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Evaluation of the applicability and suitability of Industry 4.0 concepts in different company sizes

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ABSTRACT

The implementation of Industry 4.0 represents one of the greatest challenges for companies these days. However, the transformation process for small and medium-sized enterprises is even more difficult due to different framework conditions. Consequently, assistance is needed to identify which Industry 4.0 methods are most suitable for a given organization. For this purpose, this thesis focuses on an in-depth analysis concerning the applicability of Industry 4.0 and highlights suitable Industry 4.0 concepts for different company sizes.

This assessment is based on an expert and enterprise survey in which researchers from a variety of institutions and companies of different sizes and fields of activity are included, giving their assessment of relevance regarding 42 Industry 4.0 concepts within different company sizes. A methodology based on the Assessment Tool I4.0 is being developed for this purpose. While enterprises evaluate current maturity, future target levels and importance for each Industry 4.0 concept, experts only assess the importance of each Industry 4.0 concept for each company category. The survey structure for experts and companies is defined and a standardized method for the evaluation of the surveys is introduced. Within this evaluation, the results of the two target groups are investigated and, above all, similarities and discrepancies in the assessments are underlined and discussed.

Finally, Industry 4.0 concepts, which are classified as suitable by experts and companies are presented. Ultimately, based on this analysis, the suitability of Industry 4.0 concepts for each company size will be listed, representing an initial indication or orientation guide for enterprises, which Industry 4.0 methods similar enterprises and leading research experts find most relevant. This is intended to support enterprises in the initialization of the digital transformation process.

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NOMENCLATURE

AC.	Alternating Current
2D.	Two-dimensional
3D.	Three-dimensional
AC.	Alternating Current
Acatech.	Deutsche Akademie der Technikwissenschaften
AGV.	Automated guided vehicle
AI.	Artificial Intelligence
AM.	Additive Manufacturing
App.	Application
AR.	Augmented Reality
ASTM.	American Society for Testing and Materials
CAD.	Computer Aided Design
CAx.	Computer Aided Technologies
CPPS.	Cyber-Physical Production Systems
CPS.	Cyber-Physical Systems
DSS.	Decision Support Systems
E-Kanban.	Electronic Kanban
ERP.	Enterprise Resource Planning
GSMA.	Groupe Speciale Mobile Association
HR.	Human Resources
IBM.	International Business Machines Corporation
IoS.	Internet of Services
IoT.	Internet of Things
IT.	Information Technology
M2M.	Machine to Machine Communication
MES.	Manufacturing Execution System
MIT.	Massachusetts Institute of Technology
MMI.	Men-Machine Interaction
MR.	Mixed Reality
NC.	Numerical Control
NIST.	National Institute of Standards and Technology
PC.	Personal Computer

PDM.	Product Data Management
PLC.	Programmable Logic Computer
PLM.	Product Lifecycle Management
POS.	Point of Sales
PSS.	Product Service System
QR.	Quick response
RFID.	Radio Frequency Identification
SaaS.	Software as a Service
SME.	Small and medium-sized enterprise
TPS.	Toyota Production System
UPS.	United Parcel Service
US.	United States
USB.	Universal Serial Bus
VDI.	Verein Deutscher Ingenieure
VDMA.	Verbands Deutscher Maschinen- und Anlagenbauer
VMI.	Vendor Managed Inventory
VR.	Virtual Reality
WSN.	Wireless Sensor Network
WWW.	World Wide Web

1

INTRODUCTION

The buzzword Industry 4.0 came up a few years ago and has since then triggered a veritable hype, although in some occasions it is still very much doting on practical applicability. This work refers precisely to this and is intended to point out possible suggestions or recommendations for action for the implementation of Industry 4.0 under certain requirements in the near future.

This introductory chapter is intended to provide an overview of the current developments, to explain the motivation of the work and to outline the structure. A distinction is made between three sections. The first introduces the reader to the challenges companies are facing in an ever more dynamic environment. From this the motivation is derived, which has resulted in developing a method for the evaluation of the suitability of Industry 4.0 concepts as a recommendation for action for different enterprises. The chapter concludes with a graphically supported representation of the red thread of the work.

1.1 Introduction to the topic

The industrial sector is currently confronted with enormous challenges, mainly of an economic nature, which are advancing ever faster due to a combination of social change and technological progress. External influences such as the dwindling supply of natural resources, natural disasters, global crises, rising energy prices and the ageing-up of employees are considerably increasing the pressure on industrial companies. At the same time, customers expect more and more, be it improved, innovative, high-quality products at low prices, increased variant diversity as well as support services.

In the context of globalization and simultaneously increasing awareness of issues such as resource and energy efficiency, it is therefore of fundamental importance for companies to keep up with the times and master these challenges. Above all, companies must be able to make their value chain agile in order to react flexibly to rapidly changing circumstances. More specifically, physical and virtual structures must be adapted to enable close cooperation and rapid adaptation throughout the entire life cycle, from product innovation over production up to delivery [1].

In this framework, diverse initiatives were already launched a few years ago by government and industry stakeholders. Progress in the areas of production technology coupled with information technology is intended to contribute to the reorganization and operation of modern enterprises. This evolution is being referred to as Industry 4.0, the fourth Industrial Revolution, whereas the Internet and its technologies should serve as a mainstay to connect objects, people, products, machines and processes and thus enable organizational structures that permit the adaption of agile value chains [2].

The vision of Industry 4.0 envisages a radical transformation of the manufacturing industry, fundamentally characterized by new forms of organization enabled by the latest developments in technology. Industry 4.0 embodies the evolution of the three former industrial revolutions, whereas this approach is grounded on technological approaches of the smart factory, and computer-integrated production. The concept aims at highly flexible, autonomous networking of production and components of various kinds through software and data networks. Furthermore, data accrued are specifically recorded and evaluated. This opens up new potential for autonomous control and organization of production processes or even entire value chains. In addition, this creates highly promising opportunities for novel products and business models [3].

This development offers companies numerous opportunities to extensively enhance their internal processes as well as those along the overall supply chain. Within production, the consideration of individual and short-term customer requirements may be counteracted, thus ensuring profitability even with batch size one. In addition, flexibility increases as lead-time and time-to-market can be reduced and generally the ability to react more quickly to changing market conditions is enhanced. Industry 4.0 allows resource effectiveness and efficiency to be driven forward. Modern technologies also make it possible to avoid failures in advance and to extensively analyze business processes and products. All this is reflected in productivity, which can be significantly increased through Industry 4.0. However, the opportunities do not only concern production, but also other aspects, such as increasing the deployability of employees and new forms of workplace organization in which the human being still takes on key responsibilities, but in some cases repetitive, strenuous work can be relieved of and undertaken by technical aids. Finally, Industry 4.0 also offers the possibility to strategically realign the company and to supplement existing services with new value-added potentials. By offering services, companies are increasingly transforming themselves from product providers to solution providers [4].

As good and promising as this may sound, the whole digital transformation process is not as straightforward and represents considerable challenges for companies. After this section has covered the current developments and emerging opportunities for companies in the context of Industry 4.0, the next section addresses exactly this problem. The challenges companies are confronted with in association with Industry 4.0. From this, the motivation for this thesis is derived, which is intended to prescribe the objectives for the further proceedings.

1.2 Motivation and objectives

Companies are seeking to exploit the development potential mentioned in the previous section towards increasingly networked production in the course of Industry 4.0 in order to make their production more effective and efficient and to be more competitive in the global environment [5]. In most cases, however, the digital revolution causes them considerable problems and challenges and therefore cannot be realized simply as theoretically specified in literature.

In practice, this shift not only requires large financial resources, which is a major challenge for small and medium-sized enterprises (SME's) in particular, but companies also encounter difficulties from a strategic perspective. As the term Industry 4.0 is hotly debated almost everywhere, there is a lot of confusion pervading and consequently companies are struggling to filter out ways to benefit from this novel approach. Additionally, many find it challenging to derive strategic fields of action for their specific enterprise [6]. As a result, digital change is slowing dramatically. A study by IBM in 2015 illustrates this relatively slow development of Industry 4.0. very clearly and names obsolete IT systems and technologies as main barriers that are slowing down the pace of change [7].

In response to these problems, some ideas have emerged to propose approaches that support enterprises in overcoming the uncertainty surrounding Industry 4.0. So-called Industry 4.0 roadmaps are intended to provide guidance in the planning and implementation of modern digital organization models. According to these, a strategic approach should be pursued in order to establish Industry 4.0 successfully in enterprises, bringing together the most important components within the framework of an Industry 4.0 implementation strategy.

Current models offer companies a structured approach to strategy development and implementation in relation to Industry 4.0, in that they basically intend to clarify the most relevant terms for all participants in the first instance in order to create a basic understanding. This is followed by pre-defined process steps which range from the vision development to the creation of projects over the realization of the timeline.

Although these models give companies guidance in this often-foreign territory, no concrete, practical, effortless and applicable recommendations for action are provided to enterprises. In particular, the question of which Industry 4.0 concepts could be suitable for the most diverse types of companies, be they of different sizes or from different sectors, remains unanswered up to the present.

This thesis after outlining the current development and clarifying important terminology will provide a method for evaluating Industry 4.0 concepts for enterprises based on their size. The overall ambition is accordingly to develop guidelines for the roll-out of suitable Industry 4.0 concepts based on the size of the organization. This is meant to enable companies, based on their size, to easily identify, review and then to subsequently adopt suitable concepts.

The following objectives for the work arise from the stated motivation:

- Description of current developments, resulting opportunities and challenges for industrial enterprises
- Definition and clarification of the key terminology related to Industry 4.0
- Overview of existing research approaches in the field
- Elaboration of a methodology for the evaluation of the suitability of Industry 4.0 concepts for companies of different sectors and sizes
- Development, implementation and evaluation of a survey with the involvement of companies and other experts
- Generation of a classification of Industry 4.0 concepts ranked by their suitability for a given company, based on its size
- Overview of suitability of Industry 4.0 concepts for enterprise sizes from which ideal and suitable Industry 4.0 concepts can be derived
- Evaluation and validation of the methodology and outlook for the next steps in this area of research

In summary, Industry 4.0 opens up interesting avenues for industrial enterprises. However, digital transformation is proceeding slower than expected as some major challenges need to be overcome. Initial approaches already offer structured process models for the implementation of Industry 4.0 strategies. This work is geared towards offering companies, on the basis of their size, recommendations for the introduction of Industry 4.0 concepts and thus supporting them in advancing the digital transformation without great effort.

After the depiction of the current situation and the objectives have been formulated by highlighting the central theme of the work, in the next section the structure of the work is presented to the reader by specifying the focal points discussed in the respective chapters.

1.3 Structure of the thesis

The structure of the work results as follows from the explanation of the current developments in the field of Industry 4.0 and the formulation of the objectives. Figure 1 graphically illustrates the structure of the thesis.

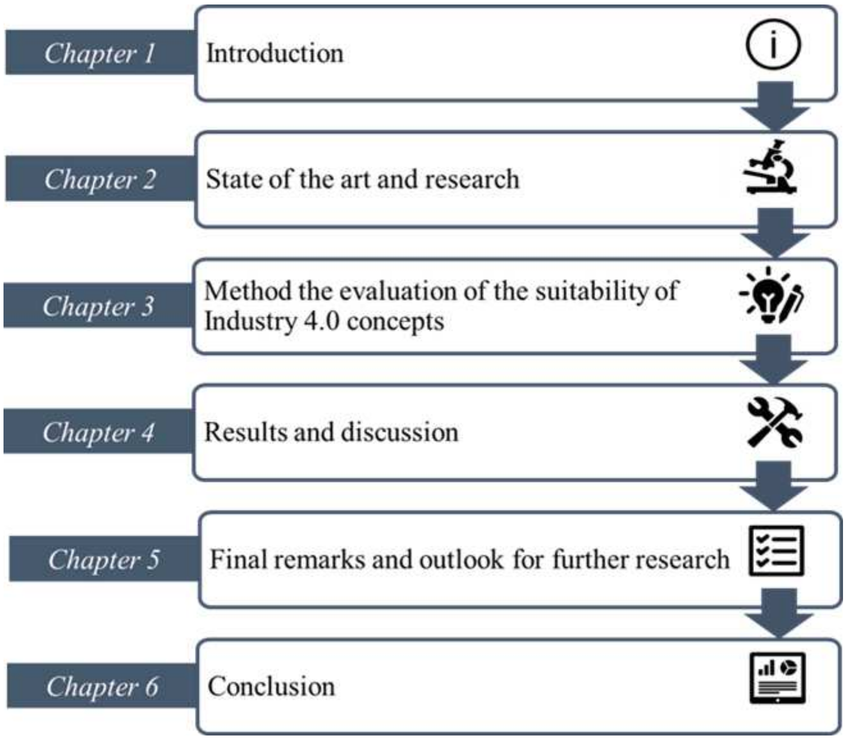

Figure 1. Structure of the Thesis.

In Chapter 1 the current situation was explained to the reader. In section 1.1 current trends were highlighted and the resulting problems have been explained. From this, the motivation and objective of the work in 1.2. were derived. Finally, in 1.3 it is shown to the reader how the work is structured.

Chapter 2 discusses the state of the art and research in more detail. The first section 2.1 lists and explains general terms in the context of Industry 4.0, which are indispensable for a holistic understanding. In 2.2, the reader is then introduced to the most relevant Industry 4.0 concepts for this work. In 2.3, current approaches for the strategic implementation of Industry 4.0 in companies are discussed. The chapter concludes with the formulation of the research question in section 2.4, which emphasizes the objectives of the work once again.

The methodological part of the work follows in Chapter 3, which aims to develop a method for evaluating the suitability of Industry 4.0 concepts for companies of different sizes. For this purpose, a basic classification is first elaborated in section 3.1. The structure of the survey is then explained in more detail in 3.2. and in 3.3. the description of the evaluation method applied for the evaluation is provided.

The presentation of results is then undertaken in Chapter 4. First, in section 4.1. general aspects of the survey are analyzed. This is followed by the presentation of the survey results in 4.2 and a detailed discussion of the results in 4.3. Finally, in 4.4 .suitable Industry 4.0 concepts for different enterprise sizes are analyzed.

In Chapter 5, first a further analysis by operating sector is undertaken with the scope of being the impetus for further research. Subsequently, an outlook to further research is given in 5.2.

The thesis concludes with Chapter 6, which sums up the results and draws a conclusion. In addition, the reader is given an outlook on the future and the potential further course of research in this thematic area.

2

STATE OF THE ART AND RESEARCH

The application of an innovative approach to evaluate and assess the suitability of Industry 4.0 concepts for different company sizes requires a certain basic knowledge of the most important terms and thematic fields related to Industry 4.0. Therefore, this chapter is devoted to the state of the art and research in order to provide the reader with a theoretical overview that is indispensable for the further understanding of the methodology threated in the main chapters of the thesis.

After the introductory first chapter with a description of the actual situation, as well as the motivation, objectives and structure of the entire work, in section 2.1 the term Industry 4.0 is elucidated in detail by going deeper into the historical development of the Fourth Industrial Revolution followed by the consequences and repercussions for society and especially companies in this day and age. The section is concluded by an overview over the most important terms and definitions appearing in the context of Industry 4.0. Section 2.2 deals with existing Industry 4.0 concepts, which can be categorized into operational, organizational, socio-cultural and technological dimensions. This is followed by a summary of currently in literature existing roadmaps for the implementation of Industry 4.0 concepts in section 2.3. Chapter 2 concludes with the formulation of the Research Question in section 2.4.

2.1 Industry 4.0 - the fourth industrial revolution

The term Industry 4.0 was introduced for the first time at the Hannover Fair in 2013 as a strategic initiative of the German government within the "High Tech Strategy 2020 Action Plan" [2]. Since then, around the term a major debate was initiated [3].

The naming of Industry 4.0 originated from the idea that after the first three industrial revolutions, namely the mechanization, electricity and information technology, the fourth industrial revolution comprises the interconnection of devices, machines and products, allowing mutual information exchange and independent control [8].

The vision of the Fourth Industrial Revolution foresees the realization of the Internet of Things (IoT), which enables companies to significantly increase flexibility and adaptability of their production systems [9].

By interconnecting machines, goods and products, smart production systems that control each other autonomously without the need for manual interference, a completely new way of organizing industrial systems becomes feasible [10].

As a consequence, factories are evolving into smart environments in which the gap between real and digital world is reducing significantly [9]. This transition to interconnected and flexible production technologies provides many advantages. Complexity drivers related to individual customer requirements resulting in an increasing number of variants, decreasing product-life-cycles or other unforeseen events such as malfunctions, failures or delivery delays can be mastered much more effectively by introducing Industry 4.0 concepts into the industrial environment. The increased adaptability leads to a better utilization of resources and therefore improves the overall efficiency. As a result, costs are decreased, and errors obviated more frequently. Finally, also the development of innovative business models can be supported significantly by exploiting Industry 4.0 related concepts. Companies are enabled to provide integrated system solutions offering complex applications in which machines and services can be combined in order to form service packages that guarantee long-term success on the market [11].

The following sub-sections provide an overview over the mentioned concepts and terms. First, in 2.1.1 the historical development of Industry 4.0 in the context of the three preceding industrial revolutions in the course of the time is depicted in detail. Afterwards in 2.1.2 consequences for companies and necessary actions are deducted. Finally, in 2.1.3 essential terms related to Industry 4.0, such as Big Data, Cyber-Physical Systems (CPS), Internet of Things (IoT), Smart Factory and Internet of Services (IoS) are clarified in order to guarantee a basic theoretical understanding as basis for the further work.

2.1.1 Historical development of industry 4.0

The naming of Industry 4.0 emerged from the naming of its predecessor, the three previous industrial revolutions. Whereas the first Industrial Revolution was the Mechanization resulting from the invention of the steam engine, the second Industrial Revolution allowed mass production by exploiting electricity. The third comprised the Digitization by the utilization of electronics and information technology [9]. The following paragraphs take a closer look at the historical development of these significant historical events that shaped today's society and economy.

