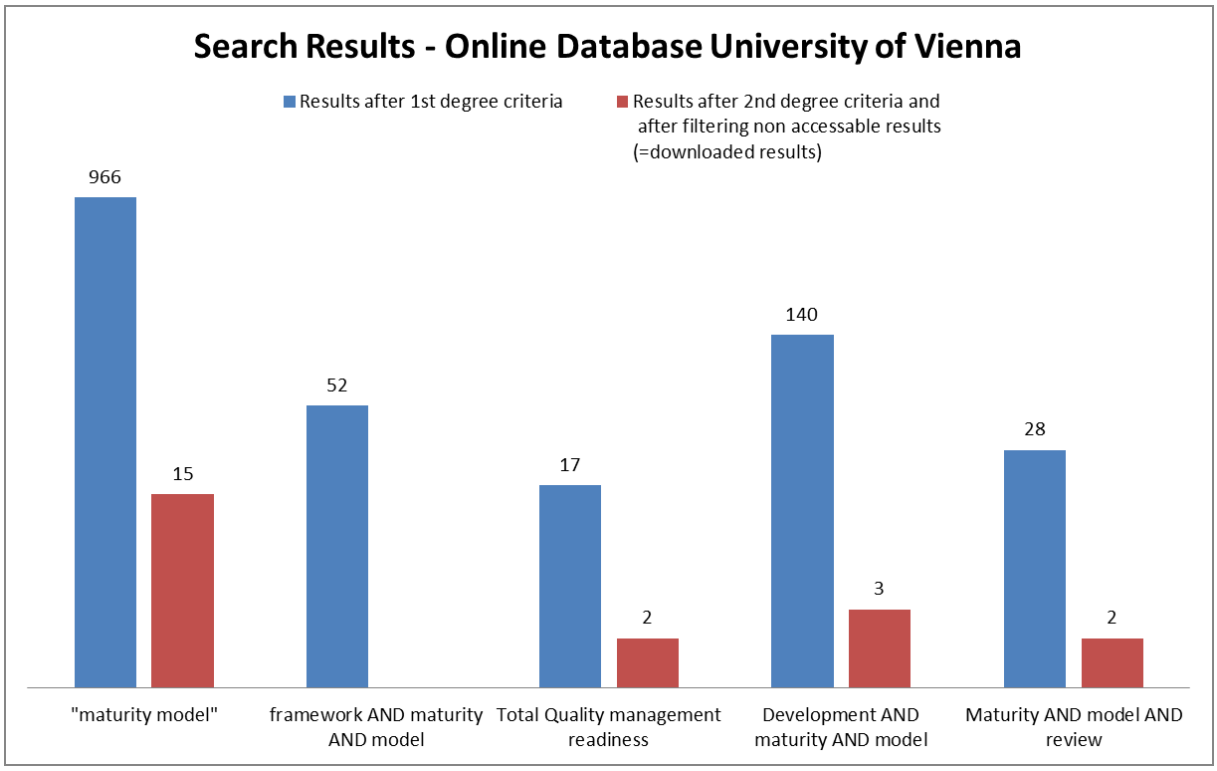


Figure 15: Search results after 1st and 2nd criteria – Library University of Vienna (log-scale)

- **Search-result scientific search engine "Google Scholar":**

Table 8: Search Results - Database of Google Scholar

Search Term (as entered)	Results after 1st degree criteria	Results after 2nd degree criteria and after filtering non accessible results (=downloaded results)
"maturity model" (first 30 pages of results considered - sorted by relevance)	1100	19
development AND maturity AND model	37	1
development AND maturity AND model	16	1
Entwicklung UND Reifegradmodell	1360	4
Reifegradmodell AND Industrie AND 4.0 (first 6 pages of results considered - sorted by relevance)	0	0

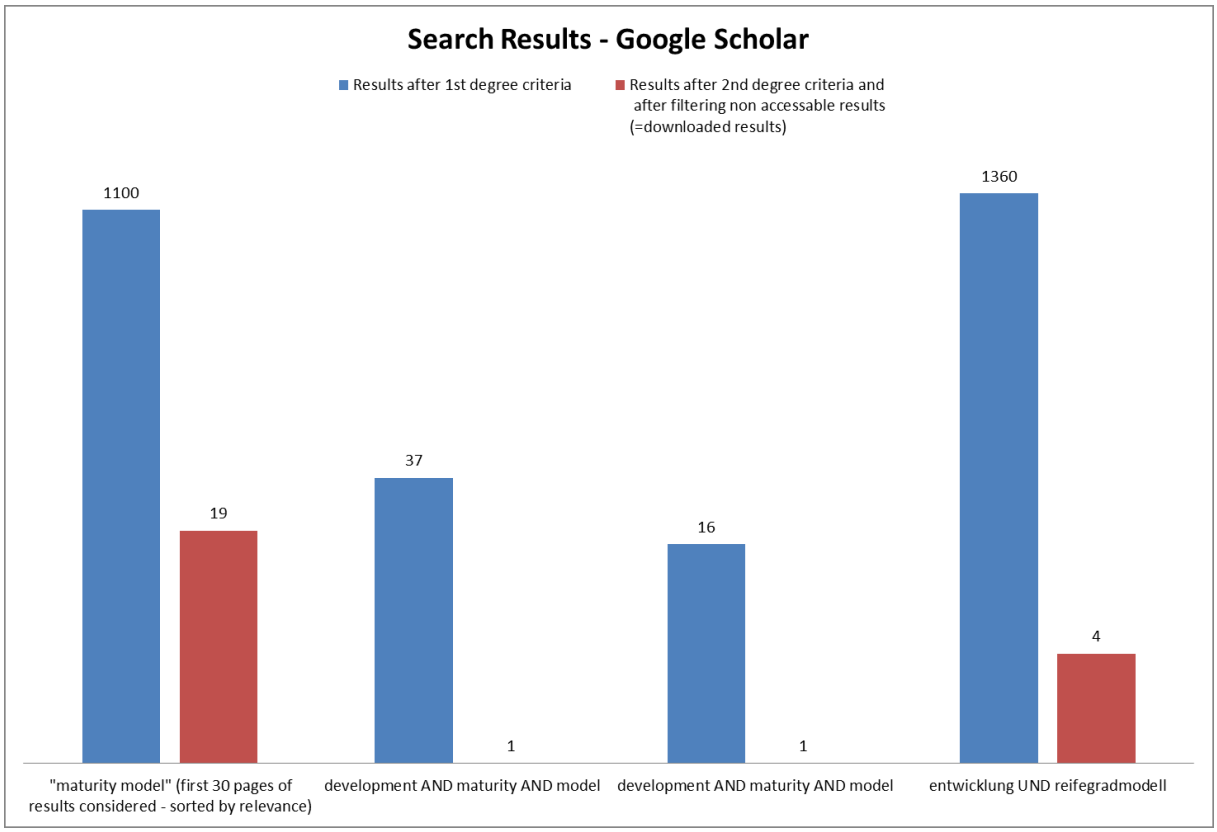


Figure 16: Search results after 1st and 2nd criteria - Google Scholar (log-scale)

After applying the 1st degree criteria in all three data-bases more than 4300 findings have been generated (including duplicates). As literature related to maturity models is getting increasingly popular (see Figure 8: Timeline of publications in maturity model research (number of articles) the number of domains-of-application is increasing as well. Maturity models with characteristics relevant for the development of the Industry 4.0 Maturity Model are assigned to mostly technical domains (e.g. lean management, maturity in digital operations etc.), which results in a high number of publications not considered after applying the 2nd degree criteria[120]. As a result, the number of 4318 publications fulfilling the 1st degree criteria is reduced to 74 included into the final set of literature. The drastic reduction of publications is also explainable with the time constraints in this thesis. As scanning thousands of results regarding suitability could not be carried out, only the most relevant (according to order of relevance from search engine) have been screened. Another reason for the low number of included publications can be found in the intended use of maturity models. They are often developed as tools applied by consulting companies which are not interested in offering the exact procedure how the model has been developed. Mostly, only superficial information about the development process is offered and the focus lies on pilot-testing and proving the applicability of the model.

[120] Criteria: Relation to the research topic, Suitability for answering the review questions, Required quality of literature, Creation of additional value for answering the review question (Yes, No)

Overall, the defined goals of the systematic literature research have been reached which are:

- Increase the understanding about maturity models and their development
- Capture the breadth of research in maturity model development
- Collect input for the development of the Industry 4.0 Maturity Model
- Ensure that no maturity model suitable for the assessment of the Industry 4.0 Maturity exists

The findings of the literature review are depicted in a concept map that summarizes the characteristics existing maturity models own. Thereby, the sub-topics of the concept map are aligned to the review questions defined before carrying out the systematic literature review.

3.2.6 Summary findings systematic literature review

As the models presented in literature have been applied successfully in practice, the characteristics depicted in the following concept map equal a summary of potential characteristics of the Industry 4.0 Maturity Model. The concept map (Figure 17) is followed by 4 detail-views (Figure 18 - Figure 21) due to the A4-format required in this work.

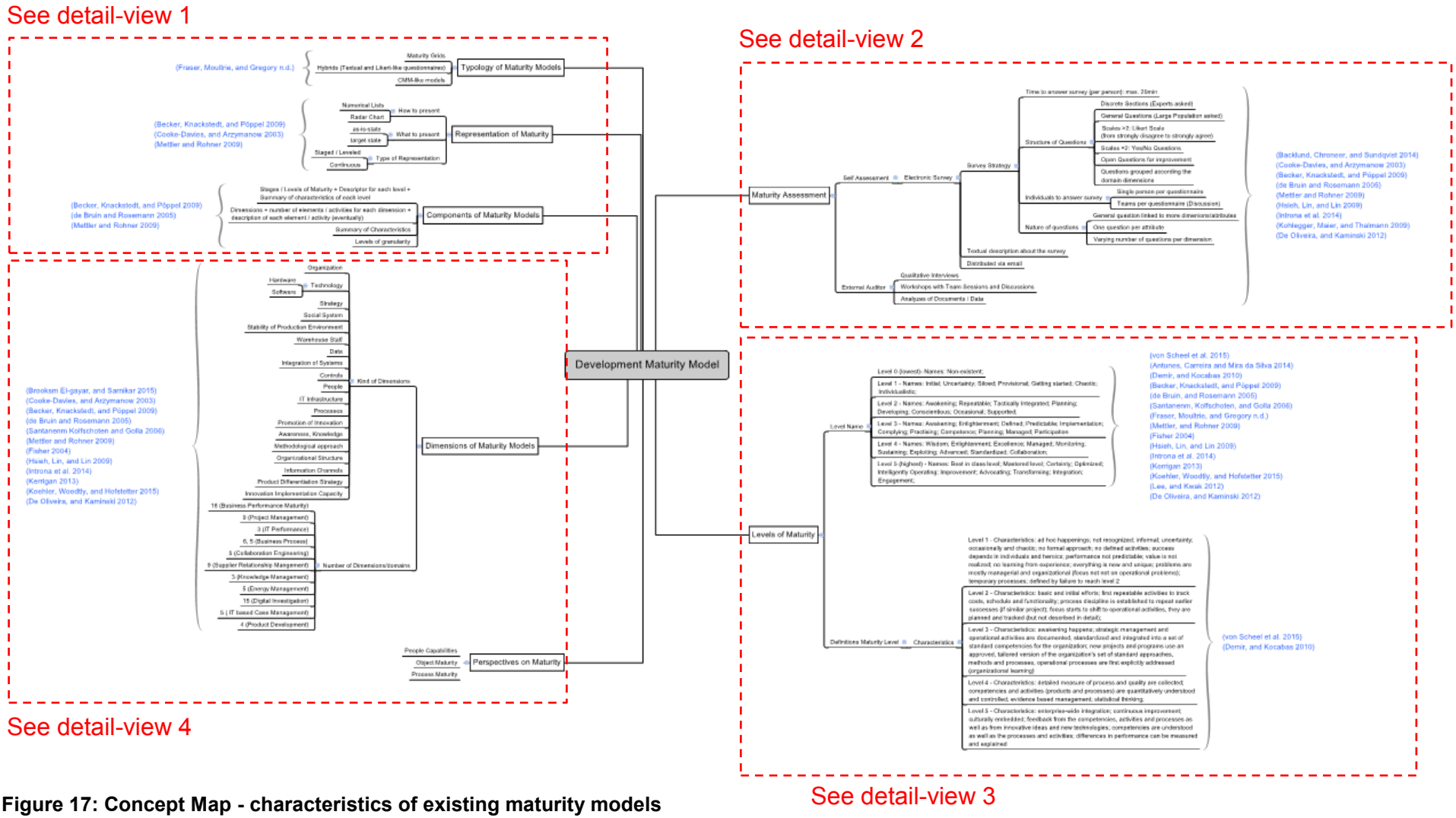


Figure 17: Concept Map - characteristics of existing maturity models

Detail Views – Concept Map

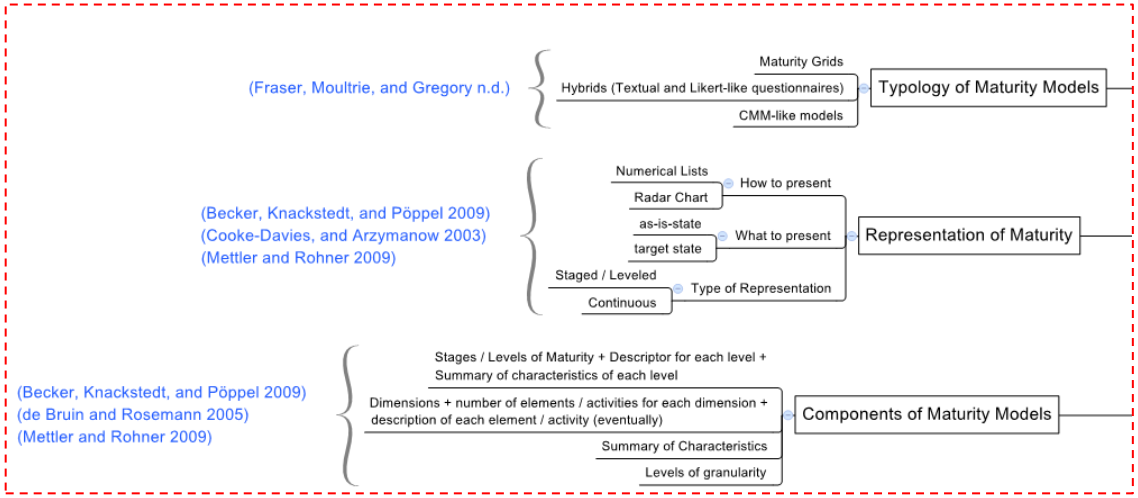


Figure 18: Maturity model characteristics - detail-view 1

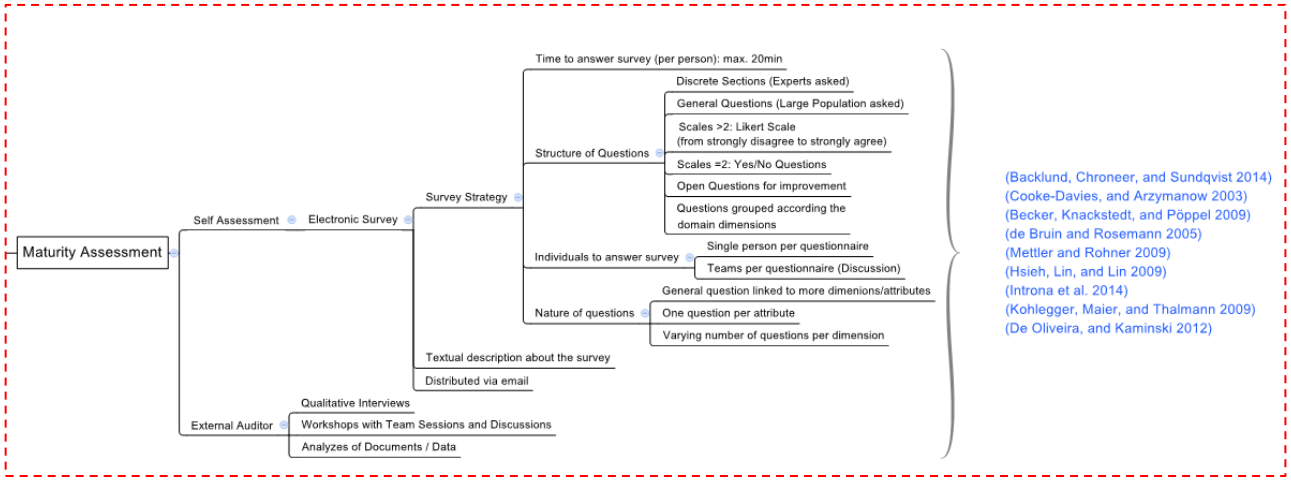


Figure 19: Maturity model characteristics - detail-view 2

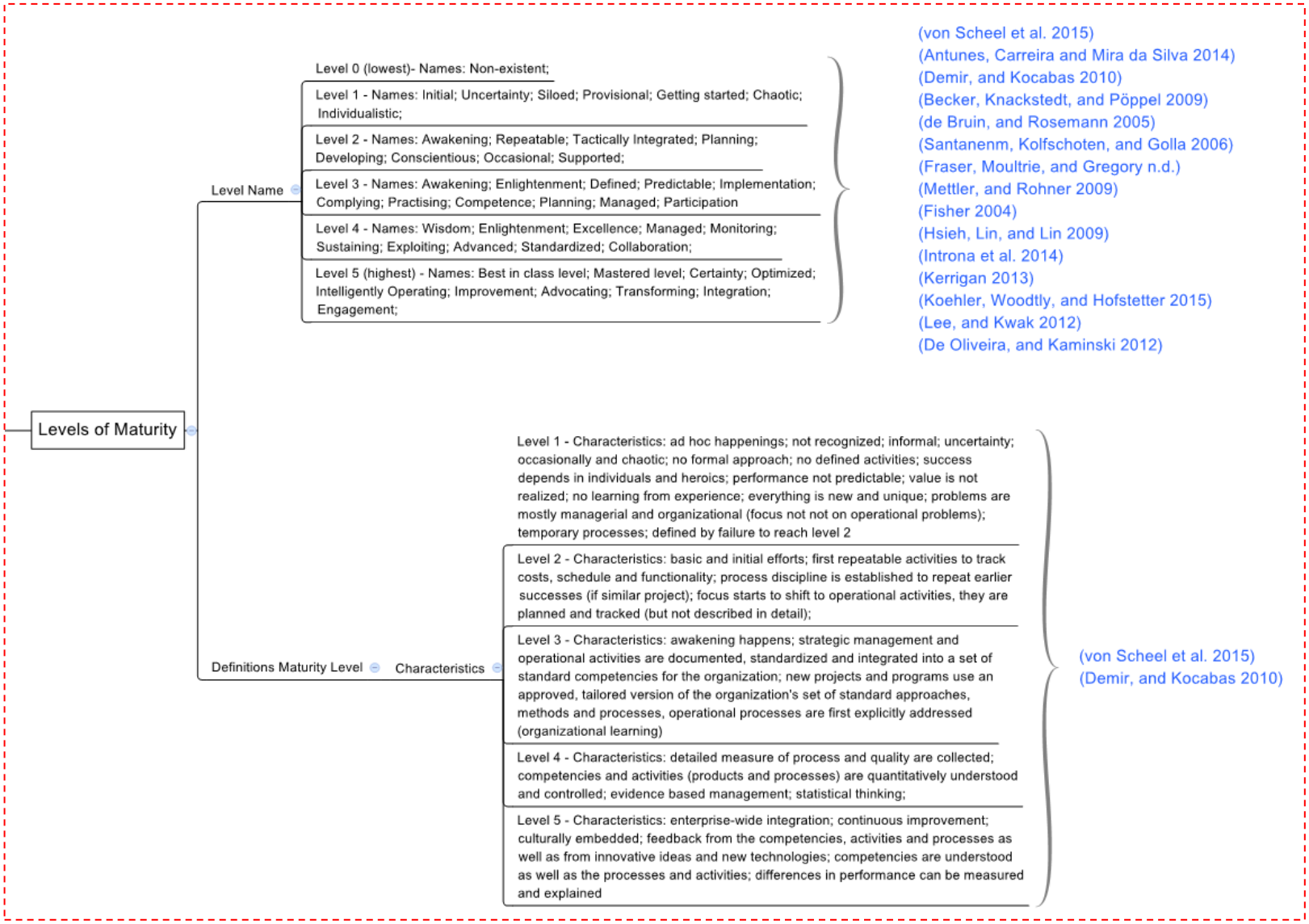


Figure 20: Maturity model characteristics - detail-view 3

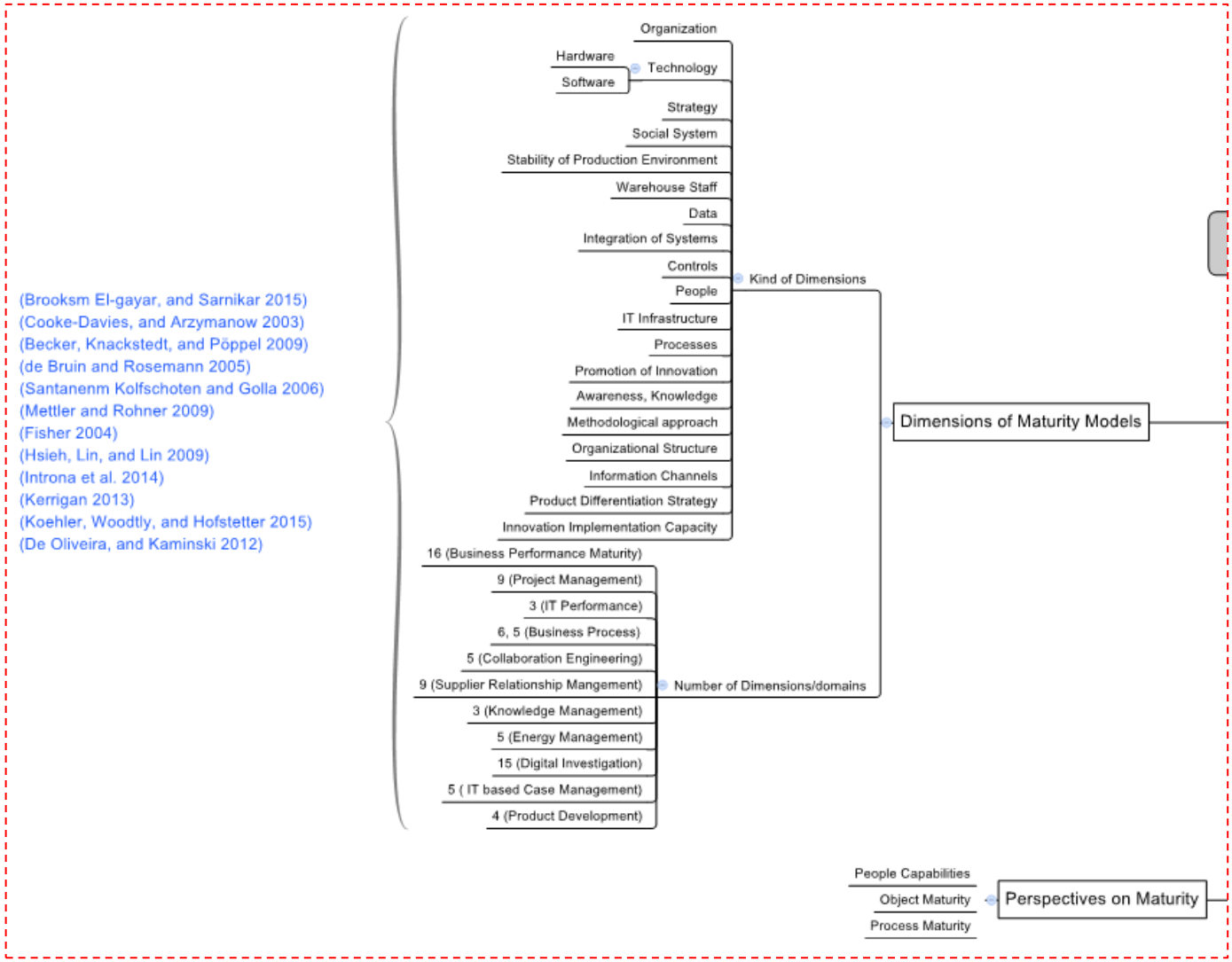


Figure 21: Maturity model characteristics - detail-view 4

The main findings depicted in the concept map[121] can be summarized as follows:

- Commonly 5 maturity levels or stages are used
- Level 1 – lowest level to Level 5 – highest level
- Each Level is named with a prominent word or phrase
- The characteristics of each maturity level are described
- The number of dimensions in which maturity is assessed reaches from 4 to 16
- The kind of dimension depends on the nature of the maturity model (e.g. Data, People, Technology, Processes, Social System, Controls etc.)
- Each maturity model consists of similar components (maturity levels, description of each level, dimensions of assessment etc.)
- The assessment of the maturity is carried out through self-assessment or with the help of external auditors
- The representation of the results is commonly offered in numerical lists and additionally by using other forms of visualization e.g. a radar-charts

3.3 Qualitative and Quantitative Survey Research utilized in the thesis

As the development of the Industry 4.0 Maturity Model is based on the design science approach, thus qualitative and quantitative research is required to satisfy the requirements of the development-guidelines.

In this chapter the theoretical background of the qualitative approach (expert interviews) and the quantitative approach (questionnaires) is presented. Moreover, the procedures for conducting the interviews (3.3.5 Procedure followed to conduct expert interviews in thesis) and for developing and distributing the questionnaire (3.3.10 Procedure followed to develop the questionnaires in thesis) are outlined. The results are used for the maturity model development in integrated manners.

3.3.1 Survey research – Introduction

Survey-based research serves for the collection of data through standardized methods. At this point, it is important to clearly distinguish the terms “survey” and “questionnaire”, as they are often used equally. The term “survey” describes the whole process starting with the identification of the research object and audience, writing, piloting and distributing the data-collection tool (e.g. questionnaire) and analyzing the results. The term “questionnaire” describes a specific way of collecting data (through questions) during the survey-process. Other tools such as case studies, field experiments or simulations could be used as well to collect the required

[121] Although the methodology of concept maps requires the insertion of cross-links between the sub-concepts, they have not been inserted in this depiction to ensure clarity

data if more efficient[122]. Scientific surveys commonly show the following characteristics: [123]

- **Systematic:** a specifically determined set of rules is followed while carrying out formal and orderly logic operations.
- **Impartial:** the units of population are selected without prejudice or preference.
- **Representative:** the units selected have to be representative of the underlying problem as well as the population affected by it.
- **Theory-based:** the survey is guided by relevant principles of human behavior and mathematical laws of probability and statistics.
- **Quantitative:** The survey assigns numerical values to non-numerical characteristics of human behavior in ways that permit uniform interpretation of these characteristics.
- **Replicable:** The survey has to be carried out in ways, so that other people using the same methods in the same ways can get essentially the same results.

3.3.2 Qualitative vs. quantitative approach

Although many researches concentrate on stressing out the incompatibilities of the two approaches, the suitability depends mostly on the issue targeted and the underlying research question. If the research question focuses on subjective experience or on understanding different perspectives, than the qualitative approach through e.g. conducting interviews sheds light on the research problem (Table 9). Qualitative research is characterized by its aim of understanding specifics of social life through the expression of words rather than numbers as data for analysis. If, on the other side frequencies, distributions or other quantifiable aspects should be analyzed, the quantitative approach has to be carried out.

Table 9: Summary of characteristics - qualitative and quantitative research[124]

Qualitative Research	Quantitative Research
Tends to focus on how people or groups of people can have (somewhat) different ways of looking at reality (usually social or psychological reality)	Tends to focus on ways of describing and understanding reality by the discovery of general “laws”
Takes account of complexity by incorporating the real-world context – can take different perspectives on board	Takes account of complexity by precise definition of the focus of interest and techniques that mean that external

[122] (Kasunic, 2005, S. 1)
[123] (Backstrom & Hursh-Cesar, 1981, S. 3–4)
[124] (Beverly, Ockleford, & Windbridge, 2007, S. 6)

	"noise" can be discounted
Studies behavior in natural settings or uses people's accounts as data; usually no manipulation of variables	Involves manipulation of some variables (independent variables) while other variables (which would be considered to be extraneous and confounding variables) are held constant
Focuses on reports of experience or on data which cannot be adequately expressed numerically	Uses statistical techniques that allow us to talk about how likely it is that something is "true" for a given population in an objective or measurable sense
Focuses on description and interpretation and might lead to development of new concepts or theory, or to an evaluation of an organizational process	Focuses on cause & effect - e.g. uses experiment to test (try to disprove) an hypothesis
Employs a flexible, emergent but systematic research process	Requires the research process to be defined in advance

More modern approaches to social science are linking the two approaches in order to neutralize the limitations the methods have. Moreover, the result from one method can help to develop or improve the other method which results in a more comprehensive approach to investigate the research issue.[125]

3.3.3 Qualitative approach – Expert Interviews

Expert Interviews are a qualitative technique to collect data information by asking a set of questions in a more or less structured way. Thereby, the "expert interviews are about a person's special knowledge and experiences which result from the actions, responsibilities or obligations… within an organization/institution"[126].

The term "expert" relates to the knowledge in the required field and is an analytical category which is generated by the researcher. Therefore, the researcher decides who is considered an expert, usually based on the person's education, experience or position. According to Littig, expert-knowledge can be: [127]

- Technical knowledge (specialized knowledge, administrative competence etc.)
- Process-related knowledge (about interactions, decision making, organizational constellations etc.)
- Interpretative-evaluating knowledge (comments, theories etc.)

[125] (Creswell, 2003, S. 13)
[126] (Littig, 2013, S. 5)
[127] (Littig, 2013)

Expert knowledge is developed through the collection of extensive experience in a certain field or area and, therefore, the expert interview relates to subjective and everyday experiences of the respondent. The person interviewed is usually willing to offer detailed information as there is no pressure-situation (compared to an oral exam or interrogation). Moreover, the asymmetric knowledge-distribution (respondent has usually an information advantage) creates a comfortable atmosphere enhanced by the fact that the answers given cannot create any disadvantageous consequences for the respondent. The most common technique while conducting an interview is the neutral approach whereby the interviewer does not classify the answers given. This clearly distinguishes the expert interview to a casual everyday-talk or interview, whereby judgements and sanctions are following the response. Thus, the neutral approach to an interview aims for eliminating the so called "costs for having an opinion" (e.g. sanctions or disapproval) and, therefore, maximizes the output.[128] Moreover, a neutral approach creates a constructive atmosphere, whereby the common goal is to create additional knowledge. The constructiveness is supported by clear willingness of the respondent to attend the interview and the common factual interest of the interviewer and the respondent in the topic.[129]

Although systematically prepared and conducted in a structured or semi-structured way, the response is unwillingly determined by a variety of influences which cannot be completely controlled (Figure 22):

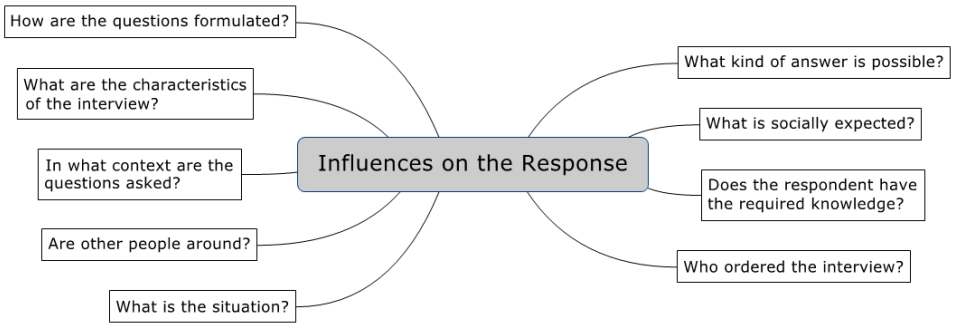


Figure 22: Influences on the response during an expert interview

These influences on the result of the interview can be assigned to three categories:

- Influences regarding the questions,
- Influences regarding the interviewer and
- Influences regarding the respondent.

Which influence dominates depends heavily on the structure of the interview, whereas two extremes are possible. The so called "structured approach" uses a prepared set of questions which are presented to each interviewee in an identical

[128] (Diekmann, 2014, S. 439)
[129] (Mieg & Näf, 2005)

way and in a strict order. At the other extreme, the interview can be completely unstructured and carried out like free-flowing conversation. In the following table the distinctions of the variables of both the structured and unstructured approach should highlight the differences:

Table 10: Differences between structured and unstructured interviews[130]

Variable	Structured Interview	Un-Structured Interview
Required preparation time	High	Low
Required contact time with respondent	Moderate	High
Analyst experience and training required	High	Low
Evaluation results and responses	Easy	Difficult
Degree of spontaneity of responses	Low	High
Depth and breadth of topic coverage	Moderate	High
Reliability and precision or responses	Moderate to High	Low to Moderate
Insight into respondent	Low	High
Overall analyst control of dialogue	High	Low to Moderate
Degree of flexibility of interaction	Low	High

In practice, most researchers follow the so called “semi-structured” approach whereby a number of open-ended questions are prepared on the topic. Open-ended questions offer guidance and ensure that the topic under investigation stays in focus on the one hand, and allow for discussing certain aspects freely and in more detail on the other hand. Based on given answers further questions encourage the interviewee to offer more details. Problems during semi-structured interviews can occur if the interviewer is not able to keep the conversation focused on the research topic and as a result cannot collect relevant data.

3.3.4 Relevance of expert interviews in thesis

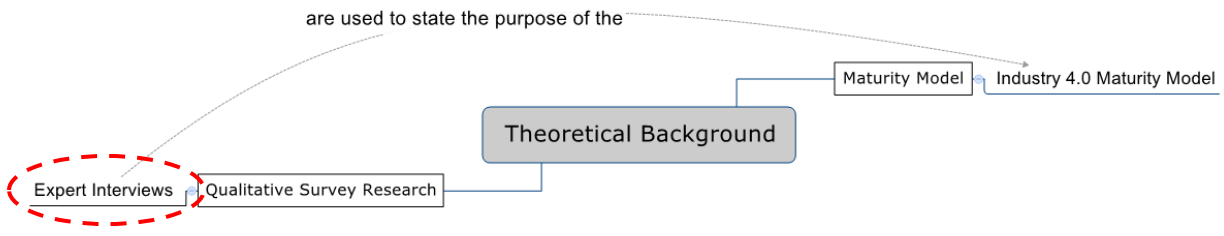


Figure 23: Relevance of expert interviews in the thesis-concept

[130] http://de.slideshare.net/poerslide/ch04-290983 (12.08.2015)

In this thesis expert interviews are used as part of the design science approach. First, the interviews are used for highlightening the problem relevance and the practical need for an Industry 4.0 Maturity Model as the experts are interviewed about real problems that Industry 4.0 creates during realization. Furthermore, possible characteristics of a maturity model applicable on the domain of Industry 4.0 can be collected. Second, the expert interviews should help to validate the design of model, its clearness and applicability as well as its contribution to research.

3.3.5 Procedure followed to conduct expert interviews in thesis

In this thesis semi-structured interviews are carried out face-to-face and by telephone. The following procedure for conducting the expert interviews has been derived from literature and reflected with research associates with experience in that area:[131] [132] [133]

STEP 1 – Definition of purpose and leading questions

General:

In a first step, the expert interview has to be integrated into the overall research approach. Therefore, the purpose and goals have to be defined, whereby two basic aspects should be reflected:

- Should the interview deliver explorative new insights
- Should the interview serve to validate existing insights

At this stage, knowledge about the research topic is required to define the leading questions that serve as guidance during the interviews. The leading questions aim for keeping the focus on the area of interest and give structure to the interview. Commonly, the leading questions reflect the sub-topics of the underlying research topic.

Outcome STEP 1: Defined purpose and leading questions

Application on the thesis: The purpose of conducting expert interviews can be found in high-lightening the practical need of the maturity model as well as in the determination of requirements the Industry 4.0 Maturity Model should fulfill. Additionally, the state of Industry 4.0 in praxis should be examined and success factors to realize Industry 4.0 collected.

Leading questions expert interview: see Appendix 7.1 Guideline Expert-Interviews

[131] https://www.uni-trier.de/fileadmin/fb4/prof/VWL/APO/4207ws0102/efstudien.pdf
[132] (Mieg & Näf, 2005)
[133] (Hiermansberger & Greindl, o. J.)

STEP 2 – Selection and contacting of experts

General:

After the topic under investigation and leading questions are defined, suitable experts have to be selected and contacted. While researching potential experts the, following guiding questions should be reflected:

- Does the expert possess the required knowledge?
- Can my affiliation be a problem (e.g. competing organizations)?
- Can the interview be carried out within the foreseen time-frame?
- How could the interview be conducted (face-to-face, telephone etc.)?
- Is the list of expert representative or one-sided?

After finishing the list of potential experts, they are be contacted by email and telephone. Explaining the purpose and goals of the interview by telephone increases the willingness of the expert to participate drastically.

Outcome Step 2: List of expert willing to conduct an interview

Application on the thesis: the expert interviews are conducted anonymized, therefore, no list showing names or affiliations of experts is provided in this thesis. The list of experts is known to the researcher and is treated confidentially.

STEP 3 – Preparation of interview guideline and conduction interviews

General:

Conducting a semi-structured interview requires the interviewer to lead the expert through the topics by asking leading questions and giving starting-points for further discussion. Following consistent structures helps the expert to state his/her opinion and simplifies the evaluation of the content in later steps. The following structure could be followed:

1. Introduction of the interviewer and the affiliation
2. Explanation of the purpose of the interview as well as the goals
3. Optional: Confirmation that interview is recorded (voice-recorder)
4. General questions to create comfort
5. Leading questions within the focus areas
6. Closing argument or discussion (informal)

The interview guideline should printed and used during the interview as a protocol to take notes (creates impression of interest and professionalism).

Outcome Step 3: Interview guideline

Application on the thesis: please see Appendix 7.1 Guideline Expert-Interviews

STEP 4 – Evaluation of the interviews

General:

After all interviews have been conducted, the results are evaluated using qualitative research methods. Commonly, the recorded interviews are transscripted which eases processing the content and extracting necessary data. The following procedure can be followed for evaluating the results in qualitative manners:[134]

1. Development of categories reflecting the hypotheses or leading questions
2. Determination of coding-units (e.g. one word, sentences or paragraphs)
3. Paraphrasing of the units (bring coding-unit to short and meaningful phrase)
4. Generalization and reduction of phrases (enable link of phrase to the leading questions)
5. Assignment of units to the created categories
6. Interpretation of results

Outcome Step 4: Generalized content of the interviews assigned to the hypotheses or leading questions

Application on the thesis: the results of the expert interviews are integrated into the development of the Industry 4.0 Maturity Model (see 3.3.6 Expert interviews Industry 4.0 – Results)

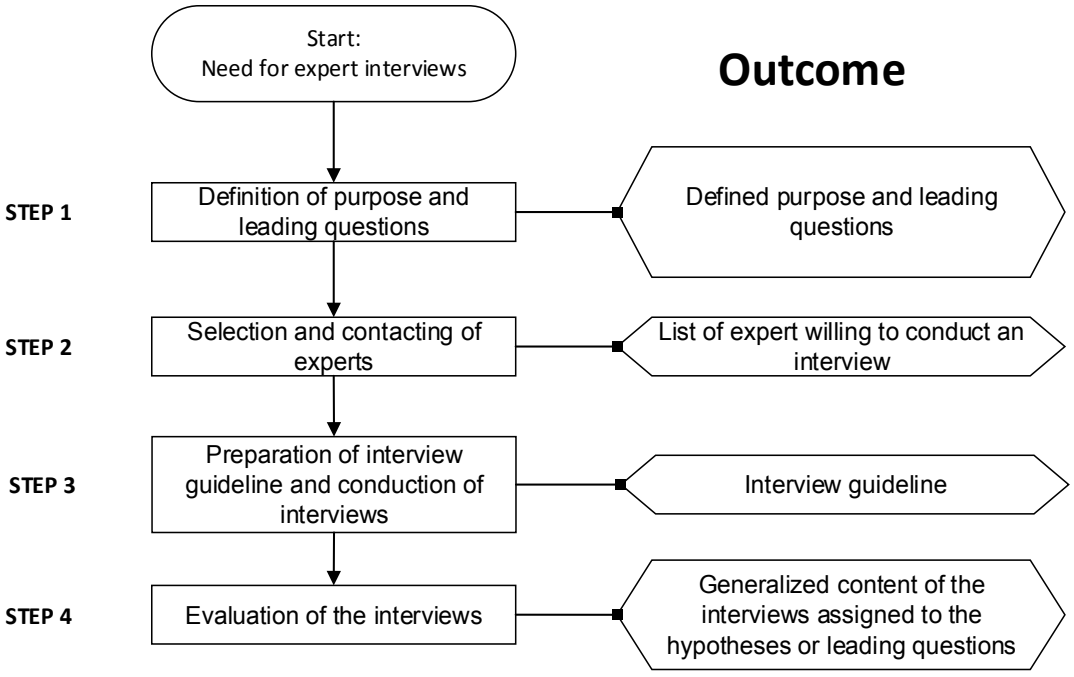


Figure 24: Procedure for conducting expert interviews

[134] (Mayring, 2010)

3.3.6 Expert interviews Industry 4.0 – Results

Six experts from the fields of academia, research, consulting, and companies engaging in Industry 4.0 have been interviewed. Each interview lasted between 45min and 90min and was carried out face-to face or via skype in a semi-structured manners following a developed interview guideline (see Appendix 7.1Guideline Expert-Interviews). In the following, a summary including the answers of all experts is presented whereby the expert's responds have been transformed to general statements as the interviews have been carried out anonymously.

- **Leading Question 1:** What is the expert's affiliation and what are their focus-areas in Industry 4.0?

Summary of Answers:

The experts contacted and interviewed are affiliated to institutions in research and business development as well as consulting companies. Moreover, experts engaged in private companies in the field of software-solutions and telecommunications have been included. Thereby, the expert's focus areas within Industry 4.0 are: Logistics 4.0; M2M-Communication; Networking of physical objects; Data-based supply chain management; Clustering of companies to engage in Industry 4.0-projects (business development); Digital operations and data-based business development; Data-security and safety in Industry 4.0; Innovation policy in Industry 4.0 and User technology experience in Industry 4.0.

- **Leading Question 2:** What is the meaning of "Industry 4.0" to the experts, what do they understand as "Industry 4.0"?

Summary of Answers:

Some experts consider the propagated "Vision of Industry 4.0" as too abstract and not applicable in real-life-industry, as companies have difficulties when transforming e.g. the vision of Cyber Physical Systems to the shop floor. Although hard to capture as a whole, distinct factors of Industry 4.0 seem realistically implementable and beneficial such, as the digitalization and virtualization of the entire value chain through modern Information and Communication Technology. Moreover, utilizing the close integration of the company's elements along the value chain as well as the close interconnection with the market, new business models and business opportunities can be created. The majority of the experts state the "generation, collection and utilization of data of all kind along the value chain" as one of the core aspects of Industry 4.0.

- **Leading Question 3:** Where do the experts see the main benefits resulting from Industry 4.0?

Summary of Answers:

When asked about the main benefits created through Industry 4.0, the re-structuring of value chain (and supply chain) resulting in cost reductions is stated as one core benefit. The autonomous communication between elements along the value chain and the global information exchange in real-time enables holistic, model-based scenario forecasts. Communication in the business world will shift drastically from the present exchange of information via people to data-based communication between software-systems, whereby the availability of all required information leads to an optimized decision making process. The re-construction of the value chain is thereby based on the utilization of data which is exchanged using standardized systems and interfaces.

The concept of “data-to-cash” allows for the creation of new business models, increased customer orientation and the individualization of products and services based on immense amounts of data about customers. The costumer life-cycle is integrated into the product life-cycle resulting in the manufacturing of individualized “smart products” at the costs of mass products.

Another main benefit is the decrease of labor-costs, which is important - especially in high-labor-cost countries like Austria or Germany. Related to labor-costs, the monitoring of job-performance as well as the clarification in cases of damage can be drastically improved (e.g. through sensors in working-equipment).

Finally, resource-efficiency and the alignment to new laws e.g. CO2-climate-regulations can be achieved through the concepts of Industry 4.0.

- **Leading Question 4:** What are the main impacts of Industry 4.0 on the business world?

Summary of Answers:

Industry 4.0 brings the partner-network along the value chain closer together, whereby smaller enterprises might be forced to align themselves to the requirements of the more powerful stakeholders (e.g. alignment to the IT-systems of the bigger enterprises). Exemplary, in the domain of logistics, hauler-companies have to align their logistics-processes to the real-time based manufacturing of production companies which creates immense challenges.

Resulting from the real-time production, the plannability and forecasting of processes is reduced and more, smaller lot-sizes are going to be ordered, produced and shipped. This will affect companies that are relying on long-term forecasts (e.g.

production and delivery of same amount of goods every month) drastically. The problem of reduced plannability is going to be enhanced by the increasing system-complexity resulting from Industry 4.0.

All experts state the utilization of big amounts of real-time data, which is created through modern Information and communication technology, is going to change the way of conducting business sustainably, as the value chain will be interconnected irreversibly by a data-highway. Companies might communicate through software-systems based on real-time data (Internet of the Things), which enables new partner-networks and replaces face-to-face communication of company's representatives. These partner-networks are developed and kept alive only as long as cost-optimized business-conduction is ensured, using real-time cost-calculation and real-time market information about prices and availability of production-factors. Various customer-data is collected and will lead to the development of new products and services, whereby the selling-focus will shift from creating revenue by only selling products to the creation of long-term dependencies through the creation of customized services ("don't sell the machine, sell the service" or "data to cash").

Resulting from these wide-reaching impacts of Industry 4.0 on the business world, job-profiles will change as well. Skilled workers, especially with suitable IT-skills are going to be favored, as pure manual work might disappear in the long-term. One expert argued that the job-profile of a "data engineer" will develop with the goal of basing all business-activities on the analysis of relevant big data.

- **Leading Question 5:** What is the state of Industry 4.0?

Summary of Answers:

All interviewed experts agree that Industry 4.0 is a "hyped topic", whereby disillusionment is occurring and the realistically implementable concepts will remain. Advantageously, the hype around Industry 4.0 shifts the production-industry back in focus and encourages stakeholders to invest. The hype of the topic also depends on the industry under focus as the progressiveness of companies in Industry 4.0 varies with the industry (e.g. companies like Apple and Google engage in Industry 4.0 since their foundation). On the contrary, manufacturing companies with a historically high degree of manual and mechanized work (e.g. traditional Car-OEMS) take longer to change their mindset as their company-culture is aligned to a more traditional approach of business operations. As a result, the companies that traditionally engage in Industry 4.0-similar domains are going to lead this industrial revolution, while some old-fashioned manufacturing companies will only implement a few concepts Industry 4.0 foresees.

Currently, companies seem to engage in Industry 4.0 as it is an easy way to "show innovativeness" and modernization, which mostly results an isolated technology-

focus. Especially small companies, which seldom capture the potential of Industry 4.0, tend to feel pressure to acquire new technology - as otherwise - they might have to deal with market-disadvantages. Furthermore, the implementation of new technology is distributed uneven as parts of the "Industry 4.0-technology" such as drones for package-delivery (Amazon) or autonomous driving for improved mobility (Google) already exist, while SMUs commonly focus on more traditional technology to create revenue. Although the utilization of new technology is seen as an enabler to Industry 4.0, their integration into the organizational structure and processes still creates fundamental problems. Enhancing the integration-problem of new technology is the fact that the importance of the IT-departments decreased since the 1990s, which results in a lack of skilled employees to implement and run these modern technology-systems.

Beside the strong technology-focus, companies currently do not have a clear idea about what benefits they actually want to create by engaging in Industry 4.0, which results in uncertainty and consequently in inactivity.

Another experts stresses, that "soft-factors" of Industry 4.0 are more difficult to implement (e.g. suitable labor-regulations or organizational structures), compared to "hard factors" such as new technology.

Moreover, experts from the field of consulting state that companies expect the external consultant to take the lead in the Industry 4.0 realization which is "programmed to fail", as only the stakeholders within the company possess the required company-specific knowledge to align their activities to Industry 4.0.

- **Leading Question 6:** What are the current problems while realizing Industry 4.0?

Summary of Answers:

Consistently, the experts state, that the high complexity of Industry 4.0 builds the main barrier which prevents companies from engaging. The high complexity is triggered by the numerous concepts that are encompassed by the overall-vision of Industry 4.0. They make the topic "too big to handle it" and not transferrable to an operational level. Furthermore, the outcomes and benefits of Industry 4.0 are not clearly calculated, demonstrated and communicated to the companies (e.g. Return on Investment). As a result, decision makers and stakeholders within the companies are not willing to invest into this uncertain area.

A lack of knowledge about the benefits of Industry 4.0 also leads to the "mindset" that companies think they already engage in Industry 4.0 or, that the current approach to conducting business "does not need to be changed". The underlying problem is the unwillingness to change existing structures and systems (e.g. IT-systems), as high

organizational effort and investments are required. Additionally, the realization of Industry 4.0 can only be carried out in the long-term and by focusing on the "big picture" which reduces the motivation of managers to get active.

Another main issue stressed by the experts is the narrow view on technological aspects of Industry 4.0. Technology (e.g. 3D-printing) is commonly seen as the core of Industry 4.0 and other important factors, such as the alignment of organizational structure or the integration of new technology into the operational processes is neglected. Moreover, the implementation of new technology goes hand-in-hand with additional expenses e.g. for maintenance which requires the creation of new sources of revenue. Two experts argue that the approach of developing the company's USP based only on the implementation of modern technology is likely to fail in the long-run, as technology can easily be acquired and consequently substituted.

Related to the technological requirements, the current utilization of countless different IT-systems on vertical levels and along the value chain prevents the envisioned "end-to-end-engineering" of Industry 4.0. The integration of new systems into existing solutions and the standardization of fragmented IT-systems are stated to be hinder the realization of Industry 4.0 in the near future.

The network-integration through modern Information and Communication Technology (ICT) leads to problems regarding dependency of companies and issues of data security and intellectual property rights. Especially traditional companies have little experience in "automatic internal and external exchange of information" (through data or open innovation) and are therefore critical. Moreover, certain stakeholders within a company have no interest in increasing transparency and consequently, data is often not utilized and placed in "data graves".

Regarding smaller enterprises, experts argue that SMUs fear to destroy their existence when engaging in Industry 4.0 (as they get transparent and thus their USP often substitutable). And as stated already, SMUs might be forced to align their business activities, their structure and their IT-systems to bigger companies unconditionally, as Industry 4.0 allows for fast exchange of partners through the digital eco system.

On the employee level, the fear of being replaced by robots and software-systems clearly slows down the realization process as first awareness has to be created.

On the customer-side the experts argue that sometimes no clear requirements for the Industry 4.0-products and services exist, which reduces the customer's willingness to pay for these goods and services. Therefore, awareness for the new business models and products has to be created first, whereby existing customer relations are hard to change. Moreover, not all manufactured products are suitable for the integration into Industry 4.0 (e.g. screws or nails), as no individualization and no real-

time demands are likely to be required. In these areas (and in services such as logistics) long-time planning and forecasting are argued to be more beneficial for the companies.

Finally, framework-conditions are still not suitable for the realization of Industry 4.0, especially in terms of data security and privacy (e.g. laws against cyber threats).

- **Leading Question 5:** What are the main criteria to successfully realize Industry 4.0?

Summary of Answers:

The experts agree on the need for clarity to the question - “why a company wants to engage in Industry 4.0”? – as no clear purpose of engagement obviously leads to little motivation for action. Clarity about the reason for engagement is closely related to the need for more knowledge about for Industry 4.0, the creation of awareness among employees and long-term thinking on the management level.

On a technological level, suitable manufacturing technology, IT-Infrastructure and the standardization of fragmented systems (e.g. ERP-systems) along the entire value chain are considered the main enablers to realize Industry 4.0. Related to the implementation of modern technology is the existence of concepts to create and process information (in the form of data) vertically and horizontally. Data has to be treated as “production factor” which can create revenue, whereby the creation of new business models suitable for selling data are essential.

Regulations related to data-security have to be introduced as their non-existence hinders the realization of Industry 4.0 fundamentally. Furthermore, technological standards should be determined and education-programs for developing required skills (mainly IT-skills) among employees and students ease the implementation and operation of new technology. Employees have to be able to work interdisciplinary along the entire value chain to handle the created system-complexity of Industry 4.0.

As part of the “soft factors” of Industry 4.0, experts stress the alignment of Industry 4.0 with the organizational structure and the operational processes as a pre-condition.

On the front-end, new business model have to be developed and sales and customer-relations reinvented.

Finally, the determination of concrete projects in Industry 4.0 helps to create awareness within the company and among customers, as visible show-cases are created.

Core Statements of the Industry 4.0 Expert Interviews

Based on the contents of the expert-interviews core statements can be extracted:

1. The vision of Industry 4.0 as a whole is to “big to be realized”, but certain sub-concepts (e.g. utilization of big data in production) will remain.
2. The main benefits are seen in optimized, model-based decision making processes, the reduction of labor costs and additional revenue streams through the utilization of big data.
3. The generation, collection and utilization of big amounts of various data are the main aspects of Industry 4.0 (data to cash).
4. Selling propositions will increasingly include after-sale services to create long-term dependencies (don’t sell the machine, sell the service).
5. Currently, companies see technology as the core of Industry 4.0 which creates a narrowed approach and neglects other important enablers.
6. The pace of realization of Industry 4.0 heavily depends on the branches under focus as certain industries already engage in Industry 4.0-related business (e.g. software solutions or high-tech electronics).
7. Industry 4.0 results in databased and real-time information-exchange through software systems instead of human interaction.
8. Companies lack a clear idea about their benefits when engaging in Industry 4.0 which results in uncertainty and inactivity.
9. The high complexity of Industry 4.0 builds the main barrier for companies to engage, as uncertainty prevents the required investments.
10. Disillusionment currently follows the hype around the futuristic scenarios of Industry 4.0, but the hype shifts the production-industry back in focus and encourages stakeholders to invest into Europe’s manufacturing sector.
11. Industry 4.0 is likely to be realized faster in countries with high labor-costs due to the replacement of manual labor by machines and robots
12. Reduced ability to plan and eliminated long-term forecasting resulting from real-time business-activities in Industry 4.0 are disadvantageous for certain branches (e.g. logistics or smaller enterprises).
13. The job-profiles will change drastically and favor employees with high skills related to Information and Communication Technology (ICT).

3.3.7 Quantitative approach – Questionnaires

Using questionnaires to collect survey-data is becoming increasingly popular, mainly due to modern technology that allows for including a large number of people quickly, easy, efficiently and at low costs. Questionnaires are commonly used to collect factual and straightforward information in order to classify people, their circumstances or relating behavior. Beside factual information, the collection of basic attitudes or

opinions of a group relating to an issue can be measured (e.g. customer satisfaction regarding a new website). Questionnaires can be carried out postal, electronic, face-to-face or on the telephone. Conducting questionnaires in electronic ways offers certain advantages as the respondents can complete the survey by themselves in their own time and the form can be returned easily per email.[135]

Table 11: Summary - Advantages and disadvantages of channels for conducting questionnaires (modified)[136]

Advantages of methods	Disadvantages of methods
Can contact a large number of people at a relatively low cost (postal, telephone)	Response rates can be low (postal) and refusal rates high (telephone, F2F)
Easy to reach people who are spread across a wide geographical area or who live in remote locations (postal, telephone)	There is little control over who completes a postal questionnaire, which can lead to bias
Respondents are able to complete postal questionnaires in their own time and telephone call-backs can be arranged for a more convenient time	Postal questionnaires are inappropriate for people with reading difficulties visual impairments and those who do not read the intended language
Telephone questionnaires can make it easier to consult disabled people	Postal and phone questionnaires must be kept relatively short
F2F questionnaires can make it easier to identify the appropriate person to complete the questionnaire	F2F and phone questionnaires require the use of trained interviewers
F2F questionnaires can be longer than postal and phone questionnaires, collect more information and allow the use of “visual aids”	F2F questionnaires are time consuming for respondents, more costly and more labour intensive than other methods

3.3.8 Questionnaire design

The survey results crucially depend on the design of the questionnaire as it serves as the main interface between the researcher and the subject of investigation. The following common procedure can be followed: [137]

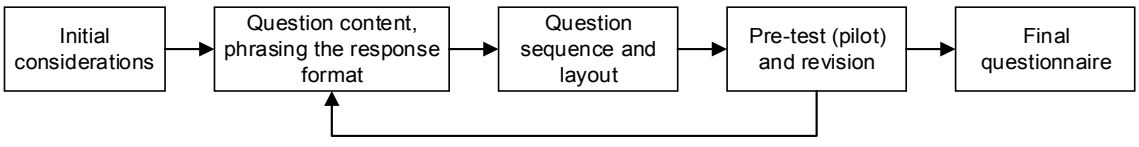


Figure 25: Process for designing a questionnaire[138]

[135] (Creswell, 2003)
[136] (Kirkless Council, 2012, S. 4)
[137] In the chapter „Methods“ a more detailed step-by-step approach is developed which is carried out in the thesis

Following some basic rules increase the quality of the questionnaire drastically; as most individuals answering the questionnaire do not possess deep knowledge about the research topic, simple and familiar words have to be used. Technical terms, jargon or slang-words can create confusion. Words, which can be interpreted differently, should be avoided as well as ambiguous meaning of words. Asking for too many things at a time (double-barreled questions) or loading questions with too much information overly demand the respondent. The answer-choices have to be distinct and mutually exclusive to avoid confusion (detailed rules for question development – see chapter 3.3.10 Procedure followed to develop the questionnaires in thesis).[139]

Types of Questions

Traditionally, questions are distinguished in two basic groups. First, so called "open ended"- questions do not follow any categories but should encourage a meaningful answer based on the subject's knowledge, opinion or feelings. Open ended questions are mainly used in explorative studies, where the outcome is uncertain. Moreover, if the possible variations of the answers given are expected to be high, or if the answers given should not be influenced in any way, open-ended questions are preferable as no categories, scales or pre-defined answer-topics are leading the thoughts of the respondent (bias through leading question). The person interviewed uses its own knowledge- and reference systems to answer the questions, which frees the answer from any leading-biases.

Open ended questions might be advantageous, but possess drawbacks such as motivating the respondent to write the often long answers using hand writing or digital media. Also the kind of response given to open questions is critical as open questions tend to be answered by persons who want to state a radical opinion or a bad experience rather than by the person who wants to state an "average answer"[140]. Generally, the response rate to open questions is lowered due to the time needed for completion (motivation-problem) and uncertainty about the expected answer (expectation-problem). The utilization of open-ended questions in research tends to decrease in the past years as the effort and costs increased compared to closed-ended questions, which can be processed and evaluated easily in software-supported manners.[141]

"Closed-ended" questions are the second basic type of questions which offer the same set of answer-choices in the same sequence to each respondent. Thereby, several structures of questions and the answer choices have to be distinguished: [142]

[138] (Kirkless Council, 2012, S. 3)
[139] (Marsden & Wright, 2010, S. 264)
[140] (Schnell, 2012, S. 83)
[141] (Beverly u. a., 2007)
[142] (Schnell, 2012, S. 88)

- **Dichotomous Question:** is a question which has two possible responses such as Yes/No, True/False or Agree/Disagree. These answer-choices have to fully exclude the other to not force the respondent to one of the choices.
- **Multiple Choice Question:** is a question which contain more answer-options whereby the respondent is required to choose one (or more options).
- **Ordinal Scale Question:** is a question which contains a set of answer-items whereby the respondent is asked to rank the range of items or to choose from an ordered set.
- **Interval Scale Question:** is a question which ask the respondent to rate aspects such the agreement strength, likelihood or satisfaction on a scale.
- **Ratio Scale Question:** is a question which requires the respondent to answer in a measurable way (e.g. hours spent in front of PC per day)

The utilization of scales requires certain pre-conditions as the basic construct has to be one-dimensional (measureable in one dimension) and the answers have to be suitable for being coded from and into categories (intervals). The intervals should have an equal meaning to each respondent and the categories and category-boarders should be conceived in the same way. In short, the transformation of the respondent's opinion to a scale for categorizing the answers requires that each respondent projects his or her opinion into a numeric value in an identical way. Scales are commonly constructed numerically with related meanings of the scale-intervals. For example: a closed ended question asking for the level of agreement would commonly use a scale reaching from 1 to 5 (or 7), whereby 1 represents "strongly disagree" and 5 represents "strongly agree".

The most widely used scale for measuring personality traits and opinions is the so called "Likter Scale". Developed in 1932 by Rensis Likert, this scale aimed for measuring people's attitudes towards an issue by offering five response alternatives - from strongly approve (1) to strongly disapprove (5). These so called "Likert-like" questionnaires are widely known, and therefore the time for answering the questions is shortened (compared to other scales). Coding the answers is easy as only a single number represents the respondent's opinion which makes the Likert-scale a quick, efficient and inexpensive method to collect data. However widely used in research, Likert-scales show some weaknesses, mostly when examining complex research issues. Attitudes of people in reality exist on a vast, multi-dimensional continuum. Likert offers a one-dimensional scale with only 5-7 choices which tends to fail measuring these continuum-like attitudes of respondents. Moreover, the sequence of questions may influence the answers given on the questions, and extreme positions (strongly agree and strongly disagree) are less likely to be chosen. In the following a short summary to present the weaknesses and strengths of Likert-scales is presented:

Table 12: Strengths and weaknesses of Likert-scales

Likert Scale Strengths	Likert Scale Weaknesses
Simple to construct	Social desirability bias: portray themselves in a more socially favorable light rather than being honest
	Central tendency bias: participants may avoid extreme response categories
	Acquiescence bias: participants May agree with statements as resented in order to "please" the experimenter
Likely to produce a highly reliable scale	Lack of reproducibility
Easy to read and complete for participants	Validity may be difficult to demonstrate

3.3.9 Relevance of questionnaires in thesis

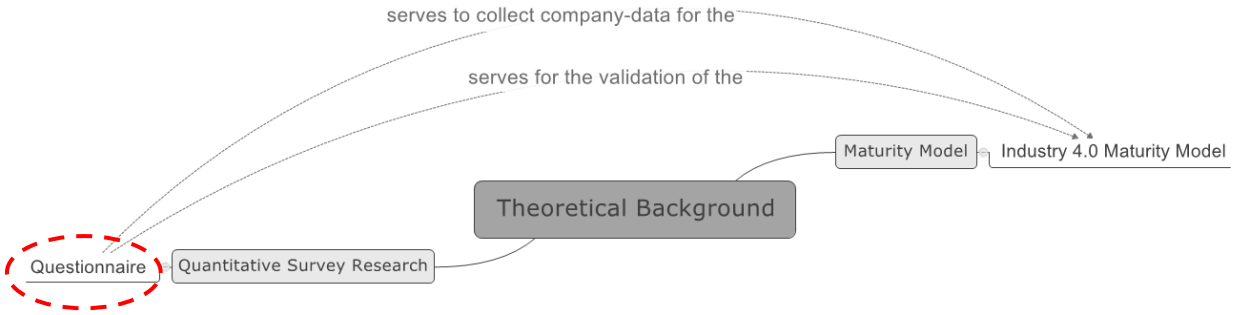


Figure 26: Relevance of questionnaires in the thesis-concept

The purpose of questionnaires in the thesis is twofolded. First, the practical relevance of the Industry 4.0 Maturity Model's content is carried out by asking experts in Industry 4.0 to rate the importance of the maturity attributes for realizing Industry 4.0 (validation of the model's content). Second, the measurement of the attributes maturity within the company is measured through questionnaires (self-assessment of maturity).

3.3.10 Procedure followed to develop the questionnaires in thesis

The following step-by-step procedure includes detailed descriptions regarding question-design, layout and criteria to ensure unbiased response: [143] [144] [145]

[143] (Diem, 2002)
[144] (Thayer-Hart, 2010)
[145] (Kasunic, 2005)

STEP 1 – Definition of objectives and basic design

General:

In a first step, the purpose and goals of the questionnaire are explained. Moreover, the researcher is required to explain how the questionnaire is integrated into the overall approach of the scientific work.

The following guiding-questions have to be answered to ensure sufficient design of the questionnaire:

- Who is the audience targeted with the questionnaire: (e.g. sample group or population, age, position, education, language barriers)
- Required size of the sample? (if not whole population)
- What is going to be measured? (e.g. attitude, knowledge, skills, goals, intentions, aspirations, behaviors, practices, perceptions)
- What kind of measure scale is used? (Yes-No, Rating-Scale, Rank ordering)
- What kind of data collection method is used? (e.g. mailed, web-based, poste)

Outcome STEP 1: Defined purpose and objectives of the questionnaire and basic questionnaire design

Application on the thesis: The purpose of the two questionnaires used in this thesis can be stated as follows:

1. Questionnaire

The first questionnaire is used to assess the practical importance of the maturity model's content. The expert ratings regarding the practical importance (1 – not important, 4 – very important) of the maturity attributes for realizing Industry 4.0 serves as the input for the weighted calculation of the companies maturity.

2. Questionnaire

The second questionnaire is used for self-assessing the Industry 4.0 within a company. The maturity-distinction of the attributes are measured by asking executives in the company to respond to the questionnaire (1 – not distinct, 5 – very distinct).

STEP 2 – Detailed questionnaire design

General:

After defining the basic design, the detailed development of the questionnaire and questions is conducted. The following practical tips derived from literature should be reflected and considered during the development:

- Title the questionnaire
- Start questionnaire with an introduction
- Start with non-threatening questions
- Put personal questions to the end
- Put most important questions up front
- Arrange questions in logical order

- Formulate question from the perspective of the audience
- Avoid questions which are suggesting an answer (leading questions)
- Ask objectionable questions
- Do not ask demanding questions
- Use mostly closed-ended questions
- Only one item per question
- No loaded questions
- Include middle category to the answer-choices
- Use plain and brief language

Sub-steps carried out during the detailed questionnaire design:

- **STEP 2.1** Determination of questions to be asked

It is essential to distinguish between the information theoretically needed to answer the underlying research question (internal question) and the questions practically suitable to be asked to the audience (external question). The core element of the questionnaire design can be seen in the transformation of the information required by the researcher into the items measurable in the audience. Thereby, the external questions can be assigned to four categories:

- Attributes: personal information about the audience
- Attitudes: questions how people feel about something
- Beliefs: questions about the opinion of individuals
- Behaviors: questions about presence, frequency and degree of behavior

Outcome STEP 2.1: Determination characteristics of questions asked

- **STEP 2.2** Generation of internal questions

The internal questions are based on the defined survey objective. In a first draft, questions are formulated for each item, for which data should be collected. The draft-questions are discussed and clarified in the research team. The questions can be prioritized to ensure that the most important questions will appear in the final questionnaire (distinguish “nice to have” and “must have”- data)

Outcome STEP 2.2: Prioritized list of internal questions

- **STEP 2.3** Transformation to external questions

The internally defined questions have to be rewritten, rewritten to be able to quantitatively assess responses. The transformation is commonly carried out by transforming the open-ended internal questions into closed-ended questions. Besides, the wording used in the internal questions is rarely suitable for asking the respondents directly. Therefore, the internal questions have to be re-written in a way, that the targeted audience understands them properly and can give clear answers.

With regard to the wording, the following aspects should be considered:

- Terminology suitable for the audience
- No phrases that are not uniformly understood

- No double negatives in the question
- No cryptic, vague or too precise wording
- Usage of simple words and short questions

Outcome STEP 2.3: List of external questions

➢ **STEP 2.4** Design of the question-sequence and overall questionnaire-layout

After the external questions are in their final state, the design of the questionnaire has to be determined:

- Length of the questionnaire: the more interested the audience is in the topic, the longer the questionnaire can be
- Questions to be included: three groups - must know, useful to know, nice to know (nice to know-questions are the first ones to be reduced, if required)
- Sequence of the questions: demographic questions, substantive questions, filter questions which do not apply to everybody
- Non-question text: survey title, instructions how to answer questions, transition paragraphs, definitions
- Questionnaire layout
  - paper-based: leave space on the page, no questions split across two pages, answer choices on the right site, uniform fonts, keep conventions, no cross-references between questions, No ALL CAPS-letters, use page numbers, survey title on all pages in header or footer;
  - web-based: server must be able to handle the data-traffic, unauthorized individuals must be prevented from participating, prevent duplicate submissions, ensure privacy, questions screen-per-screen or rolling, insert welcome screen, explain who to get to next screen, allow interruptions, testing with different platforms

Outcome STEP 2.4: Determined sequence-design and layout of the questionnaire

➢ **STEP 2.5** Development of survey documents

After the final questionnaire is developed and ready for distribution, the documents for supporting the survey must be created, such as:

- a pre-notification letter
- a questionnaire cover letter or an introduction screen (web-based)
- a reminder letter or email to support completion
- a thank-you letter or email

After the creation of these documents the time-line of their distribution has to be determined.

Outcome STEP 2.5: Survey documents

After carrying out these five sub-steps, the questionnaire exists in its final state and is ready to be distributed for pilot testing which results in feedback for further improvements.

Overall Outcome STEP 2: Questionnaire ready for pilot testing

Application on the thesis: in this thesis two questionnaires have been developed:

1. Questionnaire distributed to assess the practical importance of the maturity model's content (see Appendix 7.3 Questionnaire Expert-Rating „Importance of the Attributes")

2. Questionnaire for self-assessing the Industry 4.0-maturity within the company
(see chapter 4.2.4 Assessment of the attribute's maturity in the I40MM)

STEP 3 – Pilot testing of questionnaire

General:

After the development of the final questionnaire, a testing with a suitable target population has to be carried out. Members of the research team are not considered pilot testers, as they are unlikely to unveil flaws in the questionnaire. The pilot testing exposes weaknesses in the questions, the questionnaire layout, the process or the technology. Feedback to the following aspects should be collected:

- If the questions are understandable
- If the order of the questions seems logical
- If the answer choices are appropriate
- If all terms used are understood
- If the navigating through the questionnaire
- If the layout of the questionnaire is optimal
- If the font and size is easy to read
- If the survey wake the interest if the respondent
- If the time need for completion is appropriate
- If there is any problem related to input (web-based)
- If the navigation is easy (web-based)
- If error messages are friendly and helpful (web-based)

Outcome STEP 3: Improved questionnaire based on the feedback

Application on the thesis: The questionnaire ready for pilot testing has been distributed to 5 Students with the task to test for aspects such as: understandability, clarity and simplicity of using the digital form, length of the questions or time to finish the questionnaire. The final version of the questionnaire has been developed including the feed-back from the test-persons and additional discussion within in the research team.

STEP 4 – Distribution of the questionnaire

General:

After all documents necessary for conducting the survey are completed and the respondents have been notified (pre-notification letter), the questionnaire is ready for distribution. The following aspects should be considered:

- Control, how the questionnaire is distributed (no duplicates, correct respondents using PINs)
- How long the duration of the response window should be
- How the response rate is monitored
- When to send reminders for completion to the respondents

Outcome STEP 4: Distributed questionnaires

Application on the thesis: first, a list of recipients has been developed.

Questionnaire 1: the questionnaire for assessing the practical importance of the maturity model's content has been distributed to 123 experts (German speaking area). Within the foreseen time-frame 23 questionnaires have been returned.

Questionnaire 2: the questionnaire for self-assessing the company's Industry 4.0 maturity has been distributed to 15 companies which are already engaged in Industry 4.0. Within the foreseen time-frame 2 questionnaires have been returned, whereby the pilot testing of the maturity model does not require many returned questionnaires (one per company to assess the maturity).

STEP 5 – Analyzes of the results

General:

After the deadline for completing the questionnaire has been met, the response data is collected and available for analyzes. Using a web-based questionnaire brings the advantage that the responds already exists digitally and can be processed in software-supported manners.

Outcome STEP 5: Results of the questionnaire

Application on the thesis: the results of the questionnaires are presented in the related chapters.

Questionnaire 1: see chapter 4.2.8 I40MM details - Expert-ratings of maturity dimensions

Questionnaire 2: see chapter 4.2.9 I40MM details - Questionnaire for self-assessment of the maturity

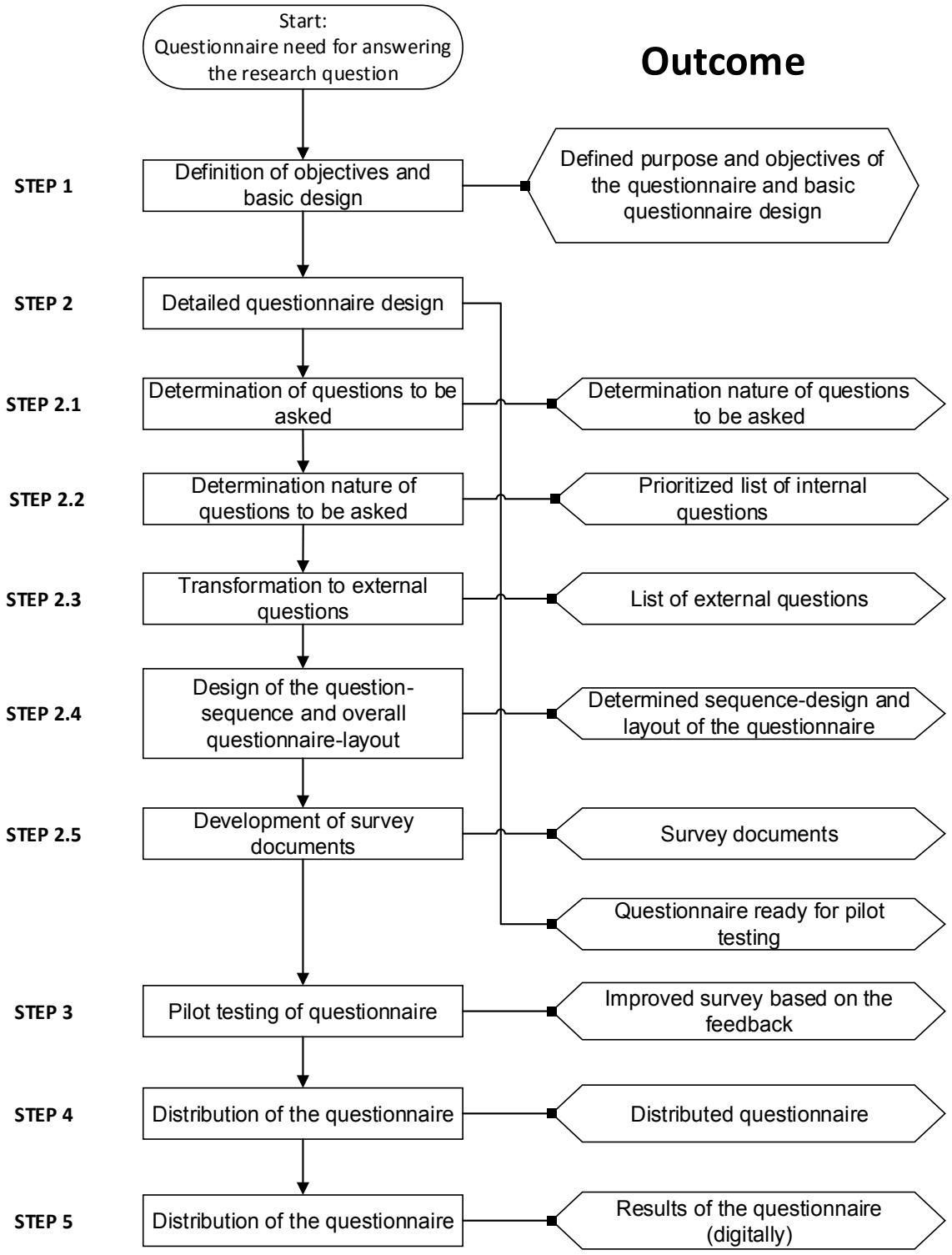


Figure 27: Procedure for the development of a questionnaire

4 Model-Development and the resulting Industry 4.0 Maturity Model (I40MM)

In this chapter the scientific basis of the I40MM is presented as well as the derived procedure to develop the model.

4.1 Development of the Industry 4.0 Maturity Model

The Industry 4.0 Maturity Model is developed using a multi-methodological approach. Thereby, the following methodologies have been applied:

- Concept Mapping
  (see 3.1 Methodological Approach at a glance – Using Concept Mapping)
- A Systematic Literature Review
  (see 3.2 Systematic Literature Review on Maturity Models)
- Expert Interviews
  (see 3.3.3 Qualitative approach – Expert Interviews)
  Questionnaires
- (see 3.3.7 Quantitative approach – Questionnaires)

The development of the Industry 4.0 Maturity Model is based on the design science approach offered by Hevner et al (2004). Two widely accepted and distributed frameworks offered by De Bruin & Rosemann (2005) and Becker et al. (2009) are building on hevner's foundations and will be used for deriving the step-by-step procedure. Thereby, the framework of De Bruin & Rosemann is considered a rather general framework depicting the six main steps for developing a maturity model:

Figure 28: Phases of framework for development a maturity model[146]

Based on this fundamental process for developing a maturity model, the work of Becker et al. depicts the maturity model development in greater detail[147]. Moreover, Becker et al. offer the application of the seven guidelines of the design science approach on maturity model development. Therefore, Becker defines seven requirements (R1 – R7) which have to be fulfilled during the maturity model development.

[146] (de Bruin & Rosemann, 2005)
[147] The references R1 – R7 in the figure are references to the guidelines offered by Hevner et al.

Table 13: Application of design research guidelines in the maturity model development; R1 - R7

Design Science Research Guideline	Description when applied on maturity model development	Requirement-Number in Becker et al.	Symbol
Guideline Nr. 1 and Guideline Nr. 4	Comparison with existing maturity models	Requirement 1	R1
Guideline Nr. 6	Maturity models must be developed iteratively (e.g. step-by-step); All principles and premises for the development (as well as usefulness, quality and effectiveness of the artifact) must be evaluated iteratively – for the problem of delimiting the evaluation criteria.	Requirement 2	R2
Guideline Nr. 3	The evaluation of all (intermediary) results must be carried out with appropriate scientific methodology.	Requirement 3	R3
Guideline Nr. 5	A multi-methodological procedure (variety of well-founded research methods) is carried out and the research methods must be finely attuned	Requirement 4	R4
Guideline Nr. 2	The relevance of the problem solution proposed by the maturity model must be demonstrated as well as the domain of the maturity model, intended benefits and conditions for its application.	Requirement 5 Requirement 6	R5 R6
Guideline Nr. 7	The presentation of results and the documentation must be targeted on the needs of specific user groups as well as the condition of its application. The design process of the maturity model must be documented in detail (parties involved, applied methods and results).	Requirement 7	R7

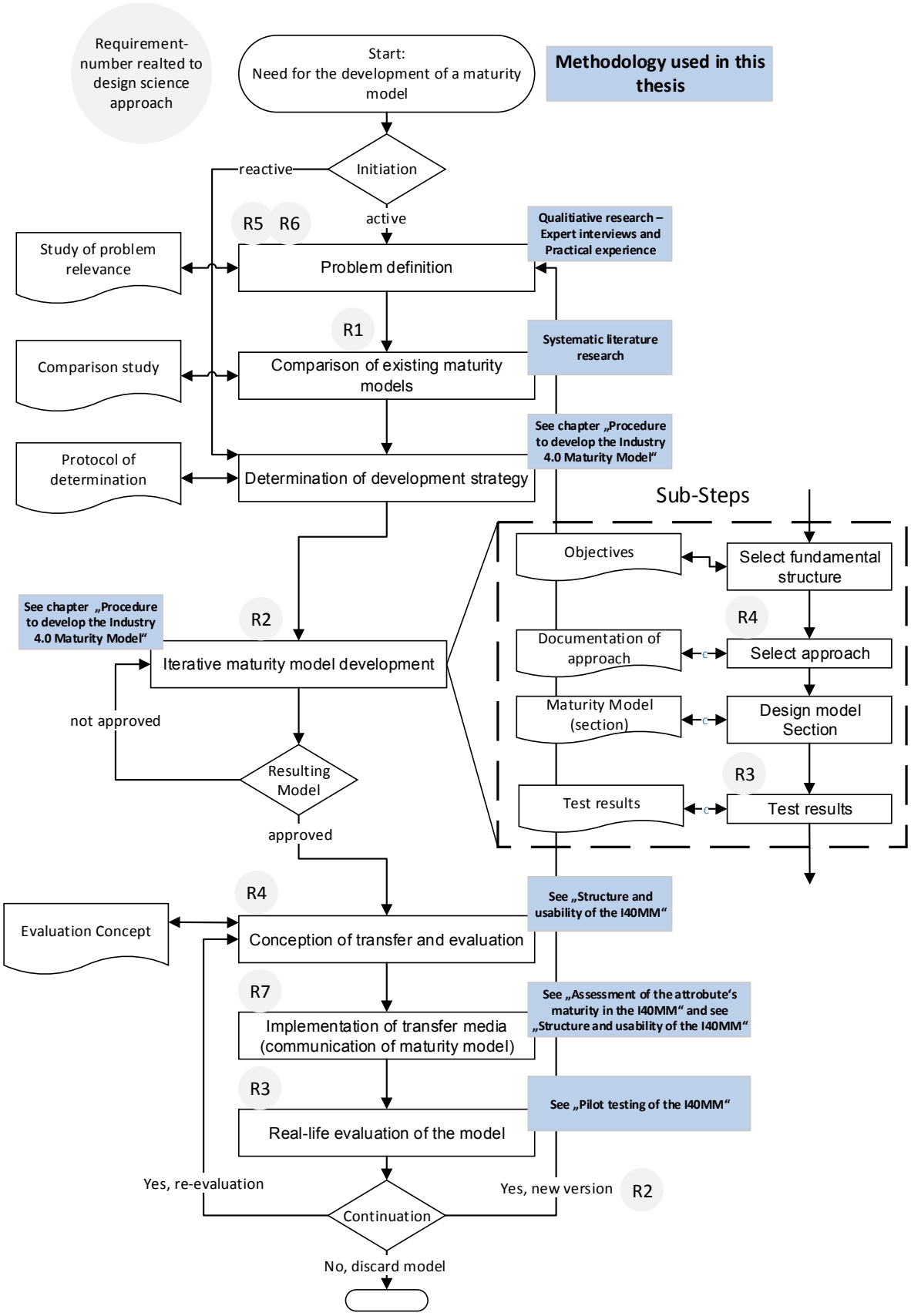


Figure 29: Procedure-model for developing maturity models based on by Becker et al.[148]

[148] (Becker et al., 2009, p. 218)

Building on these two frameworks and by including additional literature, the following procedure consisting of four main phases is developed:[149] [150] [151] [152] [153]

Phase 1 – Define

Problem Definition

At the start of the development-process, the relevance of the intended model has to be proved. This can be conducted via a literature research revealing existing issues that could be targeted with a maturity model. Otherwise, expert interviews can be used to define possible improvements created by the developed model. Overall, the actual demand for the maturity model must be clearly demonstrated.

Review and comparison of existing maturity models

To prove the need for the intended model, a literature research has to be carried out on existing maturity models. Possible results are, that the intended model is the first of its kind, or it is an improvement or adaption of existing models targeting the same domain. A comparison of the existing models allows for determining the actual research gap on the one hand, and enables the developers to include successfully tested models and their approaches into the development of the new model.

Determination of the development strategy

Based on the result of the review, several strategies for developing the model can be followed:

- The development of a completely new model
- The enhancement of an existing model
- The combination of several models into a new one
- The transfer of structures or contents from existing to new application domains

Outcome Phase 1: Determination of purpose and goal of the maturity model

Application on the thesis: see chapter 4.2.1 General Introduction to the I40MM

Phase 2 – Scope

Scoping the desired model should set boundaries for possible applications as well as the focus of the model which results in the determination of the model's characteristics.

Criterion	Characteristic			
Focus of Model	Domain Specific		General	
Development Stakeholders	Academia	Practitioners	Government	Combination

Figure 30: Decisions when scoping a maturity model[154]

[149] (Brooks, El-Gayar, & Sarnikar, 2015)
[150] (Fraser u. a., 2002)
[151] (Mettler & Rohner, 2009)
[152] (Backlund u. a., 2014)
[153] (Gove & Uzdzinski, 2013)
[154] (de Bruin & Rosemann, 2005, p. 3)

Definition of focus of the maturity model

Although most of the existing maturity models are already developed for the application in specific domains, the focus has to be set and limitations have to be described. A description of the domain targeted and the delimitations to similar domains are necessary to avoid wrong applications of the model.

Research for understanding the domain specifics

An extensive literature research on the domain of application has to be carried out for two reasons:

- To adapt the maturity model to domain specifics such as regulations, laws or driving forces within the domain
- To enable the design of the domain specific model in terms of maturity levels and characteristics, maturity dimensions etc.

Development stakeholders

While developing the maturity model certain stakeholders have to be included into the development process for validation and feedback. The stakeholders have to be determined and their role within the development process explained.

Outcome Phase 2: Determination of the model's characteristic specified for the domain of application

Application on the thesis: see chapter 4.2.2 Scope of the I40MM

Phase 3 – Design

While designing the maturity model the following aspects have to be discussed:

Criterion	Characteristic		
Audience	Internal		External
	Executives, Management		Auditors, Partners
Method of Application	Self Assessment	Third Party Assisted	Certified Practitioner
Driver of Application	Internal Requirement	External Requirement	Both
Respondents	Management	Staff	Business Partners
Application	1 entity / 1 region	Multiple entities / single region	Multiple entities / multiple region

Figure 31: Decisions when designing a maturity model[155]

Design maturity levels

The maturity level characteristics have to be defined as well as the requirements for reaching a certain level.

Design maturity assessment

A strategy for assessing the maturity in standardized and objective manners is essential and the core of the maturity model. Basically, there are two ways of carrying out the assessment:

[155] (de Bruin & Rosemann, 2005, p. 3)

- Self-assessment: electronic surveys (e.g. using questionnaires)
- Assessment via external auditor (e.g. qualitative interviews, workshops)

Combining these two approaches (e.g. validation of the survey-results by interviewing experts within the organization) can improve the reliability of the assessment.

When carrying out the survey using questionnaires two basic strategies can be followed:

1. Survey with discrete sections (more questions possible) answered by experts in the domain (less respondent and therefore no generalization)
2. Survey for large number of individuals with more general questions (more respondent but with less depth)

Design mode of representation

How to present:

Depending mostly on the nature of application, the audience targeted and the complexity of a domain, a mode of how the assessed maturity should be presented to the audience has to be determined. Commonly, a combination of numerical lists (grade of maturity of each dimension represented numerical) and a radar-chart (multi-dimensional diagram) is used for presenting the maturity of all dimensions.

What to present:

The representation of the organization's maturity can consist of two main parts:

- Presentation of the as-is-state
- Presentation of the target-state

Presenting the as-it-state refers to the assessed maturity of all dimensions and shows the organization's actual maturity. After these results are available, a target-state can be defined by carrying out interviews and group-works within the organization. Defining the target-state helps the decision-makers to specify measures to increase the maturity towards the desired target-state.

Outcome Phase 3: Designed maturity model ready for pilot-testing

Application on the thesis: see chapter 4.2.3 Design of the I40MM

Phase 4 – Test

Good face validity means good understandability and relevance of the subsequent instruments.