The first Industrial Revolution is categorized by most historians as one of the most influential events in the history of the modern society, due to its major impacts on social life and economic growth. The emergence of new technologies and items lead to a significant improvement in the accomplishment of tasks, which could be performed in a more efficient and time-saving way. Prior to the first Industrial Revolution, products made by people were mainly handmade individually, resulting in high time effort and the need for specialized workforce. This reality underwent a considerable transformation in the 19th Century with the upcoming of the first Industrial Revolution in Great Britain. Three fundamental changes were the main contributory factors for the shaping of human's life in the following centuries. First, the invention of machines allowed to replace the work of the traditional hand tools accelerating the production process and removing the need for specialization of the labor, which just had to be capable of operating the machines. Secondly, the use of steam and other types of power facilitated the achievement of physically high demanding tasks that previously had been executed by workforce or animals. Finally, also the adoption of the factory system played a key role permitting the simplification of the manufacturing processes by encouraging workers to perform only a single task instead of constructing the whole product on their own. This focus lead to decreases in production costs, an increase of efficiency and high outputs in a shorter time. Generally speaking, these modifications evolved the way of production completely, allowing the contribution of non-specialized workforce and speeding up the process enormously. The first Industrial Revolution had ongoing effects in almost all places and spheres of lives of both consumers and workers and therefore it will always bear in mind as one of the most influential events for the development of modern economy and society [12].

While the first Industrial Revolution lay the foundation of modern society, through the second Industrial Revolution, which is estimated between 1870 and 1930 by most historians [13], these innovations could be utilized effectively, and a lot of new segments were made accessible. Above all the invention of electricity is defined as a decisive milestone, enabling large-scale mass production in factories for the first time. Thanks to the alternating current (AC) generator invented by Nikola Tesla, it was possible to bring electricity into households. As a consequence, everyday life changed significantly. Refrigerators, dishwashers and the invention of the light bulb are just a few examples of inventions during this time that considerably improved the quality of life. Communication technology experienced an enormous upheaval trough the invention of the telephone. Furthermore, the invention of the diesel and gasoline engine was formative for this historical time span giving birth to the development of the automobile and the automotive industry later. Also, in the aviation sector enormous progress was made and flying became possible with the first controlled powered flight in 1903. Finally, also in chemistry today essential substances such as soda or sulfuric acid gained importance enabling the development of many new products in the field. It is impossible to imagine modern society without all these innovations. Many of today's best companies were founded during the second Industrial Revolution. Automation in the factories and the continuous optimization of processes still enable strong economic performance and a supply of the population in many areas [14].

The roots of the third Industrial Revolution go back to the early 18th century. At that time, Chales Babbage and Ada Lovelace with the development of the Analytical Engine are considered the first pioneers thinking about individually programmable computers. This work was followed by the first functional devices when the German engineer Konrad Ernst Otto Zuse developed the Z3, the first functional program controlled, freely programmable and fully automatic computer back in 1941. In the upcoming years this computer was commercialized for the first time. This was followed by new models and the development cycles became shorter and shorter by the time. The third Industrial Revolution is dated in the 1970s focusing on further automation by exploiting electronics and innovative information technology. In the following years a radical progress in the automation of production occurred through the usage of programmable logic controllers (PLC). After that, the personal computers for office and households has established forming a separate branch [15].

The fourth Industrial Revolution is currently underway. From 2013 on, when the German government launched Industry 4.0 as a core element of its High-Tech Strategy, industry has been undergoing a major and fundamental change. Development of tangible developments possibly have come to an end, so the focus is shifted towards the increasing digitization and the integration of the so called Cyber-Physical Systems (CPS). By now many companies are already producing without the need to keep inventory. They aim to manufacture their products according to the actual demand. This is possible by implementing and enhancing information processing and technology. In addition to faster production cycles, also in the field of environmental protection and operational safety significant progress has been made. The term Industry 4.0 stands for modern technology and production in the digital age. At the same time, it not only describes the industrial development of technology as for the previous revolutions, but also the changed production and working world in todays globalized world. At the moment traditional industries such as construction, consumer goods or packaging are being digitized and new forms of communication are created. By exploiting Industry 4.0 concepts companies are enabled to react faster to unforeseen and rapid developments on the markets and at the same time offer a wide range of product variants in less time. Digital, smart factories are already able to produce individual products (lot size one) on demand in an efficient manner, without exceeding in costs [16].

Subsequently, in Figure 2 the historical development of the four Industrial Revolutions is summarized providing an overview over the major milestones and bringing it into a temporal context.

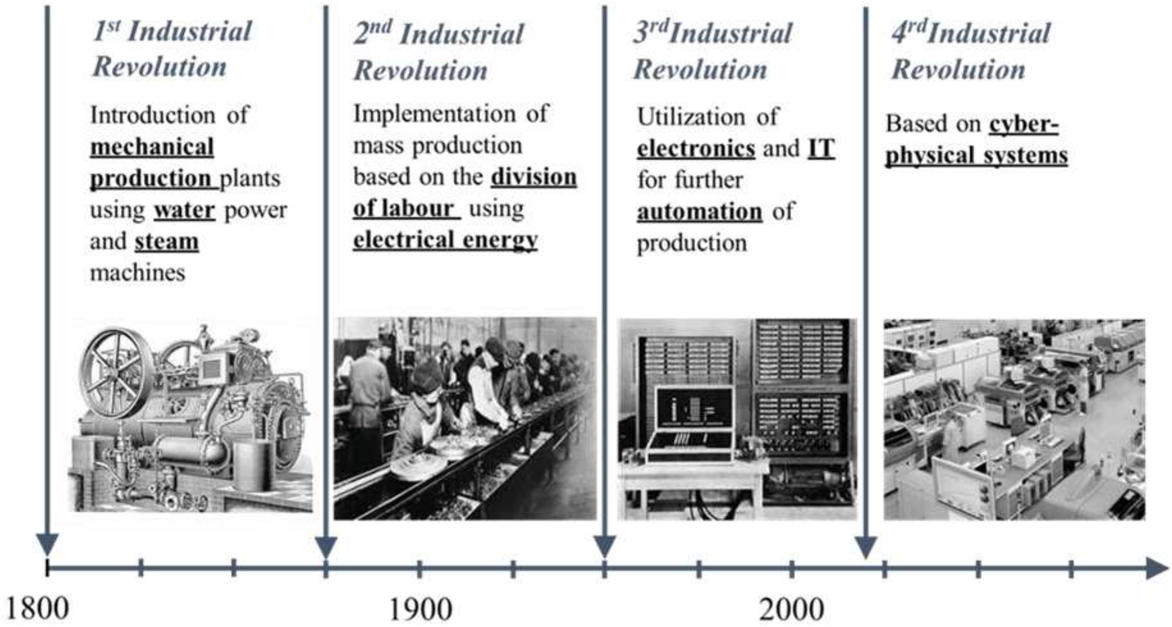

Figure 2. From Industry 1.0 to Industry 4.0 [8].

2.1.2 Digital transformation era

In the age of digitization, not only traditional product-oriented business models are changing significantly. The digitization wave passes through companies ranging from the production processes over the business processes up to a new form of overall corporate digital culture. Consequently, companies in these modern times need to adapt themselves in order to find their way through digitalization. Therefore, the current time span is often cited as the Digital Transformation Era.

The Digital Transformation of companies by definition can be described as the modification of the value creation process through further development of existing or newly implemented digital technologies, the adaptation of corporate strategies, which are based on the new digitized business models and the acquisition of the necessary competences and skills in order to master it. The pursued objectives are improved flexibility and productivity within the company on the one hand and at the same time a strong focus on customer requirements regarding digital products and services on the other hand [17].

In today's reality, digital transformation is still lagging far behind in many occasions. There are some companies that are driving the digital development very strongly, but the broad mass is struggling to follow. According to Forbes, the number of companies claiming to be successfully heading for digital transformation was ranging around 16% in 2016, meaning that 84% failed at Digital Transformation [18]. The small portion of successful transformers, the so-called digital leaders, are demonstrably more profitable than their competitors.

Digital transformation does not stop at specific industries or areas. At the same time, the utilization of digital technologies creates interesting opportunities in future markets allowing the complete redesign and optimization of the entire value chain. The prerequisite for this is opportune organizational shift coupled with proper leadership and the implementation of a new digital culture within the company. In that way not only, new sales and earnings potential are generated, but also efficiency can be dramatically enhanced providing the basis for a successful future. Digitalization is therefore an essential factor for the competitiveness of companies. The transformational dynamism leads to the need for companies to react very quickly to the developments of a digitized world by rethinking their classic business models and processes as well as their interaction with the customer [19].

The digital transformation is therefore mainly a matter of competitiveness. The German government, for example, has already recognized this and has put forward the "Digital Agenda" [20]. Similarly, companies must follow suit on this path. The question that now arises is: what are the main challenges for companies in order to manage this crucial transformation?

According to the Digital Transformation Report of the German newspaper Wirtschaftswoche (WiWo) [21], companies need to acquire skills in eight dimensions of the so-called Digital Maturity Model, depicted in Figure 3, in order to shape their business for the future.

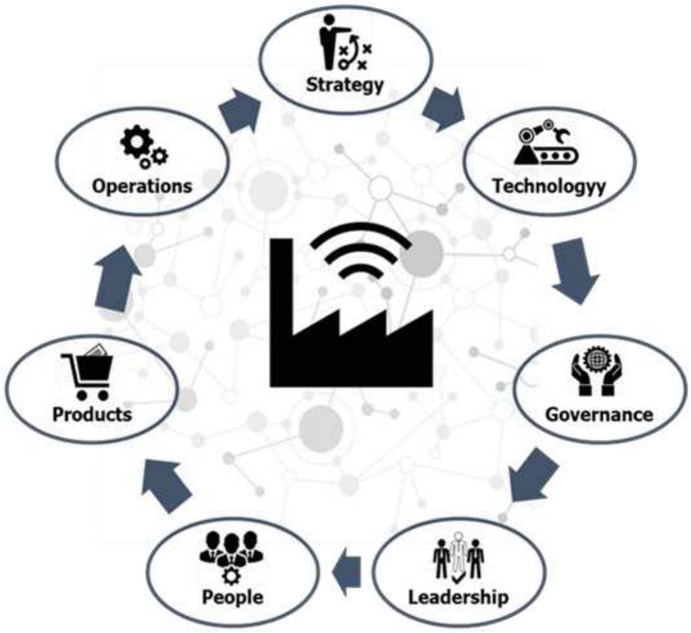

Figure 3. Fields of action within the Digital Transformation -Digital Maturity Model [21].

The successful accomplishment of the Digital Transformation requires first of all the definition of the overall Vision. Starting from there, the Digital Strategy can be defined by putting it on the test bench from a digital perspective and gradually implemented in order to pursue the company goals afterwards [22].

Secondly, leadership is an essential factor to communicate the transformation, which concerns all areas of a company. This process should be initiated and designed by the company management. New target agreements, innovative management tools and decentralized decision-making power are the key instruments to be digitally successful from this point of view [23].

Digitization is not only about efficiency improvements. New digital smart products and services result in innovative digital business models allowing the access to new business fields and the generation of customer benefits [24].

Moreover, the digitization of business and production processes is a core issue. Digitalization leads to more flexibility within an organization through increased collaboration. This effect in many cases is reinforced by the involvement of external suppliers and customers. As a consequence, the digitization of core processes must be promoted [25]. The processes within a company should be scrutinized working out possible improvements of business and production processes by digitizing them.

A new form of innovation culture is needed within the company. The differentiation of the digital leaders from the rest is mainly to be explained by a clear strategy paired with leadership and corporate culture coupled with the willingness to implement the necessary change. Throughout history, there have been enough examples of companies that, in a period of technological progress such as introduction of Enterprise Resource Planning (ERP) Systems, have completely concentrated on technologies and in doing so the organizational side was neglected resulting in a failure [22].

The current and future developments require new qualifications and competences of employees and managers. In the transformation process it is of fundamental importance to attract qualified employees and on the other hand to involve existing employees in the change process. Finally, due to the ever faster changing of requirements, continuous training plays a critical role [25].

In the area of governance, the digital strategy should be part of the target agreement, whereby measurability facilitates the control of the digital transformation and provides a verifiable indication of progress [21].

Outdated technology must be replaced, as these represent hurdles for digital transformation [21]. In the age of Industry 4.0 there are numerous possibilities to use new technologies. Examples of areas, which are changing manufacturing in the future are given by autonomous robots, simulation models, IoT, cybersecurity, cloud, additive manufacturing (AM), augmented reality (AR) or big data analytics [26]. These technologies will be examined in more detail in the section 2.2. of this chapter.

2.1.3 Terms and definitions in the context of Industry 4.0

After examining the historical perspective on the Industrial Revolutions and the explanation of how companies should be equipped for the digital age, the following sub-section provides some important definitions and explanations of the most relevant terms within Industry 4.0, namely Big Data, Internet of Things (IoT), Smart Factory, Internet of Services (IoS) and Cyber Physical Systems (CPS).

Big Data

In the course of the last decades the Internet has developed from a pure research network to a global communication platform. During this transformation, a variety of applications have emerged whose non-existence can no longer be imagined today. A recent study by Groupe Speciale Mobile Association (GSMA) shows that more than two thirds of the world's population are currently connected to a mobile phone service [27]. This enormous number of participants in combination with the growing number of possibilities in the network causes a strongly increasing volume of data, be it user data, profile data or other statistical data, resulting in an annual global data volume of 16 Zettabyte generated in 2016, with a tenfold increase forecast for 2025 [28].

These data conceal enormous potential, some of which is not yet being fully exploited today. At present, work is underway to develop procedures to bring structure into this sea of data. Once this is achieved, it will be possible to address new issues and exploit the full potential [29].

This is where the term Big Data comes in, corresponding to a generic term for any type and number of data that cannot be handled using traditional methods [30]. This results in the need for new techniques and technologies. Although the first use of the term is not entirely clear, Gartner provided an undisputed definition in 2011, based on Doug Laney's 3V model [31], which divides the challenge of enormous data growth into three dimensions, whereas the dimensions refer to an increasing volume of data, to an increased velocity at which data is processed and to the huge variety of generated data [32].

Figure 4 shows the 3 V model graphically.

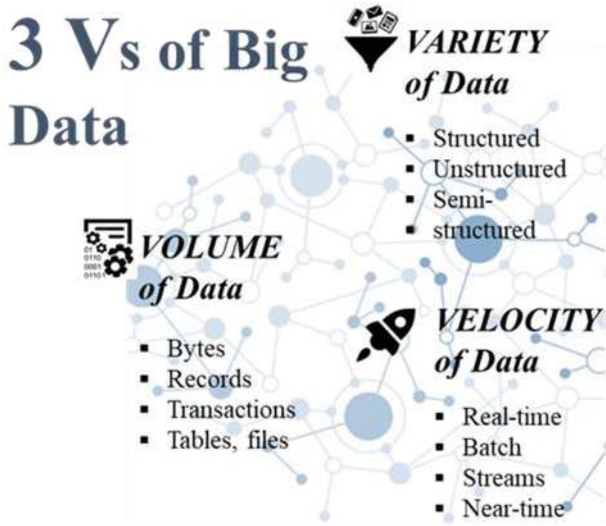

Figure 4. The 3V Model of Big Data (adopted from Beyer, 2011).

While the enormous growth in generated data volume was already addressed earlier, the other dimensions of the model, namely velocity and variety, also play fundamental roles. The velocity refers to the enormous rate at which data is generated as well as the rapid processing required for this. The variety of data is the most important aspect of Big Data. Often unstructured, different data confronts traditional databases with huge problems and cannot be processed efficiently. Within Big Data it is now possible to merge and analyze all data, structured or not, together.

Big Data is one of the most important technology drivers of our time, but there are a lot of challenges ahead in areas such as data management, data analysis, network technology and data protection to overcome in order to use them efficiently and effectively [33].

Internet of Things

After the groundbreaking invention of the World Wide Web in the 1990's, followed by the mobile Internet in the 2000's, current development is geared towards the next possibly most disruptive [34] revolution in the Internet era: the Internet of Things, often abbreviated as IoT.

The term IoT started life when one of the founders of MIT Auto-ID Center, Kevin Ashton reported that he probably had started the IoT ten years earlier in a presentation at Procter & Gamble when linking the new idea of Radio Frequency Identification (RFID) and Procter & Gamble's supply chain [35].

By definition, the IoT connects objects of the real world with objects of the virtual world [36]. In other words, it refers to a world where physical objects, persons are enabled to interact with virtual data and environment.

The term IoT characterizes the beginning of a new era in industry and society. The vision of IoT concerns the machines in the future [37]: while in the 19th century machines learned to do, in the 20th century they were taught to think, nowadays they start to learn perceiving by sensing and responding.

The full potential of the IoT for companies is achieved when networked devices interact and integrate, for example systems related to Vendor Managed Inventory (VMI) or Customer Support. According to Gartner the IoT will reach 26 billion of units in 2020, which compared to the 0.9 billion units back in 2009 represents a significant rise [38].

As a result, the information circulating along a supply chain will increase dramatically and impact the business processes from the production line to the warehousing operations up to the delivery processes, providing more accurate and transparent flow of materials and products. In the future, companies will invest into IoT to optimize their workflows, introduce tracking systems and optimize distribution. Logistics companies such as United Parcel Service (UPS) are already using IoT fleet tracking systems nowadays to save costs and increase efficiency at the same time [39].

The adoption of IoT technologies is becoming increasingly important. Companies are tempted by technological, sociological and competitive reasons to adapt and keep up with the trend. Even if the potential is great, it makes sense for these companies to precisely evaluate the necessary investment and possible opportunities or challenges through a cost-benefit analysis to ensure that the resources are used efficiently.

To turn the vision of IoT into reality, some challenges need to be overcome. The first point includes all sensors, actuators and identification systems which are attached to physical objects transforming them into smart objects enabled to participate to the IoT. Wireless Sensor Networks (WSN) are used to do this, which consist of devices that make it possible to monitor physical events and to track the location by cooperating with RFID, for example. Moreover, environmental conditions can be controlled allowing applications such as innovative approaches for maintenance. Secondly, networking technologies need to be addressed to fix communication between the different levels. Middleware systems enable the transformation of real-world data into something usable for the Internet applications. Moreover, IoT technologies require a lot of storage space, high processing speeds and high-speed broadband networks. Cloud computing offers the ideal solution for handling such massive data flows, as the data can be processed and made available for an immensely large number of devices [40].

As with previous disruptive innovations, the IoT also encounters many challenges. Above all, the explosion of data is driving the importance of security, privacy, storage management, server technologies and networks and posing huge future challenges in the field [39].

Smart Factory

In recent years, production technology has undergone considerable change. Due to globalization and the required individualization of products, not only the number of variants has risen significantly, also product life cycles became shorter and shorter, resulting in reduced planning horizons and smaller batch sizes. These external dynamics, the increasingly demanding requirements of the market have caused the companies need to be much more flexible with regard to production resources and their controlling.

Nowadays, well-planned and efficient operations are the decisive requirements for success on the market. Consequently, innovative technologies that allow planning to be accelerated, planning effort to be minimized and production to be made more flexible are needed. Consequently, companies should deal with the merging of production and information technology as early as possible to secure and develop their own competitiveness in the long term [41].

The notion Smart Factory comes up in this context and was mentioned first by the German Government within the Hannover Fair 2013. According to VDI a Smart Factory is defined as a factory whose degree of integration has reached a depth that enables self-organization functions in production and in all business processes related to production. The virtual representation of the factory enables intelligent decisions, aiming at increase efficiency, effectiveness, flexibility and adaptability [42].

In the Smart Factory, materials, machines and logistics systems communicate directly. Any data indicating the current status of the value chain, is available in real time contributing to achieve the best possible control of the overall supply chain. Decisions are no longer taken from the top, but from the lowest possible level within a framework of predefined rules. Not only internal functions of a company are integrated in the concept of Smart Factory, it also transcends the boundaries of the company involving external stakeholders such as suppliers and customers creating completely new forms value creation networks [43].

These definitions clarify that Smart Factories are not simply pure automation. A smart factory is a flexible system that optimizes and adapts itself within a network, reacts to unforeseen events in real time and manages the production process autonomously.

The induced strengths and chances of a development towards the Smart Factory are straight-forward, whereby the real strength of the concept lies the ability to adapt flexibly to the quickly changing needs of a company. Common situations in which this becomes advantageous, are represented by changing customer demand, the fast development of innovative products, predictive maintenance or even real-time modifications of production processes [44].

Daimler, for example, defines five main goals that are pursued with the Smart Factory concept. First, the increased flexibility is intended to make it possible to react more quickly to market fluctuations and individual customer requirements. Secondly, resources can be utilized far more efficiently. Due to the more flexible processes and the adjustment options of production, manufacturing processes are also designed more efficiently, leading to shorter innovation cycles and reduced time-to market. Furthermore, also advantages for the employees are followed by creating new working models, which promote the ergonomically interaction of employees. The final goal is the introduction of Smart Logistics, which should cover everything from customer orders to production up to the final delivery [45].

Even though development still has some technological hurdles ahead, it seems the right way to push ahead with the promotion of future technologies. Innovative trends such as IoT, Big Data, IoS, Cloud Computing together with intelligent technologies render the Smart Factory a realistic scenario in the near future.

Internet of Services

Over the last two decades, the Internet has undergone a series of radical changes. The first wave was dealing with scientific publications and data. The World Wide Web (WWW) revolutionized the way how documents and information had been exchanged. The following wave enabled simple commercial systems, such as web shops. Subsequently, the next wave focused on private users, whereas the most important trends were social networks and user-generated content [46].

At the same time, digitized media such as music or movies could be accessed commercially via web. Subsequently, developments such as the mobile Internet and the virtualization of computer and storage capacities in cloud computing arose. The paradigm "Software-as-a-Service" (SaaS) became more and more popular [47].

At present times the integration of the physical world and the digital world - the IoT plays an important role together with the provision of services via Internet. The IoS describes the utilization of the Internet to create a new economic area for the mediation and provision of services [48].

The IoS is considered to be one of the greatest growth potentials of the present and future Internet. The main aim here is to provide company-related services via the Internet [49]. While social networking applications primarily addressed the consumer or the individual, the IoS addresses also companies.

As a consequence, the Internet is becoming a marketplace for trade of services in which completely new business fields are emerging. This marketplace offers enormous opportunities. Services can be offered transparently, simply, quality-oriented, reliably and securely on suitable platforms [50].

Also, from a user perspective the IoS provides advantageous opportunities for medium-sized companies: by exploiting cloud computing services, they are allowed to integrate modern services online directly into their business processes, such as for example the rental of software systems. This not only contributes to save companies money, but even more importantly it allows them to concentrate more on their core competencies [48].

Cyber-Physical Systems

The latest advances in manufacturing and information technology in conjunction with microsystems technology have paved the way for the utilization of CPS. This development envisions that communication and data processing capabilities will be embedded in all types of physical objects. CPS are physical systems that are monitored, coordinated and controlled by a computing and communication center [51].

The German organization “Deutsche Akademie der Technikwissenschaften” (Acatech) characterizes CPS within the Forschungsagenda CPS as a combination of real physical objects and processes with information-processing virtual objects and processes via open information networks, which in some cases are global and interconnected at any time [52]. According to this definition, the essential new aspect compared to the traditional form of automation is that the networking takes place via open and global information networks, i.e. the Internet. This difference compared to conventional automation results in considerable implications, meaning that it is possible for systems to connect as many times as wished, to change, terminate and rebuilt the connection during the operating time. Data, information and services can be provided and used anywhere in the CPS. All in all, this introduces a new communication paradigm into automation [53].

For companies, focusing on CPS is becoming increasingly important as they will soon may be decisive for economic success or failure. According to a report by the United Sates (US) National Institute of Standards and Technology (NIST), the cost related to electronics, computing, sensors and actuators will increase rapidly in sectors such as transportation, industry and telecommunications, and will account for more than 50% of the total costs by the year 2020. Technologies such as advanced robotics, computer-controlled processes and real-time control are becoming critical for the competitiveness of companies [54].

Since CPS systems are still in the early stages of development, it is advantageous to define a uniform system for the introduction of general CPS applications. Lee, Bagheri and Kao propose the so-called 5C architecture [55], which is to be regarded as a uniform system for the implementation of CPS in industry and prescribes guidelines for achieving high efficiency, reliability and product quality. The model provides a step-by-step instruction for CPS in the field of manufacturing technology.

According to the authors, a CPS generally requires two components: first, connectivity, which ensures the acquisition of real-time data from the physical world and is responsible for the feedback in the cyber space, and secondly, intelligent data processing to construct the cyber space. However, these prerequisites are not concrete. The 5C architecture, on the other hand, provides a clear sequence of steps for building a CPS starting from data acquisition and all the way up to the final value creation.

Figure 5 illustrates a representation model including the five levels, namely the smart connection, data to information conversion, cyber, cognition, and configuration level.

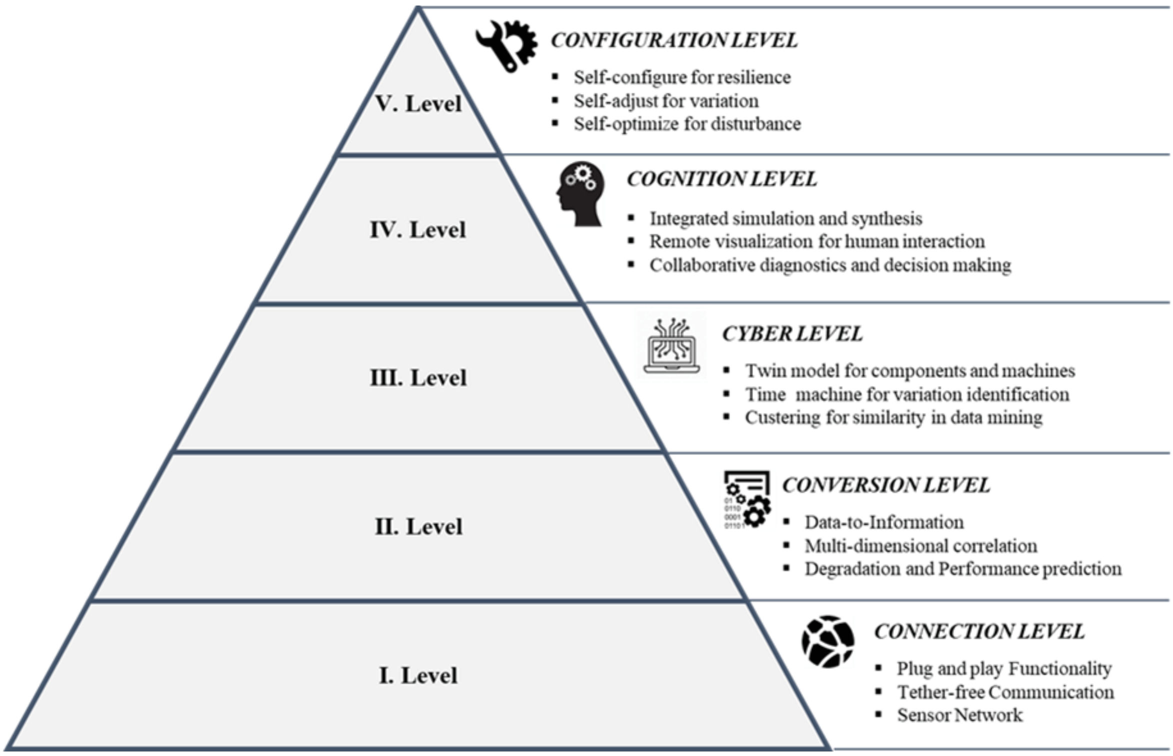

Figure 5. CPS 5C Level Architecture [55].

To develop a CPS, according to Lee, Bagheri and Kao the first step comprises the acquisition of accurate data from the machines by measuring the exploiting sensors or obtaining the data from enterprise information systems. Critical factors at this stage are the right selection of the sensors and the data acquisition of different types of data. To manage the various forms of data, seamless and tether-free methods are required. Important information is then extracted from the data through algorithms. This gives the machines self-awareness. The cyber level serves as a central information hub to which information from the connected machines is transmitted. By accessing such large amounts of data, analytics can be employed here to enable self-comparison of machines. Moreover, historical data can also be exploited to predict future behaviors. The cognitive level includes the right presentation of the knowledge gained to support experts in decision-making. The information provided makes it possible, for example, to optimize the priorities of certain tasks. Finally, the configuration level describes the feedback of the cyber space to the physical space and therefore serves as control for the self-configuration and adaptation of the machines. Corrective and preventive decisions can be applied to the system through Resilience Control Systems.

At the moment we are in the middle of a development in which CPS will revolutionize the way people interact with the physical world, offering a variety of benefits. Challenges still concern the introduction of CPS in a safe, dependent and efficient way. Affordable and flexible CPS can only be achieved through further progress in research [56].

Figure 6 finally illustrates an overview over the most important Industry 4.0 components, which were considered in detail in this sub-section and explains the interrelationships between them. Roth represents the Industry 4.0 components within a house, whereby the third level is represented by Industry 4.0, the Fourth Industrial Revolution, which leads to new visions, strategies and modified business models as well as adapted processes. In the second level, so called Cyber-Physical Production Systems (CPPS) ensure the right connection between machines and interaction of machines and manpower. The first level, the CPS, is made up by Ubiquitous Computing, which stands for the integration of digital information processing into everyday objects and practices, IoT, IoS and Cloud Computing.

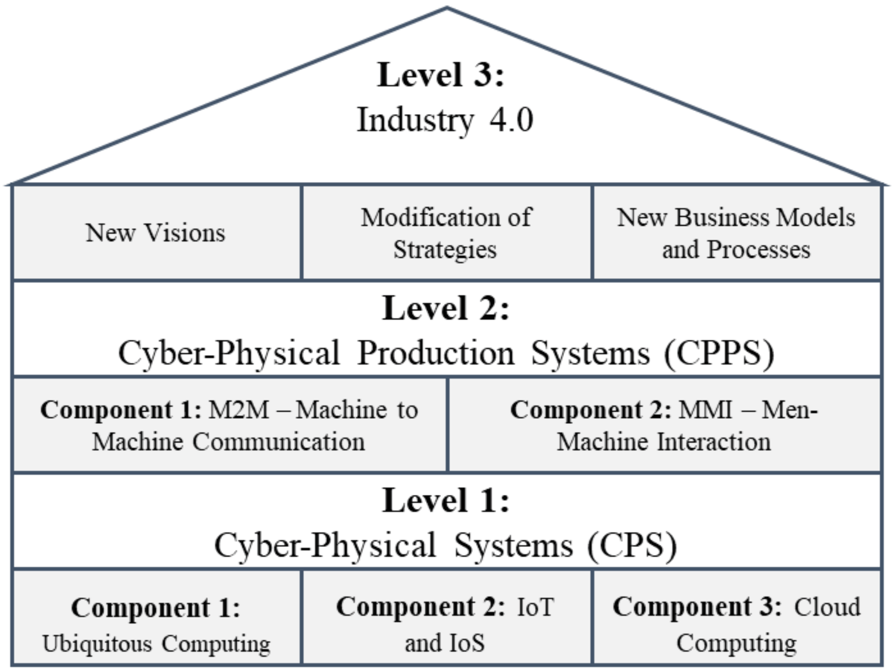

Figure 6. Overview of Industry 4.0 components [4].

After dealing with the most important terms and trends regarding Industry 4.0 in this section, the following section presents the most relevant current Industry 4.0 concepts. The clarification of these represent the basis for the evaluation of suitable Industry 4.0 concepts for different company sizes and sectors, which will be faced in the main part of the thesis.

2.2 Industry 4.0 concepts

Based on a previous research titled "Assessment model for industrial companies to define the maturity level of Industry 4.0 implementation Assessment of Industry 4.0 concepts" [57], the approach and concepts are adopted in this section. The aim of the assessment model developed within this academic work is to support companies in demonstrating the feasibility, effort and current status of digital transformation in order to assist them in maintaining their competitiveness. Special attention is devoted to the identification of Industry 4.0 concepts, since they serve as the basis for the further proceedings of the evaluation in the subsequent main chapters of this work.

Therefore, first the utilized methodology to identify the relevant Industry 4.0 concepts within the assessment model of Unterhofer is epitomized in sub-section 2.2.1. In a second moment, in sub-section 2.2.2 the concepts worked out are than described more in detail to provide the reader the common understanding, which is of crucial interest for the following evaluation.

2.2.1 Methodology to identify industry 4.0 concepts

The methodology for identifying the relevant Industry 4.0 concepts starts with a systematic literature review, in which selected journals from 2016 and 2017 are scrutinized in a first step in order to lay a solid methodical foundation. Subsequently, through performing a frequency analysis of keywords the hottest thematic researches regarding Industry 4.0 are identified. On this basis, the content analysis is initiated and as result 75 Industry 4.0 elements are identified and classified into first and second level dimensions. This constitutes the very essence of the assessment tool structure.

Based on the defined elements, specific Industry 4.0 concepts are then specified. The assessment tool distinguishes 41 Industry 4.0 concepts, which are either clustered into organizational, operational, socio-cultural or technological dimension. This classification corresponds to the first level dimension.

The second level dimension divides the concepts into even smaller sub-classes. The presented assessment tool contains 22 second level dimensions.

Figure 7 provides an overview listing first level and second level dimensions within the structure of the I4.0 assessment tool.

I. Level Dimension			
1. Operation	2. Organization	3. Socio-culture	4. Technology
II. Level Dimension			
▪ Agile Manufacturing Systems ▪ Monitoring & Decision Systems ▪ Big Data ▪ Production Planning & Control	▪ Business Models 4.0 ▪ Innovation Strategy ▪ Strategy 4.0 ▪ Supply Chain Management 4.0	▪ Human Resource 4.0 ▪ Work 4.0 ▪ Culture 4.0	▪ Additive Manufacturing ▪ Big Data ▪ Communication & Connectivity ▪ Cyber Security ▪ Deep Learning, Machine Learning, Artificial Intelligence ▪ Identification & Tracking Technology ▪ Maintenance ▪ Robotics & Automation ▪ VR, AR and Simulation ▪ Product Design and Development ▪ Standards 4.0

Figure 7. Overview 1. and 2. Level Dimension of I4.0 Assessment tool [57].

Concerning the assessment, for each Industry 4.0 concept, *Maturity levels* that describe the current progress of the Industry 4.0 concept within the company are defined, ranging from values of one to five, with one representing the worst and five the best value. Moreover, for each concept the *Importance* for the company is rated from 1 to 5.

Once the individual concepts have been evaluated, the next step is to define a target value for each concept, which again ranges between 1 and 5. Based on these two determined values, the so-called *Gap to Target* is determined as the difference between Target and Maturity Level.

The final step is to prioritize the Industry 4.0 concepts. Therefore, the *Weighted Gap* is calculated by multiplying Gap to Target and Importance for company and dividing by five. The result is ultimately a ranking of Industry 4.0 concepts based on the weighted gap, advising on which concepts the concerned company is lagging its expectations.

As introduced above, according to Unterhofer, Industry 4.0 concepts can be classified into four main dimensions, namely the operational, the organizational, the socio-cultural and finally the technological level. The following sub-sections are dedicated to the to these dimensions and the associated Industry 4.0 concepts.

2.2.2 Industry 4.0 concepts – operational level

The operational dimension includes nine Industry 4.0 concepts, which are presented in a detailed way in this section. The model foresees different levels of maturity for each concept, ranging from one to five, describing how far the concept is already established within the company.

The term Agile Manufacturing was first formulated around the year 2000 as a response to the changing economy to preserve the competitiveness of manufacturing companies. By definition agility describes the ability to move quickly and easily [58]. Emerging from the increasing individualization trends and the ever-smaller batch sizes, this concept describes the vision of reacting to the continuous and unpredictable change by developing fast-reacting mass-customized products or services that meet high quality standards and high customer-value. This is made possible by Agile Manufacturing Systems that are characterized by flexible organizational structures, competent and authorized workforce and simplified information structures, which efficiently interconnect actors along the value chain [59].

Modern manufacturing systems must be equipped for process and product innovations and adapt to changes and variations in a cost-efficient and flexible manner [60]. Self-adapting Manufacturing Systems use advanced sensing and control logic to adapt to an ever-changing environment by sensing variations in the operative environment. Through the perceived variations, they adapt to their own needs and optimize production performance in an intelligent and adaptable way. Therefore, adaptivity is accomplished by sensing variations in the environment and the subsequent adaption by implementing the optimizing strategy [61]. The benefits of this concept can be clearly seen in an example from Festo, in which stations in a production plant can be combined as desired. First, the stations log on to the production planning system detailing information about capabilities and material flow. The system than generates a suitable production plan, which allows the respective production order to be executed flexibly. The results can be used particularly to reduce the effort required for the configuration and different products can be planned and manufactured with minimal downtime [62].

The idea of continuous material flow has changed dramatically in recent years. In the past, manufacturing was associated with repetitive production processes that seldom changed. Later, the concept was also adapted for series production in small batch sizes. Within the concept of Continuous and uninterrupted material flow models, five different scenarios are distinguished in this work. The first foresees the production of lot sizes in job-shop structure, followed by cellular manufacturing models, which enable nearly fully continuous flow within a production cell. Moreover, classic production lines allow continuous flow without interruption. In technical terminology, this is also referred to as one-piece-flow. According to the next level, namely continuous flow flexible production cell/line, the product knows the sequence and goes directly to the next step in the line or cell. The last level of such models comprises continuous flow within a flexible job shop. Thereby, the product goes to the next step of the production sequence within the cell or the line.