Content validity is testing how complete the domain is represented and can be conducted through:

- Additional literature reviews
- Focus groups seeking appropriate examples related to domain components[156]

[156] If population is suitable examples should be found "easily"

Test of instruments

Any assessment instrument used has to be tested for validity and reliability. As the main instrument used is a questionnaire, the questions asked have to be tested for validity by:

- Referencing with existing literature
- Seeking agreement with domain experts
- Collecting comments on the survey during pilot-testing
- Pilot-testing the questionnaire itself

Outcome Phase 4: Pilot-tested maturity model ready for use in the field

Application on the thesis: see chapter **5** Pilot-Testing of the I40MM

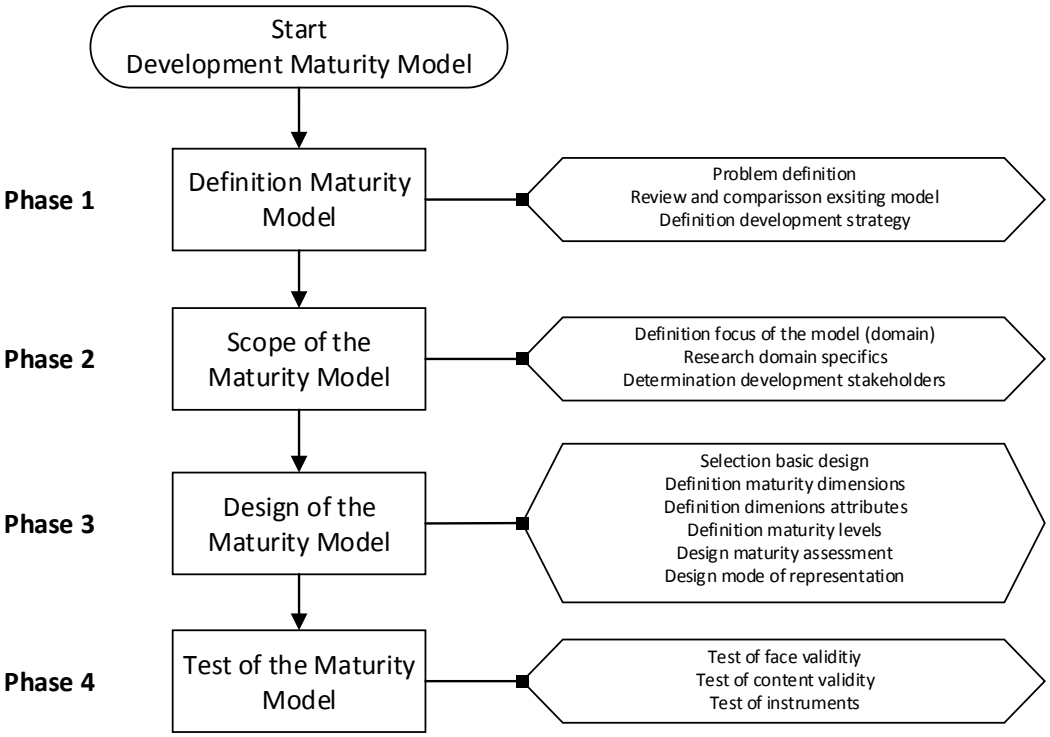


Figure 32: Procedure for the development of an Industry 4.0-maturity model (own depiction)

4.2 Result: The Industry 4.0 Maturity Model – I40MM

In the following the model has been developed which will be presented in detail. First, the model's general characteristics, its scope and design as well as the methods used for assessing the maturity within the company are explained. Afterwards, the transformation of the model into a practically applicable tool consisting of 11 pages (see chapter 4.2.7 Representation of the results – The I40MM Maturity Report) is described, including a manual how to use the model. Finally, details about the validation of the models content via expert-ratings (see chapter 4.2.8 I40MM details - Expert-ratings of maturity dimensions as well as the questionnaire for self-assessing the maturity within the company (see chapter 4.2.9 I40MM details - Questionnaire for self-assessment of the maturity) are offered.

4.2.1 General Introduction to the I40MM

- Problem Definition

Building on experience from various real-world projects carried out by the Fraunhofer Austria Research Gmbh, as well as research projects conducted through the Institute of Management Science, the need for guidance towards the realization of the Industry 4.0-Vision became obvious. The transformation into an Industry 4.0-ready company initially requires an assessment of the as-it-is state, the so called "Industry 4.0-maturity". Only by clearly defining the company's status, further measures can be coordinated and implemented. This practical experience is supported by the results of several expert interviews carried out during the development of the I40MM.

- Development Strategy

Due to the increasing number of existing maturity models from various fields, as a review of existing models is carried out to collect and summarize possible characteristics of the I40MM. Especially the so called "Digital Maturity Model" (developed by the Reutlingen University in co-operation with the consulting company neuland) seems suitable in structure and design for transformation to the area of Industry 4.0 [157].

General Introduction to the I40MM	
Problem Definition / Purpose	• Strong need of companies for guidance towards realization of Industry 4.0 vision • Definition of current as-it-as state in Industry 4.0 is required but currently not possible • Based on assessed current Industry 4.0 maturity further

[157] (Azhari, Faraby, Rossmann, Steimel, & Wichmann, 2014)

	measures can be taken • Purpose of the model: assess the current maturity of an industrial enterprise in Industry 4.0
Development Strategy	• Review of existing maturity models in related areas • Combination of the characteristics of several maturity models into a new model • Transfer of the structures from an existing maturity model to the new domain of Industry 4.0 • Re-structuration and population of the new model for assessing the Industry 4.0 maturity

4.2.2 Scope of the I40MM

To avoid wrong and misleading results, specific fields of application and boundaries are defined

- Domain of Application

This model is developed to assess the Industry 4.0 maturity in mainly the manufacturing industry (production of physical goods). The domain-specification for the area of producing industrial enterprises is related to the determination of the company-dimensions in which the maturity is assessed.

- Boundaries for Application

Within the manufacturing industry, no limitations of applicability regarding geographical location, kind of product or position along the value chain exist. The application within the service industry seems not sufficient as the Industry 4.0-maturity of a service-company cannot be assessed using the determined company-dimensions of the developed I40MM.

- Maturing in the field of Industry 4.0

To assess maturity and take measures for further development, the domain-specific meaning of “maturing” has to be defined to offer guidance to the companies. Industry 4.0 aims for the integration of modern technology, new business approaches and newly developed organizational structures along the entire value chain to generate additional customer value. Therefore, maturing in Industry 4.0 can be understood as the further development of these (and other related) items to collaboratively realize the Industry 4.0 vision.

- Maturing Items

After defining “maturing” in the area of Industry 4.0, the maturing objects are defined. In the I40MM the company is depicted using nine dimensions: Strategy, Leadership, Products, Customers, Operations, Culture, Employees, Governance and Technology.

62 Attributes assigned to the 9 company-dimensions, which have been derived from literature (Example: dimension – Strategy, Attribute: Utilization of 3D-Printing). These attributes can be understood as the maturing objects, as their further development supports the Industry 4.0 maturity of the company.

Scope of the Model	
Domain of Application	• Intended domain of application: Manufacturing Industry • Application not recommended: Service Industry • Geographical limitations of applicability: No • Product-limitations of applicability: No
Boundaries for Application	• Application of the model is not possible if the company which is intended to be assessed cannot be depicted using the determined dimensions
Maturing in the field of Industry 4.0	• Development of organizational structures and business operations, as well as the inclusion of modern technology to steadily increase the individualized customer value
Maturing Items	• 9 company-dimensions: Strategy, Leadership, Products, Customers, Operations, Culture, Employees, Governance and Technology • 62 Attributes within the nine dimensions • The maturity of the Attributes determines the maturity of the dimensions

4.2.3 Design of the I40MM

The design of the maturity model is aiming for good practical applicability. Therefore the design focus is on the simplicity of the tool. Determinations regarding structure and design are based on the review of various existing models which have been tested successfully in real-life in related fields.

- Maturity Levels

The developed model consists of five maturity levels whereas a higher level-number indicates higher maturity. The maturity levels are structured in discrete manners (maturity of a certain attribute in a domain can clearly be assigned to one of the five maturity levels). Moreover, the levels are building on each other hence reaching a higher level automatically includes the maturity-capabilities of the lower level.

- Maturity of Attributes and Dimensions

Although the maturity of the attributes within one dimension can differ, the overall maturity of one company-dimension is reresented by one decimal (e.g. Maturity of dimension “Strategy” = 3,3). The maturity of the nine dimensions is calculated using the weighted overall average of the attributes within the dimension. The input for

weighting the maturity of the attributes results from a survey which has been carried out to assess the practical importance of the attributes to realize Industry 4.0.

Design and Structure of the model	
Number of Maturity Levels	• Five Maturity Levels: 1 – Lowest Maturity 5 – Highest Maturity
Structure of Maturity Levels	• Levels are structured in discrete manners • Levels are building on each other
Maturity of Attributes	• Attributes can be assessed with maturity between 1 and 5 • Attributes are assessed using integers
Maturity of Dimensions	• Calculation of the dimension's maturity using the weighted average maturity over the attributes within the dimension

4.2.4 Assessment of the attribute's maturity in the I40MM

The maturity of the attributes is assessed using a questionnaire, which allows for self-assessing the distinction of each attribute within the company. The distinction (= maturity) of each attribute is measured by asking a related, closed-ended question that ask for a rating on a Likert-scale with five scale points. The questionnaire has to be answered by persons within the company who have encompassing knowledge within the nine company-dimensions and basic knowledge about Industry 4.0 (e.g. CEO or Management). Group-discussions as well as workshops within the company including various stakeholders result in a higher representability of the answers given thus result in a more accurate assessment of the company's maturity. External consultants can be involved to create common ground regarding the ideas of Industry 4.0 (creation of awareness).

Assessment of the attribute's maturity	
Mode of Assessment	• Self-assessment using questionnaire
Structure of Assessment	• Questionnaire containing 62 close-ended questions • Questions require rating from 1 – 5 on a Likert Scale
Supporting Tools for Assessment	• PDF-form to make questionnaire easily transferable • Group-discussions und workshops recommended • Inclusion of external consultants

4.2.5 Representation of the assessed maturity in the I40MM

The result of the maturity assessment is a 11-page PDF document which contains graphical depictions and numerical lists of the as-is-state of the companies Industry 4.0-maturity. Thereby, the maturity of the single attributes is presented as an integer

within the dimensions and the maturity of the dimensions is presented as a decimal. Radar-diagrams are used to depict the attribute's and dimension's maturity at-a-glance. The so called "maturity dashboard" builds the cover page of the maturity-report and shows the contents of the nine dimensions as well as their maturity.

Representation of the assessed maturity	
Overall Representation	• PDF-maturity report consisting of 11 pages
Representation of Attribute's Maturity	• Representation as integer • Representation of the attributes of one dimension in a radar-chart
Representation of the Dimension's Maturity	• Representation as a decimal • Representation of the dimensions in one radar-chart
Maturity Dashboard	• Summary of the dimension's content • Companies Industry 4.0 Maturity at-a-glance

4.2.6 Summary characteristics of the I40MM

General Introduction to the I40MM	
Problem Definition / Purpose	• Strong need of companies for guidance towards realization of Industry 4.0 vision • Definition of current as-it-as state in Industry 4.0 is required • Based on assessed Industry 4.0 maturity further measures can be taken • Purpose of the model: assess the current maturity of a company in Industry 4.0
Development Strategy	• Review of existing maturity models in related areas • Combination of the characteristics of several maturity models into a new model • Transfer of the structures from an existing maturity model to the new domain of Industry 4.0 • Re-structuration and population of the new model for assessing the Industry 4.0 maturity
Scope of the Model	
Domain of Application	• Intended domain of application: Manufacturing Industry • Applicable with restrictions: Logistics • Application not recommended: Service Industry
Boundaries for Application	• Application of the model is not possible if the company which is intended to be assessed cannot be depicted using the determined dimensions
Maturing in the field of Industry 4.0	• Development of organizational structures and business operations, as well as the inclusion of modern technology to steadily increase the individualized customer value
Maturing Items	• 9 company-dimensions: Strategy, Leadership, Products, Customers, Operations, Culture, Employees, Governance and Technology • 62 Attributes within the nine dimensions • The maturity of the Attributes determines the maturity of the dimensions

Design and Structure of the model	
Number of Maturity Levels	• Five Maturity Levels: 1 – Lowest Maturity and 5 – Highest Maturity
Structure of Maturity Levels	• Levels are structured in discrete manners • Levels are building on each other
Maturity of Attributes	• Attributes are assessed with values between 1 and 5 (only integers)
Maturity of Dimensions	• Calculation of the dimension's maturity using the weighted maturity of the attributes within the dimension
Assessment of the attribute's maturity	
Mode of Assessment	• Self-assessment using questionnaire
Structure of Assessment	• Questionnaire containing 62 close-ended questions • Questions require rating from 1 - 5 on a Likert Scale
Supporting Tools for Assessment	• Groups-discussions und workshops recommended • Inclusion of external consultants
Representation of the assessed maturity	
Overall Representation	• PDF-maturity report consisting of 11 pages
Representation of Attribute's Maturity	• Representation as integer • Representation of the attributes of one dimension in a radar-chart
Representation of the Dimension's Maturity	• Representation as a decimal • Representation of the dimensions in one radar-chart on Maturity Dashboard

4.2.7 Representation of the results – The I40MM Maturity Report

The development of the Industry 4.0 maturity model aimed for the creation of an artifact (resulting in a tool), that is practically applicable. Therefore, structure and layout are simplified and charts as well as a dashboard are used to summarize the results. In the following the structure of the model is presented which at the same time serves as a manual for using the model.

- **Overall structure**

The model is represented on 11 pages whereby the first pages summarize the findings and the following pages present the results in greater detail. On the first page, the so called “Maturity Dashboard” presents the overall-maturity of the nine company-dimensions in tabular and graphical manners. Moreover, the formula used for calculation, as well and the expert-rated importance of the nine company-dimensions are depicted. The second page offers description of the five maturity levels in each dimension by stating the maturity-characteristics of the different levels. The pages 3 -11 present the nine company-dimensions in detail. Each dimension is presented on one page whereby the dimension’s-attributes, the importance-rating of the attributes, the external question for assessing the attribute’s maturity within the company as well as the assessed maturity is depicted by tabular and graphical means

- **Content of the Industry 4.0 Maturity Model**

Page 1: Maturity Dashboard

First, the maturity dashboard offers a summary of the assessed maturity of the nine company-dimensions in a table (see Figure 33). The maturity of the dimensions results from the assessed maturity of the attributes described in the first column.

Dimension Description	Dimension	Overall Maturity Level
The dimension Strategy encompasses aspects such as: compatibility with company-strategies, utilization of roadmap, availability of resources, communication and documentation of strategies, suitability of business models, strategy for digital transformation	**Strategy**	**3,0**
The dimension Leadership encompasses aspects such as: willingness of leaders, and methods of leaders	**Leadership**	**3,0**
ts such as: individualization of gration into other systems, autonomy of products, digitalization of products, flexibility of products	**Products**	**3,0**
The dimension Customers encompasses aspects such as: openness of customers to innovation, integration of customers into processes, utilization of customer data, customer competence with digital media, digitalization of sales and services	**Customers**	**3,0**
This dimension Operations encompasses aspects such as: vertical and horizontal integration of processes, decentralization of processes, standardization of processes, digitalization of processes, automation of processes, autonomy of processes , flexibility of processes, stakeholder integration, inter-department collaboration, modelling and simulations in process planning	**Operations**	**3,0**
The dimension Culture encompasses aspects such as: employee-inclusion, innovativeness of the company, stakeholder-openness, adaptability of the company culture, existence of knowledge management, conduction open innovation, value of ICT in the company	**Culture**	**3,0**
The Dimension People encompasses aspects such as: openness to technology, ICT-competence of the employees, creation and promotion of ideas, interdisciplinary work, autonomy of the employees, flexibilization of work	**People**	**3,0**
The dimension Governance encompasses aspects such as: technological standards, data-security and employee-privacy standards, safety-standards, innovation programs, information management, education and training, intellectual property,suitability of labor-regulations, sourcing of work, adaption of existing standards	**Governance**	**3,0**
The dimension Technology encompasses aspects such as: Modern ICT, autonomy of machines, flexibility and adaptability of machines, utilization of mobile devices, utilization of sensors, embedded systems in machines, M2M communication, auto-ID technology, cloud computing, 3D-printing	**Technology**	**3,0**

Content of the dimension strategy (=Attributes)

Assessed maturity

Figure 33: I40MM-Dashboard; Content of the dimensions and assessed maturity

Additionally, a radar chart is used to present the results at-a-glance (see Figure 34). Optionally, the maturity's target state can be inserted into the chart to highlight the measure to be taken to transform from the is-state to the desired maturity level.

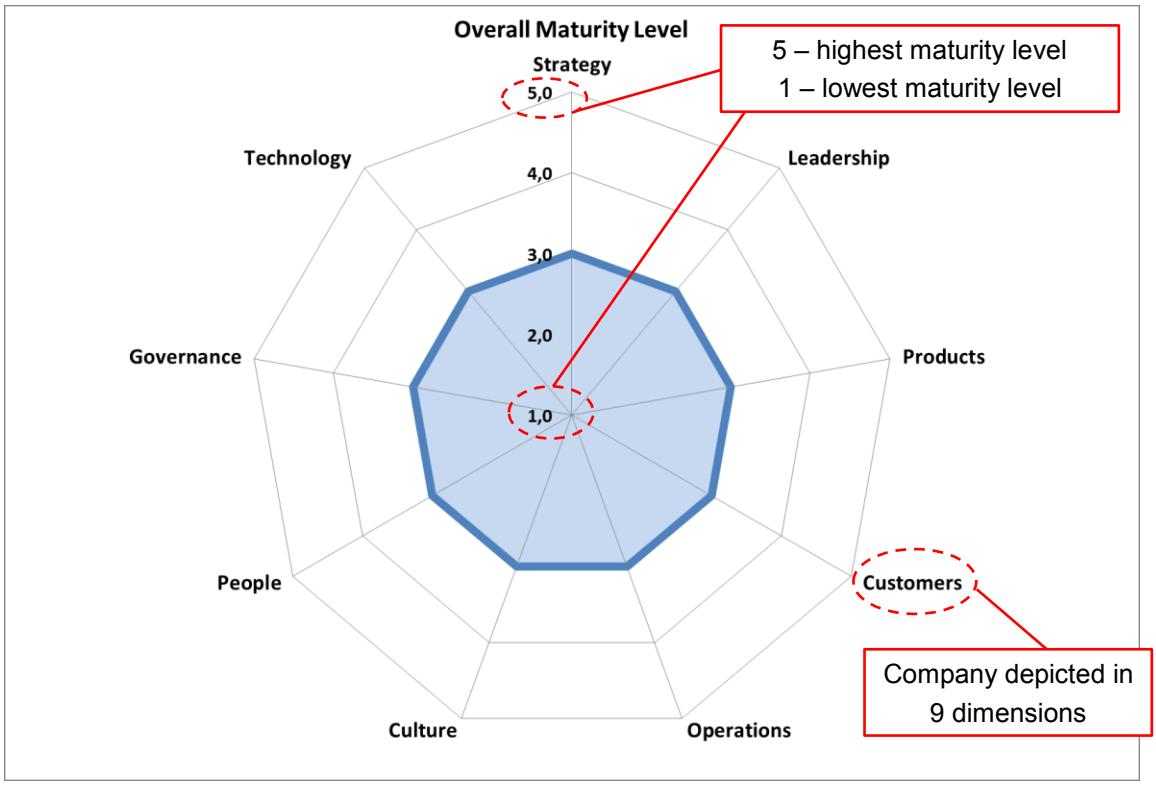


Figure 34: I40MM-Dashboard; Radar Chart depicting the maturity of the dimensions

The formulary used for calculating the dimension's maturity has the purpose of considering the practical difference of the maturing attributes for realizing Industry4.0; the more important an attribute is rated by the experts, the higher the impact this attribute has on the dimension's maturity. The expert rating of the attribute's importance ranges from 1 (not important) to 4 (very important) and has been rated by 24 experts responding to the distributed digital questionnaire.

Formula used for calculating the maturity:

$$M_{Dk} = \frac{\sum_{i=1}^{j} M_{DkAi} * g_{DkAi}}{\sum_{i=1}^{j} g_{DkAi}} \qquad 1 \leq g \leq 4 \quad 1 \leq M \leq 5$$

M ... Maturity (assessed within the company)
D ... Dimension (Company depicted in 9 dimensions)
A ... Attribute
g ... Weighting (equals the importance of the attribute rated by experts)

Figure 35: I40MM-Dashboard; Formulary used for calculating the weighted overall maturity

Resulting from the expert-rating of the attribute's importance, the importance of the related dimensions can be derived by taking the average importance of all attributes of one dimension (see Figure 36).

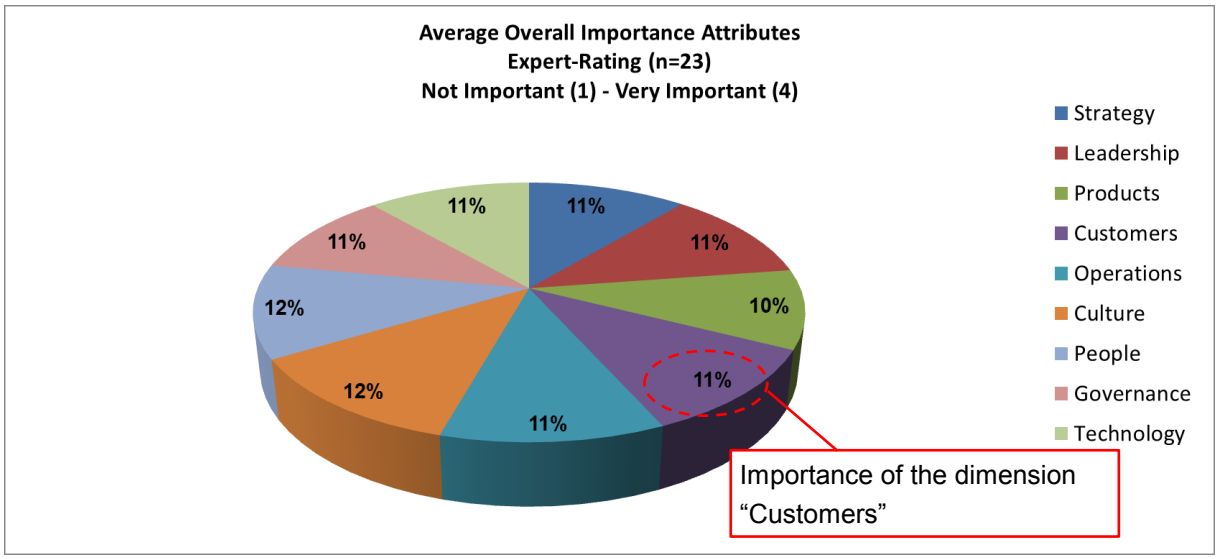


Figure 36: I40MM-Dashboard; Rated importance of the 9 dimensions

Page 2: Description of Maturity Levels

As part of every maturity model, the characteristics and the meaning of the five maturity levels have to be explained. In this Industry 4.0 Maturity Model the first level represents a low maturity in Industry 4.0 whereas the fifth maturity level represents the highest maturity (see Figure 37).

Dimension	Maturity Level Description
Overall	4. Industry 4.0 is company standard 5. The Industry 4.0-vision is developed further
Strategy	1. No strategies exists for realizing Industry 4.0 2. Strategies for realizing Industry 4.0 are developed 3. Existing strategies for Industry 4.0 are followed 4. Industry 4.0 strategies are aligned to overall strategy of the company 5. Industry 4.0 strategies are developed further
Leadership	1. No leadership-support for Industry 4.0 2. Leadership activities related to Industry 4.0 are developed 3. Leadership activities related to Industry 4.0 exist
Products	2. Planned Products are suitable for realizing Industry 4.0 3. Existing products are suitable for realizing Industry 4.0 4. Standards in product development are aligned to industry 4.0 5. Existing allow to develope Industry 4.0 further
Customers	1. Customers are not integrated into the Industry 4.0-activities 2. Customer-integration into Industry 4.0 is planned 3. Customers are integrated into Industry 4.0 4. Customers are fully aligned to Industry 4.0 standards 5. Customers help developing Industry 4.0 further
Operations	1. Company-operations are not suitable for Industry 4.0 2. Company-operations suitable for Industry 4.0 are developed 3. Company-operations suitable for Industry 4.0 exist 4. Company-operations are fully aligned to Industry 4.0 5. Company-operations are developed further based on Industry 4.0
Culture	1. Company-culture does not support Industry 4.0 2. Company-culture for realizing Industry 4.0 develops 3. Company-culture for realizing Industry 4.0 exists 4. Company-culture is fully aligned with Industry 4.0 5. Company-culture allows developing Industry 4.0 further
People	1. People do not allow for realizing Industry 4.0 2. People get prepared for Industry 4.0 3. People allow for realizing Industry 4.0 4. People are fully supporting Industry 4.0 5. People allow for developing industry 4.0 further
Governance	1. Governance does not support Industry 4.0 2. Governance for realizing Industry 4.0 is developed 3. Existing governance allows for realizing Industry 4.0 4. Governance is fully aligned with Industry 4.0 5. Governance allows developing Industry 4.0 further
Technology	1. Existing technology is not suitable for realizing Industry 4.0 2. Planned technology is suitable for realizing Industry 4.0 3. Existing technology is suitable for realizing Industry 4.0 4. Technology standards are aligned to industry 4.0 5. Technology allows for developing industry 4.0 further

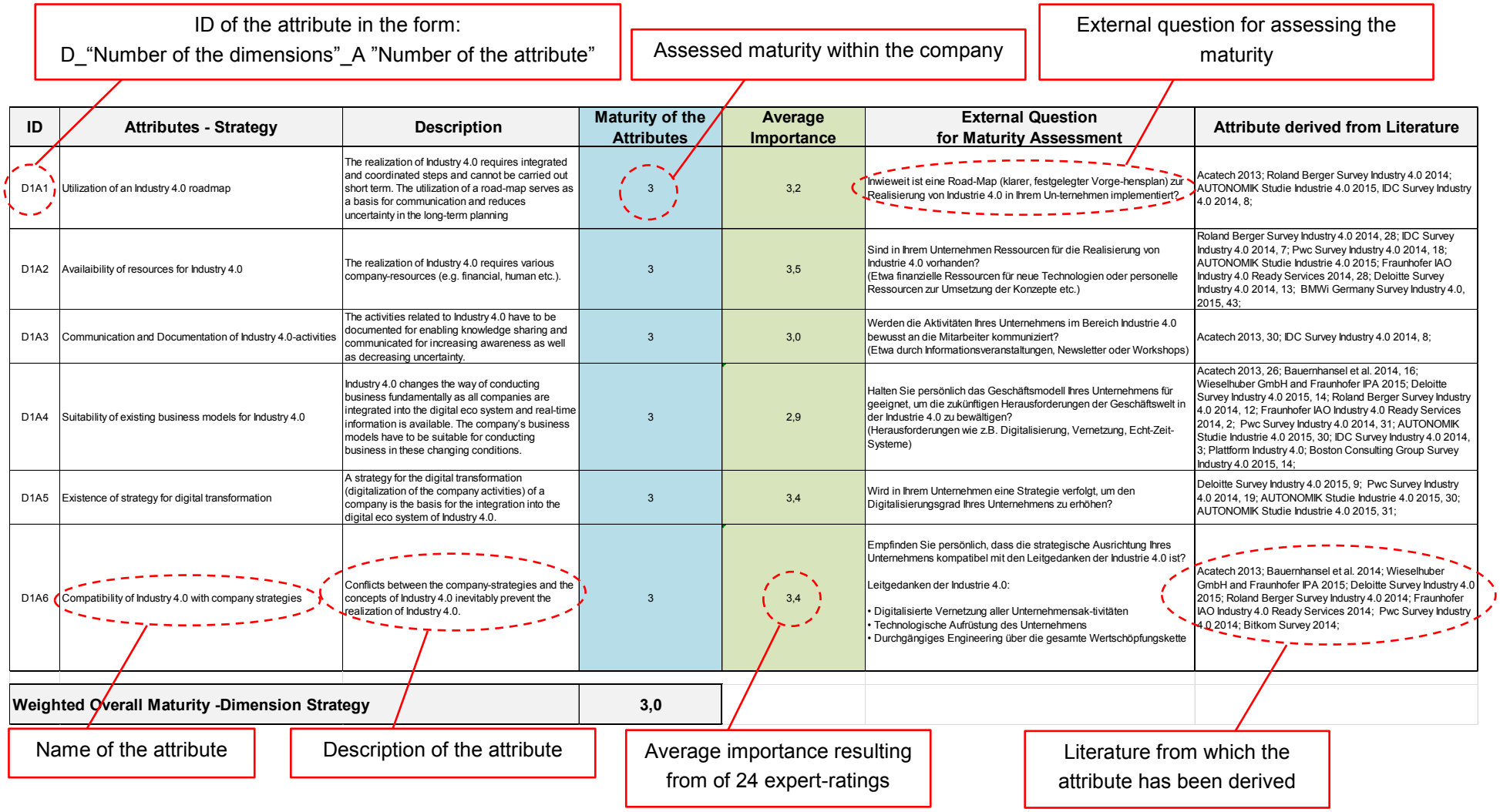
Description of the lowest maturity level in the dimension strategy

Description of the highest maturity level in the dimension strategy

Figure 37: I40MM - Maturity Levels; Description of the five maturity levels in the nine company-dimensions

Page 3 – 11: Details about the nine company dimensions (explained here using the dimension strategy)

On the pages 3 – 11 of the maturity report, details about the nine company-dimensions are presented. For each attribute within the dimension, details such as a description, the external question for assessing the maturity within the company as well as the literature for deriving the attribute is offered (the page presenting the dimension “Strategy” is used exemplary to explain the content – see Figure 38) .



ID	Attributes - Strategy	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D1A1	Utilization of an Industry 4.0 roadmap	The realization of Industry 4.0 requires integrated and coordinated steps and cannot be carried out short term. The utilization of a road-map serves as a basis for communication and reduces uncertainty in the long-term planning	3	3,2	Inwieweit ist eine Road-Map (klarer, festgelegter Vorge-hensplan) zur Realisierung von Industrie 4.0 in Ihrem Un-ternehmen implementiert?	Acatech 2013; Roland Berger Survey Industry 4.0 2014; AUTONOMIK Studie Industrie 4.0 2015, IDC Survey Industry 4.0 2014, 8;
D1A2	Availaibility of resources for Industry 4.0	The realization of Industry 4.0 requires various company-resources (e.g. financial, human etc.).	3	3,5	Sind in Ihrem Unternehmen Ressourcen für die Realisierung von Industrie 4.0 vorhanden? (Etwa finanzielle Ressourcen für neue Technologien oder personelle Ressourcen zur Umsetzung der Konzepte etc.)	Roland Berger Survey Industry 4.0 2014, 28; IDC Survey Industry 4.0 2014, 7; Pwc Survey Industry 4.0 2014, 18; AUTONOMIK Studie Industrie 4.0 2015; Fraunhofer IAO Industry 4.0 Ready Services 2014, 28; Deloitte Survey Industry 4.0 2014, 13; BMWi Germany Survey Industry 4.0, 2015, 43;
D1A3	Communication and Documentation of Industry 4.0-activities	The activities related to Industry 4.0 have to be documented for enabling knowledge sharing and communicated for increasing awareness as well as decreasing uncertainty.	3	3,0	Werden die Aktivitäten Ihres Unternehmens im Bereich Industrie 4.0 bewusst an die Mitarbeiter kommuniziert? (Etwa durch Informationsveranstaltungen, Newsletter oder Workshops)	Acatech 2013, 30; IDC Survey Industry 4.0 2014, 8;
D1A4	Suitability of existing business models for Industry 4.0	Industry 4.0 changes the way of conducting business fundamentally as all companies are integrated into the digital eco system and real-time information is available. The company's business models have to be suitable for conducting business in these changing conditions.	3	2,9	Halten Sie persönlich das Geschäftsmodell Ihres Unternehmens für geeignet, um die zukünftigen Herausforderungen der Geschäftswelt in der Industrie 4.0 zu bewältigen? (Herausforderungen wie z.B. Digitalisierung, Vernetzung, Echt-Zeit-Systeme)	Acatech 2013, 26; Bauernhansel et al. 2014, 16; Wieselhuber GmbH and Fraunhofer IPA 2015; Deloitte Survey Industry 4.0 2015, 14; Roland Berger Survey Industry 4.0 2014, 12; Fraunhofer IAO Industry 4.0 Ready Services 2014, 2; Pwc Survey Industry 4.0 2014, 31; AUTONOMIK Studie Industrie 4.0 2015, 30; IDC Survey Industry 4.0 2014, 3; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 14;
D1A5	Existence of strategy for digital transformation	A strategy for the digital transformation (digitalization of the company activities) of a company is the basis for the integration into the digital eco system of Industry 4.0.	3	3,4	Wird in Ihrem Unternehmen eine Strategie verfolgt, um den Digitalisierungsgrad Ihres Unternehmens zu erhöhen?	Deloitte Survey Industry 4.0 2015, 9; Pwc Survey Industry 4.0 2014, 19; AUTONOMIK Studie Industrie 4.0 2015, 30; AUTONOMIK Studie Industrie 4.0 2015, 31;
D1A6	Compatibility of Industry 4.0 with company strategies	Conflicts between the company-strategies and the concepts of Industry 4.0 inevitably prevent the realization of Industry 4.0.	3	3,4	Empfinden Sie persönlich, dass die strategische Ausrichtung Ihres Unternehmens kompatibel mit den Leitgedanken der Industrie 4.0 ist? Leitgedanken der Industrie 4.0: • Digitalisierte Vernetzung aller Unternehmensak-tivitäten • Technologische Aufrüstung des Unternehmens • Durchgängiges Engineering über die gesamte Wertschöpfungskette	Acatech 2013; Bauernhansel et al. 2014; Wieselhuber GmbH and Fraunhofer IPA 2015; Deloitte Survey Industry 4.0 2015; Roland Berger Survey Industry 4.0 2014; Fraunhofer IAO Industry 4.0 Ready Services 2014; Pwc Survey Industry 4.0 2014; Bitkom Survey 2014;
Weighted Overall Maturity -Dimension Strategy			**3,0**			

Figure 38: I40MM - Dimension Strategy; Attributes and their maturity

4.2.8 I40MM details - Expert-ratings of maturity dimensions attributes

The population of the maturity model (=attributes) has been derived from existing literature about Industry 4.0. After discussion within the research team, a final list of attributes assigned to the nine company-dimensions was developed. As the importance of these attributes seems to be unequally important for realization of Industry 4.0 (compare with the results of the expert interviews), the importance of the attributes has been rated by 23 experts from research, consulting and the industry. The importance-rating builds the bases for calculating the weighted average maturity of one dimension. The questionnaire has been developed with the following characteristics:

- Contains 62 closed-ended questions
- Assigned to the 9 company-dimension (equally to the maturity model's structure)
- One questions serves for the importance-rating of one attribute
- Each question is answered by a rating on a Likert-scale reaching from 1 - not important to 4 - very important)
- High understanding about Industry 4.0 is required to answer the questionnaire (expert level)
- Experience with the Industry 4.0 realization in praxis or theoretical scientific knowledge about the success factors is required
- High number of answered questionnaires increases the representability
- Time required for answering: ca. 15min

Expert Ratings of the Attribute's Importance

In the following the results of the expert-ratings are presented in detail and significant results are discussed. As the rating reaches from 1 (not important) – 4 (very important), importance-ratings with a rating of (around) 2.5 and lower are examined in detail. However, low importance ratings are considered in the maturity-assessment through the weighting of the attributes based on their importance.

- Dimension – Strategy

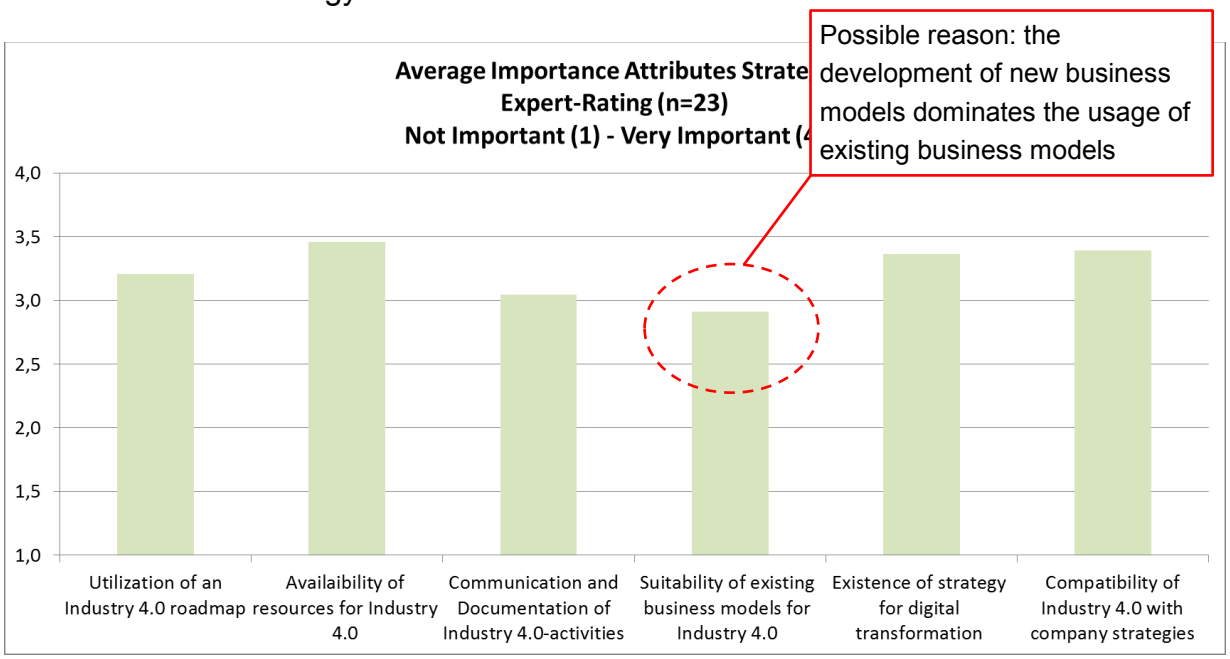


Figure 39: I40MM – Attribute Importance of the dimension "Strategy"

- Dimension – Leadership:

Figure 40: I40MM – Attribute Importance of the dimension "Leadership"

- Dimension - Products

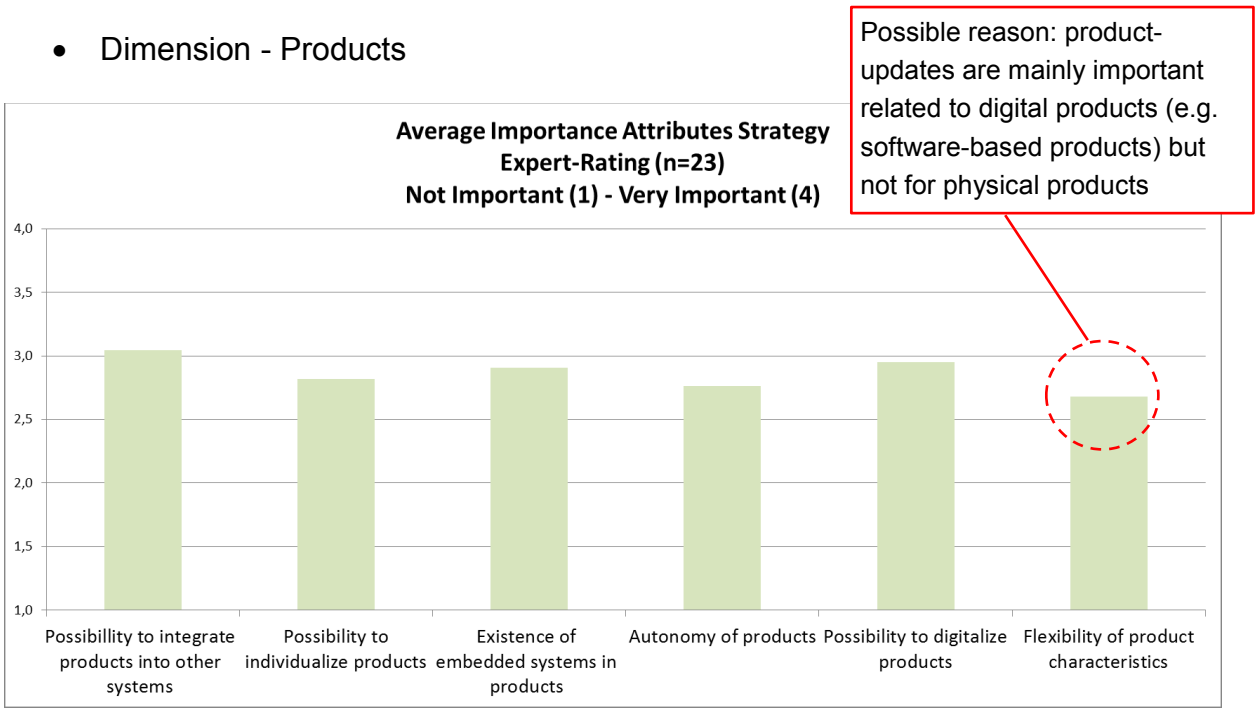


Figure 41: I40MM – Attribute Importance of the dimension "Products"

- Dimension – Customers

Figure 42: I40MM – Attribute Importance of the dimension "Operations"

- Dimension – Operations

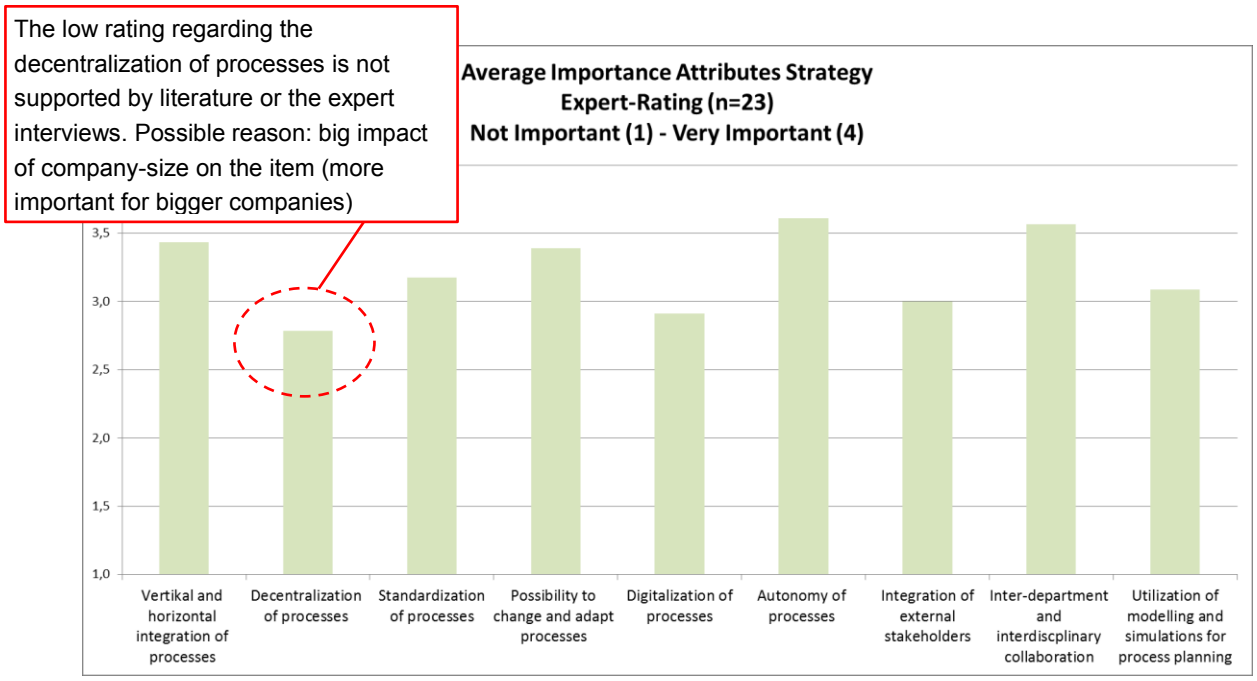


Figure 43: I40MM – Attribute Importance of the dimension "Operations"

- Dimension – Culture

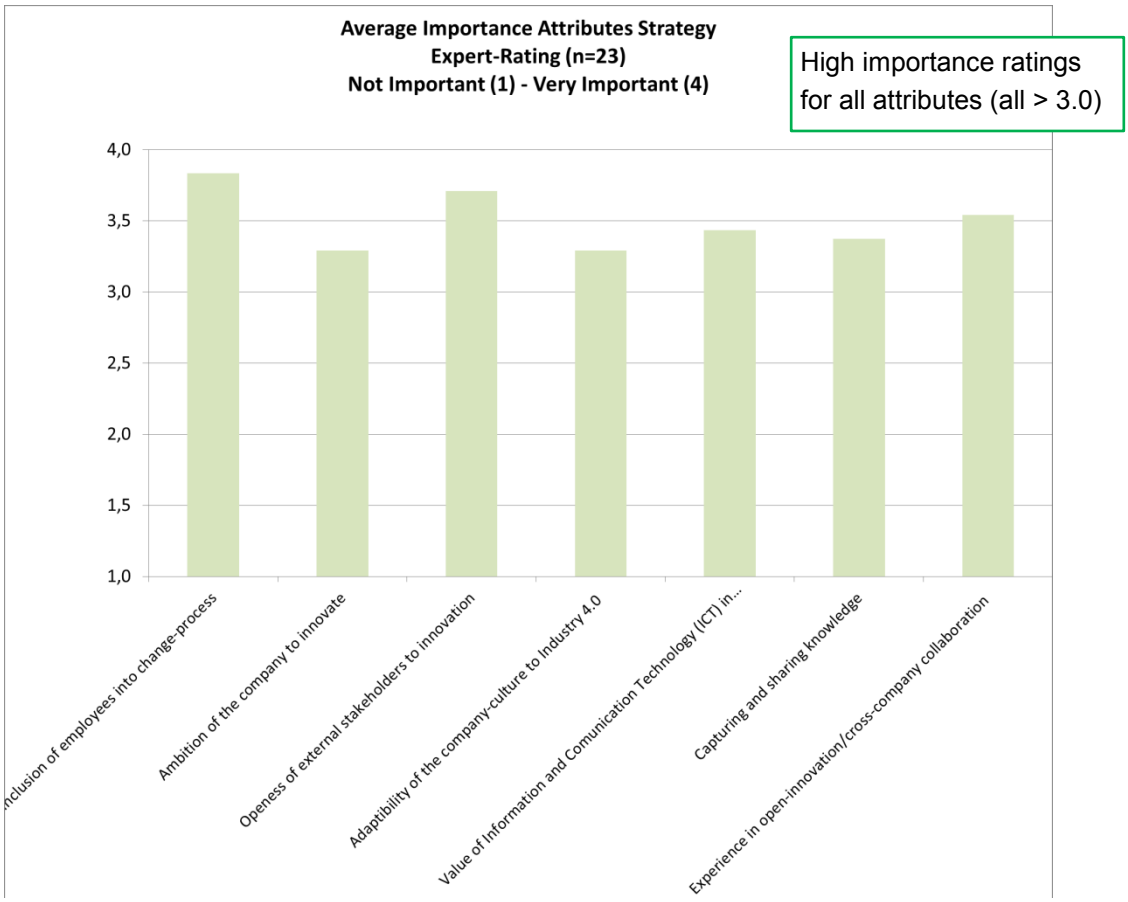


Figure 44: I40MM – Attribute Importance of the dimension "Operations"