The so-called Plug & Produce capability of components is one of the visions with regard to Industry 4.0. According to Head of Research of Mechatronic Components at Festo, Bernd Kärcher the principle is similar to that of a Universal Serial Bus (USB) interface on the computer, whereby connected devices log on directly to the main computer communicating with it [62]. In the factory of the future, machines will be self-configuring based on this concept. Thanks to the ability of Plug & Produce, individual components of machines and systems in production plants connect independently. They establish a connection to the devices in their environment and perform control functions. This means that the system is no longer centrally controlled by people, but decentral by machines. When it comes to plug and produce, machines contain chips that communicate with the other components, so that there is no need for an engineer to take care of them. This saves time, money and of course brings an increase of flexibility [63].

Decision support systems (DSS) are a class of information-based systems designed to assist decision making. Business data is analyzed, processed and presented clearly so that decision-makers work can be facilitated significantly. DSS have undergone a substantial transformation over time, with technological and organizational influences making a major contribution. Initially, these systems supported individual decision-makers. This developed into team decision support. Over time, many different applications have been developed in the field of DSS [64]. DSS can be classified to five major types, namely communications-driven, data-driven, document-driven, knowledge-driven and model-driven systems. Data-driven systems in particular offer interesting possibilities through innovative developments in the field of Data Analytics. Another important differentiating feature in this respect is the hierarchical decision level, which can be characterized by centralized or decentralized decisions [65].

Generally speaking, the term monitoring refers to the continuous supervision of the running processes [66]. Through the monitoring it is possible to react early on to failures and potential disturbing factors aiming at ensuring activities are on-schedule meeting the objective targets. Monitoring is applied in various fields, ranging from medicine over natural sciences and information science [67]. In the industrial sector, monitoring systems have a long history. Therefore, there are also today different stages of such systems, which can be distinguished fundamentally by the degree of integration and by the grade of digitization. The traditional form is represented by paper-based monitoring systems. Other systems allow the monitoring of individual processes or machines partially, while the most advanced monitoring systems foresee real time monitoring embedded into the ERP system. This corresponds to so called Integrated and Digital Real-Time Monitoring Systems.

The development towards the IoT now even enables the Remote Monitoring of Products. The possibilities of the Internet give the term remote monitoring a completely new meaning [68]. Through remote monitoring solutions, it is easy for companies to keep track of the states of their products or production processes via Internet [69]. There are different versions of such systems. While some companies still rely on the simplest forms such as spot wise or periodic product checks by operators, others are beginning to apply innovative concepts. Remote product monitoring allows products to be monitored digitally by the manufacturer via remote access. In some cases, the manufacturer not only monitors the products delivered but also controls them within the framework of Remote Product Control. These innovative technologies allow proactively identify patterns that prevent factory downtimes while reducing energy consumption, maintenance and outages.

As mentioned already in the section 2.1.3, companies are facing completely new opportunities and challenges with regard to Big Data, from which facts can be filtered out that were previously inaccessible [70]. Big Data Analytics tools allow them to take a close look at Big Data and analyze, for example, important information such as the consumer behavior of customers. The term Big Data Analytics describes the application of advanced analytical tools for extracting useful information from huge amounts of data [71]. In this area, too, the application varies greatly from company to company. While some companies do not yet process their data, others use simple programs such as Excel and thus manual data analytics. Many larger companies have already started to collect data within Big Data projects in a structured way and to evaluate them with the help of external experts. Others already utilize Big Data Analytic Tools internally and recruit internal experts, which are in charge of taking care of these issues.

The abbreviation ERP stands for Enterprise Resource Planning and describes, as the name suggests, software solutions for a company's resource planning. Various applications are integrated and a central database that processes and stores the data. ERP systems support the planning and control of processes within a company enabling many different functions, such as production, procurement, sales, controlling and much more. Such systems were previously only used in a few large industrial companies. Nowadays, many small and medium-sized enterprises also use ERP systems to facilitate the organization of work processes in the company [72]. Manufacturing Execution Systems (MES) are used one level below ERP systems. An MES is part of a production management system and is responsible for production control. Due to the direct connection to the operating processes, it enables production control in real time. The MES also records data from production processes, which can be used to optimize the processes and detect errors in the process flow. At the most advanced stage, an ERP system accesses the MES in order to plan production and deploy the company's resources as efficiently as possible. The ERP system forwards production planning to the MES. An MES offers, for example, a production flow chart for each product, a production planning system, and the current allocation of resources [73]. Within Unterhofer's assessment tool, the Industry 4.0 concept ERP/MES Integration defines the degree of integration of such systems in a company. The utilization fields are broadly diversified, ranging from no utilization of an ERP up to the full integration of ERP and MES into the company organizational structure.

Finally, Figure 8 displays the discussed operational Industry 4.0 concepts.

Operational Dimension

II. Level Dimension			
Agile Manufacturing Systems	Monitoring & Decision Systems	Big Data	Production Planning & Control
Industry 4.0 Concept			
1. Agile Manufacturing System 2. Self-adapting Manufacturing Systems 3. Continuous & uninterrupted Material Flow Models 4. Plug & Produce	5. Decision Support Systems 6. Integrated & Digital Real-time Monitoring 7. Remote Monitoring of Products	8. Big Data Analytics	9. ERP/MES

Figure 8. Overview of the discussed operational Industry 4.0 concepts classified by second level dimension [57].

2.2.3 Industry 4.0 concepts – organizational level

With regard to the organizational dimension of Industry 4.0 concepts, Unterhofer's I4.0 Assessment tool makes a distinction between ten. These are discussed in more detail in the following section.

The first concept within the organizational dimension comprises Digital Product-Service

Systems. As described at an earlier stage of this work, the speed of digitization is advancing rapidly. The center of this digital transformation is the customer with its fundamentally changed expectations of products and companies [74]. While so far, the focus has been on high-quality products, today customers expect a comprehensive solution approach. Product Service Systems (PSS) are suitable for providing such complete solutions. They consist of a traditional product component, which is usually supplemented by digital services during the product life cycle [75]. The merging of products and services, along with the potential of digitalization, opens up many opportunities for new business models. By focusing on customer benefits, Digital Product Service Systems are particularly well suited to master the challenges of the upcoming digitalization. The most common example of a traditional Product Service System is the additional provision of maintenance service together with the sale of a product. Other possibilities are offered by the combination of digital services with the product or even cloud-based product service architectures, through which services can be offered via apps, for example.

The term Servitization was first mentioned in the 1980s by Vandermerwe and Rada [76], but only in recent years has the term gained in importance. In these years, the trend is for companies to add core competences through services. As indicated in the paragraph above, companies are trying to provide more and more customer-oriented product-service solutions, whereby the service side already seems to slightly dominate today. Servitization is an innovative strategy that is pursued by most successful companies and leads to completely new relationships with customers. Also, production companies can make use of servitization to offer certain services in addition to their products. This sets them apart from the competition and thus generates competitive advantages and helps to retain customers [77]. The term Sharing Economy describes forms of collaborative consumption that are enabled primarily by technological advances [78]. Platforms such as Uber and AirBnB quickly turned into billion-dollar companies, but this seems to be just the beginning [79]. Collaborative Consumption is no longer a niche topic and it can be expected that the Sharing Economy will continue to grow, as society seems to have significantly changed its consumer habits. Sharing Economy models provide improved sustainability but also economic benefits for the consumers through the division of the total cost of ownership, which for some products are high related to the degree of utilization during the lifecycle [80]. With regard to this new type of consumption, a distinction between different models can be made, whereby ownership represents the traditional approach. In contrast, there are also models in which the customer only pays for the service. The most advanced type is given by the so-called Sharing Economy Platforms, which allow customers to share products or services with other consumers (such as AirBnB).

Digital Add-on or Upgrade is a business model within the IoT in which first a physical product is sold. In the course of time, the customer can then acquire or activate numerous digital services, such as the upgrade of horsepower for a car. If the performance of a car can be configured by software and the vehicle can be controlled via the Internet, the customer is enabled to upgrade his cars horsepower permanently or even just o for a limited amount of time (e.g. from Tesla). These models often impose low margins on the sale of the physical product. However, the digital add-ons and upgrades usually generate high margins [81].

Generally, a lock-in strategy is defined as the creation of a relationship of dependence between a customer and a provider. The lock-in effect describes the fact that for a customer the change to another provider would be uneconomical due to high switching costs and the customer is therefore bound to the provider, since a change only would make sense if the newly created benefit from the change was greater than or at least equal to the switching costs [82]. Gilette provides a typical example of the application of this business model. For example, only original Gillette razor blades can be used with Gillette razors. In many cases competitors are prevented by patents from producing compatible components [68]. As a further development of the lock-in for physical products, more and more so-called Digital Lock-in models have emerged in recent years, forcing consumers to use the provider's digital services.

Freemium is a business model in which a company makes a part of its offer available free of charge. Sales are then made with attractive and useful additional services around the free offer [68]. The term Freemium is composed of the words "free" and "premium", whereas the basic idea behind the concept is the combination of free and paid services [83]. The free offer first aims at attracting new customers. Once the customers are utilizing the free offer, the inhibition threshold for paying a fee for additional premium services decreases significantly. Especially on the Internet, companies rely on Freemium models [84]. A basic distinction can be drawn between physical and digital Freemium models. While the first offers additional free and later fee-based physical services (e.g. maintenance or the change of spare parts), digital Freemium models are based on digital services basically, such as product monitoring.

While some time ago it was only possible to buy products in physical stores, companies began to put their offers online over time and enabled customers to configure their products themselves. The next major step was to establish web shops, often referred to as E-commerce. Ultimately, we now experience that even the products themselves serve as a Point of Sale (POS). For example, a QR code on the product makes it possible to access the web-shop directly via smartphone. The Industry 4.0 concept Digital POS marks exactly this transition from traditional POS via web-based online shops to the product as POS. These are physical products supporting the digital sales and marketing services required by the customer directly on the object or indirectly via smartphone and identification technology [68].

The progressive division of labor, globalization, ever shorter product life cycles, rising costs for research and development combined with the digitalization have completely changed the innovation landscape. In today's world, this is characterized by new systems for open and networked innovation processes, whereby the interaction of large companies, SME’s, start-ups, research institutions, marketplaces and creative users represents the main focus. Open Innovation stands for the active and strategic development of the outside world in order to increase the innovation potential of companies, to accelerate innovations and to identify new potentials [85]. The objective of Open Innovation is therefore targeted innovation through the combination of internal and external expertise. There are different approaches. One possibility is to involve suppliers in the idea-finding process. Moreover, companies such as Nike organize Open Innovation competitions for private users or exploit platforms to bring external ideas into the enterprise. A rather innovative application in the field is Science Fiction Prototyping, where science fiction is utilized to investigate possible effects of future technologies [86].

In order to remain competitive, companies nowadays have to understand the signals of the time and embrace digital transformation. However, the number of Industry 4.0 applications is increasing rapidly and for companies it represents an enormous challenge to identify and select suitable methods and technologies within an Industry 4.0 Roadmap. According to the Wissenschaftliche Gesellschaft für Produktionstechnik [87], Industry 4.0 Roadmaps describe enabling and implementation strategies of Industry 4.0. Progress in this respect varies from company to company. While some do not yet include Industry 4.0 concepts in their strategy, others already have concrete ideas on how to incorporate digitization into their strategy. Mainly large companies are already defining concrete step-by-step implementation plans for Industry 4.0 [88]. In section 2.3, concrete, existing roadmaps within the framework of Industry 4.0 are examined in more detail.

In recent years, the concept of sustainability has become increasingly important. Increased pressure from various stakeholders, customers and regulators has resulted in the manufacturing industry incorporating sustainability aspects into its day-to-day operations, not just at the internal level, but throughout the overall supply chain [89]. According to the Sustainable Supply Chain Foundation, a Sustainable Supply Chain Design is characterized by the integration of environmentally viable practices along the overall value chain, including raw material sourcing, transportation, warehousing, production, distribution, consumption and waste disposal. In this context, the concept of footprint received enormous attention. Sustainable supply chain design is not only aimed at reducing a company's carbon footprint, it also aims to reduce costs [90]. Companies are therefore increasingly including these aspects in their decisions. Be it by selecting local suppliers, measuring the footprint of their own production or even of the entire supply chain.

Increasing competitive pressure is forcing companies to be more flexible and adaptable. Consequently, it represents a great challenge for companies to adjust their logistics systems, focusing very sharply on efficiency increases in the network through collaboration. Collaboration Network Models describe forms of collaboration between actors along a supply chain. Strategic alliances are becoming increasingly important. Another form is represented by Collaborative Production Networks, which usually describe a network of manufacturers with order-dispatching unit. Through collaborative cloud manufacturing networks, the network participants can be connected via a cloud-based system and receive orders, for example. Virtual company networks are an organizational form for the realization of cooperative projects aiming at achieving the highest degree of customer satisfaction.

Figure 9 depicts the organizational Industry 4.0 concepts in the context of their related second level dimensions.

Organizational Dimension

II. Level Dimension			
Business Models 4.0	Innovation Strategy	Strategy 4.0	Supply Chain Management 4.0
Industry 4.0 Concept			
10. Digital Product-Service Systems 11. Servitization & Sharing Economy 12. Digital Add-on or Upgrade 13. Digital Lock-In 14. Freemium 15. Digital Point of Sales	16. Open Innovation	17. Industry 4.0 Roadmap	18. Sustainable Supply Chain Design 19. Collaboration Network models

Figure 9: Overview of the discussed organizational Industry 4.0 concepts classified by second level dimension [57].

After the last sections have indicated which Industry 4.0 concepts can be integrated by companies within the operational and organizational dimensions, the so-called socio-cultural Industry 4.0 concepts follow in sub-section 2.2.4.

2.2.4 Industry 4.0 concepts – socio-cultural level

According to Unterhofer’s model, the socio-cultural level includes three Industry 4.0 concepts, namely Training 4.0, Role of the Operator and Cultural Transformation. The following paragraphs illuminate these in more detail.

The increasing digitalization is challenging the employees of today and imposes high demands on them. High product variety coupled with shorter life cycles result in less time for system and process training. Due to the increasing assumption of many tasks by computers, usually the more complex tasks remain for humans. Since the competence and commitment of employees are decisive for the success or failure of a company, targeted training and further education in the form of training for employees is of fundamental importance [91]. Within Industry 4.0 some exciting possibilities for so-called Training 4.0 exist. While up to now the training was exclusively designed for the job profile of the employees, nowadays the employees are trained in the wide field Industry 4.0 in order to prepare them for the upcoming change. Companies try to build up internal know how in this area through training courses hold by internal or external experts.

The tasks and Role of the Operator within Industry 4.0 are changing significantly. In general, the complexity of daily work is increasing, and the rapidly changing work environment requires employees to be flexible and adaptable [92]. The role of the worker is continuously evolving over time. Originally, workers performed purely manual work steps, which were later made considerably easier by the assistance of machines. Computer-aided technologies (CAx) and numerical control (NC) tools stand for the next level of human technical collaboration, followed by so-called cooperative working models. This involves close cooperation between man and machines (e.g. through collaborative robots). The latest development sees the role of the operator being rather that of supervisor of work aided by machines in CPPS.

Cultural Transformation stands for the progress of sensitization of employees for the digital transformation topic. One of the core challenges of digital transformation is to promote a digital culture at all hierarchical levels and across all corporate divisions. As already highlighted in section 2.1.2, the topic of innovation culture plays a key role in the Digital Maturity Model, which includes eight areas companies need to face in order to transform themselves successfully [21]. One of the core challenges of digital transformation is to promote a digital culture at all hierarchical levels and across all corporate divisions. A comprehensive culture of innovation is crucial for the move successfully into the digital future. It is decisive for companies to inject this spirit into their employees [93].

In Figure 10, the socio-cultural Industry 4.0 concepts within its second level dimensions.

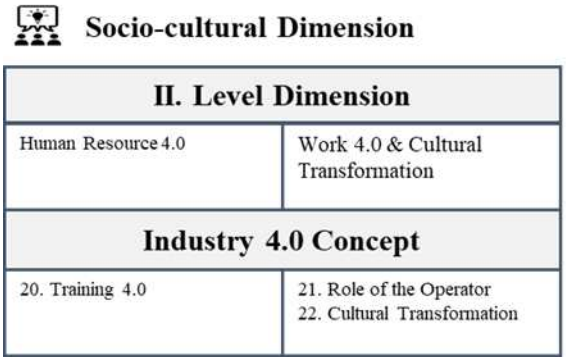

Figure 10. Overview of the discussed socio-cultural Industry 4.0 concepts classified by second level dimension.

In the next sub-section, the technological dimension of Industry 4.0 concepts is covered, which make up the majority within the I4.0 Assessment tool.

2.2.5 Industry 4.0 concepts – technological level

In this sub-section, a total of nineteen technology-based Industry 4.0 concepts are presented. This work differentiates between two fundamental typologies of technological Industry 4.0 concepts, namely those whose characteristics are rather data-driven or process-driven. This section first deals with data-driven concepts, followed by process-driven concepts.

A new technology is changing the industry all over the world. Additive Manufacturing (AM) eliminates enormous production costs and long lead times for small lot sizes, opening up groundbreaking opportunities for companies. According to the American Society for Testing and Materials (ASTM) International, AM characterizes the process of combining materials based on a three-dimensional (3D) model. In contrast to traditional manufacturing, also known as subtractive manufacturing, in this special form of manufacturing the material is added layer by layer [94]. A very commonly used synonym for AM is 3D printing. The prerequisite for printing a part or product in 3D is a 3D model. At this point, so-called 3D scanning is of considerable importance, in which digital information about the shape of a part is captured by a device with the objective to obtain a 3D digital model. AM has the potential to enormous growth and provides interesting opportunities for industrial companies. Through the integration of AM, small volumes, complex designs and light weight but strong products at the same time, are manageable. Currently some challenges regarding material cost and scalability must be mastered, but it looks like these will soon be overcome and AM will be increasing its popularity in industry [95].

Cloud computing is an IT model that extends widely beyond the utilization of processing power. The focus is on outsourcing IT services to external service providers. In addition to computing power and storage capacities, this may also include the provision of platforms with services such as security solutions and billing or the deployment of SaaS in various forms [96]. According to a report published by the NIST, Cloud Computing is a tool for ubiquitous, convenient and on-demand network access to a shared network. Configurable resources such as servers, storage, applications and services can be deployed and released quickly with minimal effort or interaction with the service provider [97]. Digitalization is driving the creation, processing and storage of ever larger amounts of data. A cloud offers the possibility of storing this continuously growing amount of data in a central place from which it can be accessed flexibly and quickly. For precisely this reason, the cloud is indispensable for all digital processes and products and provides companies with interesting opportunities, such as simultaneous access by several users and complete independence from time and place. By synchronizing to different devices, processes become partly more efficient and can be realized faster. In addition, cloud systems provide cost advantages by individually tailored solutions in terms of storage space and performance, so that companies will be saving high costs for IT systems and specialized personnel [98]. Ultimately, cloud systems make it possible to work without paper, which not only facilitates the overview but also protects the environment.

The third technological Industry 4.0 concept, namely Digital and Connected Workstations, characterizes the type of networking as well as communication of workstations and digital devices. In traditional production companies, each workstation is equipped with paper information. A slightly more advanced approach is provided by centrally accessible screens in the production hall. Other shopfloors include the deployment of mobile devices such as tablets at each station, while so-called digital workstations are attained by the implementation and the interconnection of industrial personal computers (PCs) at some or all the workstations within a production hall. This represents the most sophisticated form of Digital and Connected Workstations to date.

The Kanban principle was originally invented by Taiichi Ohno within the Toyota Production System (TPS) [99]. Kanban is basically a system for controlling the material flow according to the pull principle. So-called self-controlling circuits are exploited to ensure material supply. In Kanban, material supply is therefore based exclusively on the consumption of the process. Traditional Kanban systems usually use physical Kanban cards as information media in a cycle to visually control the production process. A Kanban for the internal or external supplier corresponds to an order. In contrast, an E-Kanban is based on the electronic control of the consumption of goods that are re-ordered via E-Kanban signals. With the E-Kanban system, a process is built up which consists of several control loops. A new order transaction is created for required material when a signal is transmitted that a container has been emptied. The E-Kanban system records the condition via an unfilled shelf on an assembly line. The signal is transmitted to the control system, which then places an order. The empty container is replaced by a full one. The introduction of an E-Kanban system in comparison to a traditional card Kanban system generates considerable benefits. The processes in logistics can be automated. Moreover, human errors can be reduced considerably. Finally, the connection to an ERP system allows the automation of ordering processes and the integration with external suppliers [100].

The next Industry 4.0 concept involves the integration of IoT and CPS into the enterprise. These terms have already been illuminated in more detail in section 2.1.3. In a nutshell, the IoT describes a world in which the interaction of physical objects and persons with the virtual world is made possible [36]. CPS characterize physical systems that are monitored, coordinated and controlled by a process and communication center [51]. In general, IoT and CPS offer interesting potential for companies. The most basic form of integrating this concept is offered by sensors and actuators which transmit data from production via Wi-Fi. In other cases, data can be made accessible for all as information. Cognitive analyses, for example, helps to optimize processes. Ultimately, the highest level refers to self-configuration and adaptation of machines or work stations based on current data.

The age of digitization brings with it a considerable risk for smart companies and their networks, namely those connected with cyber. While the integration of IoT devices is being driven forward, it is becoming increasingly important to consider the safety risks of these devices in order to avoid unplanned production downtimes, machine failures or other types of damage. Therefore, methods should be integrated to protect the connected objects from cyber-attacks [101]. According to Gartner, Cyber Security encompasses a spectrum of methods, tools and polices that are closely linked to information and operational security [102]. Cyber Security is characterized by the fact that it involves the exploitation of information technology to safeguard connected devices from cyber-attacks [103].

The term Artificial Intelligence (AI) was coined first by John McCarthy back in in 1964, defining it as the science of making intelligent machines [104]. In the following decades he shaped this innovative field, based on the idea that any form of learning or intelligence can be described so precisely that it can be simulated by a machine. Many human mental activities such as programming, understanding languages or even driving cars require a certain amount of intelligence. In the course of the last years many computer systems were created, which are able to accomplish exactly such tasks. In particular, state-of-the-art programs are already available that are able to diagnose diseases, solve differential equations or even write computer programs. Such systems have a certain degree of artificial intelligence [105]. It is predicted that AI and increasingly sophisticated algorithms will affect our lives and our civilization stronger than ever. Their area of application will continue to grow in the future and AI performance will improve. Specifically, it is to be expected that the corresponding algorithms will increasingly optimize themselves [106].

Within IoT, Object Self Service refers to the possibility that things initiate orders on the Internet independently. For example, a heating system could automatically and independently reorder heating oil as soon as the level is close to empty. This concept extends the idea of traditional customer self-service, to the products themselves. These are enabled through this concept to place orders. In the context of the direct selling business model, intermediaries are avoided. Solution Provider business models are simplified by the automatic procurement of consumable materials [68].

The next technological Industry 4.0 concept concerns Identification and Tracking Technology. The importance of these types of technology can be considered very valuable for companies, only by looking the added value related to customer service and the simplified and much more efficient management of the logistical network. Especially, globally operating companies need technologies to keep an eye on their logistics processes by exploiting Identification and Tracking Technology, and therefore minimize their complex coordination problems. Over the years, many such technologies have been developed and employed to monitor logistical supply chain networks more efficiently. In practice there exist different systems, starting with barcode labels over quick response (QR) codes and passive and active RFID tags, which have been on everyone's lips for some years now [107]. A barcode is an optical data carrier for marking objects and products. According to a standardized procedure, sequences of parallel bars are printed, which can be read by optical readers and then decoded. QR codes are two-dimensional (2D) codes that can be scanned and read by mobile devices and in which information can be stored. In doing so, they connect the physical and virtual world. The most common identification technology is RFID, an abbreviation for Radio Frequency Identification. The aim of RFID systems in logistics systems is to identify any objects contained in the supply chain and to link information to these objects in order to improve logistics processes [108].

Predictive Maintenance is a core component of Industry 4.0 and clearly differentiates from traditional maintenance approaches such as reactive or preventive maintenance. Traditional reactive maintenance is easy to implement, but carries a high risk, as troubleshooting actions are only taken once errors have occurred [109]. Unlike predictive maintenance, reactive maintenance cannot proactively prevent machine failures and can result in significant downtimes. Like predictive maintenance, preventive maintenance attempts to avoid downtimes, but does not use data collected from the machines, but instead performs maintenance measures at fixed intervals to replace wearing parts, for example. With its proactive character predictive maintenance differs significantly from conventional approaches. To make reliable predictions for predictive maintenance, it is necessary to collect, store and analyze a large amount of data, which is why big data techniques are often exploited [110].

Modern systems, technologies and machines are characterized by an increasing degree of complexity. Maintenance therefore usually requires technical personnel with specialized knowledge. The acquisition of this detailed know-how is often difficult or no longer possible. In such a case, help must be provided by experts. In order to save time and costs, the necessary knowledge transfer needs to be implemented even over long distances. This means that expert knowledge can be exchanged more quickly, unnecessary travel times are eliminated. Such support work is called Tele maintenance. Using Augmented Reality (AR) for example, information, descriptions and instructions can be virtually linked to real objects. Thus, virtual and real objects can be represented in a spatial scene, whereas the viewing, learning and remembering of complex facts is improved. These methods have enormous potential for learning maintenance work. The AR display makes it possible to link digital and visual directly to real machines and components by means of virtual information [111].

In Figure 11 below, the data-driven technological Industry 4.0 concepts are graphically depicted and associated with the respective first order dimension.

Technological Dimension – data-driven

II. Level Dimension						
Additive Manufacturing	Big Data	Communication & Connectivity	Cyber Security	Deep Learning, Machine Learning, Artificial Intellig.	Identification & Tracking Technology	Maintenance
Industry 4.0 Concept						
22. Additive Manufacturing	23. Cloud Computing	24. Digital & Connected Workstations 25. E-Kanban 26. IoT & CPS	27. Cyber Security	28. Artificial Intelligence	29. Identification & Tracking Technology	30. Predictive Maintenance 31. Tele-Maintenance

Figure 11. Overview of technological data-driven Industry 4.0 concepts classified by second level dimension [57].

In the following paragraphs, the process-driven technological Industry 4.0 concepts are addressed.

In the course of time, storage systems have changed greatly. From the high rack warehouse different types of automated storage systems developed [112], whereby the differentiation between manual and Automated Storage Systems is particularly meaningful for this work. A storage system is designed to receive, store and then retrieve goods in order to make them available appropriately. Thereby, inbound and outbound storage processes can be manual, semi-manual (e.g. forklifts) or fully automated by exploiting conveying systems. The storage system is obviously chosen according to the task of a warehouse. The most recent evolution associated with Industry 4.0 is towards automated storage systems with optimized logic for chaotic storage. With this form of storage, the products are not assigned to fixed storage locations, but are moved during storage in the warehouse. The storage locations are recorded digitally in the system, and it assists in analyzing where the item can be stored and only the system provided for this purpose knows where the article is located [113]. The aim is to distribute articles randomly to the storage locations and thereby optimize the routes through which goods can be stored and removed quickly. Certain requirements must be met for such a bearing to function at all. Above all, articles must be correctly marked, and the information system must be enabled to work independently.

While driverless driving is being tested in the automotive industry, driverless transport is already in operation in many warehouses and factories. Similar as for the storage systems, a distinction can also be made between manual and Automated Transport Systems. While many factories handle internal transports manually or with the help of forklifts, others already rely on Automated Guided Vehicles (AGV). AGVs are computer-controlled programmable transport systems that operate driverless and move material between warehouses and the various production stations within a factory. When used properly, AGVs can help to significantly increase efficiency and reduce labor costs [114].

Also, the production and the assembly have undergone a strong change in the course of the last years, from completely manual manufacturing to Automated Manufacturing and Assembly [115]. Depending on the sector, company size and type of assembly, different forms can be distinguished, whereas the most traditional form is given by manual production lines, which in some cases can be supported by mechanical elements such as press stations. Semi-automated production lines are common and consist of a combination of manual and automated workstations [116], whereby fully automated assembly lines do not require any manual work. The new technologies have recently opened up a field, namely flexible automated production lines. These systems use the capabilities of robots to flexibly handle a wide variety of tasks.

The term Collaborative Robots was first mentioned by James Edward Colgate und Michael A. Peshkin in 1999. According to their published patent, so called Collaborative Robots are a new generation of robots that work hand in hand with their human colleagues, opening up completely new paths of cooperation between man and machine [117]. Unlike conventional robots, collaborative robots allow direct contact with the worker. Modern sensor technology makes it possible to detect movements of persons and thus a safe interaction without risk of injury. Collaborative robots are flexible, easy to program and adaptable. In some industries, such as the automotive sector, these devices have been implemented for some time now, whereby Collaborative Robots usually take over monotonous, strenuous, work steps, enabling human employees to devote their time to more demanding tasks [118].

Smart Assistance Systems can be integrated into a wide variety of tasks and work steps. Despite increasing automation, there are still many manual activities to be carried out in assembly today. To automate these, assistance systems are increasingly being employed [119], helping the operator by showing the correct assembly instructions, by indicating the way to the part required by light signal and thus guide step by step through the assembly process. This is intended to relieve workers, who often have to assemble a high variety different product in the due to decreasing batch sizes and the resulting variety of variants. A general distinction is made between physical, sensor aid, cognitive and self-learning assistance systems. In the past, assistance systems have taken over mainly the automated execution of mechanical functions [120]. The best-known example for sensor aid assistance systems are driving assistance systems, which monitor the environment by recording data via sensors and ensure, for example, that a certain safety distance is maintained [121]. Similar applications are deployed also in production environment. Cognitive assistance systems are systems with which employees cooperate. The immense cognitive abilities of humans are used to support them in the execution of work steps (e.g. pick-by-light). Self-learning assistance systems collect experience and make it available to the operator depending on the situation. These adaptive systems monitor machine status and operator interaction and store successful strategies [122].

Innovative digital technologies such as Virtual Reality (VR) and Augmented Reality (AR) open up completely new possibilities for companies in the areas of product development, maintenance or service. At the same time, they are able to save time and money and offer their customers completely new product-related services. While Virtual Reality simulates images or entire worlds on the computer, into which the user can completely immerse, move and act with the help of VR glasses, in AR, virtual images are superimposed into the real world, also via glasses or other devices. As the name suggests, reality becomes an interactive, extended environment [123]. VR is currently used primarily in product development at the beginning of the product life cycle. AR is more frequently used in subsequent phases such as assembly or maintenance [124]. These two technologies are increasingly being combined. According to Milgram and Kishino, Mixed Reality (MR) can be defined as environments or systems that merge the real world with a virtual reality. In addition to a purely virtual reality, these are in particular systems of augmented reality and virtuality [125].

For security and economic considerations, it is often necessary to approach real problems in an abstract way. Questions can often no longer be answered by a static analysis. In these cases, a Simulation model should be used to investigate the problems. The Verein Deutscher Ingenieure (VDI) defines simulation as a reproduction of a system with its dynamic processes in a model for experimentation in order to arrive at findings that can be transferred to reality [126]. There are a number of options for companies to deploy simulation models. For this work mainly simple numerical, 2D, 3D and discrete 3D simulations are distinguished, whereas discrete simulation concerns the modelling of a system with respect to the timely evolution by a representation in which the variables change at separate points in time. In summary, simulation offers some interesting advantages. Some very complex real systems, which cannot be represented by mathematical models, can be investigated by exploiting simulation models. In addition, simulation allows the performance of a real system to be estimated in relation to predefined conditions. Often the simulation reveals details that would normally not have been apparent. Another point is given by the relatively simple comparability of several alternatives. Different scenarios can be created and tested quickly. Ultimately, one of the most significant components of simulation is the ability to analyze a system over a long period of time. However, all this is only possible if the models are reproduced accurately enough. Moreover, the development of complex models requires a high degree of effort in monetary and timely terms [127].

Strong technological advances have been made in product development and design in recent decades, particularly in the area of software programs, which have significantly increased efficiency. While 2D Computer Aided Design (CAD) allowed faster development and therefore reduction of time-to-market, Computer Aided 3D models were soon available providing huge advantages such as the improved visualization. In addition to CAD software, over time it became necessary to store and manage more and more relevant product data. For this purpose, so-called Product Data Management (PDM) programs were developed. PDM software are able to integrate information and processes related to a specific product, from the development over the production. Typical stored information include geometry, drawings, plans, parts, assembly drawings, specifications and bill of material. To manage product data throughout the entire product life cycle, from the product idea through the production, over maintenance, service and disposal, so-called Product Lifecycle Management (PLM) systems are employed. The utilization of PLM systems comprises important benefits, such as improved quality, reduced prototyping time and costs, savings through the reutilization of the data or features for product improvement [128].

In the area of Standards 4.0 there are considerable differences of already introduced CPS Standards, greatly varying from company to company. While some companies have not yet introduced CPS standards, others have started to partially standardize. Progressive forms of standardization are physical electro-mechanical and communication standards between machines among each other. Standards are essential to further advance digitization and to allow rapid implementation of Industry 4.0 solutions in practice. According to a survey by management consultancy Staufen [129], more than half of the companies interviewed perceive the lack of standardization as an obstacle on the way to interconnected production. Therefore, the development of standards will represent a crucial key to successful digitization [130].

Subsequently, Figure 12 summarizes the discussed technological Industry 4.0 concepts.

Technological Dimension – process-driven

II. Level Dimension				
Robotics & Automation	VR, AR and Simulation	Product Design and Development	Deep Learning, Machine Learning, Artificial Intelligence	Standards 4.0
Industry 4.0 Concept				
32. Automat. Storage Systems 33. Automat. Transport System 34. Automat. Manufacturing & Assembly 35. Collaborative Robotics 36. Smart Assistance Systems	37. VR and AR 38. Simulation	39. PDM and PLM	40. Object Self-Service	41. CPS Standards

Figure 12. Overview of technological process-driven Industry 4.0 concepts classified by second level dimension.

After the description of the individual Industry 4.0 concepts, which are essential for the survey and evaluation area in this section, the next section presents the most relevant, existing roadmaps for the implementation of Industry 4.0 in companies.

2.3 Roadmaps for industry 4.0 implementation

Generally, technology roadmaps can be defined as techniques used to support long-term strategic planning providing a structured method of exploring and communicating between evolving and developing markets, products or technologies over the course of time. This is often supported by graphical tools. Road mapping techniques may support companies to keep their focus on disruptive technologies even in turbulent times [131].

According to Garcia and Bray, Technology Roadmaps are tools employed to support the provision of information for technology investment decisions by identifying critical technologies for research and development [132].

Organizations are overwhelmed with the variety of terms and complexity associated with Industry 4.0 and are struggling to address the issue in a structured manner within their organization. Since the opportunities and future potentials of Industry 4.0 are repeatedly pointed out, it is absolutely necessary to shed light on concrete strategies for the introduction of Industry 4.0 concepts [133].

With regard to Industry 4.0, roadmaps are being required that show every step towards becoming a digital enterprise. To transform successfully, it is essential for companies to depict the Industry 4.0 Roadmap as accurately as possible [134]. Some of the most relevant, in literature existing roadmaps for the implementation of Industry 4.0 concepts are discussed in the following sub-sections.

2.3.1 Three-stage process model – TU Vienna and Fraunhofer

A cooperation between the Vienna University of Technology and the Fraunhofer Institute Austria gave rise to the elaboration of a *Three-Stage Process Model* for the strategic guidance towards the introduction of Industry 4.0 in companies. According to Schumacher, Erol and Sihn, this model's objective is to help companies to pursue and achieve their defined Industry 4.0 strategy and vision through targeted measures enabling a clear communication of targets and take concrete measures. As the name suggests, the model consists of three main phases, namely Envision, Enable and Enact [6].

Figure 13 graphically illustrates the three phases of the model and the associated activities.

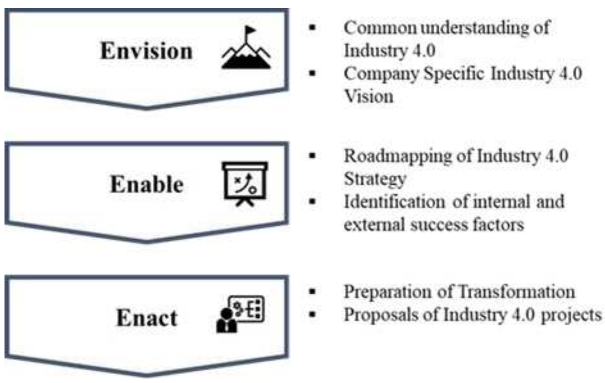

Figure 13. Graphical representation of the Three-Stages Process Modell [6].