- Dimension – People

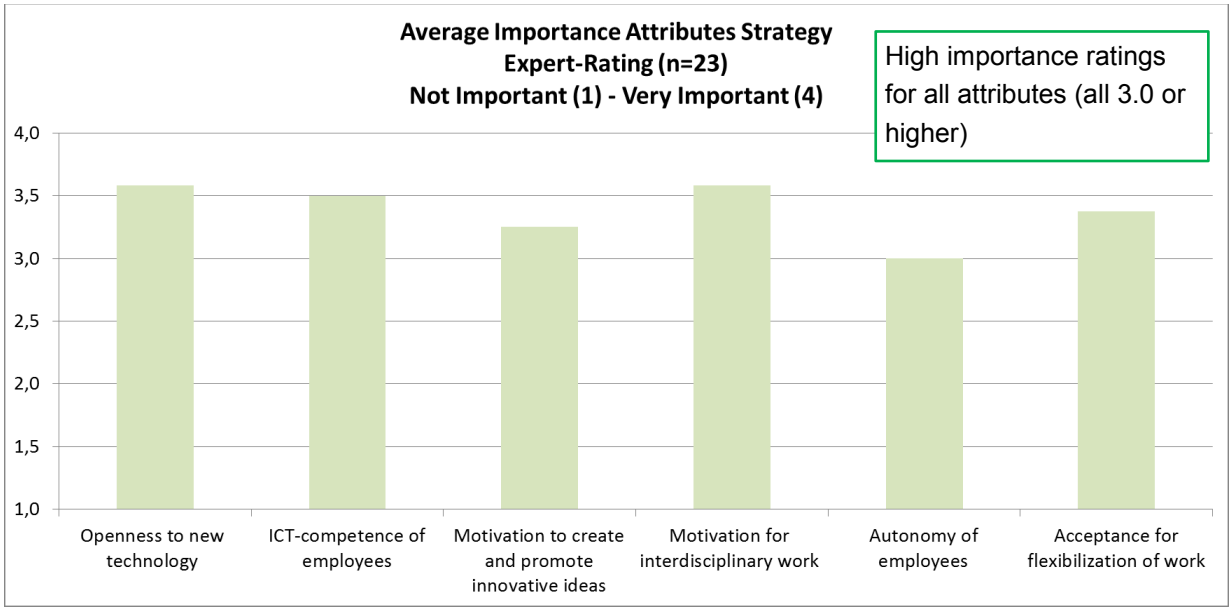


Figure 45: I40MM - Attribute Importance of the dimension "People"

- Dimension Governance

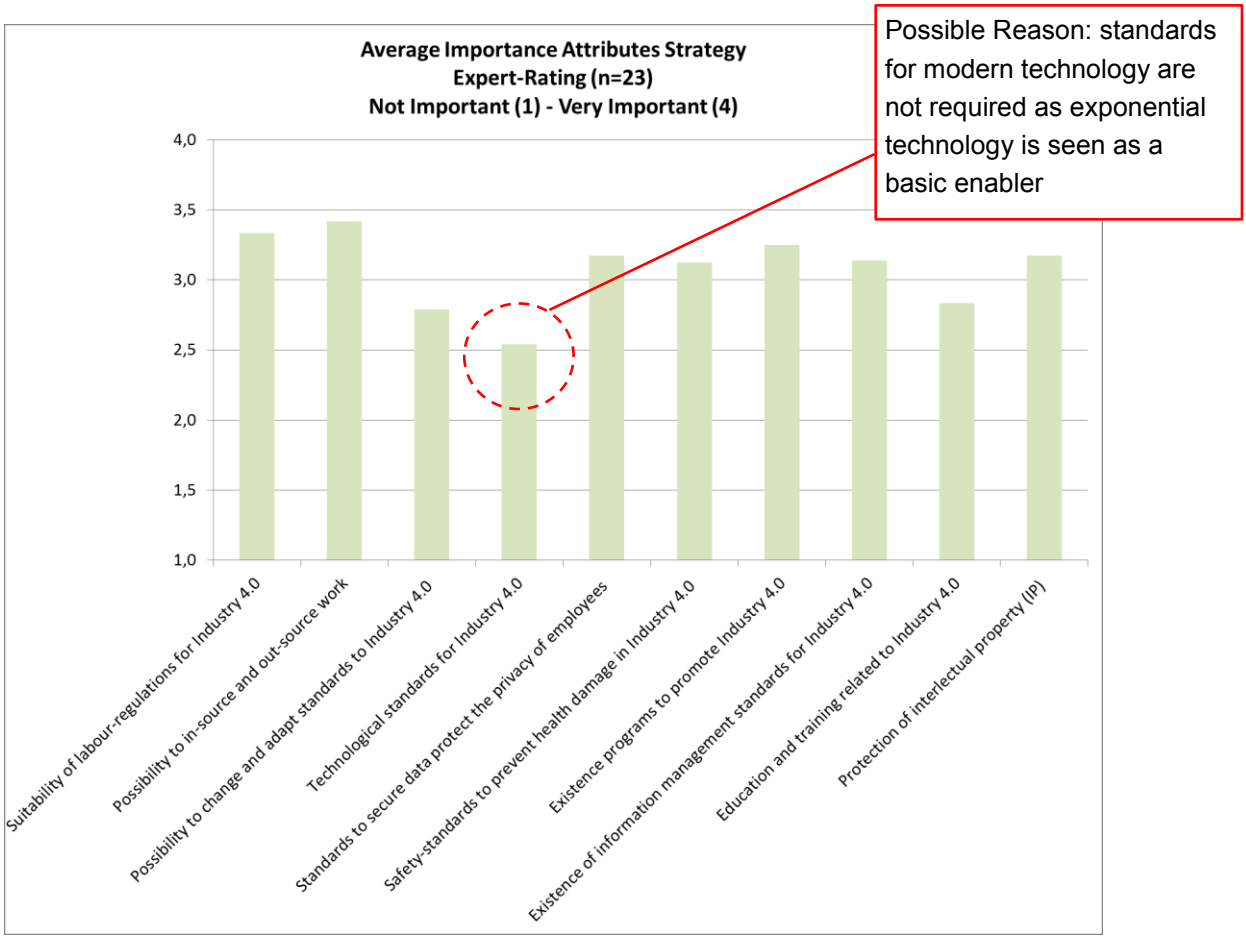


Figure 46: I40MM – Attribute Importance of the dimension "Governance"

- Dimension – Technology

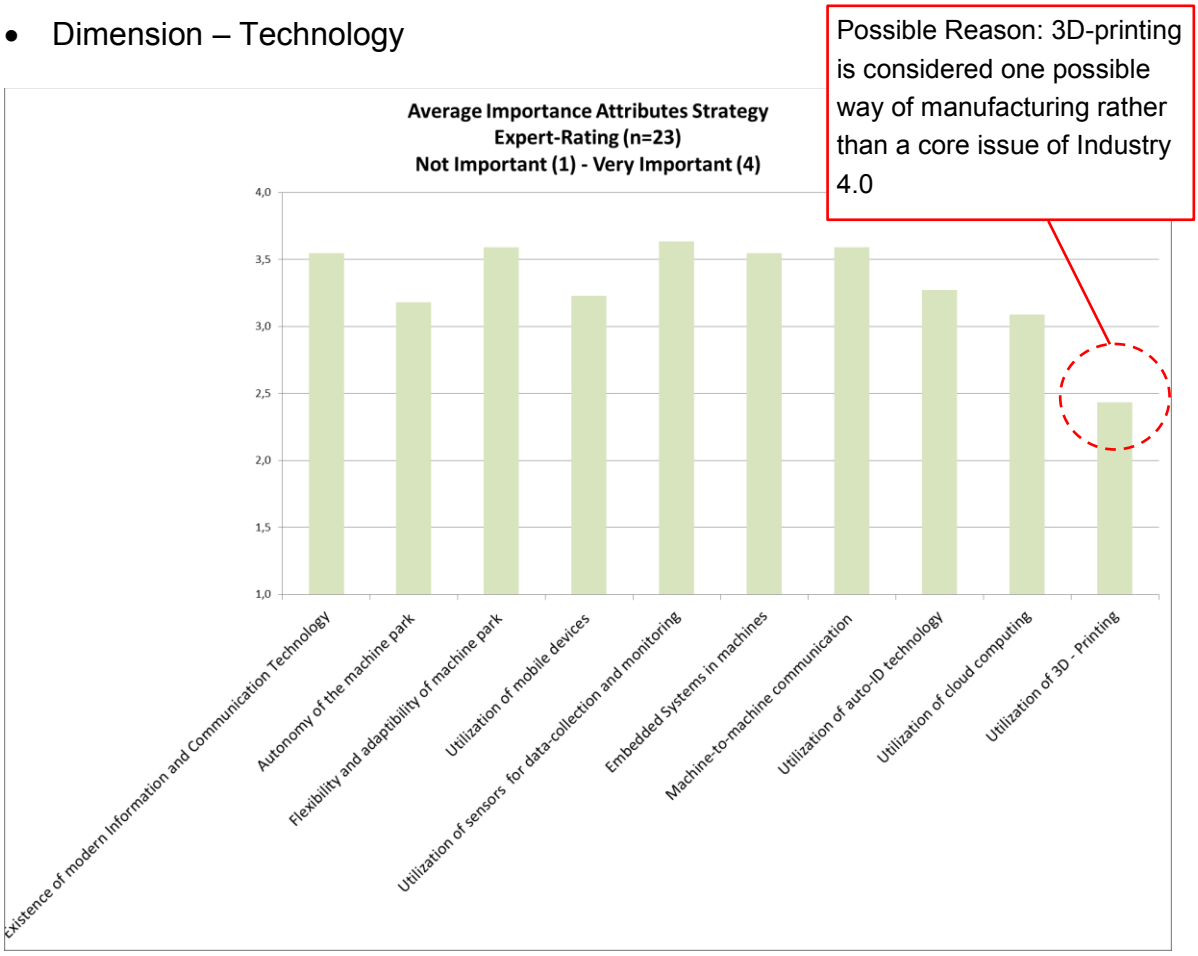


Figure 47: I40MM - Attribute Importance of the dimension "Technology"

The significantly low expert-rating for some attributes can partly be explained using the results of the expert-interviews as well as possibly weak formulations of the questions used in the questionnaire. Overall, the average importance over all attributes derived from literature is 3.2, which can be considered sufficiently high.

4.2.9 I40MM details - Questionnaire for self-assessment of the maturity

The assessment of the maturing attributes within the company is carried out using a questionnaire. Thereby, the questionnaire has been developed with the following characteristics:

- Contains 62 closed-ended questions
- Assigned to the 9 company-dimension (equally to the maturity model's structure)
- One questions serves for the assessment of one attribute's maturity
- Each question is answered by a rating on a Likert-scale reaching from 1 (lowest) to 5 (highest)
- The rating from 1 to 5 equals the maturity of the relating attribute from 1 to 5

- Basic understanding about Industry 4.0 is required to answer the questionnaire
- Comprehensive knowledge about the company's activities and structure is required (target-audience is management)
- Questionnaire can be answered in groups (e.g. work-shop to discuss the attributes and their distinctions in the company)
- Time required for answering: no fixed time as discussions should be conducted to increase the quality of the answers
- Number of responds required: at least one answer per question is required as input for the maturity model

As the pilot-testing of the maturity model is carried out in Austrian companies, the questionnaire is in German language:

Fragebogen zur Ersterhebung

Industrie 4.0:
Bewertung des Unternehmensreifegrades

Einleitung

Willkommen zur Ersterhebung des Industrie 4.0 – Reifegrades Ihres Unternehmens,

Was ist das Ziel dieses Fragebogens? Ziel ist es, in einer ersten Erhebung Kriterien in Ihrem Unternehmen zu beleuchten, welche für eine erfolgreiche Umsetzung von Industrie 4.0 wichtig sind. Damit sollen grundlegende Erkenntnisse über die Industrie 4.0-Reife Ihres Unternehmens gewonnen werden.

Wer sollte den Fragebogen beantworten? Der Fragebogen soll von Führungskräften mit umfassenden Einblick in die Unternehmensaktivitäten beantwortet werden. Umso höher die Zahl der ausgefüllten Fragebögen, desto aussagekräftiger das Ergebnis für Ihr Unternehmen.

Wie ist der Fragebogen aufgebaut? Der Fragebogen besteht aus 9 Themenbereichen mit zugeordneten Fragen, welche eine Skalen-Bewertung von 1 – 5 erfordern. Die Beantwortung dauert in etwa 30 Minuten.

Die Beantwortung des Fragebogens kann durch Anklicken des jeweiligen Feldes direkt in dieser pdf-Datei erfolgen.

Am Ende des Fragebogens befindet sich ein Feld mit der Bezeichnung "Fragebogen absenden" – durch Anklicken dieses Feldes öffnet sich selbstständig eine Email-Nachricht, welcher der ausgefüllte Fragebogen angeheftet ist.

Erklärung

Bitte lesen Sie sich die jeweilige Frage durch und geben sie rechts durch Setzen eines Kreuzes (Anklicken des jeweiligen Feldes) Ihre Bewertung ab. Die Ausprägung der jeweiligen Skala, welche von 1 -5 reicht, ist bei jeder Frage separat angegeben.

Beispiel:

Themengebiet 1: Unternehmensstrategie; **Frage 1.1**: Inwieweit ist eine Road-Map (klarer, festgelegter Vorgehensplan) zur Realisierung von Industrie 4.0 in Ihrem Unternehmen implementiert?

Ausprägung 1: Eine Road-Map zur Realisierung von Industrie 4.0 ist **nicht implementiert**
Ausprägung 5: Eine Road-Map zur Realisierung von Industrie 4.0 ist **sehr umfassend implementiert**

Antwort durch Setzen eines Kreuzes bei den Antwortkästchen rechts.

1. Unternehmensstrategie in Bezug auf Industrie 4.0

Bitte geben Sie Ihre Bewertungen (1 -5) zu den nachfolgenden Fragen an.			**1**	**2**	**3**	**4**	**5**
1.1	Inwieweit ist eine Road-Map (klarer, festgelegter Vorgehensplan) zur Realisierung von Industrie 4.0 in Ihrem Unternehmen implementiert?	**1 – 5** (Nicht implementiert – Sehr umfassend implementiert)	☐	☐	☐	☐	☐
1.2	Sind in Ihrem Unternehmen Ressourcen für die Realisierung von Industrie 4.0 vorhanden? (Etwa finanzielle Ressourcen für neue Technologien oder personelle Ressourcen zur Umsetzung der Konzepte etc.)	**1 – 5** (Nicht vorhanden – Sehr viele vorhanden)	☐	☐	☐	☐	☐
1.3	Werden die Aktivitäten Ihres Unternehmens im Bereich Industrie 4.0 bewusst an die Mitarbeiter kommuniziert? (Etwa durch Informationsveranstaltungen, Newsletter oder Workshops)	**1 – 5** (Nicht kommuniziert – Sehr umfassend kommuniziert)	☐	☐	☐	☐	☐
1.4	Halten Sie persönlich das Geschäftsmodell Ihres Unternehmens für geeignet, um die zukünftigen Herausforderungen der Geschäftswelt in der Industrie 4.0 zu bewältigen? (Herausforderungen wie z.B. Digitalisierung, Vernetzung, Echt-Zeit-Systeme)	**1 – 5** (Nicht anwendbar – Sehr gut anwendbar)	☐	☐	☐	☐	☐
1.5	Wird in Ihrem Unternehmen eine Strategie verfolgt, um den Digitalisierungsgrad Ihres Unternehmens zu erhöhen?	**1 – 5** (Wird nicht verfolgt – Wird sehr entschlossen verfolgt)	☐	☐	☐	☐	☐
1.6	Empfinden Sie persönlich, dass die strategische Ausrichtung Ihres Unternehmens kompatibel mit den Leitgedanken der Industrie 4.0 ist? Leitgedanken der Industrie 4.0: • Digitalisierte Vernetzung aller Unternehmensaktivitäten • Technologische Aufrüstung des Unternehmens • Durchgängiges Engineering über die gesamte Wertschöpfungskette	**1 - 5** (Nicht vereinbar – Sehr gut vereinbar)	☐	☐	☐	☐	☐

2. Unternehmensführung in Bezug auf Industrie 4.0

Bitte geben Sie Ihre Bewertungen (1 -5) zu den nachfolgenden Fragen an.			**1**	**2**	**3**	**4**	**5**
2.1	Empfinden Sie persönlich, Industrie 4.0 durch die Entscheidungsträger Ihres Unternehmens gestützt und gefördert werden? (Commitment of management)	**1 – 5** (Werden nicht gestützt – Werden umfassend gestützt)	☐	☐	☐	☐	☐
2.2	Empfinden Sie persönlich, dass die technischen und organisatorischen Kompetenzen der Entscheidungsträger Ihres Unternehmens geeignet für die Realisierung von Industrie 4.0 sind?	**1 – 5** (Nicht geeignet – Sehr gut geeignet)	☐	☐	☐	☐	☐
2.3	Empfinden Sie persönlich, dass die Aktivitäten im Bereich Industrie 4.0 in Ihrem Unternehmen zielgerichtet geplant, koordiniert und implementiert werden?	**1 – 5** (Nicht zielgerichtet – Sehr zielgerichtet)	☐	☐	☐	☐	☐

3. Produkte in Bezug auf Industrie 4.0

Bitte geben Sie Ihre Bewertungen (1 -5) zu den nachfolgenden Fragen an.			**1**	**2**	**3**	**4**	**5**
3.1	Besteht die Möglichkeit Ihre Produkte mit Produkten anderen Hersteller digital zu vernetzen? (Kommunikation und Interaktion der Produkte)	**1 – 5** (Nicht vernetzbar – Sehr einfach vernetzbar)	☐	☐	☐	☐	☐
3.2	Besteht die Möglichkeit Ihre Produkte auf Einzel-Kundenwunsch zu individualisieren?	**1 – 5** (Nicht individualisierbar – Sehr gut individualisierbar)	☐	☐	☐	☐	☐
3.3	Werden elektronische Rechner und Computer (Embedded Systems) in Ihre Produkte integriert? (Mit dem Ziel der Digitalisierung und Vernetzung der Produkte)	**1 – 5** (Nicht vorhanden – Sehr umfassend vorhanden)	☐	☐	☐	☐	☐
3.4	Sind Ihre Produkte darauf ausgelegt, Aufgaben automatisiert zu erfüllen?	**1 – 5** (Nicht automatisiert – Sehr stark automatisiert)	☐	☐	☐	☐	☐
3.5	Beinhalten Ihre Produkte digitale Komponenten? (Produkt empfangt, verarbeitet oder erzeugt Daten)	**1 – 5** (Sehr nieder – Sehr hoch)	☐	☐	☐	☐	☐
3.6	Lassen sich die Charakteristika Ihrer Produkte nach dem Verkauf verändern? (Möglichkeit für Product-Up-Dates)?	**1 – 5** (Nicht veränderbar – Sehr gut veränderbar)	☐	☐	☐	☐	☐

4. Unternehmenskunden in Bezug auf Industrie 4.0

Bitte geben Sie Ihre Bewertungen (1 -5) zu den nachfolgenden Fragen an.			**1**	**2**	**3**	**4**	**5**
4.1	Empfinden Sie persönlich, dass Kunden Ihres Unternehmens offen gegenüber neuen Technologien sind? (Etwa in Produkten, bei der Geschäftsabwicklung oder im Kundenservice)	**1 – 5** (Nicht offen – Sehr offen)	☐	☐	☐	☐	☐
4.2	Empfinden Sie persönlich, dass Kunden Ihres Unternehmens hohe Kompetenzen im Umgang digitalen Medien besitzen? (Etwa für die Bestellung oder Bedienung von Produkten oder beim Kundenservice)	**1 – 5** (Keine Kompetenz – Sehr hohe Kompetenz)	☐	☐	☐	☐	☐
4.3	Binden Sie Ihre Kunden stark in Ihr Unternehmen ein? (Kundenintegration)	**1 – 5** (Nicht eingebunden – Sehr stark eingebunden)	☐	☐	☐	☐	☐
4.4	Nutzen Sie in Ihrem Unternehmen digital gesammelte Daten über das Kundenverhalten? (Big Data – Analyse etwa zur Entwicklung neuer Produkte oder neuer Services)	**1 – 5** (Nicht genutzt – Sehr umfassend genutzt)	☐	☐	☐	☐	☐
4.5	Inwieweit wickeln Sie den Kunden-Kontakt Ihres Unternehmens über das Internet ab?	**1 – 5** (Nicht über das Internet – Sehr stark über das Internet)	☐	☐	☐	☐	☐

5. Unternehmensprozesse in Bezug auf Industrie 4.0

Bitte geben Sie Ihre Bewertungen (1 -5) zu den nachfolgenden Fragen an.			**1**	**2**	**3**	**4**	**5**
5.1	Sind die ablaufenden Prozesse Ihres Unternehmens sehr stark miteinander vernetzt (vertikal und horizontal)?	**1 – 5** (Nicht vernetzt – Sehr stark vernetzt)	☐	☐	☐	☐	☐
5.2	Sind die Prozesse in Ihrem Unternehmen dezentral organisiert?	**1 – 5** (Nicht dezentralisiert – Sehr stark dezentralisiert)	☐	☐	☐	☐	☐
5.3	Empfinden Sie persönlich, dass die Prozesse Ihres Unternehmens standardisiert ablaufen?	**1 – 5** (Nicht standardisiert – Sehr standardisiert)	☐	☐	☐	☐	☐
5.4	Lassen sich die Prozesse Ihres Unternehmens schnell und einfach auf veränderte Anforderungen anpassen? (Flexibilität der Prozesse)	**1 – 5** (Nicht flexibel – Sehr flexibel)	☐	☐	☐	☐	☐
5.5	Ist die Planung, Ausführung und Steuerung der Prozesse Ihres Unternehmens digitalisiert?	**1 – 5** (Nicht digitalisiert – Vollständig digitalisiert)	☐	☐	☐	☐	☐
5.6	Laufen die horizontalen Prozesse in Ihrem Unternehmen automatisiert ab? (Prozesse entlang der Wertschöpfungskette)	**1 – 5** (Nicht automatisiert – Sehr stark automatisiert)	☐	☐	☐	☐	☐
5.7	Verfolgen Sie in Ihrem Unternehmen Strategien um die externen Stakeholder in das Unternehmen einzubinden? (Etwa durch Workshops, Informationsveranstaltungen oder Trainings)	**1 – 5** (Keine Strategien – Sehr umfassende Strategien	☐	☐	☐	☐	☐
5.8	Arbeiten die Abteilungen und Teams Ihres Unternehmens abteilungsübergreifend und interdisziplinär zusammen?	**1 – 5** (Keine Zusammenarbeit – Sehr gute Zusammenarbeit)	☐	☐	☐	☐	☐
5.9	Werden digitale Modelle und Simulationen zur Prozessgestaltung und Prozessplanung in Ihrem Unternehmen eingesetzt?	**1 – 5** (Nicht eingesetzt – Sehr umfassend eingesetzt)	☐	☐	☐	☐	☐

6. Unternehmenskultur in Bezug auf Industrie 4.0

Bitte geben Sie Ihre Bewertungen (1 -5) zu der nachfolgenden Frage an.			**1**	**2**	**3**	**4**	**5**
6.1	Werden die Mitarbeiten Ihres Unternehmens stark in stattfindende Veränderungsprozesse eingebunden?	**1 – 5** (Nicht eingebunden – Sehr stark eingebunden)	☐	☐	☐	☐	☐
6.2	Empfinden Sie persönlich, dass das Vorantreiben von Innovationen ein wichtige Teil Ihrer Unternehmenskultur ist?	**1 – 5** (Keine Ambitionen – Sehr große Ambitionen)	☐	☐	☐	☐	☐
6.3	Empfinden Sie persönlich, dass das externe Netzwerk um Ihr Unternehmens offen gegenüber Innovationen ist? (Etwa offen gegenüber neuen Technologien zur Kommunikation oder zur Geschäftsabwicklung)	**1 – 5** (Nicht offen – Sehr offen)	☐	☐	☐	☐	☐
6.4	Empfinden Sie persönlich, dass Ihre Unternehmenskultur eine schnelle Anpassung an veränderte externe Anforderungen erlaubt? (Flexibilität Unternehmenskultur)	**1 – 5** (Nicht flexibel – Sehr flexibel)	☐	☐	☐	☐	☐
6.5	Empfinden Sie persönlich, dass Informations- und Kommunikationstechnologien (IKT) einen hohen Stellenwert in Ihrem Unternehmen haben?	**1 – 5** (Sehr niederer Stellenwert – Sehr hoher Stellenwert)	☐	☐	☐	☐	☐
6.6	Empfinden Sie persönlich, dass die Sammlung, Verwaltung und Verteilung von erworbenem Wissen einen hohen Stellenwert in Ihrem Unternehmen haben?	**1 – 5** (Sehr niederer Stellenwert – Sehr hoher Stellenwert)	☐	☐	☐	☐	☐
6.7	Spielt die unternehmensübergreifende Zusammenarbeit zur Entwicklung neuer Produkte oder Services eine große Rolle in Ihrem Unternehmen? (cross-company collaboration und open innovation)	**1 – 5** (Spielt sehr kleine Rolle – Spielt sehr große Rolle)	☐	☐	☐	☐	☐

7. Mitarbeiter in Bezug auf Industrie 4.0

Bitte geben Sie Ihre Bewertungen (1 -5) zu der nachfolgenden Frage an.			**1**	**2**	**3**	**4**	**5**
7.1	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Unternehmens offen gegenüber neuen Technologien sind? (Etwa für die Erfüllung ihrer Aufgaben, in Produktionsmaschinen oder in Produkten)	**1 – 5** (Nicht offen – Sehr offen)	☐	☐	☐	☐	☐
7.2	Empfinden Sie persönlich, dass Mitarbeiter Ihres Unternehmens hohe Kompetenzen im Umgang digitalen Medien besitzen? (Etwa im Bereich der modernen Informations- und Kommunikationstechnologien)	**1 – 5** (Keine Kompetenzen – Sehr hohe Kompetenzen)	☐	☐	☐	☐	☐
7.3	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Unternehmens viele Ideen und Kreativität in das Unternehmen einbringen?	**1 – 5** (Keine Ideen – Sehr viele Ideen)	☐	☐	☐	☐	☐
7.4	Empfinden Sie persönlich, dass Mitarbeiter Ihres Unternehmens hohe Bereitschaft zu interdisziplinärer und abteilungsübergreifender Zusammenarbeit zeigen?	**1 – 5** (Keine Bereitschaft – Sehr hohe Bereitschaft)	☐	☐	☐	☐	☐
7.5	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Unternehmens die zugeteilten Aufgaben mit hoher Eigenständigkeit erfüllen?	**1 – 5** (Nicht Eigenständig – Sehr Eigenständig)	☐	☐	☐	☐	☐
7.6	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Unternehmens bereit sind Arbeit zu flexibilisieren? (Etwa den Arbeitsinhalt, die Arbeitszeit oder die Erreichbarkeit der Mitarbeiter außerhalb der Bürozeiten)?	**1 – 5** (Keine Bereitschaft – Sehr hohe Bereitschaft)	☐	☐	☐	☐	☐

8. Unternehmensinterne Lenkung und Steuerung in Bezug auf Industrie 4.0

Bitte geben Sie Ihre Bewertungen (1 -5) zu den nachfolgenden Fragen an.			**1**	**2**	**3**	**4**	**5**
8.1	Sind Aspekte wie Arbeitszeit, Arbeitsinhalt oder der Erfüllungsort der Arbeit in Ihrem Unternehmen flexibel geregelt?	**1 – 5** (Nicht flexibel – Sehr flexibel)	☐	☐	☐	☐	☐
8.2	Eignen sich die Arbeitsinhalte Ihres Unternehmens für “out-sourcing“ oder “in-sourcing“ von Arbeit?	**1 – 5** (Nicht geeignet – Sehr gut geeignet)	☐	☐	☐	☐	☐
8.3	Lassen sich die in Ihrem Unternehmen implementierten Standards einfach an veränderte externe Anforderungen anpassen?	**1 – 5** (Nicht anpassungsfähig – Sehr anpassungsfähig)	☐	☐	☐	☐	☐
8.4	Halten Sie persönlich die derzeitigen technologischen Standards Ihres Unternehmens für geeignet, um die zukünftigen Herausforderungen der Industrie zu bewältigen? (Herausforderungen wie die Digitalisierung, Vernetzung and Automatisierung der Unternehmensaktivitäten)	**1 – 5** (Nicht geeignet – Sehr gut geeignet)	☐	☐	☐	☐	☐
8.5	Sind in Ihrem Unternehmen Regelungen für den Schutz von Daten bzw. zum Schutz der Privatsphäre der Mitarbeiter implementiert? (cyber-crime and privacy)	**1 – 5** (Nicht implementiert – Sehr umfassend implementiert)	☐	☐	☐	☐	☐
8.6	Verfolgt Ihr Unternehmen strenge Regelungen zur Vermeidung von Gesundheitsgefährdungen in der Produktion?	**1 – 5** (Sehr wenig geregelt – Sehr umfassende Regelungen)	☐	☐	☐	☐	☐
8.7	Verfolgt Ihr Unternehmen Programme zur Förderung von Innovationen?	**1 – 5** (Keine Programme – Sehr umfassende Programme)	☐	☐	☐	☐	☐
8.8	Verfolgt Ihr Unternehmen Standards zur Sicherung und Weitergabe von Wissen? (knowledge-management)	**1 – 5** (Nicht verfolgt – Sehr stark verfolgt)	☐	☐	☐	☐	☐

8.9	Bietet Ihr Unternehmen Aus- und Weiterbildungsprogramme für Mitarbeiter zur Erhöhung der digitalen Kompetenz bzw. der Kompetenz im Umgang mit neuartigen Technologien an?	**1 – 5** (Nicht vorhanden – Sehr umfassend vorhanden)	☐	☐	☐	☐	☐
8.10	Verfolgt Ihr Unternehmen Standards zum Schutz von geistigem Eigentum? (intellectual property)	**1 – 5** (Keine Standards – Sehr umfassende Standards)	☐	☐	☐	☐	☐

9. Im Unternehmen eingesetzte Technologien in Bezug auf Industrie 4.

Bitte geben Sie Ihre Bewertungen (1 -5) zu den nachfolgenden Fragen an.			**1**	**2**	**3**	**4**	**5**
9.1	Verwendet Ihr Unternehmen vergleichsweise moderne Informations- und Kommunikationstechnologien? (Im Vergleich zu anderen Unternehmen der selben Branche)	**1 – 5** (Nicht modern – Sehr modern)	☐	☐	☐	☐	☐
9.2	Erfüllen die Produktionsmaschinen Ihres Unternehmens ihre Aufgaben autonom (ohne menschliches Zutun)?	**1 – 5** (Nicht autonom – Sehr autonom)	☐	☐	☐	☐	☐
9.3	Wie schnell und einfach können die Produktionsmaschinen Ihres Unternehmens auf veränderte Produktionsanforderungen angepasst werden? (Flexibilität der Produktionsmaschinen)	**1 – 5** (Nicht flexibel – Sehr flexibel)	☐	☐	☐	☐	☐
9.4	Sind in Ihrem Unternehmen mobile Geräte zur Vernetzung der Unternehmensaktivitäten im Einsatz? (smart devices, tablets etc.)	**1 – 5** (Nicht im Einsatz – Sehr umfassend eingesetzt)	☐	☐	☐	☐	☐
9.5	Sind in Ihrer Produktion Sensorik-Systeme zur Generierung und Nutzung von Echtzeit-Daten im Einsatz?	**1 – 5** (Nicht im Einsatz – Sehr umfassend eingesetzt)	☐	☐	☐	☐	☐
9.6	Sind elektronische Rechner und Computer (Embedded Systems) in Ihre Produktionsmaschinen integriert? (Mit dem Ziel der Digitalisierung und Vernetzung der Maschinen)	**1 – 5** (Nicht vorhanden – Sehr umfassend vorhanden)	☐	☐	☐	☐	☐
9.7	Sind die Produktionsmaschinen Ihres Unternehmens in der Lage selbstständig miteinander zu kommunizieren bzw. Informationen auszutauschen? (M2M-Kommunikation)	**1 – 5** (Nicht in der Lage – Sehr gut in der Lage)	☐	☐	☐	☐	☐
9.8	Werden in Ihrer Produktion Auto-ID-Technologien (z.B. RFID) zur automatischen Echtzeit-Identifikation von Objekten verwendet?	**1 – 5** (Nicht im Einsatz – Sehr umfassend eingesetzt)	☐	☐	☐	☐	☐
9.9	Inwieweit wird Cloud-Computing in Ihrem Unternehmen verwendet? (ortsunabhängige Speicherung, Verwaltung und Bereitstellung von Daten)	**1 – 5** (Nicht im Einsatz – Sehr umfassend eingesetzt)	☐	☐	☐	☐	☐
9.10	Inwieweit wird generative Fertigung (z.B. 3D-Druck) in Ihrem Unternehmen eingesetzt?	**1 – 5** (Nicht im Einsatz – Sehr umfassend eingesetzt)	☐	☐	☐	☐	☐

Fragebogen Absenden

The questionnaire is developed as PDF-form which allows for digitally responding and therefore increases the willingness to answer. It should be stated that this questionnaire is used in companies eager to know their maturity in Industry 4.0 and, therefore, motivation to participate within the company.

5 Pilot-Testing of the I40MM

In order to ensure practical understandability and usability, the model has been tested within two companies. The companies considered for pilot-testing of theI40MM have to fulfill certain criteria to maximize the resulting feedback about the model's function:[158]

- Core business of the company should be in manufacturing industry as the models target-group (no service-sector)
- Industry 4.0 has to be partly implemented to foster representative results (otherwise mainly the lowest maturity level 1)
- Basic understanding about Industry 4.0 has to exist to carry out self-assessment (questionnaire)
- Management-level has to be willing to respond to the questionnaire (design of questionnaire for self-assessment requires management-level to respondent)

The maturity model was tested using the developed questionnaire for self-assessment (see chapter 4.2.9 I40MM details - Questionnaire for self-assessment of the maturity). The companies where contacted by email and the questionnaire filled out digitally using the sent PDF-form. The companies participating in the pilot-testing are anonymized, thus only little demographic data is provided. The discussion of the pilot test-results is presented in the last chapter (see chapter 6 Discussion and Outlook) as the pilot tests serve as the base for improvements and further developments of the maturity model. In this chapter a short demographic profile of the test-companies is provided, followed by the presentation of the assessment-results using the maturity dashboard. The full results of the pilot tests are provided in the Appendix (see chapter 7.4 Full Results Pilot-Testing 1 and chapter 7.5 Full Results Pilot-Testing 2).

Pilot-Test 1

Company Profile	
Branches/Industry:	• Aerospace
Number of employees:	• > 400
Core-business activity:	• Design and manufacture of aerospace components and test equipment

[158] To test the model, companies not engaging in Industry 4.0 are not suitable as maturity of the attributes would be detected → most attributes at maturity level 1

Results of the maturity assessment

Dimension Description	Dimension	Overall Maturity Level
The dimension Strategy encompasses aspects such as: compatibility with company-strategies, utilization of roadmap, availability of resources, communication and documentation of strategies, suitability of business models, strategy for digital transformation	**Strategy**	**2,7**
The dimension Leadership encompasses aspects such as: willingness of leaders, existence of central coordination, competence and methods of leaders	**Leadership**	**3,1**
The dimension Products encompasses aspects such as: individualization of products, embedded systems in products, integration into other systems, autonomy of products, digitalization of products, flexibility of products	**Products**	**5,0**
The dimension Customers encompasses aspects such as: openness of customers to innovation, integration of customers into processes, utilization of customer data, customer competence with digital media, digitalization of sales and services	**Customers**	**3,0**
This dimension Operations encompasses aspects such as: vertical and horizontal integration of processes, decentralization of processes, standardization of processes, digitalization of processes, automation of processes, autonomy of processes , flexibility of processes, stakeholder integration, inter-department collaboration, modelling and simulations in process planning	**Operations**	**3,2**
The dimension Culture encompasses aspects such as: employee-inclusion, innovativeness of the company, stakeholder-openness, adaptability of the company culture, existence of knowledge management, conduction open innovation, value of ICT in the company	**Culture**	**3,4**
The Dimension People encompasses aspects such as: openness to technology, ICT-competence of the employees, creation and promotion of ideas, interdisciplinary work, autonomy of the employees, flexibilization of work	**People**	**4,0**
The dimension Governance encompasses aspects such as: technological standards, data-security and employee-privacy standards, safety-standards, innovation programs, information management, education and training, intellectual property,suitability of labor-regulations, sourcing of work, adaption of existing standards	**Governance**	**3,7**
The dimension Technology encompasses aspects such as: Modern ICT, autonomy of machines, flexibility and adaptability of machines, utilization of mobile devices, utilization of sensors, embedded systems in machines, M2M communication, auto-ID technology, cloud computing, 3D-printing	**Technology**	**2,6**

Dimension with the highest maturity rating

Dimension with the lowest maturity rating

Figure 48: I40MM-Dashboard: dimension's maturity in numerical representation; Pilot testing 1

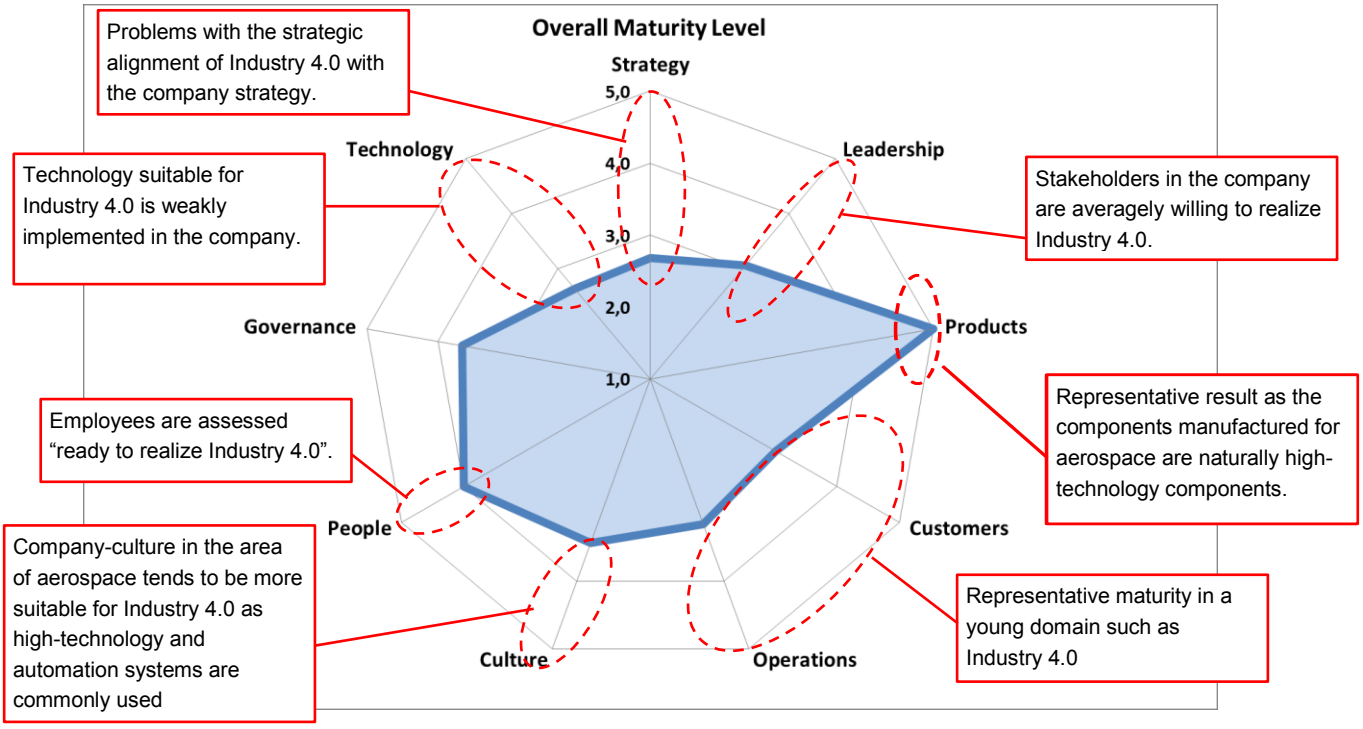


Figure 49: I40MM-Dashboard: dimension's maturity in graphical representation; Pilot testing 1

Pilot-Test 2

Company Profile	
Branches/Industry:	• Electronic systems
Number of employees:	• > 80
Core-business activity:	• Development and production of customized electronic devices in the industry and automation area

Results of the maturity assessment

Dimension Description	Dimension	Overall Maturity Level
The dimension Strategy encompasses aspects such as: compatibility with company-strategies, utilization of roadmap, availability of resources, communication and documentation of strategies, suitability of business models, strategy for digital transformation	**Strategy**	**3,6**
The dimension Leadership encompasses aspects such as: willingness of leaders, existence of central coordination, competence and methods of leaders	**Leadership**	**5,0**
The dimension Products encompasses aspects such as: individualization of products, embedded systems in products, integration into other systems, autonomy of products, digitalization of products, flexibility of products	**Products**	**3,8**
The dimension Customers encompasses aspects such as: openness of customers to innovation, integration of customers into processes, utilization of customer data, customer competence with digital media, digitalization of sales and services	**Customers**	**4,0**
This dimension Operations encompasses aspects such as: vertical and horizontal integration of processes, decentralization of processes, standardization of processes, digitalization of processes, automation of processes, autonomy of processes , flexibility of processes, stakeholder integration, inter-department collaboration, modelling and simulations in process planning	**Operations**	**4,2**
The dimension Culture encompasses aspects such as: employee-inclusion, innovativeness of the company, stakeholder-openness, adaptability of the company culture, existence of knowledge management, conduction open innovation, value of ICT in the company	**Culture**	**4,8**
The Dimension People encompasses aspects such as: openness to technology, ICT-competence of the employees, creation and promotion of ideas, interdisciplinary work, autonomy of the employees, flexibilization of work	**People**	**4,2**
The dimension Governance encompasses aspects such as: technological standards, data-security and employee-privacy standards, safety-standards, innovation programs, information management, education and training, intellectual property,suitability of labor-regulations, sourcing of work, adaption of existing standards	**Governance**	**4,2**
The dimension Technology encompasses aspects such as: Modern ICT, autonomy of machines, flexibility and adaptability of machines, utilization of mobile devices, utilization of sensors, embedded systems in machines, M2M communication, auto-ID technology, cloud computing, 3D-printing	**Technology**	**4,0**

Dimension with the lowest maturity rating

Dimension with the highest maturity rating

Figure 50: I40MM-Dashboard: dimension's maturity in numerical representation; Pilot testing 2

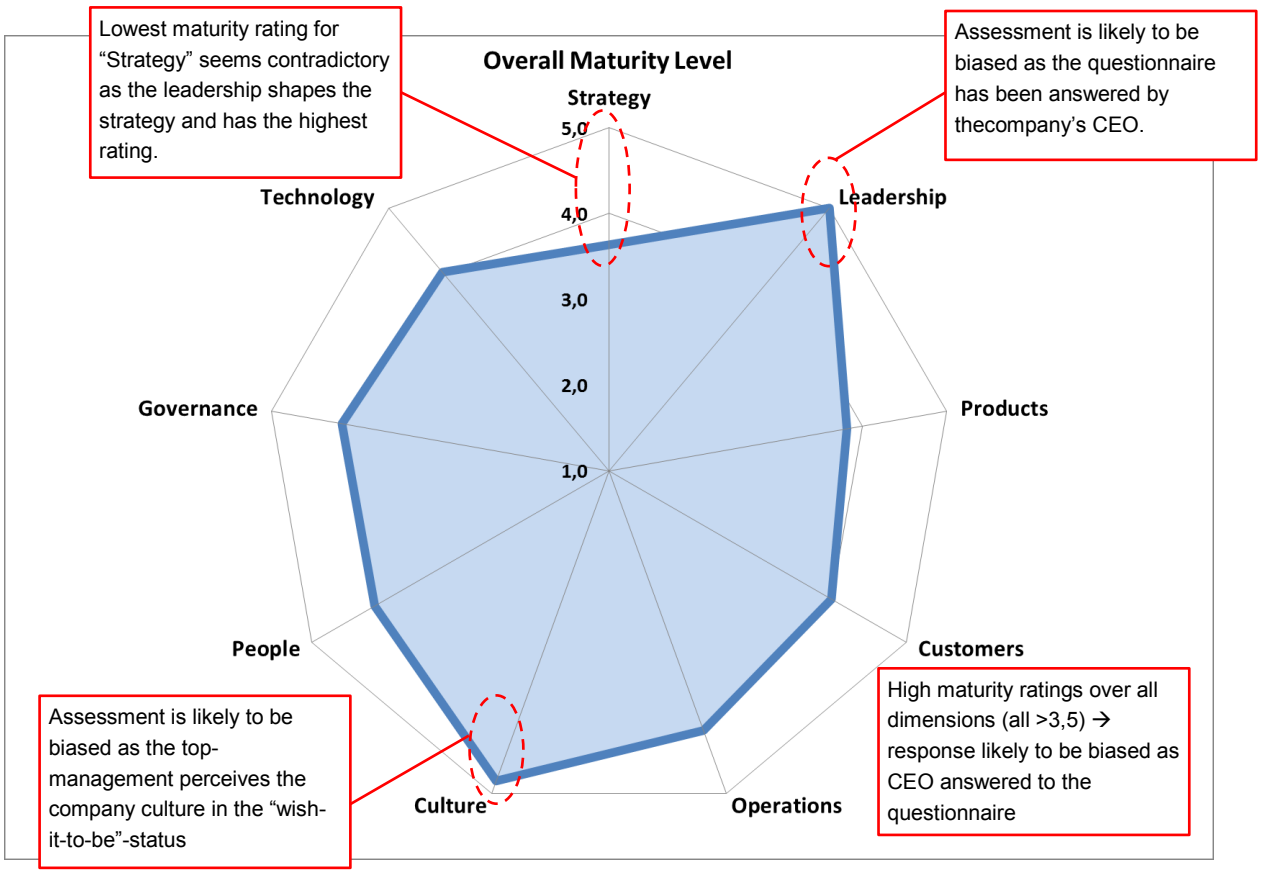


Figure 51: I40MM-Dashboard: dimension's maturity in graphical representation; Pilot testing 2

6 Discussion and Outlook

This thesis aimed for the development of a maturity model for the assessment of the Industry 4.0-maturity of industrial enterprises. The underlying research question to be answered has been defined as follows:

What are the basic determinants of Industry 4.0 maturity and which methodologies are suitable to assess the Industry 4.0 maturity?