The Envision stage involves the development of a self-tailored Industry 4.0 vision by involving internal and external stakeholders to ensure a shared understanding of the topic. The vision should represent a courageous picture of the company's future considering strengths, market, technological and social developments.

During the Enable Stage, the long-term Industry 4.0 vision is broken down into a more concrete business model. Strategies are developed that deal with the question of what needs to be accomplished in order to achieve the desired result. Road mapping techniques are used to simplify this strategy planning. The goal of this phase is to create a broken down overall strategy timeline for achieving the vision.

Finally, the Enact Stage is dedicated to transforming the strategy into concrete projects. Project goals, milestones and teams are defined, which should contribute to the achievement of the company goals. The result of this stage is the project roadmap, which can be linked to the overall strategy and therefore facilitates communication of activities among stakeholders.

2.3.2 3C Model for the introduction of industry 4.0 - Merz

Within the book Einführung und Umsetzung von Industrie 4.0, Sandra Lucia Merz adopted the *3C Model* related to the Introduction of Industry 4.0. The 3C Model was originally introduced by the Japanese strategist Kenichi Ohmae, who argued that three central components, which he also calls the strategic triangle, must always be considered in the development of any business strategy: Competitors, Clients and Company [135].

Figure 14 illustrates the 3C Model graphically.

Figure 14. Strategic triangle - 3C Model (Ohmae, 1982).

Based on this model, Merz introduces an implementation strategy for companies with regard to Industry 4.0.

First of all, the competition should be scrutinized to analyze which strategies competitors pursue with regard to Industry 4.0. Four different strategic approaches can be adopted, namely the pioneering approach, the imitation approach, the niche approach or the cooperation approach [136]. According to Merz, the choice depends on the quality of information about the competitors and on the overall objectives of the company itself [5].

Regarding customers, it is fundamental to consider who the customers are and how they can be retained, or new customers can be gained through Industry 4.0. In this case, as well, there are different approaches to create benefit characteristics for customers with the help of Industry 4.0. Examples for possible approaches are best quality, unique functionalities, highest or lowest price, high service level or product individualization. The challenge lies in identifying the customer's needs and requirements and defining the optimal approach or mix that generates the highest possible competitive advantage for the company.

For the company itself, the way of service provision is paramount. Two main questions should be addressed. What is the market performance and how is it provided and marketed [137]. These questions lead to a structured depiction of the enterprise in terms of processes, IT and products. The aim of this structuralization is to assign processes to products and to anchor Industry 4.0 concepts within the processes. Once a basic understanding of processes and IT procedures is established, allocation logic can be used to assign processes to products. In a second step, possibilities such as making production more flexible, integrating suppliers or customers into the system or greater product customization can be examined [5].

From this analysis within 3C, requirements can be derived in order to adapt the corporate strategy. This results in four possible positioning options, illustrated in Figure 15.

Figure 15. Positioning of companies in the context of their Industry 4.0 strategy [5].

For companies, the question arises where they may be located within the matrix in order to draw conclusions for their further development.

2.3.3 Roadmap implementation industry 4.0 - FH Johanneum

In a research project with an industrial company, a group of researchers from FH Johanneum have developed a further Roadmap for the Implementation of Industry 4.0. Similar to the roadmaps described above, the developed model consists of three main phases, namely analysis, target setting and realization. The subdivision comprises six sub-steps to ensure systematic identification of the actual Industry 4.0 maturity and to define the goals. The presented roadmap Industry 4.0 can be seen as a model for self-assessment and at the same time as a guide for the implementation of an Industry 4.0 strategy. The roadmap applies to five areas, which are the key business areas derived from the value-stream analysis purchasing, production, intralogistics, sales and human resources (HR).

The three main phases of the step-by-step procedure are depicted in Figure 16. In the first step, awareness for the term Industry 4.0 should be created and in particular the employees should be involved in this process. Then, in a second step, the current Industry 4.0 maturity of the company from the point of view of the individual fields of action is evaluated. In the third step, target values for the individual fields of action are then defined, from which concrete measures necessary for achieving these values are derived in step four. In the fifth step, the relevant measures are selected according to the contribution to the defined corporate strategy and made measurable by the implementation of the Balance Scorecard. In the last step, the concrete projects are then derived and a chronological sequence of these defined.

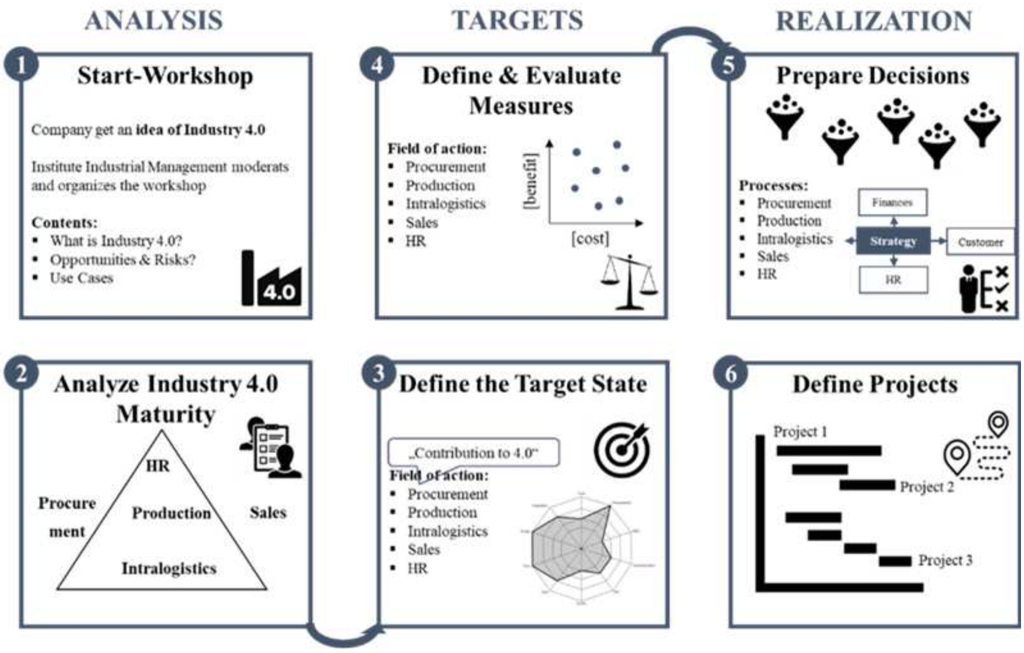

Figure 16. Roadmap Industry 4.0 [138].

2.3.4 Practical roadmap for industry 4.0 introduction in SME - Korne

Within his Practical Roadmap for Industry 4.0 Introduction to SME's, Thomas Korne distinguishes four different phases and specifies them as follows: company analysis, identify opportunities, choose and evaluate opportunities and finally establish and realize roadmap [139]. He also names possible instruments that can be utilized in the various phases to successfully complete the tasks.

Figure 17 illustrates the four phases of the proposed model, along with helpful support instruments within each phase.

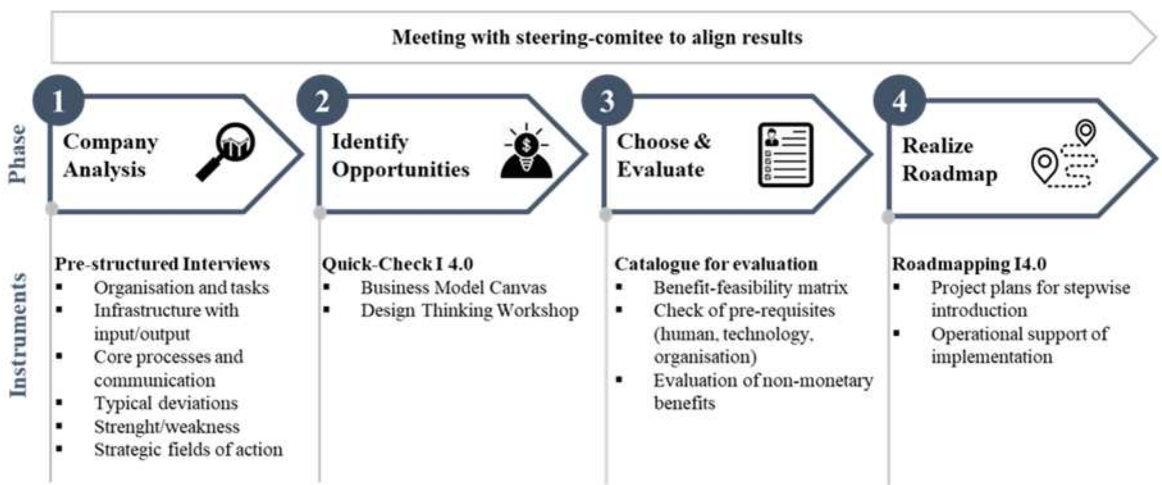

Figure 17. Practical Roadmap for Industry 4.0 Introduction to SME's [139].

During phase one, pre-structured interviews are conducted to analyze the current status of the company with regard to Industry 4.0. In addition, the organization, task distribution, resources, departments, processes, communication structures, typical problems, general strengths and weaknesses as well as strategic fields of action are illuminate in detail.

In phase two, possible opportunities are identified by making the I4.0 quick check for the department of production as well as for the products. Therefore, a matrix with six application levels and five technological development stages (maturity levels) is used, which shows different possibilities and combinations of these within the application level. This provides a significant support for the brainstorming of ideas [140].

In phase three, an evaluation catalogue is drawn up, which provides for the evaluation of cost efficiency and the feasibility of the planned measures. Within a benefit-feasibility matrix, the opportunities are then classified, whereby opportunities with simpler feasibility and higher monetary benefits are to be preferred. From this analysis, necessary pre-requisites for the Industry 4.0 transformation are then selected and derived.

In the final fourth phase, the roadmap is then finally established and implemented. The Roadmap Industry 4.0 should visualize the long-term strategy and be flexibly adaptable over time. For the step-by-step introduction it is important to carefully select the steps so that they are manageable and financially feasible [139].

In summary, Korne's roadmap provides a guideline for SME´s to identify and leverage future Industry 4.0 technologies. In order to implement this successfully, it is of fundamental importance to ensure utility value and to make monetary aspects individually measurable. A special feature of this roadmap is the Quick-Check I4.0, which supports brainstorming and idea generation.

2.3.5 Leitfaden 4.0 – VDMA

The final discussed roadmap is the so-called Leitfaden Industrie 4.0 – Orientierungshilfe Zur Einführung in den Mittelstand of the Verbands Deutscher Maschinen- und Anlagenbauer (VDMA). The aim of this guide is to offer small and medium-sized machine and plant manufacturers in particular a tool for developing their own Industry 4.0 business models. The aim is not to recommend a pre-defined strategy, but rather to recommend possible procedures for the individual development of the own competencies [141].

Within this guideline five main phases are distinguished: preparation, analysis, creativity, evaluation and introduction, as illustrated in Figure 18.

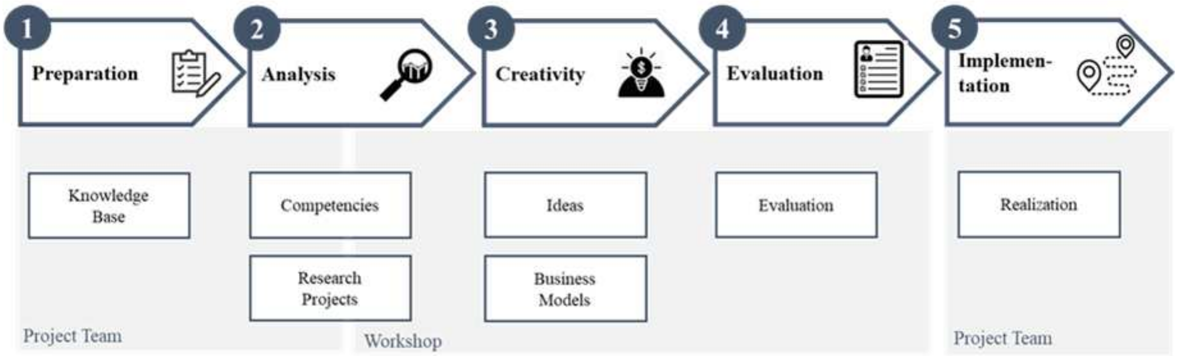

Figure 18. Structure of the VDMA Leitfaden Industrie 4.0 [141].

Very similar to the previous roadmaps, the first phase is about detailed knowledge of the own production. Furthermore, the creation of a knowledge base in the Industry 4.0 area for all parties involved also belongs within this phase. It is recommended that projects teams assume this role.

In the analysis phase, the competencies with regard to Industry 4.0 are to be identified. This analysis should be carried out both on the product side and from the point of view of production. The result is the starting point for the subsequent generation of ideas.

The creativity phase serves to develop new ideas, which are then developed into concepts or business models in a second step. It is strongly recommended that this phase should be completed within a workshop.

The concepts developed are then evaluated in the evaluation phase. In order to determine models with high market potential, the potential and necessary use of resources are compared. The aim is to generate high potential with minimal use of resources.

Finally, the responsible project team prepares the proposals and converts the results of the workshop into projects.

This roadmap stands out from the rest, above all through the workshop concept, with the help of which individually adapted business models are to be developed. The Industry 4.0 Werkzeugkasten, which is also used in Korne's Roadmap, is very helpful for developing ideas for new concepts at product and production level. Interdisciplinary teams should work together in workshops to discover the most attractive market potential possible [141].

To sum up, in recent years, several roadmaps have been developed as guidelines for the implementation of Industry 4.0 concepts. This section should give an overview of the most relevant roadmaps available in the literature. In the next section the research question of this work is elucidated.

2.4 Research question

Growing digitalization and networking are changing not only everyday life, but also markets, business interaction and relationships experience a dramatic shift. On the one hand, this digital transformation provides a great opportunity for companies to tap into undreamt-of potential through new business models. On the other hand, however, it is one of the greatest challenges for many others, as they have to adapt and change very quickly to ensure their competitiveness [4].

The idea of Industry 4.0 aims at achieving efficiency and competitive advantages, whereby these basically refer to process-technical, organizational and technical potentials of production or products.

The problem, however, is that many companies and their management are overwhelmed by the current situation. Especially the variety and complexity of terms within the Industry 4.0 context often create confusion resulting in a loss of overview of the big picture. It poses a very complex challenge for many managers to assess ways in which they can integrate the Industry 4.0 topic into their organization in the most structured way possible [142].

Currently, there is a lot of discussion about the opportunities and possibilities of Industry 4.0 for companies. In recent years, some proposals for implementation strategies for Industry 4.0

concepts have appeared in the literature, offering companies concrete suggestions on how to proceed with implementation. This is precisely what the roadmaps covered in section 2.3 are concerned with.

These usually provide general process models for the introduction of Industry 4.0, but they do not provide concrete recommendations as to which concepts are suitable for an enterprise and which not.

This is where this work is intended to set in. Based on existing roadmaps for implementation, the aim is to evaluate which of the in section 2.2 mentioned Industry 4.0 concepts could make sense for a specific company. In particular, one criterion is to be included in the analysis, namely the size of the company concerned.

The aim is therefore to develop recommendations for the introduction of suitable Industry 4.0 concepts based on the company size. This should enable enterprises, based on their size, to easily select, review and then implement appropriate concepts without great effort. Consequently, the research question (RQ), on which this work is based, is formulated as follows:

RQ: Which Industry 4.0 concepts are suitable for a given company, based on its size?

Is it possible to classify Industry 4.0 concepts by their suitability for a given company, based on its size?

Subsequently, three main hypotheses are formulated. These will be elaborated in the next chapters, and finally scrutinized in the last chapter of the thesis, the outlook.

- Hypothesis 1 (H1): Industry 4.0 concepts can be evaluated and ranked, given the size of an enterprise.
- Hypothesis 2 (H2): On the basis of the company size criterion, recommendations for the implementation of Industry 4.0 can be provided to companies without great effort.
- Hypothesis 3 (H3): This approach makes it quicker and simpler for companies to introduce suitable Industry 4.0 concepts and thus supports them in their digital transformation process.

After first exploring historical developments, important terminology, current models for the implementation of Industry 4.0, and finally the formulation of the research question, on which the work was based, the next chapter contains the methodological part of the work.

3

METHOD FOR THE EVALUATION OF THE SUITABILITY OF INDUSTRY 4.0 CONCEPTS

The purpose of this chapter is to develop a method for the evaluation of suitable Industry 4.0 concepts for different types of companies. Thereby, the main focus is laid on the assessment of the Industry 4.0 concepts presented in the second chapter according to the criteria of company size. To this end, a survey is being developed which is to include experts and researchers from the Industry 4.0 area as well as industrial companies from various sizes. In the end, this methodology should be exploited to perform the evaluation making it possible to compile a ranking with suggestions and recommendations for the implementation of Industry 4.0 concepts for each scrutinized type of enterprise.

To achieve this goal, the fundamental classification of enterprises according to the above-mentioned criteria, namely the company size, is initially undertaken in section 3.1. Subsequently, section 3.2 outlines the structure of the survey, which focuses on expert interviews on the one hand and company assessments on the other hand. Finally, the procedure for the survey evaluation is explained in section 3.3.

3.1 Classification of companies

In the first part of the methodology, it is essential to categorize the enterprises. This should serve as a reference point and basis for the structure of the survey. The classification is made according to the main criteria, the company size. In a second moment, this classification will enable enterprises to be clustered according to their size and with the objective to derive ideal fitting Industry 4.0 concepts for each of the categories.

For this purpose, this section provides a classification of enterprises based on the criteria number of employed persons, annual revenue and balance sheet total, which is one of the most commonly utilized classifications in this regard.

According to Eurostat Statistics, the very reputable glossary of the European Union, enterprises can be classified into different categories according to their size. For the classification, various criteria can be invoked, the most commonly employed however usually being the number of persons employed [143].

The number of persons employed correspond, in the framework of business statistics, to the number of persons who are working in and are paid by an observation unit, as well as persons who work outside the unit and are paid by it, such as sales representatives or delivery staff [144]. This definition clearly excludes so-called supplied manpower, which has been obtained externally from other enterprises in order to carry out repair or maintenance work, for example.