Thereby, the sub-question “what attributes in what organizational dimensions should be distinct in what ways to be considered mature in Industry 4.0” was leading through the development of the artifact.

In the following, results of the thesis and the used methodologies are discussed and conclusions are drawn. Finally, further developments of the I40MM and future research in the field of maturity models that are applied on the domain of Industry 4.0 are outlined.

6.1 Summary of Results and Findings

The thesis resulted in the development of a maturity model that allows for the self-assessment of the Industry 4.0 maturity - with the following characteristics:

- **Target audience:** Industrial enterprises (Manufacturing of goods)
- **Company-dimensions to be assesses:** 9 dimensions - Strategy, Leadership, Products, Customers, Operations, Culture, Employees, Governance, Technology
- **Maturing attributes within the company-dimensions:** 62 maturing-attributes assigned to the 9 company-dimensions
- **Mode of assessment:** Questionnaire for self-assessment containing 62 questions (1 question per attribute)
- **Time for assessment:** no fixed amount of time
- **Number of maturity levels:** 5 levels (1 – un-mature in Industry 4.0 to 5 – very mature in Industry 4.0)
- **Mode of calculating the maturity:** Weighted average of the attributes within the company-dimensions (weighting based on the expert’s importance-rating)
- **Mode of Representation:** Results are presented in a maturity-report consisting of 11 pages (page 1: maturity dashboard showing “maturity at-a-glance)
- **Software used for development:** Microsoft Excel, PDF-Acrobat

The I40MM has been developed using a multi methodological approach including a systematic literature review and qualitative and quantitative research approaches for validating the model.

The literature review resulted in 4318 findings after applying the 1st degree inclusion/exclusion-criteria (search-word, time-frame, language etc.). After applying the 2nd degree (suitability of finding, required quality etc.) only 74 publications were considered for inclusion into the model's development. The reason of the rather high ratio of findings to considered publications can be explained by the wide range of application in various domains (e.g. education or health-systems) from which only little derivations could be made. Moreover, the time constraints prevented the screening of all 4318 publications, therefore the "sorting by relevance"-function offered in most online-databases has been applied, and only the first result-pages have been screened. The results of the systematic literature review can be summarized as follows:

- **Databases used for the research:** Science Direct, Library – University of Vienna
- **Results:** 4318 after applying the 1st degree criteria
- **Considered Literature:** 74 publications considered forth e model's development
- **Presentation of the results:** Summary depicted in a concept map
- **Reasons for high ratio (findings/inclusion into the development):** time constraints while screening the findings, wide range of application-domains of maturity models, little information about maturity model development in the publications

Simultaneously, expert interviews have been carried out (qualitative research) to state the practical need of the model, capture the state of Industry 4.0 and collect information for the model's population. The expert interviews support the holistic approach, as they include practical aspects into the models development:

- **Number of experts:** 6 Interviews with 7 experts (1 double-interview)
- **Expert's affiliation:** Research, business development, strategic consulting, companies in telecommunication and software solutions;
- **Interviewing language:** German
- **Structure of the interview:** Semi-structured (using developed interview guideline)
- **Conduction of the interview:** voice recorded face-to-face and Skype-talks(1 interview)
- **Confidentiality of the interview:** Anonymously
- **Duration:** 45-60min, double-interview 90min

- **Approach to content-analysis:** No transcription, qualitative analyzes and transformation to general statements about Industry 4.0
- **Approach of result representation:** Written Summary - merging the expert's answers to generalized statements

After populating the model based on the literature review and the exert interviews, the practical relevance of the models content has been validated by expert ratings of the maturity-attribute's importance for realizing Industry 4.0. The result of the ratings serves for the weighted calculation of the 9 company-dimension's maturity. Therewith, the importance-differences of of attributes for assessing I40 maturity have been considered.

Target audience of the importance-survey: Experts in Industry 4.0

- **Mode for assessment:** Questionnaire distributed per email
- **Language of the questionnaire:** German
- **Duration for answering:** ca. 15min
- **Approach:** Rating of the 62 maturing items in the 9 company-dimensions (= population of the maturity model)
- **Scale:** Likert-scale with 4 distinctions (1 – attribute is not important to realize Industry 4.0 to 4 – attribute is very important to realize Industry 4.0)
- **Number of questionnaires distributed:** ca. 120 Questionnaires
- **Number of Responds:** 23 answered questionnaires
- **Average importance Rrating over all dimensions:** 3,2 out of 4
- **Dimension with highest average importance rating:** Culture (3,5)
- **Dimension with lowest average importance rating:** Products (2,9)

Finally, in order to assess each maturity-attribute's distinction within the company, a detailed questionnaire has been developed:

- **Target audience of the questionnaire:** Management-level with comprehensive knowledge about the company-structure and activities
- **Mode of assessment:** Questionnaire as a digital PDF-form
- **Duration for answering:** 45min or more
- **Approach:** 62 questions assigned to the 9 company-dimensions
- **Scale:** Likert-scale to rate the maturing attribute's distinction in the company (1 – not distinct, 5 – very distinct)

The maturity model then was tested in two companies that are already engaging in Industry 4.0 to ensure representative results (avoid "level 1 – results"). Although potential for improvement can be derived from the pilot-tests, the testing of the I40MM has been considered successful:

- **Number of pilot-testing's:** Testing in 2 Companies (Manufacturer of aerospace testing-systems and manufacturer of electronic parts)
- **Approach to assessment:** distribution of the questionnaire per email
- **Feedback regarding usability of the questionnaire:** positive feedback regarding formulation of the questions and suitability of the attributes for assessing the Industry 4.0 maturity
- **Result of the maturity assessment pilot-company 1:** Dimension with the highest maturity rating – Products (5.0); Dimension with the lowest maturity rating – Technology (2,6)
- **Result of the maturity assessment pilot-company 2:** Dimensions with the highest maturity rating – Leadership (5.0); Dimension with the lowest maturity rating – Strategy (3,6)

Considering the first company's core business (manufacturing of parts used aerospace) and the respondent's position answering the questionnaire, the results of the first pilot-testing seem realistic and representative. The results of the second pilot testing seem to be "too mature", especially as Industry 4.0 is such a young field. Consequently, maturity-ratings of 5.0 in the dimensions "Leadership" and 4.8 in the dimension "Culture" seem unrealistic. One source for the biased answers could be the fact, that only one person per company responded to the questionnaire. In the first pilot-testing, the Production Manager responded to the questionnaire which resulted in the company's products to be level 5-mature[159]. In the second pilot-testing, the CEO responded to the questionnaire which resulted in the dimensions "Leadership" and "Culture" to be assessed with the highest maturity level possible. The resolving of these potential response-biases is issued in the further development of the model.

6.2 Discussion of used Methodology

Following the design science approach offered by Hevner, the application of Hevner's development-guidelines were carried out based on Becker's procedure model for maturity model development in the following order: Initiation → Problem definition (1) → Comparison with existing maturity models (2) → Determination of development strategy (3) → Iterative model development (4) → Concept transfer and evaluation (5) → Implementation of transfer media (6) → Real-life evaluation of the model (7).

The *problem definition (1)* was based on the real-life experience of researchers of the Institute of Management Science and the Fraunhofer Austria Research GmbH collected in various workshops and projects. The intensive exchange with the Research team was complemented by an extensive literature research on "Industry

[159] It has to be noted that components used in aerospace are likely to be very suitable for the integration into Industry 4.0

4.0”. Moreover, expert interviews have been carried out to include additional insights and to focus the problem definition. Simultaneously, *existing maturity models (2) were compared* by carrying out a systematic literature review on “maturity models” and by depicting the findings in a concept map. Based on the results of these findings, the *development strategy (3)* of transferring the structure of existing maturity models to the domain of Industry 4.0 was chosen. The model was then developed in an *iterative manners (4)* by including the research team of the Institute of Management Science and the Fraunhofer Research GmbH. Moreover, the results of the expert-rating regarding practical importance of the models population were considered for the models development and a literature research on “Industry 4.0” was carried out. The model was *made transferable (5)* as it was developed using the software Microsoft Excel. The excel-file contains all required background information, the functions and formulary for calculating the maturity. The conversion into a *PDF-maturity report (6) represented on 11 pages enhanced the transferability of the model further*. Furthermore, the questionnaires used to measure the maturity-attributes in the company was developed using a *PDF-form (6)* which can automatically be returned to the research team through an embedded sending-function in the form. Finally, the *model has been tested* with two pilot-companies whereby feedback regarding practicability and usability was collected and used for further improvement (7).

The actual approach used to develop the I40MM is based on well proven scientific methods. However, to improve the approach chosen, critical reflection leads to the following potential for improvement to reach “ideal design”:

- Time constraints prevented a more detailed comparison of existing maturity models
- Time constraints also prevented a more detailed analysis of the existing model’s structures regarding suitability for the application on Industry 4.0
- A clearer determination of the development strategy at early stage would help to create a better development-focus
- Additional expert interviews or workshops would increase the quality of the model’s content (representative population)
- Additional modes for the model’s transfer such as an online tool would enhance the models distribution and therefore real-life evaluation and feedback
- A different approach to measure the maturity-attribute’s distinction within the company should be developed to avoid response-biases (e.g. that the CEO over-estimate the capabilities of the leadership or that product managers overestimate their Product’s suitability for Industry 4.0)

Overall, the carried out approach to the model's development is considered sufficient and target-aimed, however it could be improved when implementing the aspects described above.

6.3 Further Research Directions

Based on the feedback from the research team from the Institute of Management Science and the Fraunhofer Research GmbH as well as the pilot tests carried out, the following three next-steps are planned:

1. Clearer distinction of the model, if general or domain-specific (as the generic-level of the attributes varies too much)
2. Additional research on the maturity-attributes, as the attributes determine the model's representability
3. Additional pilot-testing of the model in different industries to verify the model's functionality

Further research will be conducted especially on the population (maturity attributes) of the maturity model. Workshops within the research team or with the inclusion of external stakeholders should lead to the definition and prioritization of additional attributes to encompass the aspects of Industry 4.0 in more comprehensive manners.

Moreover, further domain-related specifications of the maturity model are one possible future research approach. Focusing the model for the use in e.g. manufacturing companies in the OEM-sector increases the accuracy and eases the collection of suitable maturity attributes.

Based on the expert-interviews and the expert-rating of the attribute's importance comprehensive information about the success factors for a successful realization of Industry 4.0 has been collected. Therefore, road-maps and phase-models for the realization of Industry 4.0 could be derived as comprehensive information about the success factors for a successful realization of Industry 4.0 has been collected.

As part of the development of roadmaps, the definitions of desired maturity-target-states in Industry 4.0 are going to be added to the I40MM features. Consequently, tracking maturity developments over time could be realized through the development of an easy-to-use online-tool that could be used for self-assessment within the company and the automatic creation of the maturity-report as a downloadable PDF-document.

6.4 Conclusion

Relating to the initially defined research question of - what are the basic determinants of Industry 4.0 maturity - this thesis offers the following answer: maturity in Industry 4.0 is determined by 62 Attributes in 9 company dimensions, whereby these attributes determine the general Industry 4.0 maturity of industrial enterprises. Consequently, these identified maturity attributes are included into a model that allows for assessing the Industry 4.0 maturity of a company – the I40MM.

The second part of the research question asking - which methodologies are suitable to assess the Industry 4.0 maturity - can be answered as well. Following Becker's approach for the creation of a maturity model allows deriving a step-by-step procedure applicable on the development of the I40MM. Thereby, methodologies such as quantitative and qualitative survey research and systematic literature research proved sufficient to ensure a strong scientific basis.

In the near future, the increasing popularity of Industry 4.0 - resulting in high investments and funding - is not likely to come to an end. Therefore, the need for guidance and the reduction of uncertainty in Industry 4.0 is going to get increased attention as well. Tackling these issues, the Industry 4.0 Maturity Model proves to be a first step to offer industrial enterprises a scientifically grounded and practically validated information basis for taking coordinated measures towards the successful realization of Industry 4.0.

7 Appendix

7.1 Guideline Expert-Interviews

The expert interviews have been carried out following a developed guideline to support structure and to lead through the interview.

Guideline Expert Interview

Institution:

Name:

Date:

Purpose of the interview

This interview helps collect and discuss success factors for the realization of Industry 4.0. The determination of these generic factors should help to develop a model for assessing the maturity of companies in Industry 4.0.

Goals of the Interview

- To find the main practical problems during the realization of Industry 4.0
- To collect personal experiences with the realization of Industry 4.0
- To find success factors which are critical for the realization of Industry 4.0 in praxis

Introduction to success factors for realizing Industry 4.0

In our opinion, success factors for realizing Industry 4.0 can be assigned to nine dimensions of an organization (Strategy, Leadership, Products, Customers, Operations, Culture, Employees, Governance and Technology). Moreover, we argue, that a certain distinction of these factors within the organization enhances the realization of Industry 4.0.

Structure of the interview / Topics to be discussed

1. Introduction of myself, my institute, reason for the survey
2. Explanation why we are conducting expert interviews
3. Explanation of my role during this survey (relation to master thesis)
4. Introduction of the experts, their field and affiliation
5. Relation of the expert to Industry 4.0 (personal relation of Industry 4.0)
6. Discussion of main problems with Industry 4.0 during the realization
7. Discussion of possible success factors for realizing Industry 4.0
8. Optional: Discussion main problems when assessing maturity of companies

Interview Questions (related to the topics)

Einleitung zum Interview

Vielen Dank, dass Sie sich die Zeit für dieses Interview nehmen. Es handelt sichhierbei um ein halb-strukturiertes Interview, bei dem Ich einen groben Leitfaden gerne verfolgen würde, aber keine standardisierten Detailfragen vorkommen. Eingangs will ich Sie gleich Fragen, ob es für Sie in Ordnung ist, wenn ich das Gespräch aufzeichne. Sollten Antworten aus dem Gespräch zitiert werden, geschieht dies ausschließlich in anonymer Form. Dazu habe ich Ihnen eine Einverständniserklärung mitgebracht.

Ich werde Ihnen kurz den Ablauf des Interviews erklären:

Ich werde Ihnen im Folgenden erklären, warum wir dieses Interview mit Ihnen führen wollen und was wir uns davon erhoffen. Danach würde Ich gerne Ihre allgemeine Verbindung zu Industrie 4.0 erfahren bzw. was Sie eigentlich mit diesem großen Thema verbinden. Dies soll gefolgt werden von einem offenen Gespräch über die Probleme bei der Realisierung von Industrie 4.0 bzw. über mögliche Erfolgsfaktoren, welche eine Realisierungfördern können.

Ad1. Introduction of myself, my institute, reason for the survey

Wir führen derzeit am Institut für Managementwissenschaften an der Technischen Universität eine Studie zum Thema „Kritische Erfolgsfaktoren für eine erfolgreiche Realisierung von Industrie 4.0“ durch. Diese Studie soll in Zukunft der Entwicklung eines Modells zur Messung der Industrie 4.0-Reife von produzierenden Unternehmen als Basis dienen.

Ad2. Explanation why we are conducting expert interviews

Ziel der Studie ist es, generische Faktoren zu finden, deren positive Ausprägung in einem Unternehmen eine erfolgreiche Realisierung von Industrie 4.0 unterstützen. Nach der theoretischen Ableitung von möglichen Faktoren aus existierender Literatur wollen wir nun Experten aus Industrie und Forschung einbeziehen, um:

- deren persönlichen Erfahrungen/Einschätzungen bzgl. der Problematiken während der Industrie 4.0 Realisierung zu erfahren
- deren persönlichen Erfahrungen/Einschätzungen bzgl. möglicher Erfolgsfaktoren für eine Erfolgreiche Realisierung von Industrie 4.0 zu erfahren
- Wo liegen die Probleme und was muss im Unternehmen getan werden

Ad3. Explanation of my role during this survey (Relation to master thesis)

Die Praktische Umsetzung der Studie (Ableitung der Faktoren aus der Literatur bzw. Einbeziehung von Experten) ist teil meiner Masterarbeit. Ich arbeite seit zwei Jahren am Institut für Managementwissenschaften als Hilfswisschenschaftlicher Mitarbeiter und werden nach Beendigung meiner Masterarbeit dort eine Fixstelle annehmen.

Ad4. Introduction of the experts, their field and affiliation

- Ich würde Sie nun kurz bitten Ihre Rolle in dieser Firma/Institution bzw. Ihre Aufgabengebiet zu beschreiben?

Ad5. Relation of the expert to Industry 4.0 (personal relation to Industry 4.0)

- Bitte erläutern Sie, welche Verbindung Sie zu Industrie 4.0 haben?
  - Welche Projekte in diesem Bereich haben sie durchgeführt?
  - Wie berührt Sie dieses Thema bei Ihrer Tätigkeit?
- Wie stehen Sie diesem Thema generell gegenüber?
  - Positiv/Unsicher/Kritisch etc.
- Was bedeutet Industrie 4.0 für Sie persönlich?
  - Könnten Sie in ein bis zwei Sätzen formulieren was Sie ganz persönlich unter Industrie 4.0 verstehen (keine Definition nötig)
- Wo sehen Sie die größten Vorteile?
  - Wie glauben Sie kann Industrie 4.0 Ihrem Unternehmen helfen?
  - Wo sehen Sie die größten Potentiale in Ihrem Bereich?

Ad6. Discussion of main problems with Industry 4.0 during the realization

- Wo sehe sie für Unternehmen generell die größten Probleme bei der Realisierung von Industrie 4.0?
  - Wo hat Ihr Unternehmen die größten Probleme bei der Einführung von Industrie 4.0?
  - Wo sehen Sie die Gründe für die Probleme in Ihrem Unternehmen?
  - Was würden Sie bei einem neuerlichem Start ins Thema Industrie 4.0 nun anders angehen als beim ersten mal?
- Warum denken Sie tun sich Unternehmen schwer die Visionen der Industrie 4.0 zu realisieren?
  - Aus Ihrer Projekterfahrung, wo haben Unternehmen die größten bei der Umsetzung von Industrie 4.0?
  - Welche Gründe für die Nicht-Umsetzung von Industrie 4.0 in Unternehmen fallen Ihnen aus Ihrer Erfahrung ein?
  - Wo haben Sie bei der Durchführung von Industrie 4.0-Projekten die größten Probleme bzw. wo bestehen die größten Herausfoderungen?

Ad7. Discussion of possible success factors for realizing Industry 4.0

- Wenn Sie an die Realisierung von Industrie 4.0 in Ihrem Unternehmen denken, welche Vorraussetzungen mussten als erstes geschaffen werden, um das Thema

Industrie 4.0 anzugehen?
  - Was wurde als erstes getan, um das Thema an die Mitarbeiter heranzutragen?
  - Wie wird das Thema im Unternehmen bearbeitet und vorwärts gebracht?
  - Welche Aspekte der Industrie 4.0 werden derzeit in Ihrem Unternehmen angegangen?
- Was halten Sie für die wichtigsten Faktoren, welche bei der Realisierung von Industrie 4.0 im Fokus stehen sollten?
  Stichworte: Strategy, Leadership, Products, Customers, Operations, Culture, Employees, Governance und Technology
- Welche Voraussetzungen muss ein Unternehmen schaffen, um Industrie 4.0 erfolgreich realisieren zu können (in Ihrem Bereich)?

Ad8. Discussion main problems when assessing maturity of companies in Industry 4.0

- Wenn ich Ihnen nun sage “Ich will die Industrie 4.-Reife Ihres Unternehmens ermitteln“, welche möglichen Problematiken kommen Ihnen hierzu in den Sinn?
- Wo sehen Sie die größten Probleme bei der Bewertung der Industrie 4.0 Reife eines Unternehmens?

7.2 Full Results – Expert Interviews

7.2.1 Expert Interview 1 (Double Interview)

Profile of the expert	
Institution/Branch:	• University – Research
Position:	• Research Associates

For the expert Industry 4.0 is understood as:
• Industry 4.0 contains all processes and measures which are necessary to create a integration of the physical and digital world including all stakeholders • Industry 4.0 is rather a concept than a vision as concrete technological requirements for the realization can be stated

Expert's area of engagement in Industry 4.0:

- Logistics 4.0
- Supply Chain Management

State of Industry 4.0 in praxis:

- Companies are stuck in the transition from acquiring new technologies to integration into their processes and structure
- Industry 4.0 is a hyped topic, but changes will remain in the long-term
- Some companies do not see the benefits of Industry 4.0, but they have to follow to not have disadvantages in the long-run
- Parts of Industry 4.0 are already implemented (e.g. autonomous driving, or delivery by drones)

Current problems during the realization of Industry 4.0:

- Besides the pure implementation of technology, the purpose and right application has to be found (e.g. no application of the cloud in the company)
- Technology is seen as the only aspect to realize Industry 4.0
- Existing systems are fragmented and stakeholders are not cooperating
- Concepts of Industry 4.0 are constructed with a very long time-horizon fir implementation, and is therefore hard to scope for companies
- Companies do not want to give away information and data (data exchange)
- Companies do not see the benefit
- Companies fear to destroy their own existence with Industry 4.0
- Employees in companies fear to get replaced by software and robots
- Logistics companies have the feeling they already implemented these aspects
- Complexity in logistics will increase drastically as Industry 4.0 leads to non-plannable distribution processes (as orders are triggered in real-time)
- Integration of all stages of the supply-chain in real time is not realistic
- Position of logistics companies at the interfaces between other stakeholders is problematic as real-time business operations between the stakeholders require immense flexibility of the logistics companies
- Real-time in logistics is critical as transport-modes need time to move from A to B or to be available at a certain time at a location
- The cost-reductions achieved with optimized planning processes in logistics are eliminated with Industry 4.0 as forecasting is substituted by real-time activities

Impacts of Industry 4.0 on the industry:

• The Industry 4.0 approach of logistic-companies has to align itself to the production companies (e.g. decentralization of production through 3D-printing influences distribution) • Industry 4.0 could lead to many small deliveries instead of e.g. big trucks and ships • The services in logistics will change drastically, but the outcome is still uncertain
Important criteria for the realization of Industry 4.0:
• Vertical and horizontal integration of processes • Standardized Systems (IT, ERP etc.) along the value chain • To process and exploit the information objects can carry along the value chain • To handle the complexity of the topic • The acquisition of modern IT-Infrastructure • Skilled workers to handle the complexity
Potential and benefits of Industry 4.0:
• The integration of all stakeholders along the value chain • New structuring of supply chains in more flexible manners • Reduction of costs along the supply chain • Offering individual products and services • Communication of objects along the supply chain creates “transparent chain” • To offer additional services besides the pure delivery process from A to B

7.2.2 Expert Interview 2

Profile of the expert	
Institution/Branch:	• Telecommunication
Position:	• Management

For the expert Industry 4.0 is understood as:
• Industry 4.0 is the digitalization and virtualization of the entire value chain mostly in the production industry, but also in the service sector
Expert’s area of engagement in Industry 4.0:

- Machine to Machine networking and communication
- Networking of physical of objects

State of Industry 4.0 in praxis:

- Industry 4.0 is strongly technology-oriented
- Companies want to implement Industry 4.0 as they want to be “innovative”
- Companies don’t know what problems they can target with Industry 4.0

Current problems during the realization of Industry 4.0:

- Some isolated technologies e.g. 3D-printing or drones are sold as “Industry 4.0”
- Too many concepts are encompassed by Industry 4.0 which makes it too complex and too big to handle
- Focus in Industry 4.0 is too much on technology
- Complexity of the Industry 4.0 is too high
- Legal issues are not regulated (e.g. in case of damage or for services)
- Transformation from a strategic level to the operative levels
- Understanding of benefits on a management-level is not existing
- Generated data is not structured and in the following not utilized

Impacts of Industry 4.0 on the industry:

- Products and services might be totally virtualized
- Services are connected to products (after-sales) which are changing the business relations with the customers (customer awareness)
- Complexity along the value chain increased with Industry 4.0

Important criteria for the realization of Industry 4.0:

- Structuring the concepts of Industry 4.0
- Transformation of Industry 4.0 vision to processes and organizational structure
- Integration of new solutions into existing systems
- Organizational structure has to be adapted to Industry 4.0
- Companies have to determine the actual problems which should be targeted with Industry 4.0

Potential and benefits of Industry 4.0:

- Verification and prove of work (e.g. through sensors objects)
- Development of smart products
- Creation of new business models based on data-generation

- Optimization and re-engineering of processes
- Resource efficiency (smart grids, smart metering)
- Potential in areas where laws are forcing companies to act

Profile of the expert	
Institution/Branch:	• Software producer
Position:	• Middle Management

7.2.3 Expert Interview 3

For the expert Industry 4.0 is understood as:
• -
Expert's area of engagement in Industry 4.0:
• Supply chain management based on data-generation
State of Industry 4.0 in praxis:
• Integration and networking through data and information and communication technology is stressed too much, firstly the organizational structures have to be created • Uncertainty about the outcomes of Industry 4.0 • Uncertainty who is taking the lead in Industry 4.0 • IT-departments became less important in the 1990s, now companies lack modern information and communication technology • Companies do not feel pressure to realize Industry 4.0 • Companies only react put do not react in self-motivated manners
Current problems during the realization of Industry 4.0:
• Companies fear the intern integration through data • Topic is too complex especially for small companies • Focus is too much on technology • Data is generated and collected but not utilized (data-grave) • Need to explain new business models to the customers • B2B-relations are hard to change and adapt to Industry 4.0 • Technology alone cannot create a USP

Impacts of Industry 4.0 on the industry:
• Data-Highway connects elements along the value chain (irreversible) • Data about the customer and market is collected and new business models develop • Shift from selling only products to combination of products and services • Planning and forecasts are not possible with Industry 4.0 • Business planning changes as models and forecast are used to calculate costs • Communication between human and machine is substituted by data
Important criteria for the realization of Industry 4.0:
• Interdisciplinary co-operation along the value chain • Re-invention of the sales-and customer-relations • Development of unique business models • Skilled workers are required • IT-infrastructure to process the generated data
Potential and benefits of Industry 4.0:
• To sell generated data (data to cash approach) • Use data do individualize products and services

7.2.4 Expert Interview 4

Profile of the expert	
Institution/Branch:	• Business Development Agency
Position:	• Middle Management

For the expert Industry 4.0 is understood as:
• The creation of new business models and business opportunities based on the collection and utilization of data • The interconnection of the company with the market through data
Expert's area of engagement in Industry 4.0:
• Inform and encourages companies to engage in Industry 4.0-projects (part of

the innovation programs)
State of Industry 4.0 in praxis:
• Industry 4.0 a hyped topic which encourages stakeholders to focus on industry and production
Current problems during the realization of Industry 4.0:
• The visionary approaches of Industry 4.0 cannot be realized by companies as the vision is too high level and cannot be transformed to the operational level • Technology is not enough the create market advantages • Companies believe they already carry out Industry 4.0 • Fear employees have to be replaced by robots • No willingness of law-makers and unions to change existing regulations to support industry 4.0 • Companies do not want to closely cooperate with others in industry 4.0 (open innovation)
Impacts of Industry 4.0 on the industry:
• Communication will be conducted in real-time using data • Human-Machine interfaces will disappear and Machine-to-Machine interfaces will replace them • Representation of companies will shift from humans to intelligent software and hardware (e.g. in the customer service) • Industry 4.0 shortens to planning horizon (no planning for the next six months) • Re-construction of the production-network based on information (best place to produce) • New ways of price-calculations based on information • Job-profiles will change drastically • Data-administrators will develop in companies (Data Engineer)
Important criteria for the realization of Industry 4.0:
• Governance and regulations have to be adapted in Europe to “allow” Industry 4.0 • Data has to be generated, collected and processed to enable advantages • Adapt education to the needs of Industry 4.0 • Companies need know what they want to do with Industry 4.0
Potential and benefits of Industry 4.0:

• Standardization of interfaces which enables digital communication • Utilization of data widen the products and services offered • Widen the partner-network and reduce the costs e.g. for the procurement of raw-materials • Interconnection of global information and modelling of results • Lot-Size one to the costs of mass products

7.2.5 Expert Interview 5

Profile of the expert	
Institution/Branch:	• Consulting Company
Position:	• Middle Management

For the expert Industry 4.0 is understood as:
• Digitalization of the whole production industries and the intelligent utilization of generated data of all kind
Expert's area of engagement in Industry 4.0:
• Digital operations (focus on automotive suppliers) • Utilization of data to enhance business
State of Industry 4.0 in praxis:
• Companies do not change their mind-set because of Industry 4.0 • Focus of companies lies less on optimization of production, but more on the development of new markets or customer segments • Parts of Industry 4.0 are already implemented (certain technologies) • Industry 4.0 is not a hype as companies following the concepts of Industry 4.0 (Google, Apple) were very successful • Old fashioned companies (Car OEMs) meet futuristic companies (Apple, Google) → new ways of doing business are created which is Industry 4.0
Current problems during the realization of Industry 4.0:
• The meaning of what Industry 4.0 encompasses is unclear • Isolated concepts (e.g. 3D-printing) are understood as "Industry 4.0"

- Focus is too much on technology
- All “fancy” concepts of production management are encompassed by Industry 4.0 which makes to the topic too big and blurry
- Companies have to explain the concepts of Industry 4.0 to the customers as the customers do not actively require it
- If labor costs are low, Industry 4.0 is not necessarily required
- People in the company deciding about the realization of Industry 4.0 mostly do not understand the concepts properly
- Companies are too self-confident about their current way of conducting business (especially technology world leaders)
- Companies fail to see the big picture (the Industry 4.0 vision), they focus on small concepts of Industry 4.0
- Companies think Industry 4.0 is like “drilling for oil”, but it is rather like “fracking” as the potential is hard to exploit (although they know it is there)
- Companies are not willing to change existing systems (e.g. quality management system)
- Missing use-cases are preventing companies to follow
- High investments necessary prevent companies from engaging in Industry 4.0
- Missing awareness and willingness of the management prevents further implementations of the concepts
- Industry 4.0 requires various technology in manufacturing (e.g. sensors) which increases the need for e.g. maintenance of parts which are not directly connected to value creation
- Big companies have thousands of different systems on the shop-floor level which makes horizontal and vertical integration difficult (solution: e.g. waiting until old systems are eliminated naturally)

Impacts of Industry 4.0 on the industry:

- Integration and networking through data and the Internet of the Things
- Data gets the new “channel of communication” (replacing the face-to-face communication)
- Two options: either cost-saving or the generation of increased revenue

Important criteria for the realization of Industry 4.0:

- The production-factor “data” has to be included
- Companies have to know why they want to engage in Industry 4.0
- Knowledge about the benefits of Industry 4.0
- To include the right people into the realization process
- Knowledge about the utilization of data
- Long-term thinking regrading realization of Industry 4.0

• Decision whether Industry 4.0 should be used for interne optimizations or if Industry 4.0 should be used create new products and get new customers (intern vs. extern view)
Potential and benefits of Industry 4.0:
• The utilization of data along the entire value chain • Integration and networking through data • Increase understanding about customers through the generation of data • Communication in real-time based on data • Reduce labor-costs in manufacturing • Integration of the customer life-cycle into the product-lifecycle

7.2.6 Expert Interview 6

Profile of the expert	
Institution/Branch:	• Research Company
Position:	• Senior Researcher

For the expert Industry 4.0 is understood as:
• Digitalization of all value creation processes as well as the and the integration of all elements along the value chain
Expert's area of engagement in Industry 4.0:
• Data security / Big Data • Industry 4.0 in Energy and Mobility • Innovation policy in Industry 4.0 (Governance) • User technology experience (socio-technological aspects)
State of Industry 4.0 in praxis:
• Industry 4.0 is a hype with pushed by the German industry which will lead to industrial changes in the long-term • Companies start to invest into new technology related to Industry 4.0 • Disillusionment about Industry 4.0 as starting • Awareness-building about Industry 4.0 is finished • Technological and operational problems are mostly easily solved, soft-factors

(e.g. governance) are more difficult to align to Industry 4.0
Current problems during the realization of Industry 4.0:
• Lack of awareness about the economic potential of data • Issues with data security and privacy prevent fast realization of integration and networking • Utilization of systems in big companies force small companies to align their systems • Not all industries are aiming for individualization of products (e.g. production of screws) • Calculation of benefits and costs is currently not really possible • New dependencies through partner-networks are created • High investments for technology are preventing companies to engage • Customers are not always willing to pay for the novelties of Industry 4.0 (market-push)
Impacts of Industry 4.0 on the industry:
• Companies are connected through modern information and communication technology • Companies which are using modern technology will dominate in Industry 4.0 • Certain elements of Industry 4.0 will develop, others will disappear
Important criteria for the realization of Industry 4.0:
• Derivation and determination of concrete projects in Industry 4.0 • Regulations for data-security have to be development • Pre-condition suitable for Industry 4.0 e.g. technology have to exist
Potential and benefits of Industry 4.0:
• Individualization of products • cost optimized production • Increased Resource-efficiency • Increased flexibility of companies

7.3 Questionnaire Expert-Rating „Importance of the Attributes“

The questionnaire has been sent to experts from industry, consulting and research who have been researched web-based. Including the emails sent to the attending experts of the “Fraunhofer Sommerfest” approximately 120 experts have been contacted. Altogether 23 experts answered the questionnaire which results in a respond rate of around 19%.

Questionnaire distributed for the expert-rating (in German language):

Umfrage

Industrie 4.0:
Kritische Erfolgsfaktoren

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Sehr geehrte/r TeilnehmerIn,

entlang des folgenden Fragebogens möchten wir Sie bitten kritische Erfolgsfaktoren zur Umsetzung der Industrie 4.0 Konzeption aus Ihrer Sicht zu bewerten. Dabei geht es um eine Einschätzung basierend auf Ihren Erfahrungen und Ihrer Expertise.

Falls Sie in einem Unternehmen tätig sind bitte folgende Fragen beantworten:

1.	**Welche Funktion üben Sie im Unternehmen aus?**	☐ Geschäftsführer	☐ Mittleres Management		☐ Produktionsleiter	
		☐ Meister	☐ Betriebsrat		☐ andere:	
2.	**In welcher Branche ist Ihr Unternehmen tätig?**	☐ Maschinen-/Anlagenbau	☐ Chemische Industrie		☐ Lebensmittel Industrie	
		☐ Fahrzeugbau	☐ Konsumgüter		☐ Elektronik	
		☐ Medizintechnik	☐ Energietechnik		☐ andere:	
3.	**Mitarbeiter in Ihrem Standort im Jahr 2014?**	☐ 1 – 50	☐ 51 - 250	☐ 251 - 1000	☐ 1001 – 5000	☐ > 5000
4.	**Was macht den Großteil der Unternehmens-tätigkeit aus?**	☐ Service und Dienstleistungen	☐ Herstellung Endkunden-produkte	☐ Herstellung Industrie-produkte	☐ Zulieferer von Halbzeugen	☐ Zulieferer von Fertig-erzeugnissen

Wesentliche Erfolgsfaktoren für eine erfolgreiche Umsetzung der Industrie 4.0-Konzeption sind vor allem in folgenden Unternehmens-Dimensionen zu sehen: Strategie, Leadership, Products, Customers, Operations, Culture, Employees, Governance, Technology;

Im Folgenden bitten wir Sie, die kritischen Erfolgsfaktoren dieser neun Dimensionen nach Wichtigkeit für eine erfolgreiche Umsetzung der Industrie 4.0-Konzeption aus Ihrer Sicht zu bewerten.