The most common form of segmenting enterprise sizes is the division into four different categories, based on the number of persons employed. As the graphic below illustrates, two further criteria are applied for the classification, namely the annual values of turnover and balance sheet total of an enterprise.

Subsequently, Figure 19 provides an overview of the four categories and the distinction between the various types of enterprises.

eurostat Statistics

	Description	Abbreviation	Number of employees	Turnover	Balance Sheet Total
SMEs	***Micro*** *enterprises*	*XS*	less than 10	≤ € 2 million	≤ € 2 million
SMEs	***Small*** *enterprises*	*S*	from 10 to 49	≤ € 10 million	≤ € 10 million
SMEs	***Medium*** *-sized enterprises*	*M*	from 50 to 249	≤ € 50 million	≤ €43 million
	Large *enterprises*	*L*	250 or more	> € 50 million	> € 43 million

Figure 19. Classification of company sizes by number of employees [143].

According to the EU standards, four company sizes are distinguished: micro, small, medium-sized and large companies. Therefore, if a company employs fewer than ten persons, generates an annual revenue up to two million euros and boasts a balance sheet total equal or less than two million euros it is classed as a micro enterprise, abbreviated as “XS” within the proceeding of this work. With a number of persons employed from ten to 49, annual sales revenue and balance sheet total up to ten million euros a company is called a small enterprise, abridged by “S”. If the number of persons employed ranges from 50 to 249, annual turnover and balance sheet total are equal or less than 50 and 43 million euros respectively, it is categorized as a medium-sized enterprise, shortened by “M”. Large enterprises, abbreviated by “L”, are those that employ 250 persons or more, having annual sales revenues and balance sheet totals greater than 50 and 43 million euros respectively.

Small and medium-sized enterprises, abbreviated generally as SMEs, are enterprises with a number of persons employed smaller than 250. Accordingly, micro, small and medium sized enterprises belong into it. According to the definition of the European Commission, to be considered as SMEs, enterprises should not only have less than 250 persons employed but also, they cannot exceed an annual revenue of 50 million euros or a balance sheet total of 43 million euros. Within this work, this nomenclature and classification form the basis for the categorization of companies by their size.

3.2 Survey design

The aim of the survey is to find out to which extent Industry 4.0 concepts are suitable for the above discussed different company sizes. The survey is intended to cluster Industry 4.0 concepts for companies in this way and examine whether it is possible to derive the concepts on the basis of this criteria.

This section is dedicated to survey design, with a first look at general aspects of the survey in 3.2.1 followed by the specific procedure of survey construction in 3.2.2. Last but not least, the tools for conducting this survey are introduced, whereas for the enterprise evaluation and the expert survey specific Excel-based form are developed, which are then exploited to conduct the survey. This will also be addressed in a more detail way in sub-section 3.2.3.

3.2.1 General aspects of the survey

To achieve the expressed objectives, two main attendee groups are distinguished, whereas the first part consists of an expert survey, which is intended to shed light on how experts assess the importance of Industry 4.0 concepts for the various types of enterprises. In a second step, companies belonging to the diverse size clusters discussed are interviewed in order to detect the actual maturity, future target levels and also the relative importance of each Industry 4.0 concept to them.

Within the framework of the project "Industry 4.0 for SME's", financed by the Horizon 2020 research fund of the European Research MSCA RISE program (grant number 734713), in which besides the Free University of Bolzano nine other partner universities from Slovakia, Austria, USA, Thailand and India are involved, more than 50 experienced and early-stage researchers are working. These researchers are very well suited as participants in the survey, as they have excellent knowledge in the field of Industry 4.0, by dealing with the subject matter on a daily basis.

As this project does not only involve universities, but also enterprises from the field, these are also integrated into the study. At the moment 47 enterprises from industry participated in workshops of the project and serve as partners in practical questions and testing of the theoretically developed models. By including these, not only the knowledge of the experts but also a certain practical relevance is to be incorporated in order to discover from a practical point of view what may be important for the companies concerned and what may be less of a relevance.

In addition to these participants, attempts will be made to include several other enterprises in the survey in order to obtain more significant results. For these, lower return rates must certainly be expected. However, this is to be rewarded by benefits that companies gain by completing the survey. One of the ideas is to keep companies informed of how far their company is in the Industry 4.0 environment and where there is still a shortage. This may be supported by graphical representations. This point will be dealt with in greater detail below in sub-section 3.2.2, which is dealing with the general procedure of the survey.

3.2.2 Survey structure

This section is intended to give an overview of the structure of the survey. Of course, a distinction is drawn between the two different classes, Industry 4.0 experts and enterprises. In order to shed light on the design procedures of the two surveys, the main steps of these two are defined, whereby first the expert survey design and subsequently the sequence related to the enterprise survey design are addressed.

With regard to the procedure for the expert survey, in the first step the participants are explained what the survey is about, how it is structured and how they should proceed. In the next moment, various general information is retrieved, ranging from name to e-mail over research focus.

Once this basic information has been gathered, the next step relates to the core of the evaluation. Here the experts evaluate the suitability of Industry 4.0 concepts within all company sizes. With a view to obtaining more information from the survey than solely the differentiation by size, the researchers are presented with two identical questionnaires, one to determine the suitability of Industry 4.0 concepts within all sizes of enterprises in the manufacturing sector, the second containing the same questions, but dealing with the construction sector. All this with the ulterior idea of recognizing possible patterns not only by company size, but in a second moment possibly also by sector. However, this point will be discussed in greater detail later in this paper, in section 5.1.

For this purpose, the researchers evaluate the suitability of the corresponding Industry 4.0 concepts for micro, small, medium and large enterprises within manufacturing and construction within a separate Excel sheet. The importance of the various concepts is evaluated from one to five, where one reflects the lowest and five the highest importance of a given concept. The denomination of the five levels of importance within the expert survey is represented by the following:

- 1 – "not at all important"
- 2 – "slightly important"
- 3 – "important"
- 4 – "fairly important"
- 5 – "very important"

In addition, a supplemental response option "no answer" is implemented in order to give the respondent the possibility of not evaluating a concept for whatsoever reason.

The last major step in the survey design is to give respondents encouragement to complete the questionnaire and make it more lucrative for them. In short, filling in the form must also be of benefit to the respondent. To achieve this, an information sheet is enclosed when sending out the survey with all important information concerning the study. Respondents are then informed that they will receive the results of the study. The researchers are themselves concerned with the subject and are also interested in science making progress in this regard even better, if they can contribute to it by their share. By assuring them the results of the study, it can be expected to significantly increase the encouragement to completely fill out the survey.

Figure 20 graphically depicts the discussed three main steps and the associated information of the survey design for the expert's form.

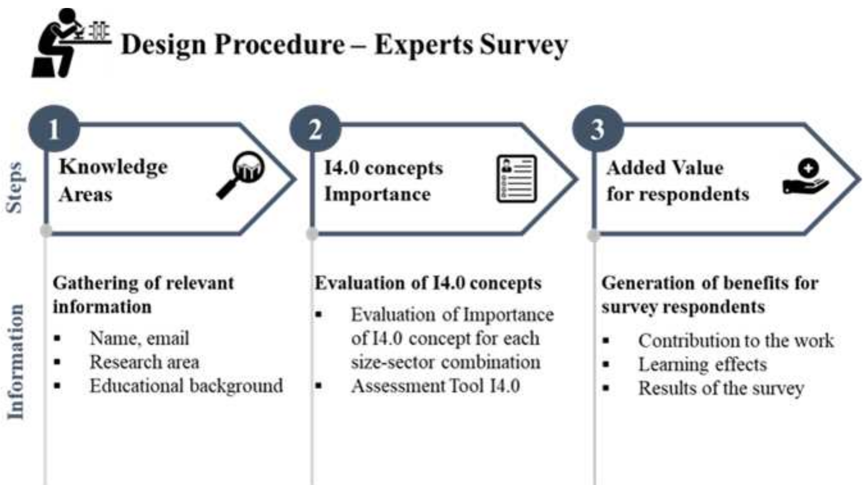

Figure 20. Overview over the design of the expert survey.

The survey design for the enterprises has in fact a quite similar structure, but some fundamental discrepancies have to be taken into account. In this sense, unlike experts, which are asked to assess manufacturing and construction sector, companies are only asked to evaluate the category to which their enterprises belong to.

Therefore, in a first moment, company information is requested to allow the categorization into the clusters. These pieces of information are number of persons employed, turnover, balance sheet total and operating sector.

These criteria are exactly those mentioned in section 3.1, which are required for the allocation of the enterprises to the different size classes (micro, small, medium, large). Selection fields are activated to request this information, allowing the respondent to choose from several options or intervals respectively.

In addition, similar to the expert survey, the activity sector of the enterprises is also queried here in order to possibly analyze in a second moment not only patterns according to the size of the enterprise but also to deal with the possibly appearing patterns based on the additional criterion operating sector.

Afterwards follows the evaluation of maturity and target levels of the individual Industry 4.0 concepts in relation to the enterprise. The evaluation of the maturity levels and target values is quite straightforward for the companies, since the different embodiments of each Industry 4.0 concept are described very precisely in the Excel file and sometimes even with practical examples.

Additionally, it should be specified how important the concepts are to the company (again from 1 to 5). The denomination of the five levels of importance within the enterprise survey is represented by the following:

- 1 – “not at all important”
- 2 – “slightly important”
- 3 – “important”
- 4 – “fairly important”
- 5 – “very important”

In case a company does not want or cannot fill in a certain field, it is also possible to leave it empty. This will of course be taken into account in the subsequent evaluation.

It is particularly vital to create added value for companies and to encourage the respondents to completely participate in the survey. One way of doing so, is to provide visual graphics that show the Industry 4.0 readiness and target levels in relation to the concepts already during the filling process.

The current status report in the form of spider web diagrams, which compares the current value of each Industry 4.0 concept with its target value, is displayed visually appealing to the participant and the corresponding sheet can be easily printed out.

Besides this, the participants are shown a ranking list of Industry 4.0 concepts, which offer the highest potential for their company. Therefore, a list with the top potentials is displayed in a printable spreadsheet.

In addition, the companies are also informed that the result of the entire work will be handed over to them and thus they get a general recommendation for assessing their situation related to Industry 4.0

Finally, it is noteworthy that unlike the expert survey, the enterprise survey is provided in three languages, namely Italian, German and English. Moreover, the enterprise survey, unlike the expert survey, is designed in three languages, namely German, Italian and English, to enable companies to complete the questionnaire in their preferred language and make it as user-friendly as possible for them considering the fact that companies from all around the world will participate in the survey. The experts involved are renowned scientists who are confronted on a daily basis with the English language and the terminology used in Industry 4.0, and who for the most part have a high level of mastery of the language, which is why no translation was needed.

Below, Figure 21 shows an overview of the main steps for the survey design of the enterprise's forms and the relevant information within them.

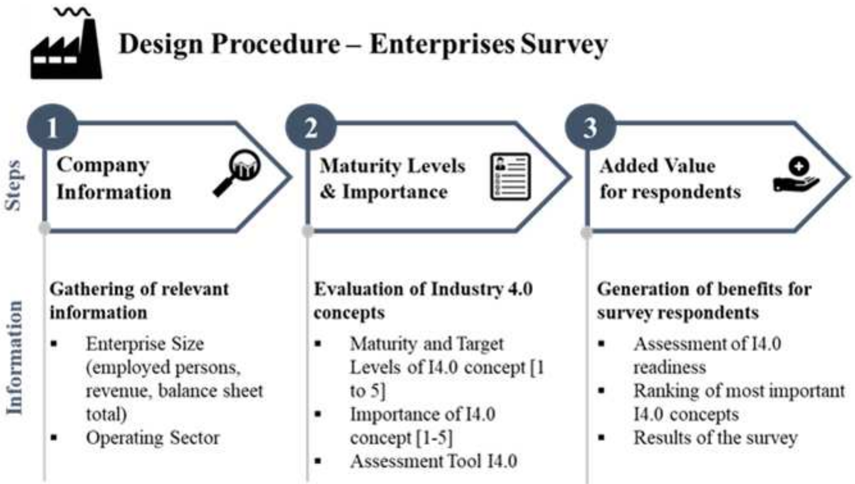

Figure 21. Overview over the design of the enterprise survey.

After the general aspects and the basic structure of the two types of survey have been clarified, the next section is intended to provide information on how and by means of which tool the survey is then conducted.

3.2.3 Survey generation

The content of the survey is to evaluate the Industry 4.0 concepts described in section 2.2 of this paper for the different types of enterprises. Experts should thus give their opinion as to which concepts are suitable and important in which enterprise types. On the other hand, companies assess their current maturity and target levels in terms of Industry 4.0 concepts. Moreover, they are asked to state the importance of every Industry 4.0 concept to them. In the end, the goal is to define suitable concepts for the different types of enterprises and thus to provide guidelines for the introduction of Industry 4.0 concepts for the various company sizes.

In order to achieve this, a survey is established which is basically founded on the "I4.0 Assessment Tool" developed by Unterhofer [57]. The approach for identifying the Industry 4.0 concepts within the model and the main functionalities were discussed in sub-section 2.2.1. Similar as the assessment tool, the survey is carried out through the use of Excel. Nevertheless, the main parts of the two forms of survey, as already indicated a few times, are very differently designed. Whereas the enterprises are asked about their current maturity, target levels and finally the importance of the various Industry 4.0 concepts within their organization, the expert survey is based solely on the evaluation of the importance of each Industry 4.0 concept for any of the company sizes within construction and manufacturing sector.

The **expert survey** is based on evaluating the importance of all Industry 4.0 concepts for the different company sizes within the manufacturing and construction sector. The target audience here are experts or scientists who are very familiar with the matter related to Industry 4.0.

The researchers are asked for their assessment for each company size. As discussed previously, also sector relevant data are to be taken into account in order to analyze possible patterns in a second moment. In this case, since the data volume with respect to the enterprise survey is already very high, it is useful for this target group to consult only two macro sectors manufacturing and construction. This is mainly done in order to avoid that the participants cancel the survey completion at an early stage due to the overwhelming amount of data requested. Within the enterprise survey more detailed information about the operating sector (micro sector level) is taken in to account.

In a first step, basic information are provided to the participants and details are given on how to proceed with the survey. Participants are also told how much time will be required to complete the survey. The survey is generally created with the aid of Excel VBA in order to make the handling more attractive and to facilitate the input for the participants, e.g. by integrating buttons.

Below, Figure 22 shows the first two sheets of the survey, in which the participants are introduced to the study, the procedure is explained more in detail and some general information are gathered. The buttons provide a user-friendly operation.

Figure 22. Introduction sheet (left) and general information sheet (right) of the expert survey.

This is followed by the core part of the survey, namely the evaluation of the Industry 4.0 concepts themselves. The respondents are asked to select the statement, which describes their opinion on the importance of the individual Industry 4.0 concepts in the most appropriate way for each of the different enterprise sizes, first for the manufacturing and then for the construction sector.

Figure 23 graphically illustrates the structure of the excel work sheet dedicated to the evaluation of the Industry 4.0 concepts for the manufacturing sector by the experts. For the construction sector the same evaluation sheet is to be filled in. Note that the first part is explanatory in nature, while the second part deals with the core of the survey, the evaluation of the concepts.


unibz SME 4.0

MANUFACTURING

How do you assess the importance of the following Industry 4.0 concepts for **MICRO, SMALL, MEDIUM** and **LARGE** enterprises, operating in the **MANUFACTURING** sector?

*Please filll the green cells with numbers ranging from **1 to 5**, specifying your opinion about the **importance** of the relevant Industry 4.0 Concept for the given Company Size within the Manufacturing sector!*

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	INDUSTRY 4.0 CONCEPT	Micro Enterprises	Small Enterprises	Medium Enterprises	Large Enterprises
Operational Dimension	Agile manufacturing system				
	Self-adapting manufacturing systems				
	Continuos and uninterrupted material flow				
	Plug an Produce				
	Decision Support Systems				
	Integrated and Digital Real-Time				
	Remote Monitoring of Products				
	Big Data Analytics				
	ERP/MES				
Organizational Dimension	Digital Product-Service Systems				
	Servitization and Sharing Economy				
	Digital Add-on or Upgrade				
	Digital Lock-In				
	Freemium				
	Digital Point of Sales				
	Open Innovation				
	Industry 4.0 Roadmap				
	Sustainable Supply Chain Design				
	Collaboration Network Models				
Social	Training 4.0				
	Role of the Operator				
	Cultural Transformation				
Tech. Dimension (data)	Additive Manufacturing (3D-Printing)				
	Cloud Computing				
	Digital and connected workstations				
	E-Kanban				
	IoT and CPS				
	Cyber Security				
	Artificial Intelligence				
	Identification and Tracking Technology				
	Predictive Maintenance				
	Tele-Maintenance				
Tech. Dimension (process)	Automated Storage Systems				
	Automated Transport Systems				
	Automated Manufacturing & Assembly				
	Collaborative Robotics				
	Smart Assistance Systems				
	VR and AR				
	Simulation				
	PDM and PLM				
	Object Self Service				
	CPS Standards				

Figure 23. Industry 4.0 assessment within the expert survey.

As illustrated in Figure 24 the assessment is supported by selection fields, which show what the individual numbers from one to five mean and thus facilitate the input. In addition to the explanations of the concepts by means of the comment function an information sheet is enclosed to remove any doubts that may arise regarding certain concepts.

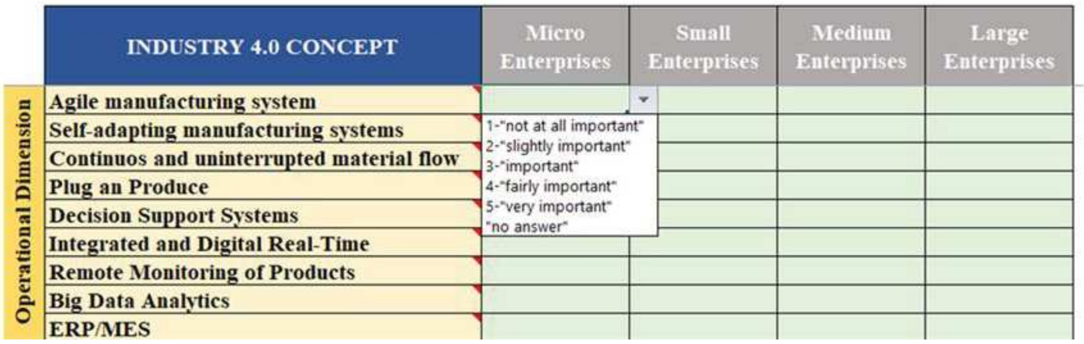

Figure 24. Facilitated completion of the survey by introducing selection fields.