Unternehmensstrategie in Bezug auf Industrie 4.0 – Dimension "Strategie"

6.	Bitte bewerten Sie folgende Erfolgskriterien nach Wichtigkeit für eine erfolgreiche Umsetzung von Industrie 4.0 in einem Unternehmen	Un-wichtig	teils wichtig	wichtig	sehr wichtig
6.1	Vereinbarkeit der Unternehmensstrategie mit dem Konzept der Industrie 4.0				
6.2	Verwendung einer Industrie 4.0 – Roadmap				
6.3	Bereitstellung von Unternehmensressourcen zur Umsetzung von Industrie 4.0				
6.4	Kommunikation und Dokumentation der Aktivitäten zur Umsetzung von Industrie 4.0				
6.5	Eignung von vorhandenen Geschäftsmodellen für die Anwendung in Industrie 4.0				
6.6	Strategie für die digitale Transformation des Unternehmens				

Weitere für Sie wichtige Erfolgskriterien:

Unternehmensführung in Bezug auf Industrie 4.0 – Dimension "Leadership"

7.	Bitte bewerten Sie folgende Erfolgskriterien nach Wichtigkeit für eine erfolgreiche Umsetzung von Industrie 4.0 in einem Unternehmen	Un-wichtig	teils wichtig	wichtig	sehr wichtig
7.1	Bereitschaft von Führungskräften Industrie 4.0 zu realisieren				
7.2	Direkte Koordinationsstelle für die Umsetzung von Industrie 4.0				
7.3	Führungskompetenzen, -methoden und -werkezuge für die Umsetzung von Industrie 4.0				

Weitere für Sie wichtige Erfolgskriterien:

Angebotene Produkte in Bezug auf Industrie 4.0 – **Dimension "Products"**

8.	Bitte bewerten Sie folgende Erfolgskriterien nach Wichtigkeit für eine erfolgreiche Umsetzung von Industrie 4.0 in einem Unternehmen	Un-wichtig	teils wichtig	wichtig	sehr wichtig
8.1	Möglichkeit Produkte des Unternehmens zu individualisieren				
8.2	Embedded Systems in Produkten des Unternehmens (eingebettet Computersteuerung in Produkten)				
8.3	Integrierbarkeit von Produkten des Unternehmens in Systeme anderer Hersteller				
8.4	Fähigkeit von Produkten des Unternehmens Aufgaben autonom (selbstständig) zu erfüllen				
8.5	Möglichkeit Produkte des Unternehmens zu digitalisieren				
8.6	Veränderbarkeit der Produkt-Charakteristiken nach dem Verkauf (Product-Up-Dates)				

Weitere für Sie wichtige Erfolgskriterien:

Unternehmenskunden in Bezug auf Industrie 4.0 – **Dimension "Customers"**

9.	Bitte bewerten Sie folgende Erfolgskriterien nach Wichtigkeit für eine erfolgreiche Umsetzung von Industrie 4.0 in einem Unternehmen	Un-wichtig	teils wichtig	wichtig	sehr wichtig
9.1	Offenheit von Kunden gegenüber Innovation				
9.2	Einbindung von Kunden in Unternehmensprozesse des Unternehmens				
9.3	Generierung und Sammlung von Kunden-Daten				
9.4	Kompetenz der Kunden im Umgang mit digitalen Medien				
9.5	Möglichkeit Kunden-Services des Unternehmens zu digitalisieren				

Weitere für Sie wichtige Erfolgskriterien:

Interne und externe Unternehmensabläufe in Bezug auf Industrie 4.0 – **Dimension "Operations"**

10.	Bitte bewerten Sie folgende Erfolgskriterien nach Wichtigkeit für eine erfolgreiche Umsetzung von Industrie 4.0 in einem Unternehmen	Un-wichtig	teils wichtig	wichtig	sehr wichtig
10.1	Vertikale und horizontale Integration der Unternehmensprozesse				
10.2	Dezentralisierung der Unternehmensprozesse				
10.3	Standardisierung der Unternehmensprozesse				
10.4	Digitalisierung der Unternehmensprozesse				
10.5	Autonomie der Unternehmensprozesse				
10.6	Anpassbarkeit und Veränderbarkeit der Unternehmensprozesse				
10.7	Integration der internen und externen Stakeholder (Entscheidungsträger) in die Unternehmensprozesse				
10.8	Abteilungsübergreifende und interdisziplinäre Zusammenarbeit				
10.9	Verwendung von digitalen Modellen und Simulationen zur Prozessgestaltung				

Weitere für Sie wichtige Erfolgskriterien:

Unternehmenskultur in Bezug auf Industrie 4.0 – **Dimension "Culture"**

11.	Bitte bewerten Sie folgende Erfolgskriterien nach Wichtigkeit für eine erfolgreiche Umsetzung von Industrie 4.0 in einem Unternehmen	Un-wichtig	teils wichtig	wichtig	sehr wichtig
11.1	Einbindung der Mitarbeiter in Veränderungsprozessen				
11.2	Ambitionen des Unternehmens eigene Innovationen hervorzubringen				
11.3	Offenheit von Entscheidungsträgern gegenüber Innovationen und neuen Technologien				
11.4	Anpassungsfähigkeit der Unternehmenskultur an Industrie 4.0				
11.5	Wissensgewinnung und Wissensverwaltung im Unternehmen				
11.6	Firmenübergreifende Zusammenarbeit des Unternehmens				
11.7	Hoher Stellenwert von Informations- und Kommunikationstechnologien im Unternehmen				
Weitere für Sie wichtige Erfolgskriterien:					

Mitarbeiter in Bezug auf Industrie 4.0 – **Dimension "People"**

12.	Bitte bewerten Sie folgende Erfolgskriterien nach Wichtigkeit für eine erfolgreiche Umsetzung von Industrie 4.0 in einem Unternehmen	Un-wichtig	teils wichtig	wichtig	sehr wichtig
12.1	Offenheit der Mitarbeiter gegenüber neuen Technologien				
12.2	Kompetenz der Mitarbeiter im Umgang mit Informations- und Kommunikationstechnologien (IKT)				
12.3	Motivation der Mitarbeiter eigene Ideen in das Unternehmen einzubringen				
12.4	Bereitschaft der Mitarbeiter zu interdisziplinärer Zusammenarbeit				
12.5	Eigenständigkeit (Autonomie) der Mitarbeiter				
12.6	Akzeptanz der Mitarbeiter in Bezug auf die Flexibilisierung der Arbeit				
Weitere für Sie wichtige Erfolgskriterien:					

Unternehmensinterne Lenkung und Steuerung in Bezug auf Industrie 4.0 – **Dimension "Governance"**

13.	Bitte bewerten Sie folgende Erfolgskriterien nach Wichtigkeit für eine erfolgreiche Umsetzung von Industrie 4.0 in einem Unternehmen	Un-wichtig	teils wichtig	wichtig	sehr wichtig
13.1	Technologische Standards für Industrie 4.0				
13.2	Standards zur Sicherung von Daten und Mitarbeiterinformationen				
13.3	Vermeidung von Gesundheitsgefährdungen im Kontext von Industrie 4.0				
13.4	Existenz von Innovationsprogrammen für Industrie 4.0				
13.5	Standards für Informationsmanagementsystemen des Unternehmens in Industrie 4.0				
13.6	Existenz von Aus- und Weiterbildungsprogrammen für Industrie 4.0				
13.7	Standards zum Schutz des geistigen Eigentums für Industrie 4.0				
13.8	Anpassung der Arbeitsregelungen in Ihrem Unternehmen an die Industrie 4.0				
13.9	Möglichkeit des „In-Sourcing" und „Out-Sourcing" von Arbeitsaufgaben				
13.10	Anpassungsfähigkeit der Unternehmensstandards				

Weitere für Sie wichtige Erfolgskriterien:

Im Unternehmen eingesetzte Technologien in Bezug auf Industrie 4.0 – **Dimension "Technology"**

14.	Bitte bewerten Sie folgende Erfolgskriterien nach Wichtigkeit für eine erfolgreiche Umsetzung von Industrie 4.0 in einem Unternehmen	Un-wichtig	teils wichtig	wichtig	sehr wichtig
14.1	Moderne Informations- und Kommunikationstechnologien				
14.2	Autonomie des Maschinenparks				
14.3	Flexibilität/ Wandlungsfähigkeit des Maschinenparks				
14.4	Verwendung mobiler Geräte				
14.5	Verwendung von Sensorik zur Datenerfassung und Überwachung				
14.6	Embedded Systems (eingebettete Hardware- und Softwarekomponenten) in Maschinen				
14.7	Möglichkeit zur Maschine-zu-Maschine Kommunikation und Interaktion				
14.8	Verwendung von Auto-ID-Technologie (z.B. RFID, Barcodes, QR,...)				
14.9	Verwendung von Daten-Clouds (Online-Zugang zu nicht ortsgebundenen Daten)				
14.10	Verwendung von generativer Fertigung (z.B.3D-Druck)				

Weitere für Sie wichtige Erfolgskriterien:

Ich habe Interesse ein Reifegradmodell zur „Evaluierung der Unternehmensreife für Industrie 4.0" zu testen

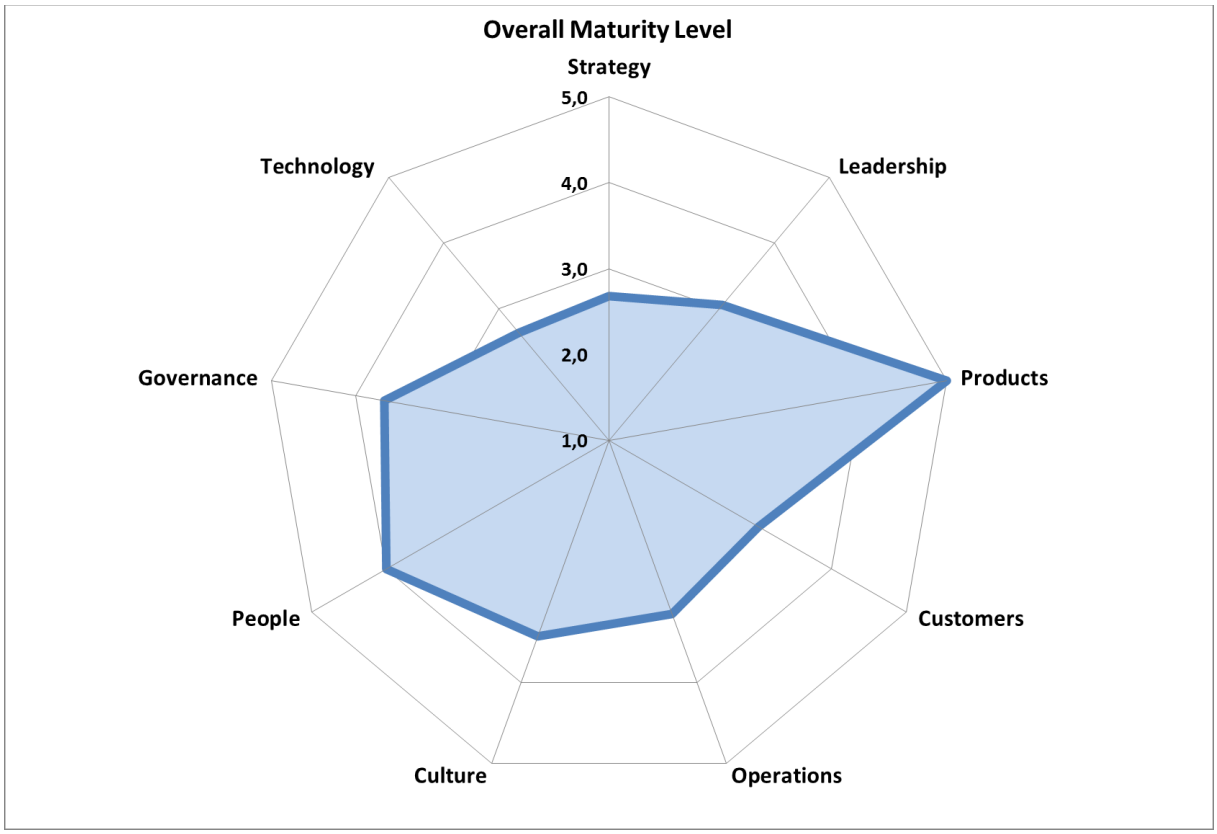
Fragebogen absenden

5

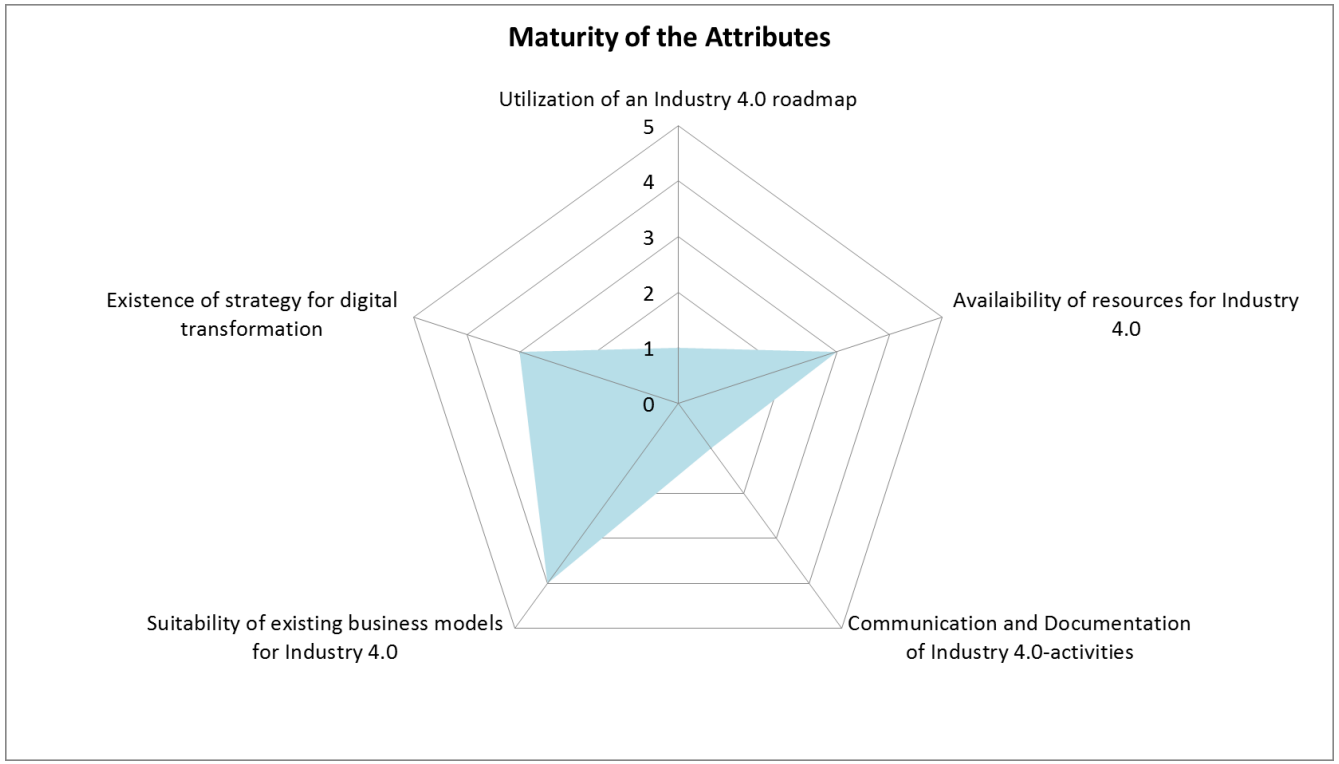
7.4 Full Results Pilot-Testing 1

In the following the detailed results of the maturity model applied on a company are presented. The answered questionnaire is not presented in this Appendix as the answers are equally to the content in the column “Maturity of the Attribues”.

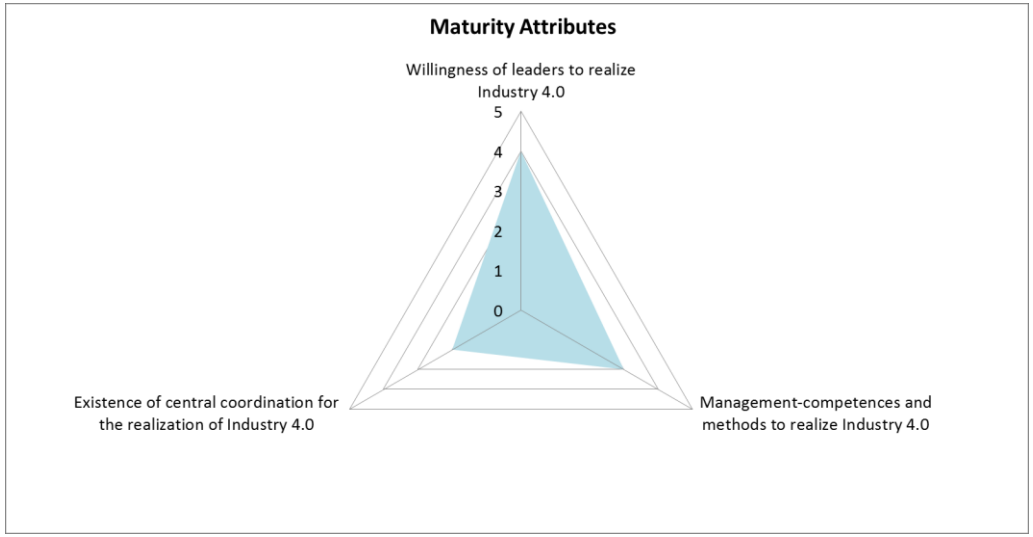
Dimension Description	Dimension	Overall Maturity Level
The dimension Strategy encompasses aspects such as: compatibility with company-strategies, utilization of roadmap, availability of resources, communication and documentation of strategies, suitability of business models, strategy for digital transformation	**Strategy**	**2,7**
The dimension Leadership encompasses aspects such as: willingness of leaders, existence of central coordination, competence and methods of leaders	**Leadership**	**3,1**
The dimension Products encompasses aspects such as: individualization of products, embedded systems in products, integration into other systems, autonomy of products, digitalization of products, flexibility of products	**Products**	**5,0**
The dimension Customers encompasses aspects such as: openness of customers to innovation, integration of customers into processes, utilization of customer data, customer competence with digital media, digitalization of sales and services	**Customers**	**3,0**
This dimension Operations encompasses aspects such as: vertical and horizontal integration of processes, decentralization of processes, standardization of processes, digitalization of processes, automation of processes, autonomy of processes , flexibility of processes, stakeholder integration, inter-department collaboration, modelling and simulations in process planning	**Operations**	**3,2**
The dimension Culture encompasses aspects such as: employee-inclusion, innovativeness of the company, stakeholder-openness, adaptability of the company culture, existence of knowledge management, conduction open innovation, value of ICT in the company	**Culture**	**3,4**
The Dimension People encompasses aspects such as: openness to technology, ICT-competence of the employees, creation and promotion of ideas, interdisciplinary work, autonomy of the employees, flexibilization of work	**People**	**4,0**
The dimension Governance encompasses aspects such as: technological standards, data-security and employee-privacy standards, safety-standards, innovation programs, information management, education and training, intellectual property,suitability of labor-regulations, sourcing of work, adaption of existing standards	**Governance**	**3,7**
The dimension Technology encompasses aspects such as: Modern ICT, autonomy of machines, flexibility and adaptability of machines, utilization of mobile devices, utilization of sensors, embedded systems in machines, M2M communication, auto-ID technology, cloud computing, 3D-printing	**Technology**	**2,6**



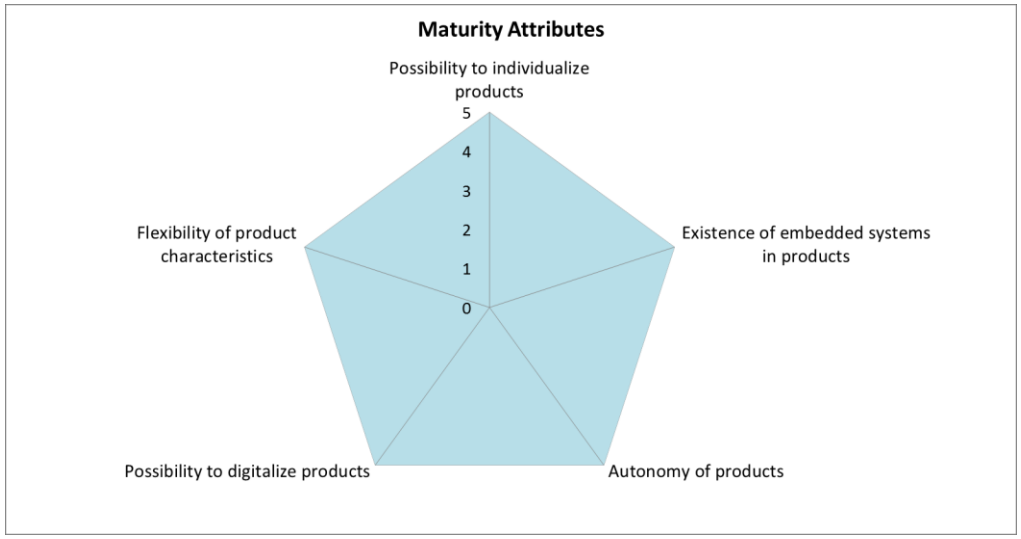
ID	Attributes - Strategy	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D1A1	Utilization of an Industry 4.0 roadmap	The realization of Industry 4.0 requires integrated and coordinated steps and cannot be carried out short term. The utilization of a road-map serves as a basis for communication and reduces uncertainty in the long-term planning	1	3,2	Inwieweit ist eine Road-Map (klarer, festgelegter Vorge-hensplan) zur Realisierung von Industrie 4.0 in Ihrem Un-ternehmen implementiert?	Acatech 2013; Roland Berger Survey Industry 4.0 2014; AUTONOMIK Studie Industrie 4.0 2015, IDC Survey Industry 4.0 2014, 8;
D1A2	Availaibility of resources for Industry 4.0	The realization of Industry 4.0 requires various company-resources (e.g. financial, human etc.).	3	3,5	Sind in Ihrem Unternehmen Ressourcen für die Realisierung von Industrie 4.0 vorhanden? (Etwa finanzielle Ressourcen für neue Technologien oder personelle Ressourcen zur Umsetzung der Konzepte etc.)	Roland Berger Survey Industry 4.0 2014, 28; IDC Survey Industry 4.0 2014, 7; Pwc Survey Industry 4.0 2014, 18; AUTONOMIK Studie Industrie 4.0 2015; Fraunhofer IAO Industry 4.0 Ready Services 2014, 28; Deloitte Survey Industry 4.0 2014, 13; BMWi Germany Survey Industry 4.0, 2015, 43;
D1A3	Communication and Documentation of Industry 4.0-activities	The activities related to Industry 4.0 have to be documented for enabling knowledge sharing and communicated for increasing awareness as well as decreasing uncertainty.	1	3,0	Werden die Aktivitäten Ihres Unternehmens im Bereich Industrie 4.0 bewusst an die Mitarbeiter kommuniziert? (Etwa durch Informationsveranstaltungen, Newsletter oder Workshops)	Acatech 2013, 30; IDC Survey Industry 4.0 2014, 8;
D1A4	Suitability of existing business models for Industry 4.0	Industry 4.0 changes the way of conducting business fundamentally as all companies are integrated into the digital eco system and real-time information is available. The company's business models have to be suitable for conducting business in these changing conditions.	4	2,9	Halten Sie persönlich das Geschäftsmodell Ihres Unternehmens für geeignet, um die zukünftigen Herausforderungen der Geschäftswelt in der Industrie 4.0 zu bewältigen? (Herausforderungen wie z.B. Digitalisierung, Vernetzung, Echt-Zeit-Systeme)	Acatech 2013, 26; Bauernhansel et al. 2014, 16; Wieselhuber GmbH and Fraunhofer IPA 2015; Deloitte Survey Industry 4.0 2015, 14; Roland Berger Survey Industry 4.0 2014, 12; Fraunhofer IAO Industry 4.0 Ready Services 2014, 2; Pwc Survey Industry 4.0 2014, 31; AUTONOMIK Studie Industrie 4.0 2015, 30; IDC Survey Industry 4.0 2014, 3; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 14;
D1A5	Existence of strategy for digital transformation	A strategy for the digital transformation (digitalization of the company activities) of a company is the basis for the integration into the digital eco system of Industry 4.0.	3	3,4	Wird in Ihrem Unternehmen eine Strategie verfolgt, um den Digitalisierungsgrad Ihres Unternehmens zu erhöhen?	Deloitte Survey Industry 4.0 2015, 9; Pwc Survey Industry 4.0 2014, 19; AUTONOMIK Studie Industrie 4.0 2015, 30; AUTONOMIK Studie Industrie 4.0 2015, 31;
D1A6	Compatibility of Industry 4.0 with company strategies	Conflicts between the company-strategies and the concepts of Industry 4.0 inevitably prevent the realization of Industry 4.0.	4	3,4	Empfinden Sie persönlich, dass die strategische Ausrichtung Ihres Unternehmens kompatibel mit den Leitgedanken der Industrie 4.0 ist? Leitgedanken der Industrie 4.0: • Digitalisierte Vernetzung aller Unternehmensak-tivitäten • Technologische Aufrüstung des Unternehmens • Durchgängiges Engineering über die gesamte Wertschöpfungskette	Acatech 2013; Bauernhansel et al. 2014; Wieselhuber GmbH and Fraunhofer IPA 2015; Deloitte Survey Industry 4.0 2015; Roland Berger Survey Industry 4.0 2014; Fraunhofer IAO Industry 4.0 Ready Services 2014; Pwc Survey Industry 4.0 2014; Bitkom Survey 2014;
Weighted Overall Maturity -Dimension Strategy			**2,7**			


Maturity of the Attributes
Utilization of an Industry 4.0 roadmap
5
4
3
2
1
0
Availaibility of resources for Industry 4.0
Communication and Documentation of Industry 4.0-activities
Suitability of existing business models for Industry 4.0
Existence of strategy for digital transformation

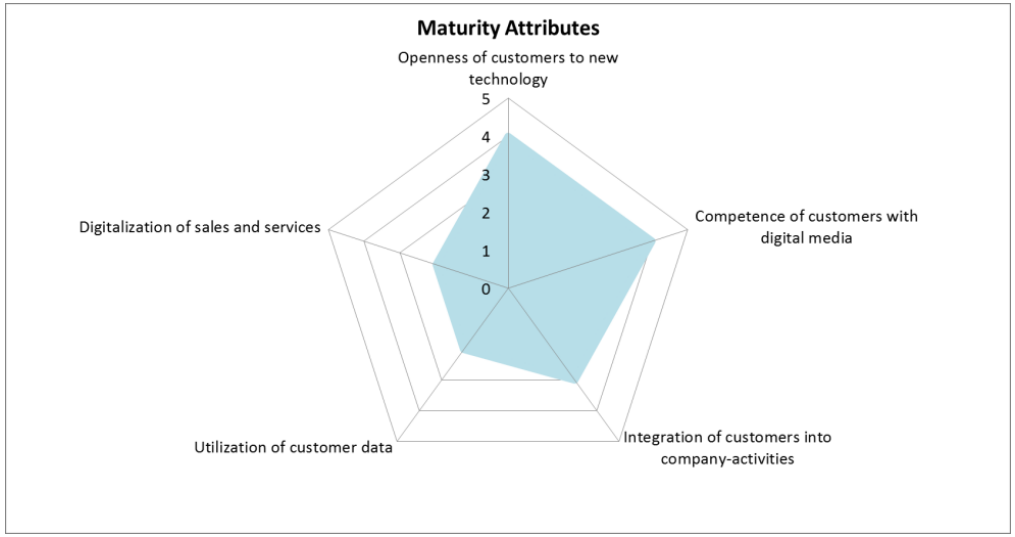
ID	Attributes - Leadership	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D2A1	Willingness of leaders to realize Industry 4.0	Leaders shape the employees opinion, control the resources and have decision making power. Therefore, the leader's willingness to realize Industry 4.0 is crucial.	4	3,8	Empfinden Sie persönlich, Industrie 4.0 durch die Entscheidungsträger Ihres Unternehmens gestützt und gefördert werden? (Commitment of management)	Deloitte Survey Industry 4.0 2015, 14; Fraunhofer IAO Industry 4.0 Ready Services 2014, 30;
D2A2	Management-competences and methods to realize Industry 4.0	The realization of Industry 4.0 requires the inclusion of various departments and stakeholders within of a company. Central coordination ensures that all measures taken are carried out effectively and in collaborative manners	3	3,0	Empfinden Sie persönlich, dass die technischen und organisatorischen Kompetenzen der Entscheidungsträger Ihres Unternehmens geeignet für die Realisierung von Industrie 4.0 sind?	Deloitte Survey Industry 4.0 2015, 14; Roland Berger Survey Industry 4.0 2014, 29; BMWi Germany Survey Industry 4.0, 2015, 42;
D2A3	Existence of central coordination for the realization of Industry 4.0	The realizationof major novelties such as Industry 4.0 requires extraordinary managerial competences and methods to readuce "fear of change" and uncertainty.	2	3,3	Empfinden Sie persönlich, dass die Aktivitäten im Bereich Industrie 4.0 in Ihrem Unternehmen zielgerichtet geplant, koordiniert und implementiert werden?	Pwc Survey Industry 4.0 2014, 10; Experton Group Survey 2014; AUTONOMIK Studie Industrie 4.0 2015, 30; BMWi Germany Survey Industry 4.0, 2015, 42;
Overall Maturity - Dimension Leadership			**3,1**			



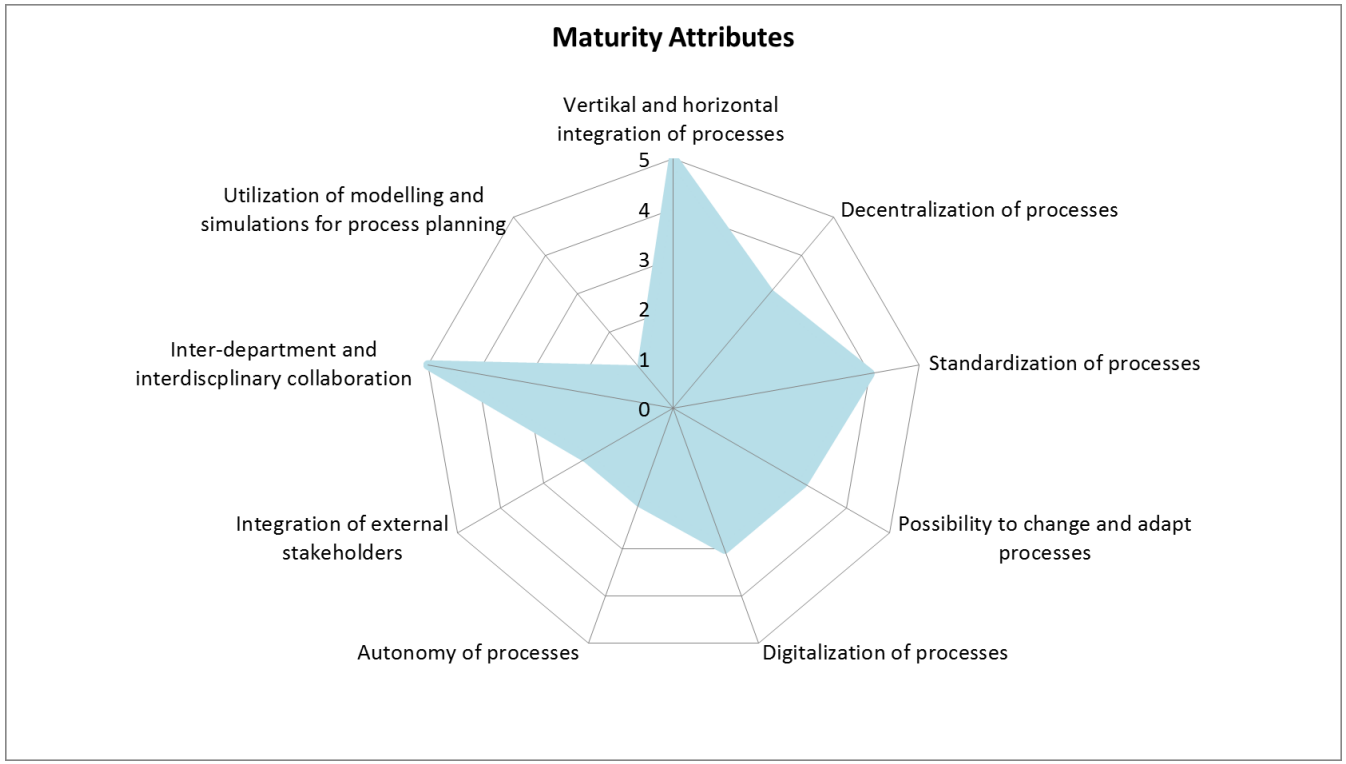
ID	Attributes - Products & customers	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D3A1	Possibility to integrate products into other systems	Industry 4.0 requires the merger of complementary products. Therefore, products must be easy to integrate into other systems. Therefore, easy and flawless integration of products integration is required.	5	3,0	Besteht die Möglichkeit Ihre Produkte mit Produkten anderen Hersteller digital zu vernetzen? (Kommunikation und Interaktion der Produkte)	Pwc Survey Industry 4.0 2014, 23; Plattform Industry 4.0; Wieselhuber GmbH and Fraunhofer IPA 2015, 14; IDC Survey Industry 4.0 2014, 3;
D3A2	Possibility to individualize products	Offering individualized products to the costs of mass products is a core issues of Industry 4.0.	5	2,8	Besteht die Möglichkeit Ihre Produkte auf Einzel-Kundenwunsch zu individualisieren?	Acatech 2013, 19; Bauernhansel et al. 2014, 14;Deloitte Survey Industry 4.0 2014, 6; BMWi Germany Survey Industry 4.0, 2015, 46;
D3A3	Existence of embedded systems in products	Embedded Systems (integration of software and hardware into the products) enable real time computing and are, therefore, the basis for the development of smart products.	5	2,9	Werden elektronische Rechner und Computer (Embedded Systems) in Ihre Produkte integriert? (Mit dem Ziel der Digitalisierung und Vernetzung der Produkte)	Pwc Survey Industry 4.0 2014; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 12;
D3A4	Autonomy of products	The complexity of the systems in the products of Industry 4.0 require these objects to act autonomous as human beings cannot capture the complexity on the one hand, and tasks carried out autonomous relieve the customer and, therefore, increase comfort on the other hand.	5	2,8	Sind Ihre Produkte darauf ausgelegt, Aufgaben automatisiert (und autonom) zu erfüllen?	Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; AUTONOMIK Studie Industrie 4.0 2015, 26; Deloitte Survey Industry 4.0 2014, 7;
D3A5	Possibility to digitalize products	Products which can carry out their purpose with a high degree of digitalization (e.g. vacuum-cleaner robot) increase the customer value and are easier to integrate into Industry 4.0.	5	3,0	Beinhalten Ihre Produkte digitale Komponenten? (Produkt empfangt, verarbeitet oder erzeugt Daten)	Pwc Survey Industry 4.0 2014, 30; Fraunhofer IAO Industry 4.0 Ready Services 2014, 14; Boston Consulting Group Survey Industry 4.0 2015, 12;
D3A6	Flexibility of product characteristics	Industry 4.0 results in faster product developments and shorter product life-cycles. Therefore, the products and product features which are easy to change and update because of developments are advantageous.	5	2,7	Lassen sich die Charakteristika Ihrer Produkte nach dem Verkauf verändern? (Möglichkeit für Product-Up-Dates)?	Plattform Industry 4.0; AUTONOMIK Studie Industrie 4.0 2015, 31; Boston Consulting Group Survey Industry 4.0 2015, 12;
Overall Maturity - Dimension Products			**5,0**			



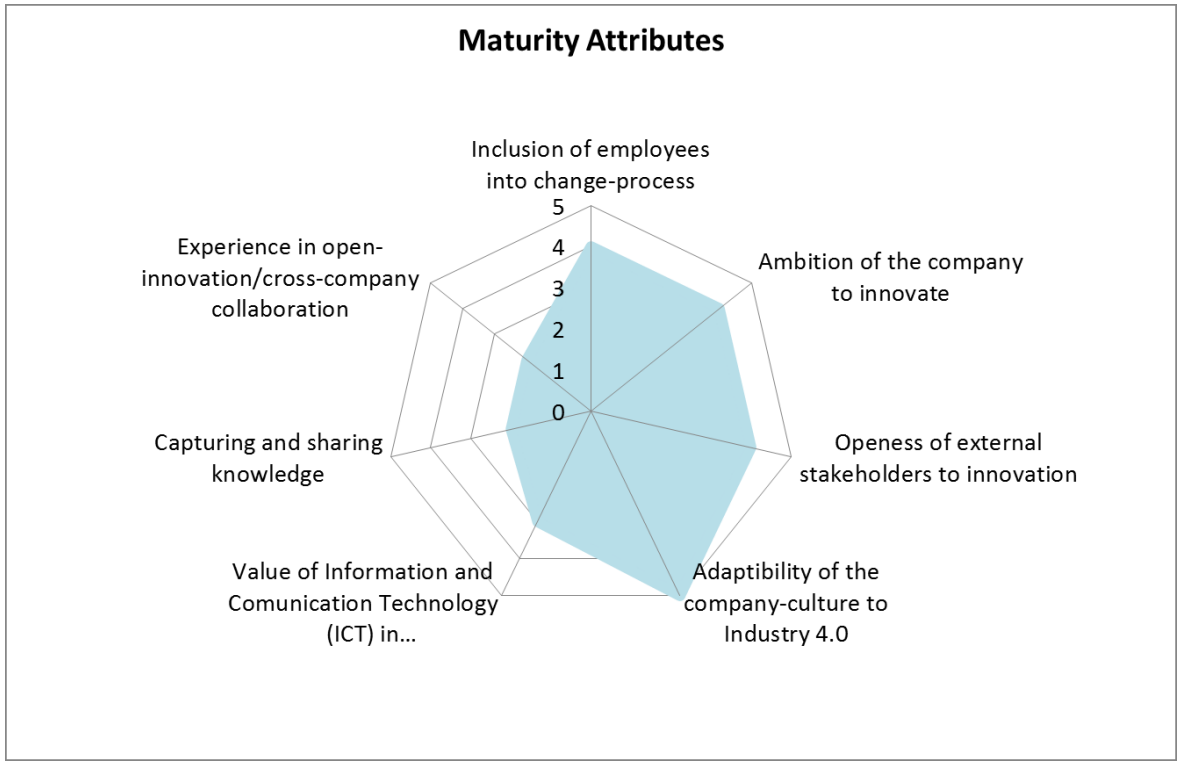
ID	Attributes - Customers	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D4A1	Openness of customers to new technology	Industry 4.0 results in various new innovations and therefore technologies. High openess of the customersto innovation reduces the effort neccessary for creating awareness.	4	3,2	Empfinden Sie persönlich, dass Kunden Ihres Unternehmens offen gegenüber neuen Technologien sind? (Etwa in Produkten, bei der Geschäftsabwicklung oder im Kundenservices)	Roland Berger Survey Industry 4.0 2014, 29;Fraunhofer IAO Industry 4.0 Ready Services 2014, 29;
D4A2	Competence of customers with digital media	Industry 4.0 is mainly realized through digitalization. Digitalized products and services require customers which are competent to digitalization (e.g. online banking).	4	3,0	Empfinden Sie persönlich, dass Kunden Ihres Unterneh-mens hohe Kompetenzen im Umgang digitalen Medien besitzen? (Etwa für die Bestellung oder Bedienung von Produkten oder beim Kundenservice)	Pwc Survey Industry 4.0 2014, 30; AUTONOMIK Studie Industrie 4.0 2015, 31;
D4A3	Integration of customers into company-activities	Industry 4.0 aims for customer orientation and is customer driven. The integration of customers into company-activities (e.g. leader user method) eases the customization of products and eliminates interfaces between the company and customers.	3	3,4	Binden Sie Ihre Kunden stark in Ihr Unternehmen ein? (Kundenintegration)	Deloitte Survey Industry 4.0 2015, 9; Roland Berger Survey Industry 4.0 2014, 33; Deloitte Survey Industry 4.0 2014, 11; AUTONOMIK Studie Industrie 4.0 2015, 32;
D4A4	Utilization of customer data	The generation and collection of data about the customers and customer behavior allows for the development of new business models and eases customer orientation.	2	2,7	Nutzen Sie in Ihrem Unternehmen digital gesammelte Daten über das Kundenverhalten? (Big Data – Analyse etwa zur Entwicklung neuer Produkte oder neuer Services)	Pwc Survey Industry 4.0 2014, 25; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10;
D4A5	Digitalization of sales and services	To integrate sales and services into the digital eco system of Industry 4.0, the digitalization is inevitable.	2	3,3	Inwieweit wickeln Sie den Kunden-Kontakt Ihres Unternehmens über das Internet ab? (Etwa Kunden-Beratung, Verkauf oder Support)	Pwc Survey Industry 4.0 2014, 30; Fraunhofer IAO Industry 4.0 Ready Services 2014, 14; AUTONOMIK Studie Industrie 4.0 2015, 30; Wieselhuber GmbH and Fraunhofer IPA 2015, 14; Boston Consulting Group Survey Industry 4.0 2015, 12;
Weighted Overall Maturity - Dimension Customers			**3,0**			



ID	Attributes - Operations	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D5A1	Vertikal and horizontal integration of processes	To reduce the operational fragmentation within the company, processes should be constructed in integrated and networked manners. As a result, fast and coherent processes are created througout the company.	5	3,4	Sind die ablaufenden Prozesse Ihres Unternehmens sehr stark miteinander vernetzt (vertikal und horizontal)?	Acatech 2013, 6; Bauernhansel et al. 2014, 16; Pwc Survey Industry 4.0 2014, 21; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 3; AUTONOMIK Studie Industrie 4.0 2015, 32; BMWi Germany Survey Industry 4.0, 2015, 12;
D5A2	Decentralization of processes	The changing external conditions of Industry 4.0 require a dynamic process landscape. Decentralized processes can be planned and controlled more efficiently.	3	2,8	Sind die Prozesse in Ihrem Unternehmen dezentral organisiert?	Acatech 2013, 20; Bauernhansel et al. 2014, 15; Boston Consulting Group Survey Industry 4.0 2015, 3 AUTONOMIK Studie Industrie 4.0 2015, 7; BMWi Germany Survey Industry 4.0, 2015, 143; Plattform Industry 4.0;
D5A3	Standardization of processes	Industry 4.0 requires higher process-change rates due to the flexibilization of the markets. Standardized processes are better suited to be changed as their structures and outcomes are better understood.	4	3,2	Empfinden Sie persönlich, dass die Prozesse Ihres Unter-nehmens standardisiert ablaufen?	Acatech 2013, 6
D5A4	Possibility to change and adapt processes	Due to external changes (which are uccoring on a faster pace in Industry 4.0), processes are required to be changed and adapt easily.	3	3,4	Lassen sich die Prozesse Ihres Unternehmens schnell und einfach auf veränderte Anforderungen anpassen? (Flexibilität der Prozesse)	Acatech 2013, 20; Plattform Industry 4.0; AUTONOMIK Studie Industrie 4.0 2015, 7; Deloitte Survey Industry 4.0 2014, 7; IDC Survey Industry 4.0 2014, 4; Boston Consulting Group Survey Industry 4.0 2015, 12;
D5A5	Digitalization of processes	The integration of the company activities into the digital eco system of Industry 4.0 requires high digitalization of the processes.	3	2,9	Ist die Planung, Ausführung und Steuerung der Prozesse Ihres Unternehmens digitalisiert?	Acatech 2013, 20^; Pwc Survey Industry 4.0 2014, 21; AUTONOMIK Studie Industrie 4.0 2015, 7; BMWi Germany Survey Industry 4.0, 2015, 143; Boston Consulting Group Survey Industry 4.0 2015, 3;
D5A6	Autonomy of processes	The operational complexity through Industry 4.0 can be reduced by processes which running autonomously.	2	3,6	Laufen die horizontalen Prozesse in Ihrem Unternehmen automatisiert ab? (Prozesse entlang der Wertschöpfungskette)	Bauernhansel et al. 2014, 15; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 3; Deloitte Survey Industry 4.0 2014, 6; BMWi Germany Survey Industry 4.0, 2015, 36;
D5A7	Integration of external stakeholders	Cooperation and networking in Industry 4.0 allows for the creation of unique strategic networks, therefore, strategically important stakeholders have to be integrated into the company activities.	2	3,0	Verfolgen Sie in Ihrem Unternehmen Strategien um die externen Stakeholder in das Unternehmen einzubinden? (Etwa durch Workshops, Informationsveranstaltungen oder Trainings)	Acatech 2013, 26; Deloitte Survey Industry 4.0 2015, 9; Pwc Survey Industry 4.0 2014, 9; AUTONOMIK Studie Industrie 4.0 2015, 16; BMWi Germany Survey Industry 4.0, 2015, 15; Boston Consulting Group Survey Industry 4.0 2015, 3;
D5A8	Inter-department and interdiscplinary collaboration	In Industry 4.0 the product life cycle gest shortened and, therefore, companies are required to innovate more frequently. Collaboration and interdisciplinary between departments can lead to faster and more disruptive innovation.	5	3,6	Arbeiten die Abteilungen und Teams Ihres Unternehmens abteilungsübergreifend und interdisziplinär zusammen?	Pwc Survey Industry 4.0 2014; AUTONOMIK Studie Industrie 4.0 2015,39; BMWi Germany Survey Industry 4.0, 2015, 143;
D5A9	Utilization of modelling and simulations for process planning	Industry 4.0 aims for preventive optimization instead of trial and error improvement. Therefore, digital models and simulations are enable to depict systems and optimize them.	1	3,1	Werden digitale Modelle und Simulationen zur Prozessgestaltung und Prozessplanung in Ihrem Unternehmen eingesetzt?	Bauernhansel et al. 2014, 19; Pwc Survey Industry 4.0 2014, 23; Boston Consulting Group Survey Industry 4.0 2015, 3
Weighted Overall Maturity - Dimension Operations			**3,2**			


Maturity Attributes
Vertikal and horizontal integration of processes
Decentralization of processes
Standardization of processes
Possibility to change and adapt processes
Digitalization of processes
Autonomy of processes
Integration of external stakeholders
Inter-department and interdiscplinary collaboration
Utilization of modelling and simulations for process planning
0
1
2
3
4
5

ID	Attributes - Culture	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D6A1	Inclusion of employees into change-process	Industry 4.0 requires changes such as new technology, changes of the organizational-structur, changes in labor conditions and others. The more included the employees are into the change process, the easierthe realization of Industry 4.0 is, as fear and uncertainty is reduced and awareness is created.	4	3,8	Werden die Mitarbeiten Ihres Unternehmens stark in stattfindende Veränderungsprozesse eingebunden?	Roland Berger Survey Industry 4.0 2014, 29; Deloitte Survey Industry 4.0 2014, 14; Boston Consulting Group Survey Industry 4.0 2015, 14;
D6A2	Ambition of the company to innovate	Industry 4.0 is inseparably connected to innovation of all kind (technology, marketing, organizaitonal, operations etc). Companies which show more ambition to innovate are likely to realize the ideas of Industry 4.0 faster and more efficient.	4	3,3	Empfinden Sie persönlich, dass das Vorantreiben von Innovationen ein wichtige Teil Ihrer Unternehmenskultur ist?	AUTONOMIK Studie Industrie 4.0 2015; Deloitte Survey Industry 4.0 2014, 7; BMWi Germany Survey Industry 4.0, 2015, 45;
D6A3	Openess of external stakeholders to innovation	External stakeholders (e.g. business partners, law-makers etc.) influence the realization of Industry 4.0 for example through new regulations or resistance. The higher their openess to innovation and novelties, the faster the realization of Industry 4.0.	4	3,7	Empfinden Sie persönlich, dass das externe Netzwerk um Ihr Unternehmens offen gegenüber Innovationen ist? (Etwa offen gegenüber neuen Technologien zur Kommunikation oder zur Geschäftsabwicklung)	Fraunhofer IAO Industry 4.0 Ready Services 2014, 30;AUTONOMIK Studie Industrie 4.0 2015, 32; AUTONOMIK Studie Industrie 4.0 2015,39;
D6A4	Adaptibility of the company-culture to Industry 4.0	The paradigmshifts created by Industry 4.0 require companies to overthink their paradigms and in the following the company culture.	5	3,3	Empfinden Sie persönlich, dass Ihre Unternehmenskultur eine schnelle Anpassung an veränderte externe Anforde-rungen erlaubt? (Flexibilität Unternehmenskultur)	Roland Berger Survey Industry 4.0 2014, 13; IDC Survey Industry 4.0 2014, 7; Plattform Industry 4.0; AUTONOMIK Studie Industrie 4.0 2015, 32; BMWi Germany Survey Industry 4.0, 2015, 44;
D6A5	Value of Information and Comunication Technology (ICT) in the company	The more Information Technology (IT) is valued within the company the easier the digital transformation can be conducted which builds the bases for the realization of Industry 4.0.	3	3,4	Empfinden Sie persönlich, dass Informations- und Kom-munikationstechnologien (IKT) einen hohen Stellenwert in Ihrem Unternehmen haben?	Fraunhofer IAO Industry 4.0 Ready Services 2014, 30; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 33;
D6A6	Capturing and sharing knowledge	The close collaboration within the company required in Industry 4.0 is based on efficient ways of capturing and sharing knowledge in digital manners.	2	3,4	Empfinden Sie persönlich, dass die Sammlung, Verwaltung und Verteilung von erworbenem Wissen einen hohen Stellenwert in Ihrem Unternehmen haben?	AUTONOMIK Studie Industrie 4.0 2015, 32; Deloitte Survey Industry 4.0 2014, 7, BMWi Germany Survey Industry 4.0, 2015, 36; BMWi Germany Survey Industry 4.0, 2015, 143;
D6A7	Experience in open-innovation/cross-company collaboration	Inter-company collaboration builts the base for the creation of strategic networks and alliances within Industry 4.0.	2	3,5	Spielt die unternehmensübergreifende Zusammenarbeit zur Entwicklung neuer Produkte oder Services eine große Rolle in Ihrem Unternehmen? (cross-company collaboration und open innovation)	Roland Berger Survey Industry 4.0 2014, 12; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10; AUTONOMIK Studie Industrie 4.0 2015, 17; Deloitte Survey Industry 4.0 2014, 7; BMWi Germany Survey Industry 4.0, 2015, 36; Plattform Industry 4.0;
Overall Maturity - Dimension Culture			**3,4**			


Maturity Attributes
Inclusion of employees into change-process
5
4
3
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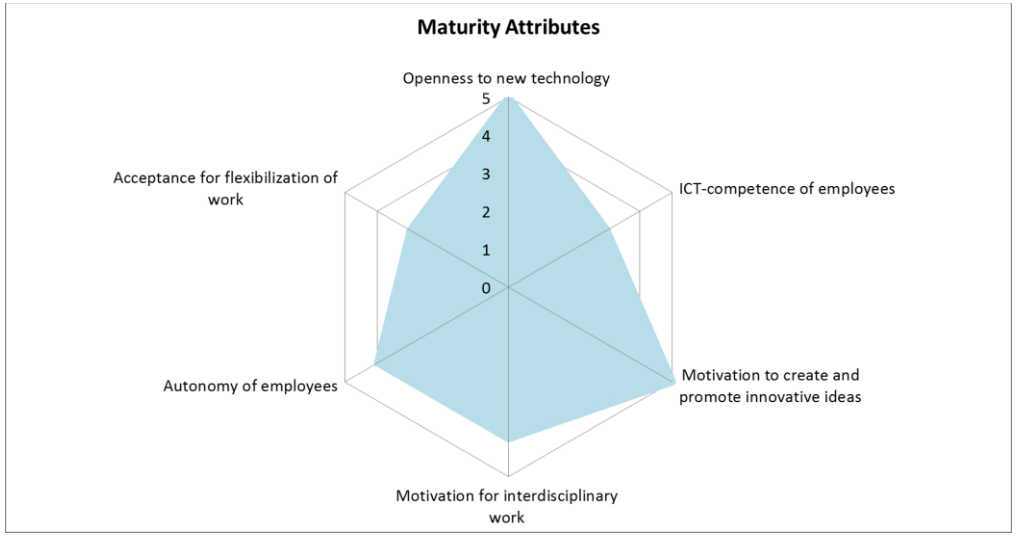
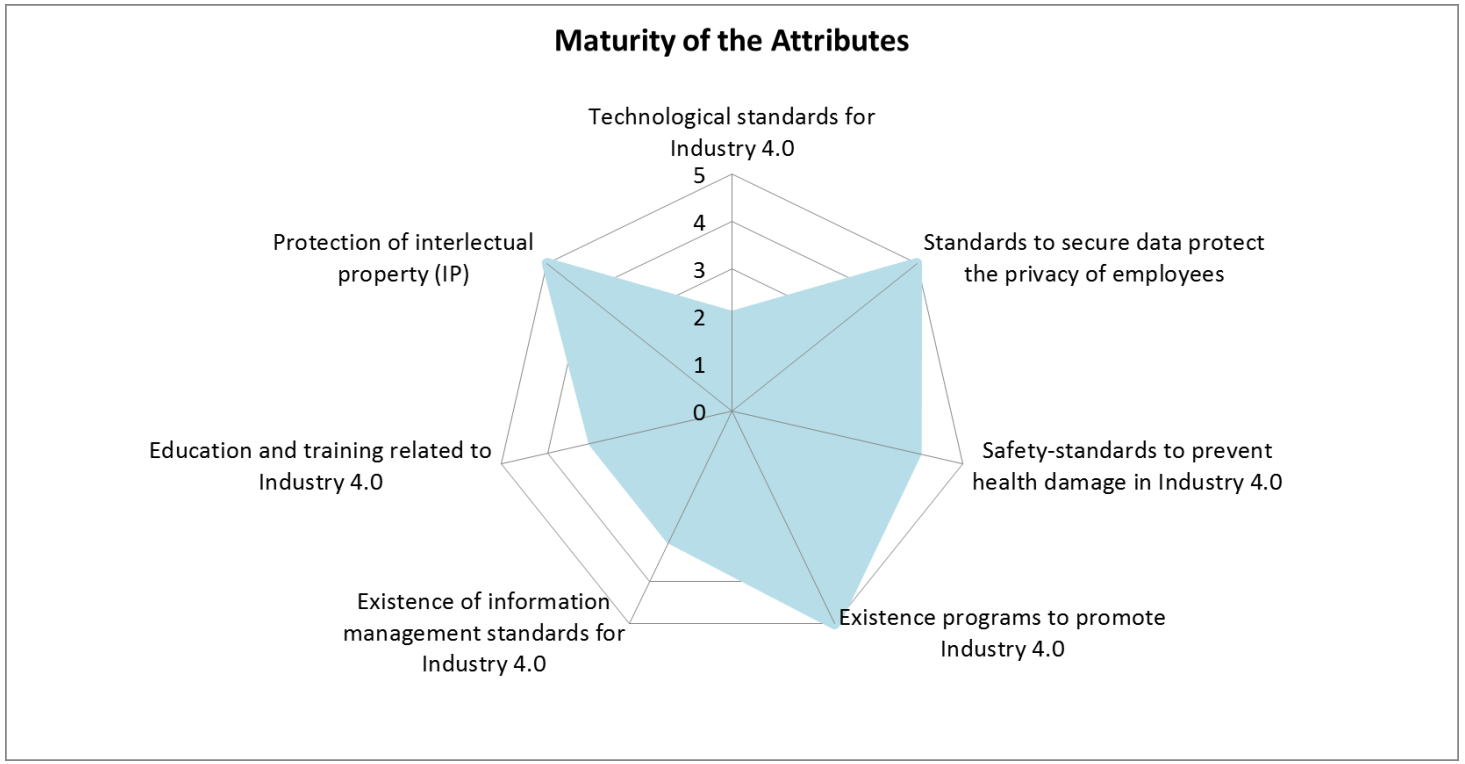
0
Ambition of the company to innovate
Openess of external stakeholders to innovation
Adaptibility of the company-culture to Industry 4.0
Value of Information and Comunication Technology (ICT) in...
Capturing and sharing knowledge
Experience in open-innovation/cross-company collaboration

ID	Attributes - People	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D7A1	Openness to new technology	The implementation of new technology (e.g. mobile devices or robots) is carried out more efficiently and faster with employees who are open to novelties such as new technologies.	5	3,6	Empfinden See persönlich, dass die Mitarbeiter Ihres Un-ternehmens offen gegenüber neuen Technologien sind? (Etwa für die Erfüllung ihrer Aufgaben, in Produktionsma-schinen oder in Produkten)	Acatech 2013, 27; Deloitte Survey Industry 4.0 2015, 14; Roland Berger Survey Industry 4.0 2014, 28; BMWi Germany Survey Industry 4.0, 2015, 143; Boston Consulting Group Survey Industry 4.0 2015, 14;
D7A2	ICT-competence of employees	Industry 4.0 builds on the utilization of ICT and, therefore, employees with related competences fasten the realization as no training or additional human resource is needed.	3	3,5	Empfinden Sie persönlich, dass Mitarbeiter Ihres Unternehmens hohe Kompetenzen im Umgang digitalen Medien besitzen? (Etwa im Bereich der modernen Informations- und Kom-munikationstechnologien)	Deloitte Survey Industry 4.0 2015, 14; Deloitte Survey Industry 4.0 2014, 14; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 14;
D7A3	Motivation to create and promote innovative ideas	Industry 4.0 depends on a high engagement of all employees in the brainwork of the company, therefore, the motivation of employees to be innovative supports the realization of Industry 4.0.	5	3,3	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Un-ternehmens viele Ideen und Kreativität in das Unterneh-men einbringen?	Roland Berger Survey Industry 4.0 2014, 12; Deloitte Survey Industry 4.0 2014, 14; Plattform Industry 4.0;
D7A4	Motivation for interdisciplinary work	Approaches such as co-operation, open innovation or the integration of processes requires employees who are motivitated to work interdesciplinary.	4	3,6	Empfinden Sie persönlich, dass Mitarbeiter Ihres Unter-nehmens hohe Bereitschaft zu interdisziplinärer und abteilungsübergreifender Zusammenarbeit zeigen?	Roland Berger Survey Industry 4.0 2014, 12;Plattform Industry 4.0; Deloitte Survey Industry 4.0 2014, 14; BMWi Germany Survey Industry 4.0, 2015, 143;
D7A5	Autonomy of employees	The increasing system complexity as well as the decentralization of Industry 4.0 requires employees who are willing to decide and work self-reliant.	4	3,0	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Un-ternehmens die zugeteilten Aufgaben mit hoher Eigen-ständigkeit erfüllen?	Bauernhansel et al. 2014, 15; Plattform Industry 4.0; Deloitte Survey Industry 4.0 2014, 14; Plattform Industry 4.0;
D7A6	Acceptance for flexibilization of work	In Industry 4.0 working conditions are likely to change frequently (e.g. working hours, work content, reachability outside work etc.). High flexibility of the employees is required to meet these challenges.	3	3,4	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Un-ternehmens bereit sind Arbeit zu flexibilisieren? (Etwa den Arbeitsinhalt, die Arbeitszeit oder die Erreich-barkeit der Mitarbeiter außerhalb der Bürozeiten)?	Acatech 2013, 27; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10; IDC Survey Industry 4.0 2014, 4; Plattform Industry 4.0;
Weighted Overall Maturity - Dimension People			**4,0**			



ID	Attributes - Governance	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D8A1	Suitability of labour-regulations for Industry 4.0	The frequently changing working conditions in Industry 4.0 require flexible employees as well as labor laws that meet these changing working conditions.	4	3,3	Sind Aspekte wie Arbeitszeit, Arbeitsinhalt oder der Erfül-lungsort der Arbeit in Ihrem Unternehmen flexibel geregelt?	Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015;
D8A2	Possibility to in-source and out-source work	The interconnected and real-time based business environement in Industry 4.0 allows for in- and out-sourcing of work. Active exchange of services (work) with the market decreases labor-costs and increases knowledge-transfer.	3	3,4	Eignen sich die Arbeitsinhalte Ihres Unternehmens für "out-sourcing" oder "in-sourcing" von Arbeit?	Plattform Industry 4.0; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10; AUTONOMIK Studie Industrie 4.0 2015, 16;
D8A3	Possibility to change and adapt standards to Industry 4.0	Existing standards in business operations are changed by Industry 4.0 (e.g. standards of procurement change as the suppliers change based on real-time offers). Therefore, the adaption of existing standars is required.	2	2,8	Lassen sich die in Ihrem Unternehmen implementierten Standards einfach an veränderte externe Anforderungen anpassen?	Plattform Industry 4.0; BMWi Germany Survey Industry 4.0, 2015, 18;
D8A4	Technological standards for Industry 4.0	Accelareting the realization process of Industry 4.0 requires modern technology (e.g. 3D-Printing or robots), whereby standards ensure that the technology aquired is suitable for Industry 4.0.	2	2,5	Halten Sie persönlich die derzeitigen technologischen Standards Ihres Unternehmens für geeignet, um die zu-künftigen Herausforderungen der Industrie zu bewältigen? (Herausforderungen wie die Digitalisierung, Vernetzung and Automatisierung der Unternehmensaktivitäten)	Acatech 2013, 43; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10; AUTONOMIK Studie Industrie 4.0 2015; Wieselhuber GmbH and Fraunhofer IPA 2015, 17; BMWi Germany Survey Industry 4.0, 2015, 18;
D8A5	Standards to secure data protect the privacy of employees	The digitalization and virtualization of all company activities in Industry 4.0 increases risk for cyber threats. Therefore, standards to protect internal data and privacy of the employees are required.	5	3,2	Sind in Ihrem Unternehmen Regelungen für den Schutz von Daten bzw. zum Schutz der Privatsphäre der Mitarbeiter implementiert? (cyber-crime and privacy)	Acatech 2013, 6; Deloitte Survey Industry 4.0 2015, 12; IDC Survey Industry 4.0 2014, 7; Deloitte Survey Industry 4.0 2014, 11; Plattform Industry 4.0; Bitkom Survey 2014, 22; Boston Consulting Group Survey Industry 4.0 2015, 3; AUTONOMIK Studie Industrie 4.0 2015, 17; BMWi Germany Survey Industry 4.0, 2015, 18;
D8A6	Safety-standards to prevent health damage in Industry 4.0	Physiological and mental stress through changing working conditions in Industry 4.0 as well an decreasing chance of humans to intervene due to more automation create the need for standards to prevent health damage of the employees.	4	3,1	Verfolgt Ihr Unternehmen strenge Regelungen zur Ver-meidung von Gesundheitsgefährdungen in der Produktion?	Acatech 2013, 6; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 18;
D8A7	Existence programs to promote Industry 4.0	Actively carrying out activities to create awareness, reduce fear and uncertainty and to allow for developing focus-areas support the successfull realization of Industry 4.0.	5	3,3	Verfolgt Ihr Unternehmen Programme zur Förderung von Innovationen?	Acatech 2013, 6; Deloitte Survey Industry 4.0 2015, 14; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 15;
D8A8	Existence of information management standards for Industry 4	Information and Communication Technology is a core aspect of Industry 4.0 which allows for the generation, collection and availability of information and as a result in the horizontal and vertical integration along the value chain.	3	3,1	Verfolgt Ihr Unternehmen Standards zur Sicherung und Weitergabe von Wissen? (knowledge-management)	IDC Survey Industry 4.0 2014, 7; AUTONOMIK Studie Industrie 4.0 2015,45; BMWi Germany Survey Industry 4.0, 2015, 18;
D8A9	Education and training related to Industry 4.0	Industry 4.0 requires the development of new skills and competences among employees. Programs which support the developing these fasten the realization of Industry 4.0 and avoid replacing work-force.	3	2,8	Bietet Ihr Unternehmen Aus- und Weiterbildungspro-gramme für Mitarbeiter zur Erhöhung der digitalen Kom-petenz bzw. der Kompetenz im Umgang mit neuartigen Technologien an?	Acatech 2013, 6; Deloitte Survey Industry 4.0 2015, 14; Deloitte Survey Industry 4.0 2014, 14; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 15;
D8A10	Protection of interlectual property (IP)	Industry 4.0 is inevitable related to innovation which therefore, existing standards and regulations to protect intellectual property are required, especially due to the close intercompany-communication and information-exchange in Industry 4.0	5	3,2	Verfolgt Ihr Unternehmen Standards zum Schutz von geistigem Eigentum? (intellectual property)?	Acatech 2013, 26; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 18; AUTONOMIK Studie Industrie 4.0 2015, 8; Deloitte Survey Industry 4.0 2014, 7,
Weighted Overall Maturity - Dimension Governance			**3,7**			


Maturity of the Attributes
Technological standards for Industry 4.0
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3
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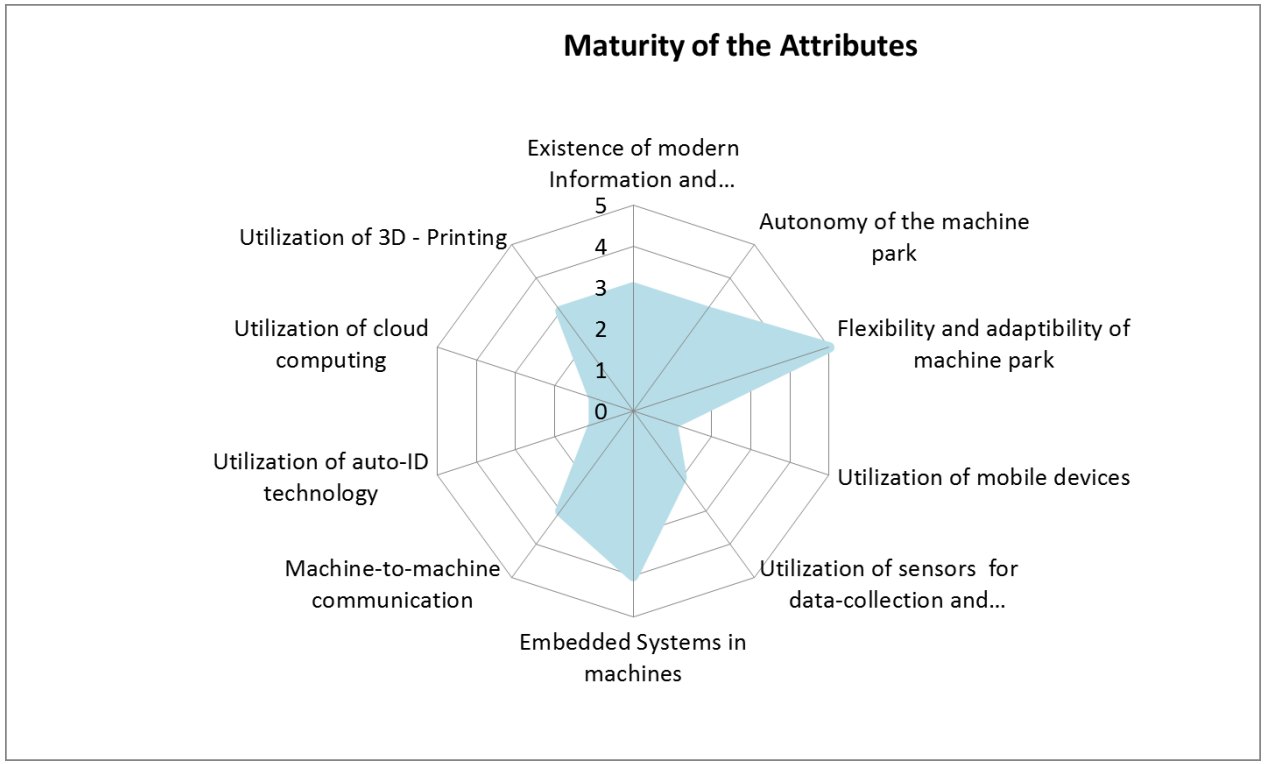
0
Standards to secure data protect the privacy of employees
Safety-standards to prevent health damage in Industry 4.0
Existence programs to promote Industry 4.0
Existence of information management standards for Industry 4.0
Education and training related to Industry 4.0
Protection of interlectual property (IP)

ID	Attributes - Technology	Description	Maturity of the Attributes	Average Importance	External Question	Attribute derived from Literature
D9A1	Existence of modern Information and Communication Technolc	Information and Communication Technology allows for the integration into the digital eco as well as the horizontal and vertical integration along the vlaue chain, the basic issues of Industry 4.0.	3	3,5	Verwendet Ihr Unternehmen vergleichsweise moderne Informations- und Kommunikationstechnologien? (Im Vergleich zu anderen Unternehmen der selben Branche)	Acatech 2013, 6; Deloitte Survey Industry 4.0 2015; IDC Survey Industry 4.0 2014, 13; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 17; AUTONOMIK Studie Industrie 4.0 2015, 7; BMWi Germany Survey Industry 4.0, 2015, 18; BMWi Germany Survey Industry 4.0, 2015, 47;
D9A2	Autonomy of the machine park	The increasing system complexity as well as the decentralization of Industry 4.0 requires machines which can decide and work independent.	3	3,2	Erfüllen die Produktionsmaschinen Ihres Unternehmens ihre Aufgaben autonom (ohne menschliches Zutun)?	Bauernhansel et al. 2014, 16; Deloitte Survey Industry 4.0 2015, 8; Boston Consulting Group Survey Industry 4.0 2015, 3; AUTONOMIK Studie Industrie 4.0 2015, 23; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A3	Flexibility and adaptibility of machine park	Fast changing framework-conditions in Industry 4.0 (due to real-time information) requires a flexible machine park (e.g. change of orders).	5	3,6	Wie schnell und einfach können die Produktionsmaschinen Ihres Unternehmens auf veränderte Produktionsanforde-rungen angepasst werden? (Flexibilität der Produktionsmaschinen)	Bauernhansel et al. 2014, 16; Deloitte Survey Industry 4.0 2015, 8; Deloitte Survey Industry 4.0 2014, 8; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A4	Utilization of mobile devices	The decentralization and flexibilization of all company activities in Industry 4.0 requires the utilization of mobile devices to ensure fast information-exchange.	1	3,2	Sind in Ihrem Unternehmen mobile Geräte zur Vernetzung der Unternehmensaktivitäten im Einsatz? (smart devices, tablets etc.)	Bauernhansel et al. 2014, 16; Bitkom Survey 2014, 22; Bitkom Survey 2014, 22; AUTONOMIK Studie Industrie 4.0 2015, 21; BMWi Germany Survey Industry 4.0, 2015, 18; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A5	Utilization of sensors for data-collection and monitoring	The utilization of big amounts of manufaturing-data in Industry 4.0 requires the installation of various sensors througout the production-process.	2	3,6	Sind in Ihrer Produktion Sensorik-Systeme zur Generierung und Nutzung von Echtzeit-Daten im Einsatz?	Bauernhansel et al. 2014, 16; Deloitte Survey Industry 4.0 2015, 9; Pwc Survey Industry 4.0 2014, 25; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; Bitkom Survey 2014, 22; Deloitte Survey Industry 4.0 2014, 6; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A6	Embedded Systems in machines	Real-time computing is a core aspect of Industry 4.0, which is enabled through Embedded Systems (integration of computer system within a larger physical system).	4	3,5	Sind elektronische Rechner und Computer (Embedded Systems) in Ihre Produktionsmaschinen integriert? (Mit dem Ziel der Digitalisierung und Vernetzung der Ma-schinen)	Bauernhansel et al. 2014, 16; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; Bitkom Survey 2014, 18; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A7	Machine-to-machine communication	Industry 4.0 requires machines which can interact without human intervention to automatize and autotomize activities.	3	3,6	Sind die Produktionsmaschinen Ihres Unternehmens in der Lage selbstständig miteinander zu kommunizieren bzw. Informationen auszutauschen? (M2M-Kommunikation)	Bauernhansel et al. 2014, 16; Deloitte Survey Industry 4.0 2015, 9; Roland Berger Survey Industry 4.0 2014, 14; IDC Survey Industry 4.0 2014, 7; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; Bitkom Survey 2014, 22; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A8	Utilization of auto-ID technology	Industry 4.0 aims for the real-time identification of all relevant objects within the company which requires Auto-ID Technology.	1	3,3	Werden in Ihrer Produktion Auto-ID-Technologien (z.B. RFID) zur automatischen Echtzeit-Identifikation von Ob-jekten verwendet?	Pwc Survey Industry 4.0 2014, 25; Plattform Industry 4.0; Deloitte Survey Industry 4.0 2014, 8; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A9	Utilization of cloud computing	Cloud computing allows for storing and sharing information which supports the digitalization in Industry 4.0.	1	3,1	Inwieweit wird Cloud-Computing in Ihrem Unternehmen verwendet? (ortsunabhängige Speicherung, Verwaltung und Bereitstel-lung von Daten)	Bauernhansel et al. 2014, 22 ; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; Bitkom Survey 2014, 18; Boston Consulting Group Survey Industry 4.0 2015, 3; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A10	Utilization of 3D - Printing	Offering customized products in Industry 4.0 can be realized using 3D-printing.	3	2,4	Inwieweit wird generative Fertigung (z.B. 3D-Druck) in Ihrem Unternehmen eingesetzt?	Deloitte Survey Industry 4.0 2015, 17; AUTONOMIK Studie Industrie 4.0 2015, 26; Plattform Industry 4.0;
Weighted Overall Maturity -Dimension Technology			**2,6**			


Maturity of the Attributes
Existence of modern Information and...
Autonomy of the machine park
Flexibility and adaptibility of machine park
Utilization of mobile devices
Utilization of sensors for data-collection and...
Embedded Systems in machines
Machine-to-machine communication
Utilization of auto-ID technology
Utilization of cloud computing
Utilization of 3D - Printing
5
4
3
2
1
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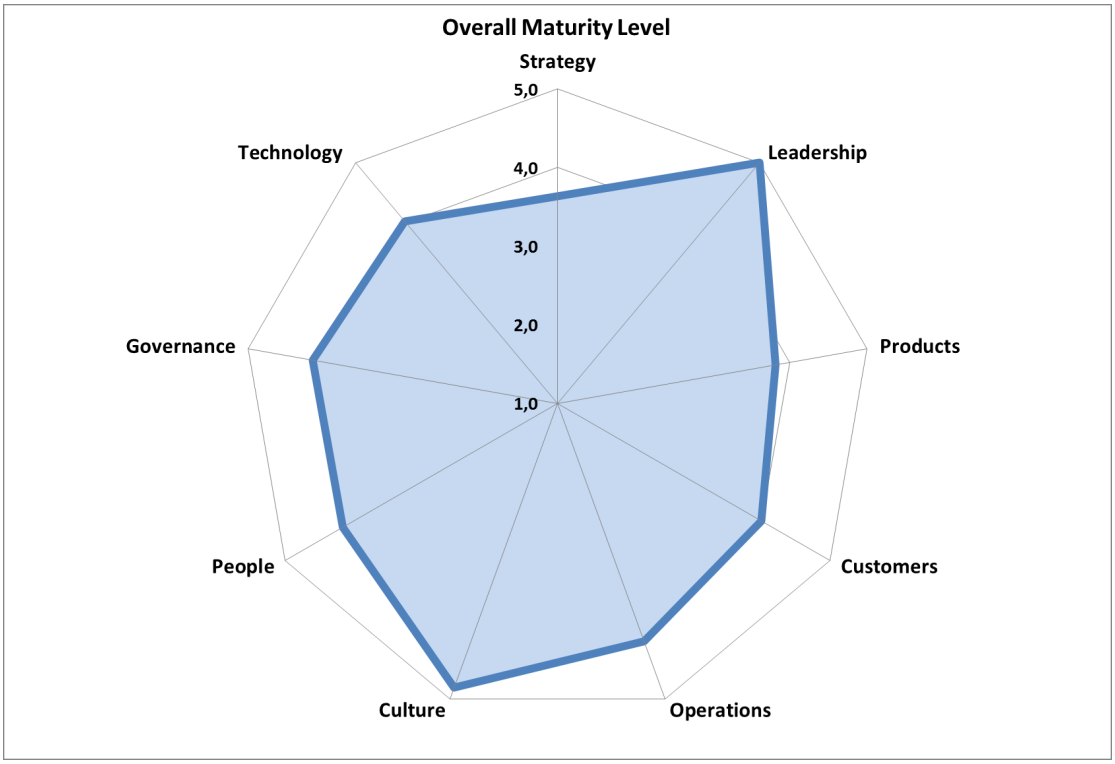
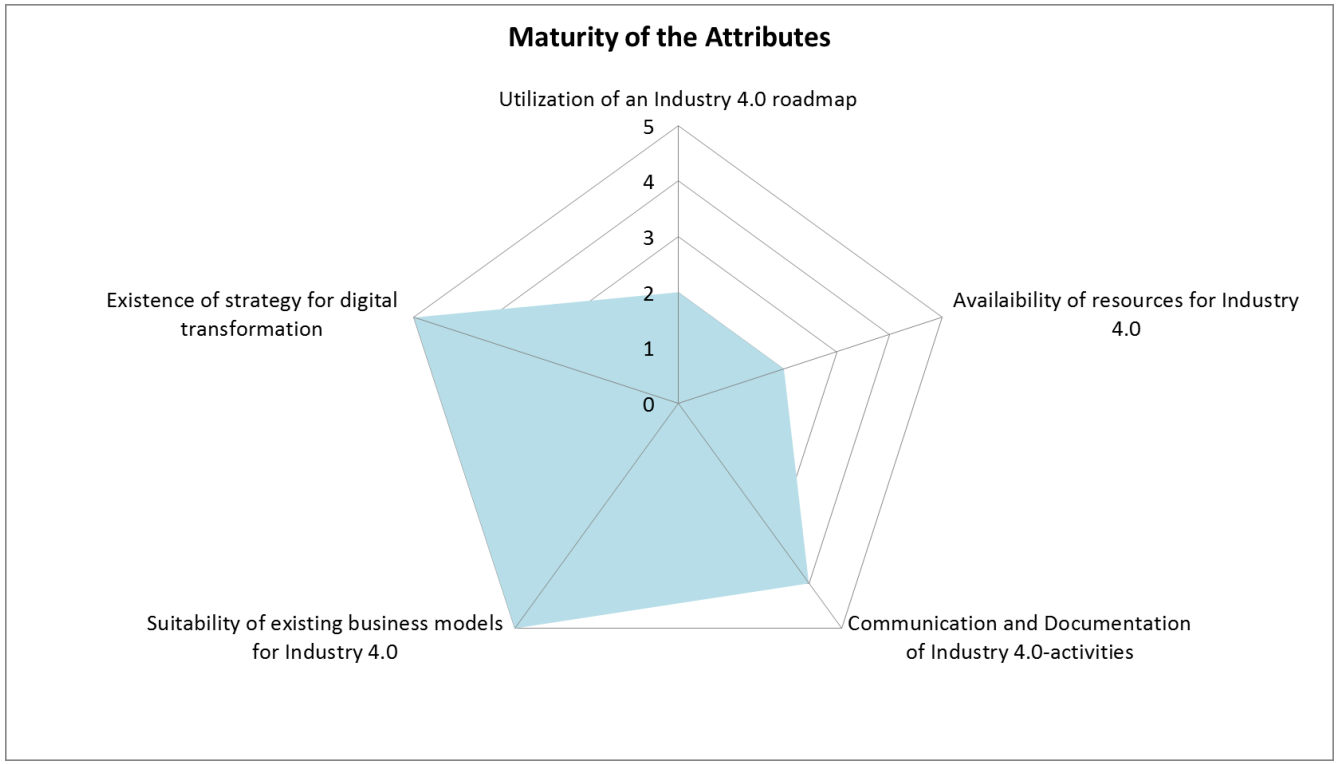
7.5 Full Results Pilot-Testing 2

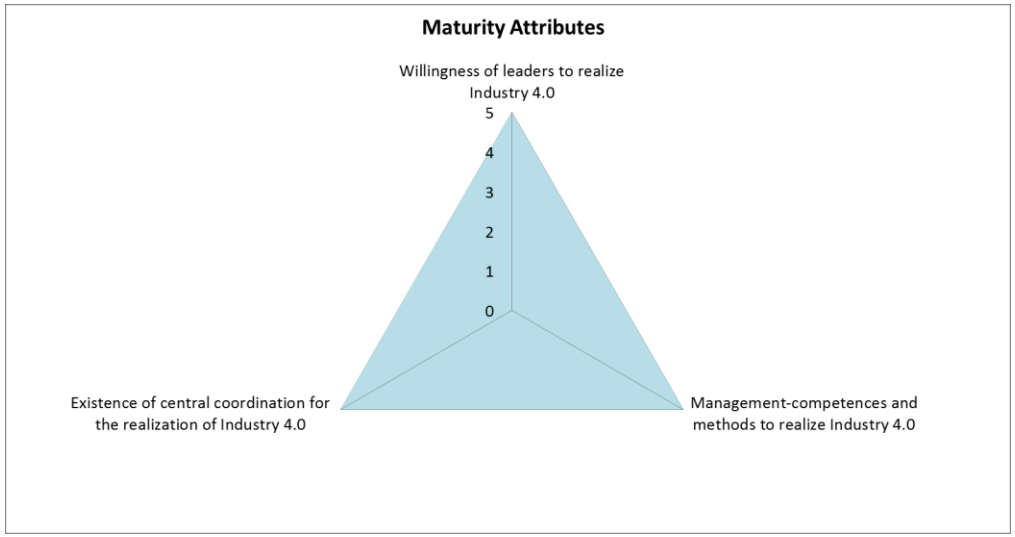
Dimension Description	Dimension	Overall Maturity Level
The dimension Strategy encompasses aspects such as: compatibility with company-strategies, utilization of roadmap, availability of resources, communication and documentation of strategies, suitability of business models, strategy for digital transformation	**Strategy**	**3,6**
The dimension Leadership encompasses aspects such as: willingness of leaders, existence of central coordination, competence and methods of leaders	**Leadership**	**5,0**
The dimension Products encompasses aspects such as: individualization of products, embedded systems in products, integration into other systems, autonomy of products, digitalization of products, flexibility of products	**Products**	**3,8**
The dimension Customers encompasses aspects such as: openness of customers to innovation, integration of customers into processes, utilization of customer data, customer competence with digital media, digitalization of sales and services	**Customers**	**4,0**
This dimension Operations encompasses aspects such as: vertical and horizontal integration of processes, decentralization of processes, standardization of processes, digitalization of processes, automation of processes, autonomy of processes , flexibility of processes, stakeholder integration, inter-department collaboration, modelling and simulations in process planning	**Operations**	**4,2**
The dimension Culture encompasses aspects such as: employee-inclusion, innovativeness of the company, stakeholder-openness, adaptability of the company culture, existence of knowledge management, conduction open innovation, value of ICT in the company	**Culture**	**4,8**
The Dimension People encompasses aspects such as: openness to technology, ICT-competence of the employees, creation and promotion of ideas, interdisciplinary work, autonomy of the employees, flexibilization of work	**People**	**4,2**
The dimension Governance encompasses aspects such as: technological standards, data-security and employee-privacy standards, safety-standards, innovation programs, information management, education and training, intellectual property,suitability of labor-regulations, sourcing of work, adaption of existing standards	**Governance**	**4,2**
The dimension Technology encompasses aspects such as: Modern ICT, autonomy of machines, flexibility and adaptability of machines, utilization of mobile devices, utilization of sensors, embedded systems in machines, M2M communication, auto-ID technology, cloud computing, 3D-printing	**Technology**	**4,0**



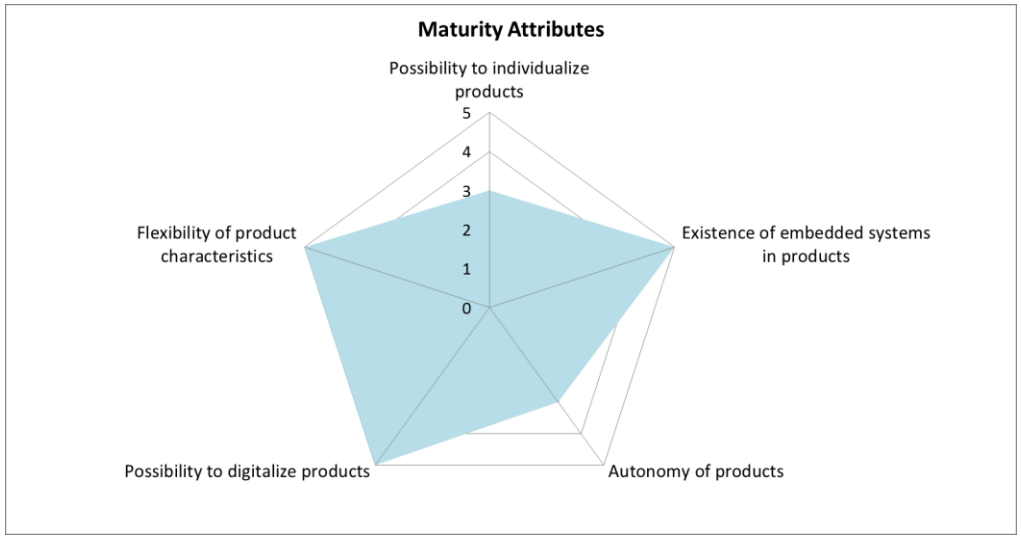
ID	Attributes - Strategy	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D1A1	Utilization of an Industry 4.0 roadmap	The realization of Industry 4.0 requires integrated and coordinated steps and cannot be carried out short term. The utilization of a road-map serves as a basis for communication and reduces uncertainty in the long-term planning	2	3,2	Inwieweit ist eine Road-Map (klarer, festgelegter Vorge-hensplan) zur Realisierung von Industrie 4.0 in Ihrem Un-ternehmen implementiert?	Acatech 2013; Roland Berger Survey Industry 4.0 2014; AUTONOMIK Studie Industrie 4.0 2015, IDC Survey Industry 4.0 2014, 8;
D1A2	Availaibility of resources for Industry 4.0	The realization of Industry 4.0 requires various company-resources (e.g. financial, human etc.).	2	3,5	Sind in Ihrem Unternehmen Ressourcen für die Realisierung von Industrie 4.0 vorhanden? (Etwa finanzielle Ressourcen für neue Technologien oder personelle Ressourcen zur Umsetzung der Konzepte etc.)	Roland Berger Survey Industry 4.0 2014, 28; IDC Survey Industry 4.0 2014, 7; Pwc Survey Industry 4.0 2014, 18; AUTONOMIK Studie Industrie 4.0 2015; Fraunhofer IAO Industry 4.0 Ready Services 2014, 28; Deloitte Survey Industry 4.0 2014, 13; BMWi Germany Survey Industry 4.0, 2015, 43;
D1A3	Communication and Documentation of Industry 4.0-activities	The activities related to Industry 4.0 have to be documented for enabling knowledge sharing and communicated for increasing awareness as well as decreasing uncertainty.	4	3,0	Werden die Aktivitäten Ihres Unternehmens im Bereich Industrie 4.0 bewusst an die Mitarbeiter kommuniziert? (Etwa durch Informationsveranstaltungen, Newsletter oder Workshops)	Acatech 2013, 30; IDC Survey Industry 4.0 2014, 8;
D1A4	Suitability of existing business models for Industry 4.0	Industry 4.0 changes the way of conducting business fundamentally as all companies are integrated into the digital eco system and real-time information is available. The company's business models have to be suitable for conducting business in these changing conditions.	5	2,9	Halten Sie persönlich das Geschäftsmodell Ihres Unternehmens für geeignet, um die zukünftigen Herausforderungen der Geschäftswelt in der Industrie 4.0 zu bewältigen? (Herausforderungen wie z.B. Digitalisierung, Vernetzung, Echt-Zeit-Systeme)	Acatech 2013, 26; Bauernhansel et al. 2014, 16; Wieselhuber GmbH and Fraunhofer IPA 2015; Deloitte Survey Industry 4.0 2015, 14; Roland Berger Survey Industry 4.0 2014, 12; Fraunhofer IAO Industry 4.0 Ready Services 2014, 2; Pwc Survey Industry 4.0 2014, 31; AUTONOMIK Studie Industrie 4.0 2015, 30; IDC Survey Industry 4.0 2014, 3; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 14;
D1A5	Existence of strategy for digital transformation	A strategy for the digital transformation (digitalization of the company activities) of a company is the basis for the integration into the digital eco system of Industry 4.0.	5	3,4	Wird in Ihrem Unternehmen eine Strategie verfolgt, um den Digitalisierungsgrad Ihres Unternehmens zu erhöhen?	Deloitte Survey Industry 4.0 2015, 9; Pwc Survey Industry 4.0 2014, 19; AUTONOMIK Studie Industrie 4.0 2015, 30; AUTONOMIK Studie Industrie 4.0 2015, 31;
D1A6	Compatibility of Industry 4.0 with company strategies	Conflicts between the company-strategies and the concepts of Industry 4.0 inevitably prevent the realization of Industry 4.0.	4	3,4	Empfinden Sie persönlich, dass die strategische Ausrichtung Ihres Unternehmens kompatibel mit den Leitgedanken der Industrie 4.0 ist? Leitgedanken der Industrie 4.0: • Digitalisierte Vernetzung aller Unternehmensak-tivitäten • Technologische Aufrüstung des Unternehmens • Durchgängiges Engineering über die gesamte Wertschöpfungskette	Acatech 2013; Bauernhansel et al. 2014; Wieselhuber GmbH and Fraunhofer IPA 2015; Deloitte Survey Industry 4.0 2015; Roland Berger Survey Industry 4.0 2014; Fraunhofer IAO Industry 4.0 Ready Services 2014; Pwc Survey Industry 4.0 2014; Bitkom Survey 2014;
Weighted Overall Maturity -Dimension Strategy			**3,6**			


Maturity of the Attributes
Utilization of an Industry 4.0 roadmap
5
4
3
2
1
0
Availaibility of resources for Industry 4.0
Communication and Documentation of Industry 4.0-activities
Suitability of existing business models for Industry 4.0
Existence of strategy for digital transformation

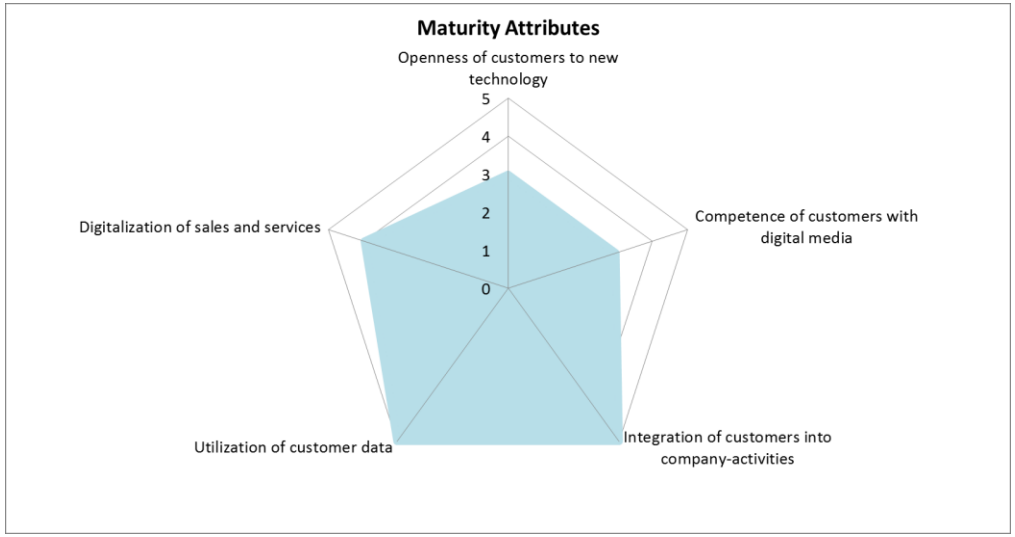
ID	Attributes - Leadership	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D2A1	Willingness of leaders to realize Industry 4.0	Leaders shape the employees opinion, control the resources and have decision making power. Therefore, the leader's willingness to realize Industry 4.0 is crucial.	5	3,8	Empfinden Sie persönlich, Industrie 4.0 durch die Entscheidungsträger Ihres Unternehmens gestützt und gefördert werden? (Commitment of management)	Deloitte Survey Industry 4.0 2015, 14; Fraunhofer IAO Industry 4.0 Ready Services 2014, 30;
D2A2	Management-competences and methods to realize Industry 4.0	The realization of Industry 4.0 requires the inclusion of various departments and stakeholders within of a company. Central coordination ensures that all measures taken are carried out effectively and in collaborative manners	5	3,0	Empfinden Sie persönlich, dass die technischen und organisatorischen Kompetenzen der Entscheidungsträger Ihres Unternehmens geeignet für die Realisierung von Industrie 4.0 sind?	Deloitte Survey Industry 4.0 2015, 14; Roland Berger Survey Industry 4.0 2014, 29; BMWi Germany Survey Industry 4.0, 2015, 42;
D2A3	Existence of central coordination for the realization of Industry 4.0	The realizationof major novelties such as Industry 4.0 requires extraordinary managerial competences and methods to readuce "fear of change" and uncertainty.	5	3,3	Empfinden Sie persönlich, dass die Aktivitäten im Bereich Industrie 4.0 in Ihrem Unternehmen zielgerichtet geplant, koordiniert und implementiert werden?	Pwc Survey Industry 4.0 2014, 10; Experton Group Survey 2014; AUTONOMIK Studie Industrie 4.0 2015, 30; BMWi Germany Survey Industry 4.0, 2015, 42;
Overall Maturity - Dimension Leadership			**5,0**			



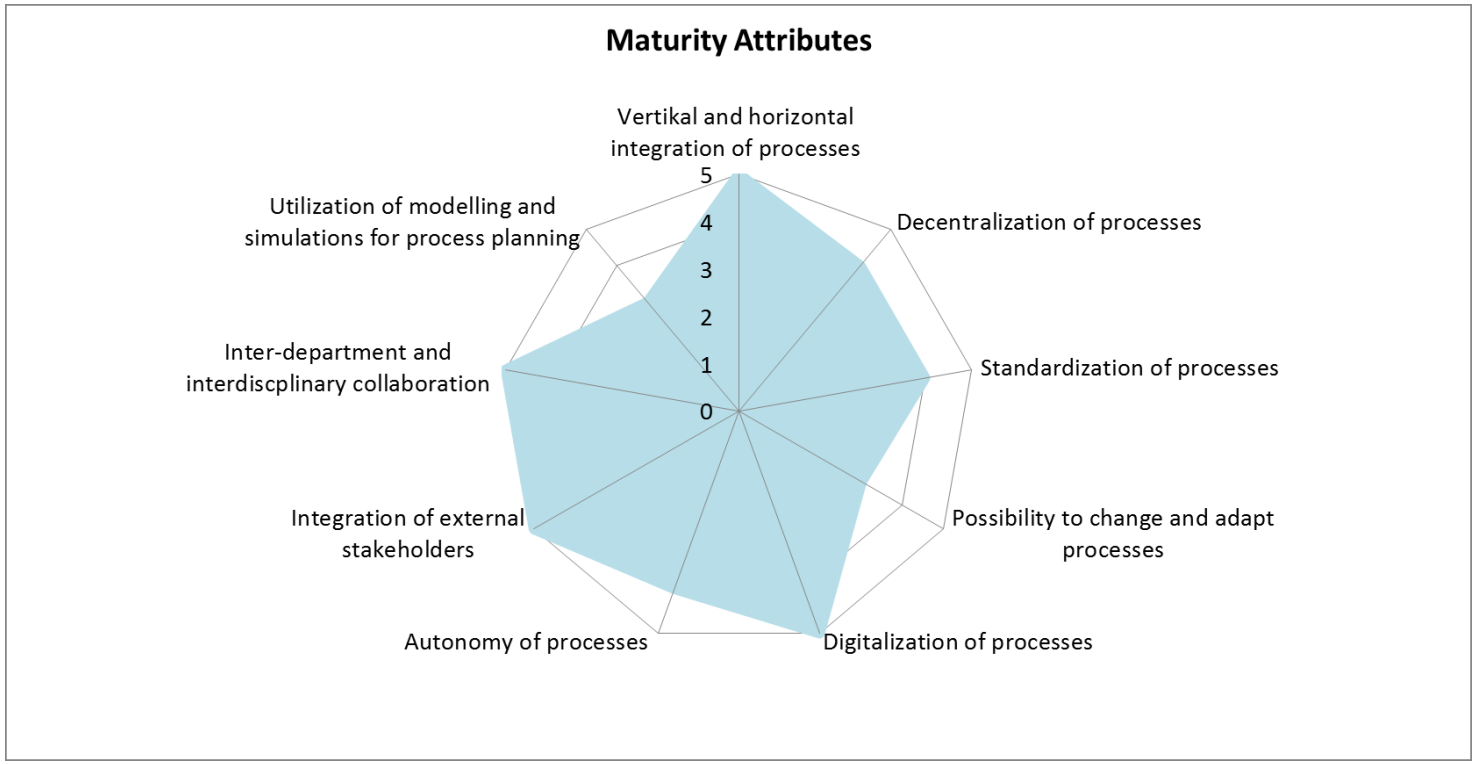
ID	Attributes - Products & customers	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D3A1	Possibility to integrate products into other systems	Industry 4.0 requires the merger of complementary products. Therefore, products must be easy to integrate into other systems. Therefore, easy and flawless integration of products integration is required.	2	3,0	Besteht die Möglichkeit Ihre Produkte mit Produkten anderen Hersteller digital zu vernetzen? (Kommunikation und Interaktion der Produkte)	Pwc Survey Industry 4.0 2014, 23; Plattform Industry 4.0; Wieselhuber GmbH and Fraunhofer IPA 2015, 14; IDC Survey Industry 4.0 2014, 3;
D3A2	Possibility to individualize products	Offering individualized products to the costs of mass products is a core issues of Industry 4.0.	3	2,8	Besteht die Möglichkeit Ihre Produkte auf Einzel-Kundenwunsch zu individualisieren?	Acatech 2013, 19; Bauernhansel et al. 2014, 14;Deloitte Survey Industry 4.0 2014, 6; BMWi Germany Survey Industry 4.0, 2015, 46;
D3A3	Existence of embedded systems in products	Embedded Systems (integration of software and hardware into the products) enable real time computing and are, therefore, the basis for the development of smart products.	5	2,9	Werden elektronische Rechner und Computer (Embedded Systems) in Ihre Produkte integriert? (Mit dem Ziel der Digitalisierung und Vernetzung der Produkte)	Pwc Survey Industry 4.0 2014; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 12;
D3A4	Autonomy of products	The complexity of the systems in the products of Industry 4.0 require these objects to act autonomous as human beings cannot capture the complexity on the one hand, and tasks carried out autonomous relieve the customer and, therefore, increase comfort on the other hand.	3	2,8	Sind Ihre Produkte darauf ausgelegt, Aufgaben automatisiert (und autonom) zu erfüllen?	Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; AUTONOMIK Studie Industrie 4.0 2015, 26; Deloitte Survey Industry 4.0 2014, 7;
D3A5	Possibility to digitalize products	Products which can carry out their purpose with a high degree of digitalization (e.g. vacuum-cleaner robot) increase the customer value and are easier to integrate into Industry 4.0.	5	3,0	Beinhalten Ihre Produkte digitale Komponenten? (Produkt empfangt, verarbeitet oder erzeugt Daten)	Pwc Survey Industry 4.0 2014, 30; Fraunhofer IAO Industry 4.0 Ready Services 2014, 14; Boston Consulting Group Survey Industry 4.0 2015, 12;
D3A6	Flexibility of product characteristics	Industry 4.0 results in faster product developments and shorter product life-cycles. Therefore, the products and product features which are easy to change and update because of developments are advantageous.	5	2,7	Lassen sich die Charakteristika Ihrer Produkte nach dem Verkauf verändern? (Möglichkeit für Product-Up-Dates)?	Plattform Industry 4.0; AUTONOMIK Studie Industrie 4.0 2015, 31; Boston Consulting Group Survey Industry 4.0 2015, 12;
Overall Maturity - Dimension Products			**3,8**			



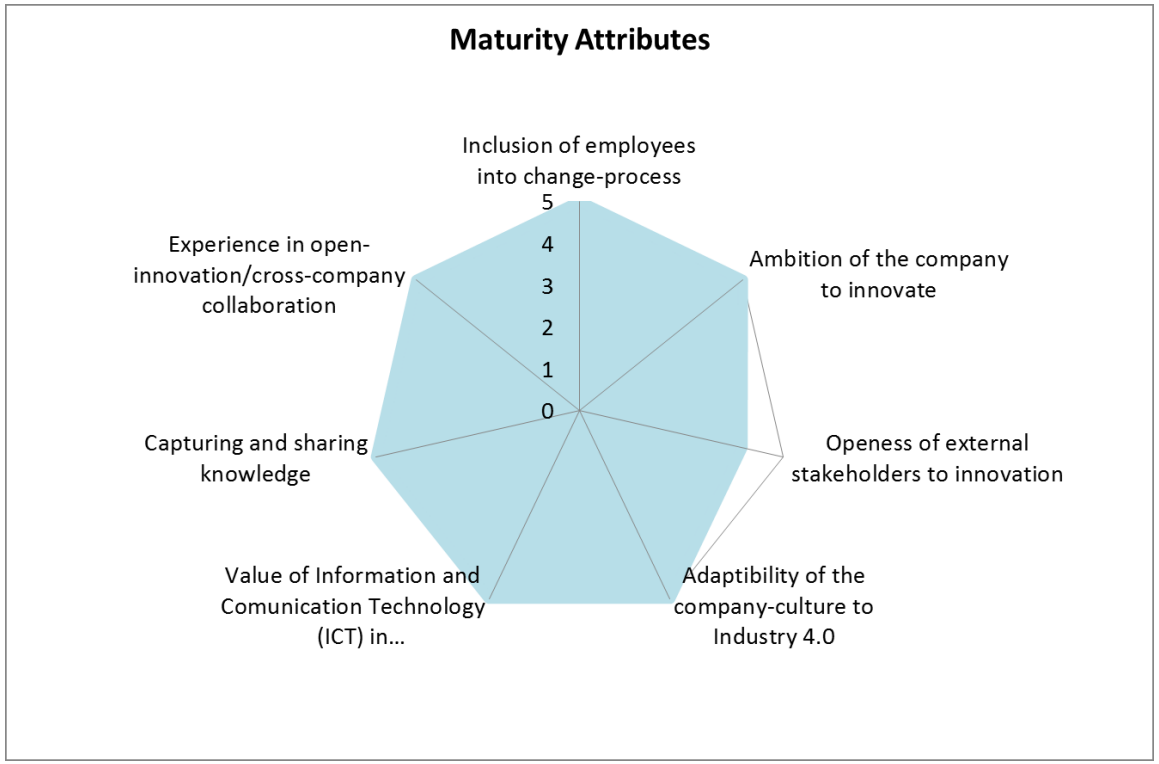
ID	Attributes - Customers	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D4A1	Openness of customers to new technology	Industry 4.0 results in various new innovations and therefore technologies. High openess of the customersto innovation reduces the effort neccessary for creating awareness.	3	3,2	Empfinden Sie persönlich, dass Kunden Ihres Unternehmens offen gegenüber neuen Technologien sind? (Etwa in Produkten, bei der Geschäftsabwicklung oder im Kundenservices)	Roland Berger Survey Industry 4.0 2014, 29;Fraunhofer IAO Industry 4.0 Ready Services 2014, 29;
D4A2	Competence of customers with digital media	Industry 4.0 is mainly realized through digitalization. Digitalized products and services require customers which are competent to digitalization (e.g. online banking).	3	3,0	Empfinden Sie persönlich, dass Kunden Ihres Unterneh-mens hohe Kompetenzen im Umgang digitalen Medien besitzen? (Etwa für die Bestellung oder Bedienung von Produkten oder beim Kundenservice)	Pwc Survey Industry 4.0 2014, 30; AUTONOMIK Studie Industrie 4.0 2015, 31;
D4A3	Integration of customers into company-activities	Industry 4.0 aims for customer orientation and is customer driven. The integration of customers into company-activities (e.g. leader user method) eases the customization of products and eliminates interfaces between the company and customers.	5	3,4	Binden Sie Ihre Kunden stark in Ihr Unternehmen ein? (Kundenintegration)	Deloitte Survey Industry 4.0 2015, 9; Roland Berger Survey Industry 4.0 2014, 33; Deloitte Survey Industry 4.0 2014, 11; AUTONOMIK Studie Industrie 4.0 2015, 32;
D4A4	Utilization of customer data	The generation and collection of data about the customers and customer behavior allows for the development of new business models and eases customer orientation.	5	2,7	Nutzen Sie in Ihrem Unternehmen digital gesammelte Daten über das Kundenverhalten? (Big Data – Analyse etwa zur Entwicklung neuer Produkte oder neuer Services)	Pwc Survey Industry 4.0 2014, 25; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10;
D4A5	Digitalization of sales and services	To integrate sales and services into the digital eco system of Industry 4.0, the digitalization is inevitable.	4	3,3	Inwieweit wickeln Sie den Kunden-Kontakt Ihres Unternehmens über das Internet ab? (Etwa Kunden-Beratung, Verkauf oder Support)	Pwc Survey Industry 4.0 2014, 30; Fraunhofer IAO Industry 4.0 Ready Services 2014, 14; AUTONOMIK Studie Industrie 4.0 2015, 30; Wieselhuber GmbH and Fraunhofer IPA 2015, 14; Boston Consulting Group Survey Industry 4.0 2015, 12;
Weighted Overall Maturity - Dimension Customers			**4,0**			



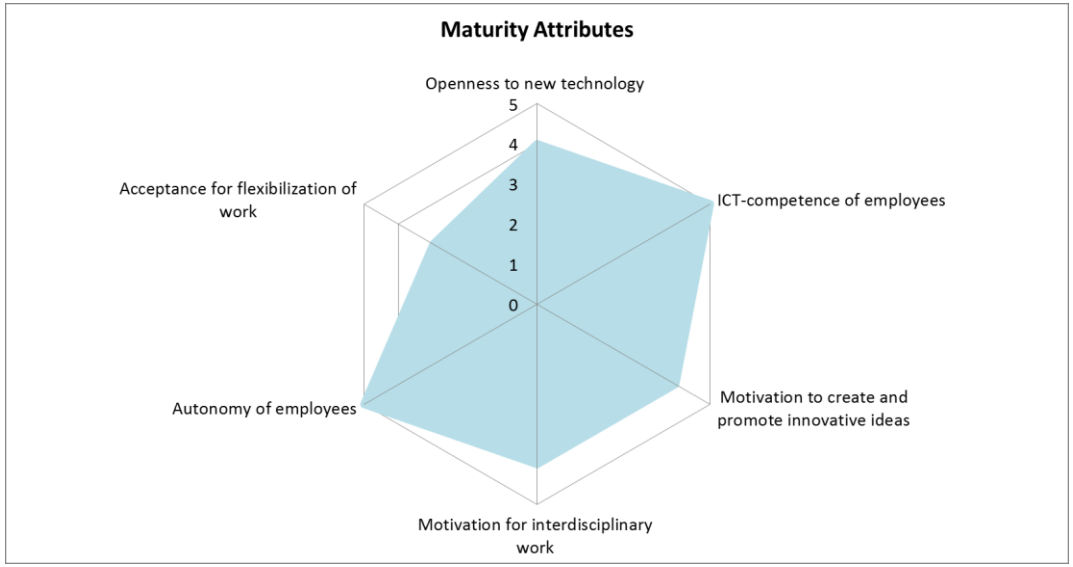
ID	Attributes - Operations	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D5A1	Vertikal and horizontal integration of processes	To reduce the operational fragmentation within the company, processes should be constructed in integrated and networked manners. As a result, fast and coherent processes are created througout the company.	5	3,4	Sind die ablaufenden Prozesse Ihres Unternehmens sehr stark miteinander vernetzt (vertikal und horizontal)?	Acatech 2013, 6; Bauernhansel et al. 2014, 16; Pwc Survey Industry 4.0 2014, 21; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 3; AUTONOMIK Studie Industrie 4.0 2015, 32; BMWi Germany Survey Industry 4.0, 2015, 12;
D5A2	Decentralization of processes	The changing external conditions of Industry 4.0 require a dynamic process landscape. Decentralized processes can be planned and controlled more efficiently.	4	2,8	Sind die Prozesse in Ihrem Unternehmen dezentral organisiert?	Acatech 2013, 20; Bauernhansel et al. 2014, 15; Boston Consulting Group Survey Industry 4.0 2015, 3 AUTONOMIK Studie Industrie 4.0 2015, 7; BMWi Germany Survey Industry 4.0, 2015, 143; Plattform Industry 4.0;
D5A3	Standardization of processes	Industry 4.0 requires higher process-change rates due to the flexibilization of the markets. Standardized processes are better suited to be changed as their structures and outcomes are better understood.	4	3,2	Empfinden Sie persönlich, dass die Prozesse Ihres Unter-nehmens standardisiert ablaufen?	Acatech 2013, 6
D5A4	Possibility to change and adapt processes	Due to external changes (which are uccoring on a faster pace in Industry 4.0), processes are required to be changed and adapt easily.	3	3,4	Lassen sich die Prozesse Ihres Unternehmens schnell und einfach auf veränderte Anforderungen anpassen? (Flexibilität der Prozesse)	Acatech 2013, 20; Plattform Industry 4.0; AUTONOMIK Studie Industrie 4.0 2015, 7; Deloitte Survey Industry 4.0 2014, 7; IDC Survey Industry 4.0 2014, 4; Boston Consulting Group Survey Industry 4.0 2015, 12;
D5A5	Digitalization of processes	The integration of the company activities into the digital eco system of Industry 4.0 requires high digitalization of the processes.	5	2,9	Ist die Planung, Ausführung und Steuerung der Prozesse Ihres Unternehmens digitalisiert?	Acatech 2013, 20^; Pwc Survey Industry 4.0 2014, 21; AUTONOMIK Studie Industrie 4.0 2015, 7; BMWi Germany Survey Industry 4.0, 2015, 143; Boston Consulting Group Survey Industry 4.0 2015, 3;
D5A6	Autonomy of processes	The operational complexity through Industry 4.0 can be reduced by processes which running autonomously.	4	3,6	Laufen die horizontalen Prozesse in Ihrem Unternehmen automatisiert ab? (Prozesse entlang der Wertschöpfungskette)	Bauernhansel et al. 2014, 15; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 3; Deloitte Survey Industry 4.0 2014, 6; BMWi Germany Survey Industry 4.0, 2015, 36;
D5A7	Integration of external stakeholders	Cooperation and networking in Industry 4.0 allows for the creation of unique strategic networks, therefore, strategically important stakeholders have to be integrated into the company activities.	5	3,0	Verfolgen Sie in Ihrem Unternehmen Strategien um die externen Stakeholder in das Unternehmen einzubinden? (Etwa durch Workshops, Informationsveranstaltungen oder Trainings)	Acatech 2013, 26; Deloitte Survey Industry 4.0 2015, 9; Pwc Survey Industry 4.0 2014, 9; AUTONOMIK Studie Industrie 4.0 2015, 16; BMWi Germany Survey Industry 4.0, 2015, 15; Boston Consulting Group Survey Industry 4.0 2015, 3;
D5A8	Inter-department and interdiscplinary collaboration	In Industry 4.0 the product life cycle gest shortened and, therefore, companies are required to innovate more frequently. Collaboration and interdisciplinary between departments can lead to faster and more disruptive innovation.	5	3,6	Arbeiten die Abteilungen und Teams Ihres Unternehmens abteilungsübergreifend und interdisziplinär zusammen?	Pwc Survey Industry 4.0 2014; AUTONOMIK Studie Industrie 4.0 2015,39; BMWi Germany Survey Industry 4.0, 2015, 143;
D5A9	Utilization of modelling and simulations for process planning	Industry 4.0 aims for preventive optimization instead of trial and error improvement. Therefore, digital models and simulations are enable to depict systems and optimize them.	3	3,1	Werden digitale Modelle und Simulationen zur Prozessgestaltung und Prozessplanung in Ihrem Unternehmen eingesetzt?	Bauernhansel et al. 2014, 19; Pwc Survey Industry 4.0 2014, 23; Boston Consulting Group Survey Industry 4.0 2015, 3
Weighted Overall Maturity - Dimension Operations			**4,2**			


Maturity Attributes
Vertikal and horizontal integration of processes
Decentralization of processes
Standardization of processes
Possibility to change and adapt processes
Digitalization of processes
Autonomy of processes
Integration of external stakeholders
Inter-department and interdiscplinary collaboration
Utilization of modelling and simulations for process planning
5
4
3
2
1
0

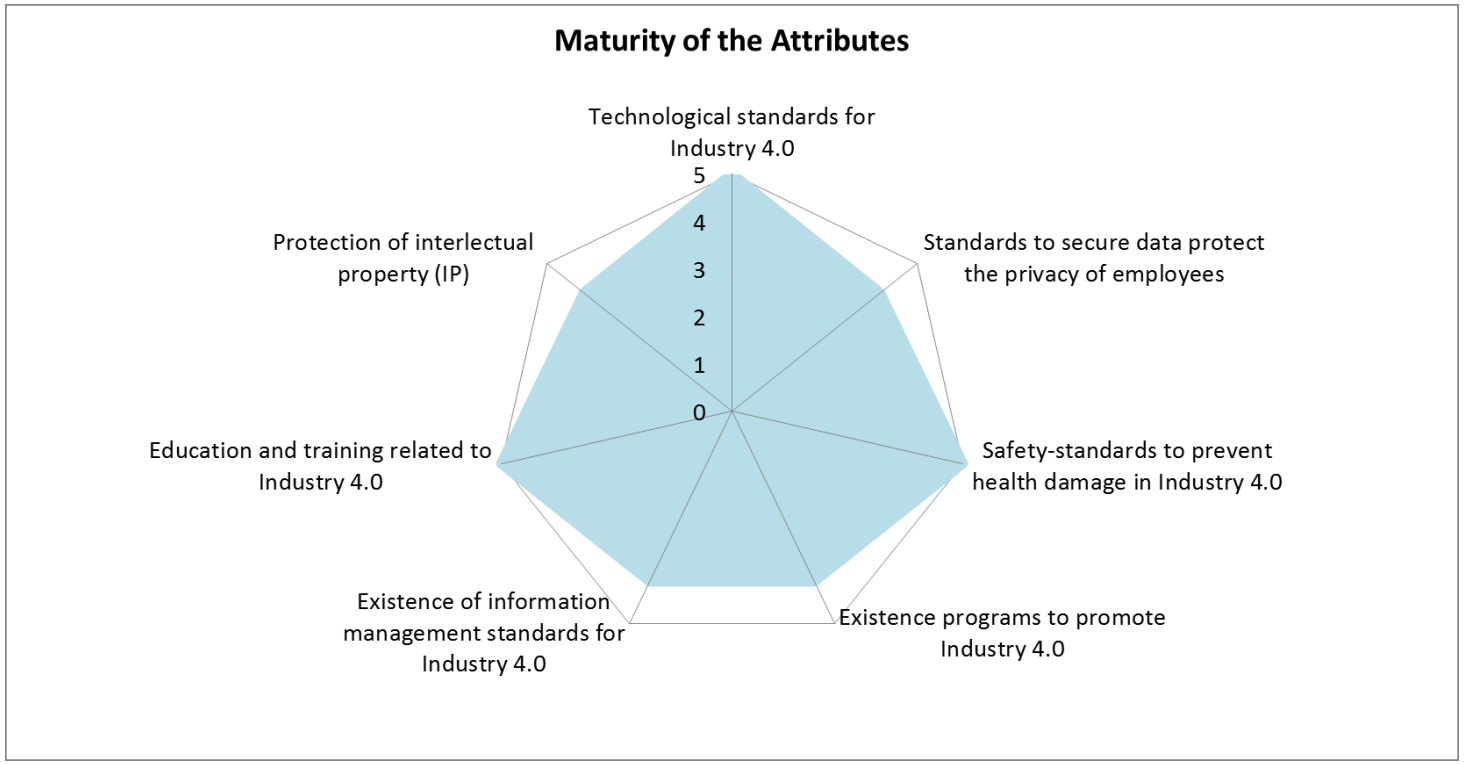
ID	Attributes - Culture	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D6A1	Inclusion of employees into change-process	Industry 4.0 requires changes such as new technology, changes of the organizational-structur, changes in labor conditions and others. The more included the employees are into the change process, the easierthe realization of Industry 4.0 is, as fear and uncertainty is reduced and awareness is created.	5	3,8	Werden die Mitarbeiten Ihres Unternehmens stark in stattfindende Veränderungsprozesse eingebunden?	Roland Berger Survey Industry 4.0 2014, 29; Deloitte Survey Industry 4.0 2014, 14; Boston Consulting Group Survey Industry 4.0 2015, 14;
D6A2	Ambition of the company to innovate	Industry 4.0 is inseparably connected to innovation of all kind (technology, marketing, organizaitonal, operations etc). Companies which show more ambition to innovate are likely to realize the ideas of Industry 4.0 faster and more efficient.	5	3,3	Empfinden Sie persönlich, dass das Vorantreiben von Innovationen ein wichtige Teil Ihrer Unternehmenskultur ist?	AUTONOMIK Studie Industrie 4.0 2015; Deloitte Survey Industry 4.0 2014, 7; BMWi Germany Survey Industry 4.0, 2015, 45;
D6A3	Openess of external stakeholders to innovation	External stakeholders (e.g. business partners, law-makers etc.) influence the realization of Industry 4.0 for example through new regulations or resistance. The higher their openess to innovation and novelties, the faster the realization of Industry 4.0.	4	3,7	Empfinden Sie persönlich, dass das externe Netzwerk um Ihr Unternehmens offen gegenüber Innovationen ist? (Etwa offen gegenüber neuen Technologien zur Kommunikation oder zur Geschäftsabwicklung)	Fraunhofer IAO Industry 4.0 Ready Services 2014, 30;AUTONOMIK Studie Industrie 4.0 2015, 32; AUTONOMIK Studie Industrie 4.0 2015,39;
D6A4	Adaptibility of the company-culture to Industry 4.0	The paradigmshifts created by Industry 4.0 require companies to overthink their paradigms and in the following the company culture.	5	3,3	Empfinden Sie persönlich, dass Ihre Unternehmenskultur eine schnelle Anpassung an veränderte externe Anforde-rungen erlaubt? (Flexibilität Unternehmenskultur)	Roland Berger Survey Industry 4.0 2014, 13; IDC Survey Industry 4.0 2014, 7; Plattform Industry 4.0; AUTONOMIK Studie Industrie 4.0 2015, 32; BMWi Germany Survey Industry 4.0, 2015, 44;
D6A5	Value of Information and Comunication Technology (ICT) in the company	The more Information Technology (IT) is valued within the company the easier the digital transformation can be conducted which builds the bases for the realization of Industry 4.0.	5	3,4	Empfinden Sie persönlich, dass Informations- und Kom-munikationstechnologien (IKT) einen hohen Stellenwert in Ihrem Unternehmen haben?	Fraunhofer IAO Industry 4.0 Ready Services 2014, 30; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 33;
D6A6	Capturing and sharing knowledge	The close collaboration within the company required in Industry 4.0 is based on efficient ways of capturing and sharing knowledge in digital manners.	5	3,4	Empfinden Sie persönlich, dass die Sammlung, Verwaltung und Verteilung von erworbenem Wissen einen hohen Stellenwert in Ihrem Unternehmen haben?	AUTONOMIK Studie Industrie 4.0 2015, 32; Deloitte Survey Industry 4.0 2014, 7, BMWi Germany Survey Industry 4.0, 2015, 36; BMWi Germany Survey Industry 4.0, 2015, 143;
D6A7	Experience in open-innovation/cross-company collaboration	Inter-company collaboration builts the base for the creation of strategic networks and alliances within Industry 4.0.	5	3,5	Spielt die unternehmensübergreifende Zusammenarbeit zur Entwicklung neuer Produkte oder Services eine große Rolle in Ihrem Unternehmen? (cross-company collaboration und open innovation)	Roland Berger Survey Industry 4.0 2014, 12; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10; AUTONOMIK Studie Industrie 4.0 2015, 17; Deloitte Survey Industry 4.0 2014, 7; BMWi Germany Survey Industry 4.0, 2015, 36; Plattform Industry 4.0;
Overall Maturity - Dimension Culture			**4,8**			


Maturity Attributes
Inclusion of employees into change-process
5
4
3
2
1
0
Ambition of the company to innovate
Openess of external stakeholders to innovation
Adaptibility of the company-culture to Industry 4.0
Value of Information and Comunication Technology (ICT) in...
Capturing and sharing knowledge
Experience in open-innovation/cross-company collaboration

ID	Attributes - People	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D7A1	Openness to new technology	The implementation of new technology (e.g. mobile devices or robots) is carried out more efficiently and faster with employees who are open to novelties such as new technologies.	4	3,6	Empfinden See persönlich, dass die Mitarbeiter Ihres Un-ternehmens offen gegenüber neuen Technologien sind? (Etwa für die Erfüllung ihrer Aufgaben, in Produktionsma-schinen oder in Produkten)	Acatech 2013, 27; Deloitte Survey Industry 4.0 2015, 14; Roland Berger Survey Industry 4.0 2014, 28; BMWi Germany Survey Industry 4.0, 2015, 143; Boston Consulting Group Survey Industry 4.0 2015, 14;
D7A2	ICT-competence of employees	Industry 4.0 builds on the utilization of ICT and, therefore, employees with related competences fasten the realization as no training or additional human resource is needed.	5	3,5	Empfinden Sie persönlich, dass Mitarbeiter Ihres Unternehmens hohe Kompetenzen im Umgang digitalen Medien besitzen? (Etwa im Bereich der modernen Informations- und Kom-munikationstechnologien)	Deloitte Survey Industry 4.0 2015, 14; Deloitte Survey Industry 4.0 2014, 14; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 14;
D7A3	Motivation to create and promote innovative ideas	Industry 4.0 depends on a high engagement of all employees in the brainwork of the company, therefore, the motivation of employees to be innovative supports the realization of Industry 4.0.	4	3,3	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Un-ternehmens viele Ideen und Kreativität in das Unterneh-men einbringen?	Roland Berger Survey Industry 4.0 2014, 12; Deloitte Survey Industry 4.0 2014, 14; Plattform Industry 4.0;
D7A4	Motivation for interdisciplinary work	Approaches such as co-operation, open innovation or the integration of processes requires employees who are motivitated to work interdesciplinary.	4	3,6	Empfinden Sie persönlich, dass Mitarbeiter Ihres Unter-nehmens hohe Bereitschaft zu interdisziplinärer und abteilungsübergreifender Zusammenarbeit zeigen?	Roland Berger Survey Industry 4.0 2014, 12;Plattform Industry 4.0; Deloitte Survey Industry 4.0 2014, 14; BMWi Germany Survey Industry 4.0, 2015, 143;
D7A5	Autonomy of employees	The increasing system complexity as well as the decentralization of Industry 4.0 requires employees who are willing to decide and work self-reliant.	5	3,0	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Un-ternehmens die zugeteilten Aufgaben mit hoher Eigen-ständigkeit erfüllen?	Bauernhansel et al. 2014, 15; Plattform Industry 4.0; Deloitte Survey Industry 4.0 2014, 14; Plattform Industry 4.0;
D7A6	Acceptance for flexibilization of work	In Industry 4.0 working conditions are likely to change frequently (e.g. working hours, work content, reachability outside work etc.). High flexibility of the employees is required to meet these challenges.	3	3,4	Empfinden Sie persönlich, dass die Mitarbeiter Ihres Un-ternehmens bereit sind Arbeit zu flexibilisieren? (Etwa den Arbeitsinhalt, die Arbeitszeit oder die Erreich-barkeit der Mitarbeiter außerhalb der Bürozeiten)?	Acatech 2013, 27; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10; IDC Survey Industry 4.0 2014, 4; Plattform Industry 4.0;
Weighted Overall Maturity - Dimension People			**4,2**			



ID	Attributes - Governance	Description	Maturity of the Attributes	Average Importance	External Question for Maturity Assessment	Attribute derived from Literature
D8A1	Suitability of labour-regulations for Industry 4.0	The frequently changing working conditions in Industry 4.0 require flexible employees as well as labor laws that meet these changing working conditions.	5	3,3	Sind Aspekte wie Arbeitszeit, Arbeitsinhalt oder der Erfül-lungsort der Arbeit in Ihrem Unternehmen flexibel geregelt?	Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015;
D8A2	Possibility to in-source and out-source work	The interconnected and real-time based business environement in Industry 4.0 allows for in- and out-sourcing of work. Active exchange of services (work) with the market decreases labor-costs and increases knowledge-transfer.	2	3,4	Eignen sich die Arbeitsinhalte Ihres Unternehmens für "out-sourcing" oder "in-sourcing" von Arbeit?	Plattform Industry 4.0; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10; AUTONOMIK Studie Industrie 4.0 2015, 16;
D8A3	Possibility to change and adapt standards to Industry 4.0	Existing standards in business operations are changed by Industry 4.0 (e.g. standards of procurement change as the suppliers change based on real-time offers). Therefore, the adaption of existing standars is required.	4	2,8	Lassen sich die in Ihrem Unternehmen implementierten Standards einfach an veränderte externe Anforderungen anpassen?	Plattform Industry 4.0; BMWi Germany Survey Industry 4.0, 2015, 18;
D8A4	Technological standards for Industry 4.0	Accelareting the realization process of Industry 4.0 requires modern technology (e.g. 3D-Printing or robots), whereby standards ensure that the technology aquired is suitable for Industry 4.0.	5	2,5	Halten Sie persönlich die derzeitigen technologischen Standards Ihres Unternehmens für geeignet, um die zu-künftigen Herausforderungen der Industrie zu bewältigen? (Herausforderungen wie die Digitalisierung, Vernetzung and Automatisierung der Unternehmensaktivitäten)	Acatech 2013, 43; Fraunhofer IAO Industry 4.0 Ready Services 2014, 10; AUTONOMIK Studie Industrie 4.0 2015; Wieselhuber GmbH and Fraunhofer IPA 2015, 17; BMWi Germany Survey Industry 4.0, 2015, 18;
D8A5	Standards to secure data protect the privacy of employees	The digitalization and virtualization of all company activities in Industry 4.0 increases risk for cyber threats. Therefore, standards to protect internal data and privacy of the employees are required.	4	3,2	Sind in Ihrem Unternehmen Regelungen für den Schutz von Daten bzw. zum Schutz der Privatsphäre der Mitarbeiter implementiert? (cyber-crime and privacy)	Acatech 2013, 6; Deloitte Survey Industry 4.0 2015, 12; IDC Survey Industry 4.0 2014, 7; Deloitte Survey Industry 4.0 2014, 11; Plattform Industry 4.0; Bitkom Survey 2014, 22; Boston Consulting Group Survey Industry 4.0 2015, 3; AUTONOMIK Studie Industrie 4.0 2015, 17; BMWi Germany Survey Industry 4.0, 2015, 18;
D8A6	Safety-standards to prevent health damage in Industry 4.0	Physiological and mental stress through changing working conditions in Industry 4.0 as well an decreasing chance of humans to intervene due to more automation create the need for standards to prevent health damage of the employees.	5	3,1	Verfolgt Ihr Unternehmen strenge Regelungen zur Ver-meidung von Gesundheitsgefährdungen in der Produktion?	Acatech 2013, 6; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 18;
D8A7	Existence programs to promote Industry 4.0	Actively carrying out activities to create awareness, reduce fear and uncertainty and to allow for developing focus-areas support the successfull realization of Industry 4.0.	4	3,3	Verfolgt Ihr Unternehmen Programme zur Förderung von Innovationen?	Acatech 2013, 6; Deloitte Survey Industry 4.0 2015, 14; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 15;
D8A8	Existence of information management standards for Industry 4	Information and Communication Technology is a core aspect of Industry 4.0 which allows for the generation, collection and availability of information and as a result in the horizontal and vertical integration along the value chain.	4	3,1	Verfolgt Ihr Unternehmen Standards zur Sicherung und Weitergabe von Wissen? (knowledge-management)	IDC Survey Industry 4.0 2014, 7; AUTONOMIK Studie Industrie 4.0 2015,45; BMWi Germany Survey Industry 4.0, 2015, 18;
D8A9	Education and training related to Industry 4.0	Industry 4.0 requires the development of new skills and competences among employees. Programs which support the developing these fasten the realization of Industry 4.0 and avoid replacing work-force.	5	2,8	Bietet Ihr Unternehmen Aus- und Weiterbildungspro-gramme für Mitarbeiter zur Erhöhung der digitalen Kom-petenz bzw. der Kompetenz im Umgang mit neuartigen Technologien an?	Acatech 2013, 6; Deloitte Survey Industry 4.0 2015, 14; Deloitte Survey Industry 4.0 2014, 14; Plattform Industry 4.0; Boston Consulting Group Survey Industry 4.0 2015, 15;
D8A10	Protection of interlectual property (IP)	Industry 4.0 is inevitable related to innovation which therefore, existing standards and regulations to protect intellectual property are required, especially due to the close intercompany-communication and information-exchange in	4	3,2	Verfolgt Ihr Unternehmen Standards zum Schutz von geistigem Eigentum? (intellectual property)?	Acatech 2013, 26; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 18; AUTONOMIK Studie Industrie 4.0 2015, 8; Deloitte Survey Industry 4.0 2014, 7,
Weighted Overall Maturity - Dimension Governance			**4,2**			


Maturity of the Attributes
Technological standards for Industry 4.0
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4
3
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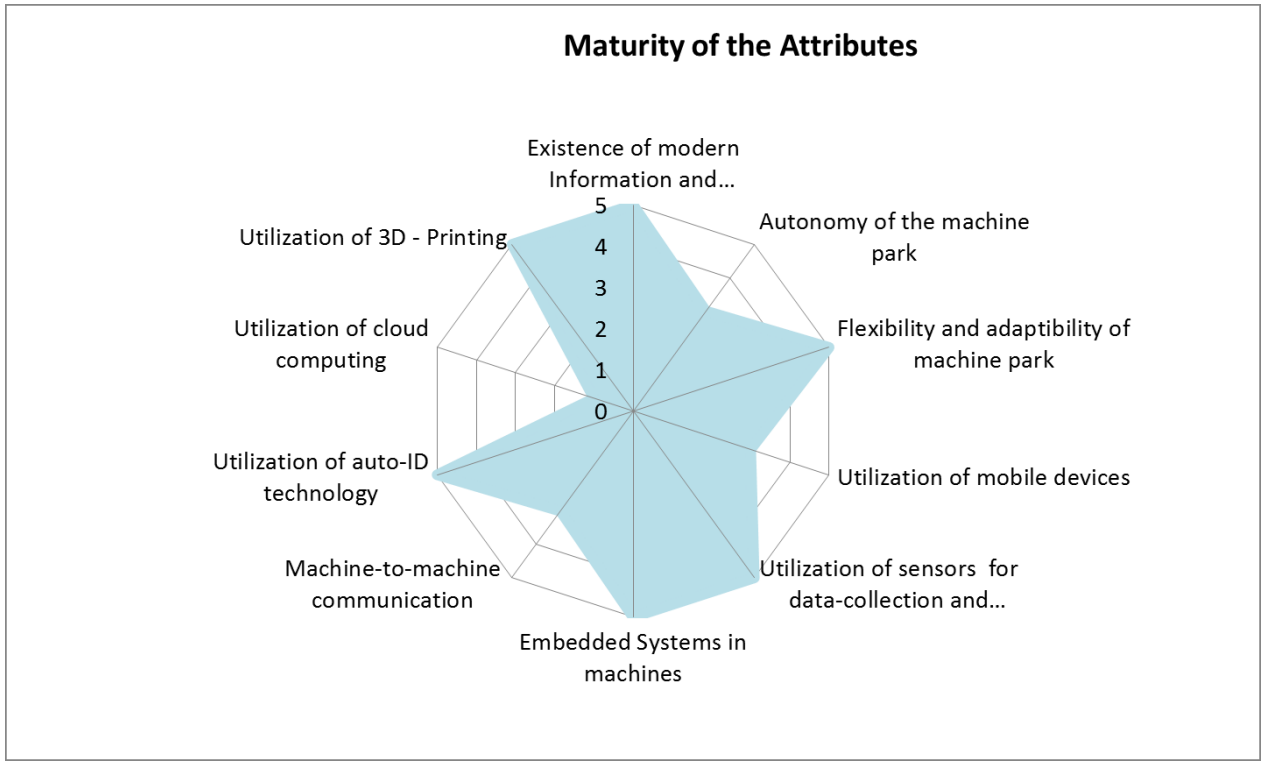
0
Standards to secure data protect the privacy of employees
Safety-standards to prevent health damage in Industry 4.0
Existence programs to promote Industry 4.0
Existence of information management standards for Industry 4.0
Education and training related to Industry 4.0
Protection of interlectual property (IP)

ID	Attributes - Technology	Description	Maturity of the Attributes	Average Importance	External Question	Attribute derived from Literature
D9A1	Existence of modern Information and Communication Technol	Information and Communication Technology allows for the integration into the digital eco as well as the horizontal and vertical integration along the vlaue chain, the basic issues of Industry 4.0.	5	3,5	Verwendet Ihr Unternehmen vergleichsweise moderne Informations- und Kommunikationstechnologien? (Im Vergleich zu anderen Unternehmen der selben Branche)	Acatech 2013, 6; Deloitte Survey Industry 4.0 2015; IDC Survey Industry 4.0 2014, 13; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 17; AUTONOMIK Studie Industrie 4.0 2015, 7; BMWi Germany Survey Industry 4.0, 2015, 18; BMWi Germany Survey Industry 4.0, 2015, 47;
D9A2	Autonomy of the machine park	The increasing system complexity as well as the decentralization of Industry 4.0 requires machines which can decide and work independent.	3	3,2	Erfüllen die Produktionsmaschinen Ihres Unternehmens ihre Aufgaben autonom (ohne menschliches Zutun)?	Bauernhansel et al. 2014, 16; Deloitte Survey Industry 4.0 2015, 8; Boston Consulting Group Survey Industry 4.0 2015, 3; AUTONOMIK Studie Industrie 4.0 2015, 23; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A3	Flexibility and adaptibility of machine park	Fast changing framework-conditions in Industry 4.0 (due to real-time information) requires a flexible machine park (e.g. change of orders).	5	3,6	Wie schnell und einfach können die Produktionsmaschinen Ihres Unternehmens auf veränderte Produktionsanforde-rungen angepasst werden? (Flexibilität der Produktionsmaschinen)	Bauernhansel et al. 2014, 16; Deloitte Survey Industry 4.0 2015, 8; Deloitte Survey Industry 4.0 2014, 8; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A4	Utilization of mobile devices	The decentralization and flexibilization of all company activities in Industry 4.0 requires the utilization of mobile devices to ensure fast information-exchange.	3	3,2	Sind in Ihrem Unternehmen mobile Geräte zur Vernetzung der Unternehmensaktivitäten im Einsatz? (smart devices, tablets etc.)	Bauernhansel et al. 2014, 16; Bitkom Survey 2014, 22; Bitkom Survey 2014, 22; AUTONOMIK Studie Industrie 4.0 2015, 21; BMWi Germany Survey Industry 4.0, 2015, 18; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A5	Utilization of sensors for data-collection and monitoring	The utilization of big amounts of manufaturing-data in Industry 4.0 requires the installation of various sensors througout the production-process.	5	3,6	Sind in Ihrer Produktion Sensorik-Systeme zur Generierung und Nutzung von Echtzeit-Daten im Einsatz?	Bauernhansel et al. 2014, 16; Deloitte Survey Industry 4.0 2015, 9; Pwc Survey Industry 4.0 2014, 25; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; Bitkom Survey 2014, 22; Deloitte Survey Industry 4.0 2014, 6; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A6	Embedded Systems in machines	Real-time computing is a core aspect of Industry 4.0, which is enabled through Embedded Systems (integration of computer system within a larger physical system).	5	3,5	Sind elektronische Rechner und Computer (Embedded Systems) in Ihre Produktionsmaschinen integriert? (Mit dem Ziel der Digitalisierung und Vernetzung der Ma-schinen)	Bauernhansel et al. 2014, 16; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; Bitkom Survey 2014, 18; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A7	Machine-to-machine communication	Industry 4.0 requires machines which can interact without human intervention to automatize and autotomize activities.	3	3,6	Sind die Produktionsmaschinen Ihres Unternehmens in der Lage selbstständig miteinander zu kommunizieren bzw. Informationen auszutauschen? (M2M-Kommunikation)	Bauernhansel et al. 2014, 16; Deloitte Survey Industry 4.0 2015, 9; Roland Berger Survey Industry 4.0 2014, 14; IDC Survey Industry 4.0 2014, 7; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; Bitkom Survey 2014, 22; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A8	Utilization of auto-ID technology	Industry 4.0 aims for the real-time identification of all relevant objects within the company which requires Auto-ID Technology.	5	3,3	Werden in Ihrer Produktion Auto-ID-Technologien (z.B. RFID) zur automatischen Echtzeit-Identifikation von Ob-jekten verwendet?	Pwc Survey Industry 4.0 2014, 25; Plattform Industry 4.0; Deloitte Survey Industry 4.0 2014, 8; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A9	Utilization of cloud computing	Cloud computing allows for storing and sharing information which supports the digitalization in Industry 4.0.	1	3,1	Inwieweit wird Cloud-Computing in Ihrem Unternehmen verwendet? (ortsunabhängige Speicherung, Verwaltung und Bereitstel-lung von Daten)	Bauernhansel et al. 2014, 22 ; Geschäftsmodell-Innovation durch Industrie 4.0 2015, 14; Bitkom Survey 2014, 18; Boston Consulting Group Survey Industry 4.0 2015, 3; BMWi Germany Survey Industry 4.0, 2015, 18;
D9A10	Utilization of 3D - Printing	Offering customized products in Industry 4.0 can be realized using 3D-printing.	5	2,4	Inwieweit wird generative Fertigung (z.B. 3D-Druck) in Ihrem Unternehmen eingesetzt?	Deloitte Survey Industry 4.0 2015, 17; AUTONOMIK Studie Industrie 4.0 2015, 26; Plattform Industry 4.0;
Weighted Overall Maturity -Dimension Technology			**4,0**			


Maturity of the Attributes
Existence of modern Information and...
Autonomy of the machine park
Flexibility and adaptibility of machine park
Utilization of mobile devices
Utilization of sensors for data-collection and...
Embedded Systems in machines
Machine-to-machine communication
Utilization of auto-ID technology
Utilization of cloud computing
Utilization of 3D - Printing
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9 List of Figures

10 List of Tables

11 List of Abbreviations

e.g.	exempli gratia (meaning of „for example“)
I40MM	Industry 4.0 Maturity Model
CPS	Cyber Physical System
IoT	Internet of Things
etc.	et cetera
SMU	Small and Medium Enterprise
F2F	Face-to-Face
M2M	Machine-to-Machine