In the worksheet, corresponding to the evaluation of the enterprise sizes, buttons are set up to allow to save and send the completed document by one click, and to make these processes as straightforward as possible for the user. By clicking on "Save" and "Send Email" the file is automatically saved and attached to the standard email program with preset subject and receiver so that it is of minimal effort for the participant to send the file. This is illustrated in Figure 25.

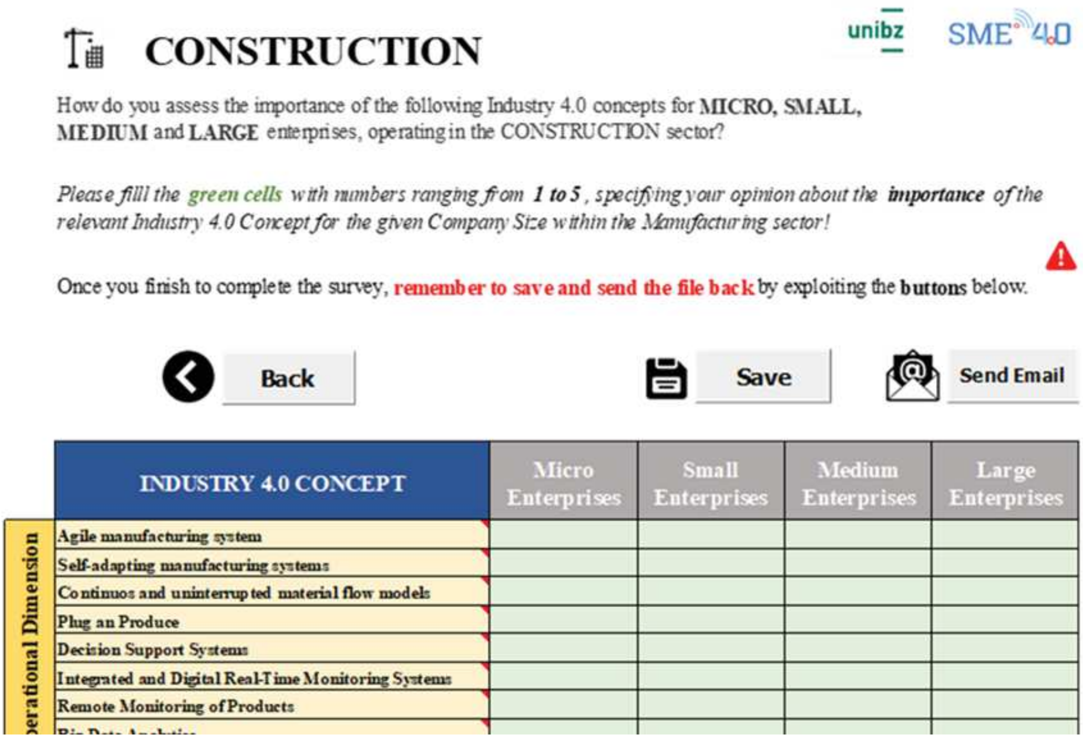

Figure 25: Representation of the last sheet of the expert survey (only partially illustrated).

The experts survey will be presented and explained at the annual meeting of the "Industry 4.0 for SMEs" project. The survey is then sent to the selected scientists in order to be completed.

For the **enterprise survey**, again an Excel tool based on the Assessment Tool I4.0 is built up and designed in a graphically appealing way to make the completion as fluid as possible. Furthermore, the Excel form represents a huge advantage in this case, as it describes the maturity levels of the various Industry 4.0 concepts in detail, thus facilitating the assignment of maturity and target levels for the participating companies. The enterprise survey consists of three main parts, whereas in the first part participants are introduced to the study and told how to proceed with the survey, followed by the gathering of some general information, as illustrated in Figure 26.

Figure 26. Introduction sheet (left) and general information sheet (right) of the enterprise survey.

Similarly, as for the expert survey, the companies are asked for some general information, in this case about their company. Relevant enterprise related data such as persons employed, annual turnover, balance sheet total and field of activity of the company are queried in order to classify the respective enterprise into the appropriate company size category. While name, email and company name are read in via text field, other information like sector, employees, revenue and balance sheet total is entered via selection field, with the intervals for persons employed, annual sales revenue, balance sheet total and operating sector exactly corresponding to the ranges defined in section 3.1. The sector data are collected to create a database, in order to possibly identify in a second moment possible patterns related to the sector. This will be discussed in chapter 5.

This is followed by the core part of the survey, which encompasses the evaluation of maturity levels, target levels and the importance of the individual Industry 4.0 concepts to the enterprise. Each of these need to be evaluated with a value ranging from one to five, with "1" corresponding to "Maturity Level 1" and "5" to "Maturity Level 5". In terms of maturity and target levels, the numbers from one to five represent the different degrees of evolution of an Industry 4.0 concept within the organization, which were explained in detail in section 2.2 of this work. The exact development stages of these levels are explained directly in the tool for each Industry 4.0 concept, so that the survey participants can easily select the maturity and target level which corresponds to their enterprise best. While the maturity levels indicate the current status of a concept within the organization, the target level values represent the future aspired evolution of the various concepts. With regard to the evaluation of importance, the meaning of the numbers from one to five is slightly deviating from the previous two values, with "1" standing for "not at all important" concepts, "2" for "slightly important", "3" for "important", "4" for "fairly important" and finally "5" standing for "very important" concepts. Subsequently, Figure 27 illustrates a part of the evaluation sheet for the enterprise survey.

Industry 4.0 Evaluation

Please evaluate the current maturity, target levels and importance of the following Industry 4.0 concepts for your company!

*Filll the green cells with numbers ranging from **1 to 5**, specifying your firms **current I4.0 score**, the future **target level** and the **importance** of the relevant Industry 4.0 Concept within your organization!*

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INDUSTRY 4.0 CONCEPT	Maturity Level 1	Maturity Level 2	Maturity Level 3	Maturity Level 4	Maturity Level 5	I4.0 score	Target	Importance
Agile manufacturing system	**No flexibility of manufacturing system** /system produces only one kind of product with a certain capacity	**Scalable manufacturing system** /system is able to de/increase the volume capacity	**Modular and reconfigurable manufacturing system** /system is able to be adapted for other	**Flexible manufacturing system** /system is able to produce different variants of a product	**Agile/changeable manufacturing system** /system is designed to be utilized also for new products	4	5	5
Self-adapting manufacturing systems	**No adaptability of the manufacturing system** /system can not be reconfigured for other products	**Manual reconfiguration of manufacturing system** /worker reconfigures the line manually	**Semi-automted recofiguration of manufacturing system** /combination of manual and auomtated	**Automated reconfiguration of manufacturing system** /worker decides the need of automated	**Self-adapting and intelligent manufacturing system** /no need for the worker to reconfigure the system	3	4	5
Continuos and uninterrupted material flow models	**Job Shop production** /lot size production in job shop structure with semi-finished goods inventory	**Cellular manufacturing** /nearly continuos flow concentrated in a specific production cell	**Production line** /continuos flow without interruption (one-piece-flow)	**Continuos flow flexible production cell/line** /product knows the production sequence and goes to the next process step within the cell/line	**Continuos flow flexible job shop** /product knows the production sequence and goes to the next process step in the job shop	2	3	3

Figure 27. Evaluation sheet for the enterprise Industry 4.0 assessment.

Once all necessary fields have been completed, in the next sheet of the survey the user is able to compare the Industry 4.0 maturity level of his company with the target levels and thus obtain a graphically prepared analysis of the current situation that prevails in the company in this respect, as illustrated in Figure 28.

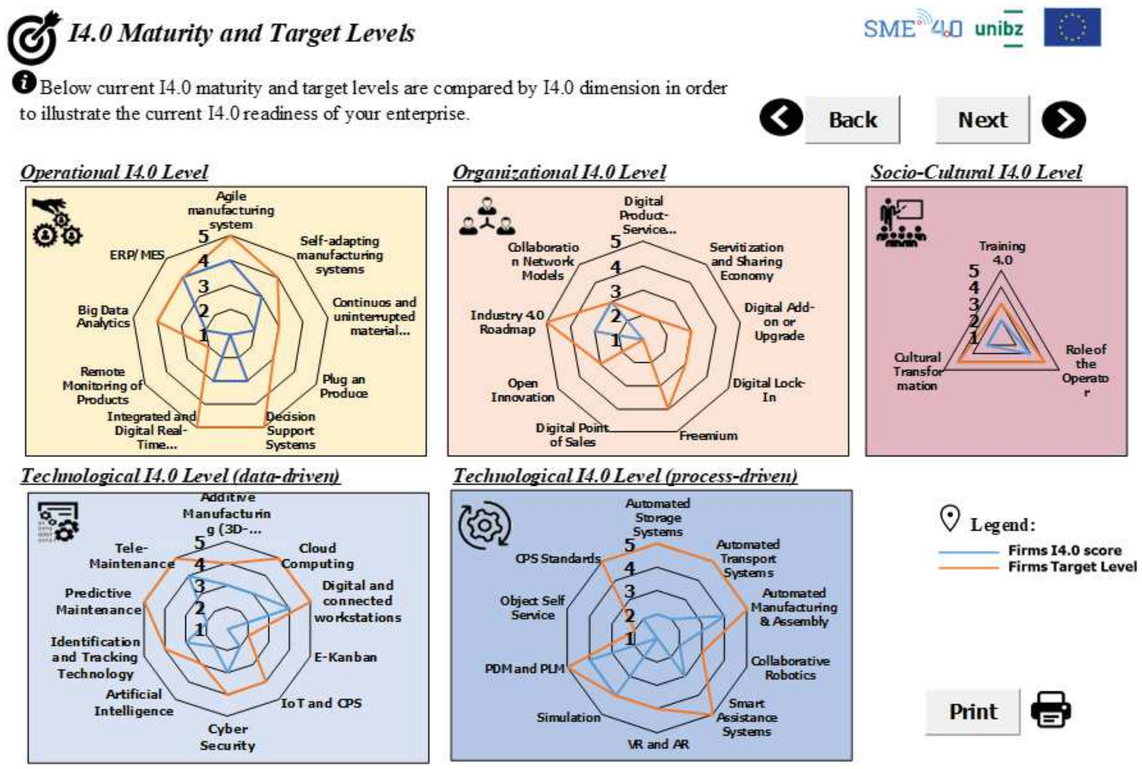
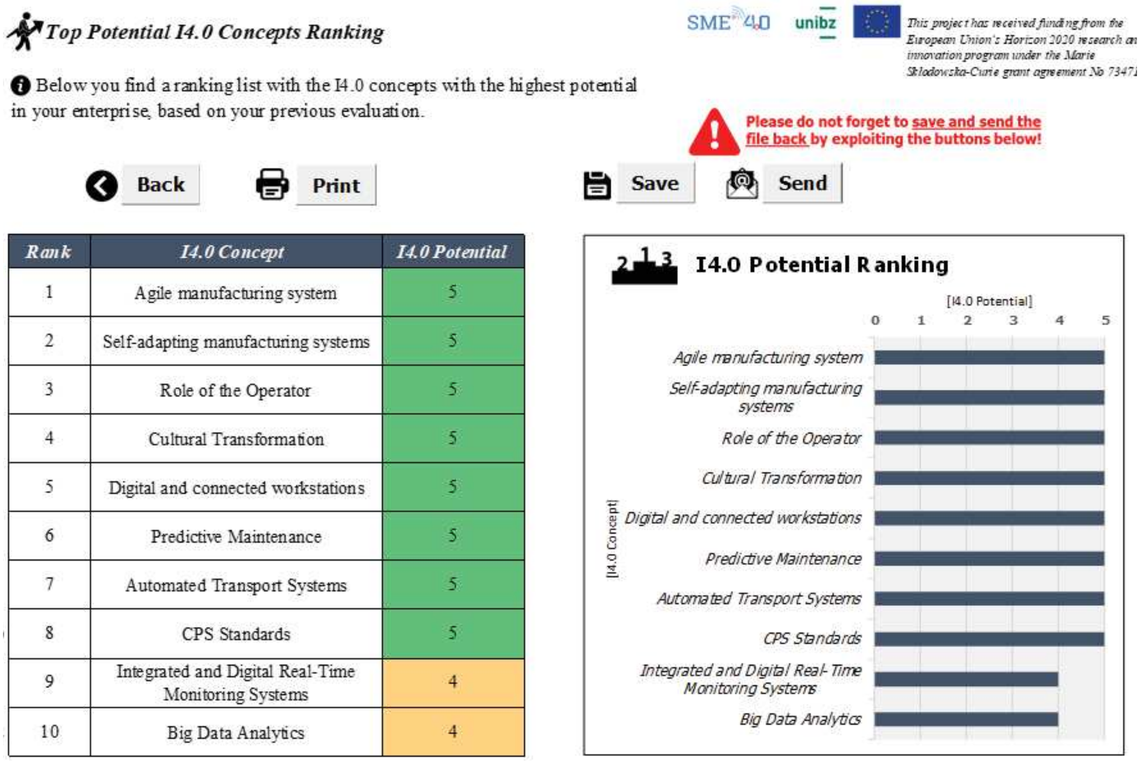


Figure 28. Current Industry 4.0 Maturity and Target Levels sheet (example).

The spiderweb diagrams indicate the current Industry 4.0 maturity (in blue) and target levels (in orange) based on the respondent's input for each of the different Industry 4.0 dimensions. Thus, they reveal in which areas the company is already well positioned and in which there may still be some lagging behind. By clicking the print button, this sheet can easily be printed out and used by companies for further analysis and reporting purposes.

In addition, the next sheet, in Figure 29 displays a ranking of Industry 4.0 concepts with high potential for the user's organization.



Rank	I4.0 Concept	I4.0 Potential
1	Agile manufacturing system	5
2	Self-adapting manufacturing systems	5
3	Role of the Operator	5
4	Cultural Transformation	5
5	Digital and connected workstations	5
6	Predictive Maintenance	5
7	Automated Transport Systems	5
8	CPS Standards	5
9	Integrated and Digital Real-Time Monitoring Systems	4
10	Big Data Analytics	4

Figure 29: Top Potential Industry 4.0 concepts (example).

This sheet can also be printed-out. As already mentioned earlier, these represent essential elements, as they offer the user certain benefits and encourage him to fully complete the survey. The survey will be sent to the companies involved in the Industry 4.0 for SMEs project and to other selected companies. In this context it is clarified that the document should be filled in by a manager who is best acquainted with the subject and knows the company best in this respect. After filling out the form, the file should be saved and sent back.

After first discussing the classification of the enterprises to be evaluated and the design of the two different surveys, the next section is concerned with the way in which these are evaluated.

3.3 Survey evaluation

As a final step in the methodological part of this work, the evaluation method for the survey is to be developed. This is precisely the reason why the following section deals with this point. The question of how the survey is addressed in order to evaluate its results arises. The ultimate goal is to create a ranking for suitable Industry 4.0 concepts per company size through the assessment of the survey results and thus provide enterprises with a sort of guidance to support the implementation of Industry 4.0 concepts. For this reason, as already discussed above, the survey addresses two different target groups, namely scientists and enterprises. The consideration of these two target groups should above all combine the inclusion of theoretical and practical aspects and ensure that the recommendations for action are not only theoretically substantiated, but also have practical relevance.

To achieve this final goal, the following section first deals with the development of the evaluation method of the expert survey in 3.3.1 and then the enterprise survey in 3.3.2. These two survey evaluation methods are similar in structure, although they differ fundamentally in some respects. For this reason, some special considerations must also be taken into consideration during evaluation. In principle, the initial situation for the evaluation is first analyzed in both cases. Then, in a first moment, the response rate is evaluated by either simply calculating it or by introducing a heatmap that graphically shows the response rate of each company category supported by colors, respectively. It is then discussed how to calculate the individual ratings of the Industry 4.0 concepts per category. As a consequence, it is possible to derive the respective rankings from these values. As a final point, graphics can be derived from these results, which support the outcomes graphically in a clear way.

3.3.1 Evaluation of the expert survey

The completed Excel forms represent the basis or starting point for the evaluation of the expert survey. These are filled and send back via email by the scientists after the form has been sent to them. The final results are derived from these statements.

The first point of the evaluation is the assessment of the response rate, which is calculated by dividing the survey participants by the number of invitations sent out for processing. This value is calculated as a percentage, which is the reason that the resulting quotient is multiplied by 100, as follows:

$$(1) \quad Experts\ Response\ Rate\ [\%] = \frac{Survey\ Participants}{Survey\ Invitations} * 100$$

This value constitutes an initial indication of the degree of participation in the survey. Once the value regarding the response rate has been calculated, the next step involves the core part of the survey evaluation, comprising the calculation of the relevant importance values of the individual Industry 4.0 concepts for each company type. Each researcher is asked within the survey to assess the importance of the diverse Industry 4.0 concepts with respect to the different company sizes. For each category of enterprises, it should be calculated which Industry 4.0 concepts were rated the highest or most important by the respondents. Consequently, a ranking of the ten most important Industry 4.0 concepts is to be created for each company type.

But first of all, the question arises: what is the most suitable way to calculate the stated importance of the individual Industry 4.0 concepts? In general, the assessed importance of a single generic Industry 4.0 concept for a category can be calculated as follows:

$$(2) \quad Avg. Importance\ I4.0\ concept_{size} = \frac{\sum Importance\ Values}{Number\ of\ answers - "No\ Opinion"}$$

The calculation is relatively straightforward. First, the evaluated importance values of the given Industry 4.0 concept are added and then divided by the number of answers, minus the answers given in "No answer" in the questionnaire. The fact that respondents are also given the opportunity not to reply if they do not have an opinion or simply do not want or cannot answer means that it is of fundamental significance that this value is used within the calculation and not the total number of answers so as not to distort the results. The result of this calculation is therefore an average value of the evaluated importance of the Industry 4.0 concept. The opinions of the scientists are weighted as equivalent within this study. This value is then computed for every Industry 4.0 concept within each size-category.

Once all values of the Avg. Importance I4.0 concepts values for all company sizes have been calculated, it is now possible to analyze these values and to generate a ranking of the suitable Industry 4.0 concepts for each size category. The calculated values range from one to five, making it quite straightforward to order them in descending magnitude, with the highest value corresponding to the Industry 4.0 concept, which scientists consider to be most suitable for the given company size.

(3) $Ranking_{size} = Sort_{descending}\,[Avg.Importance\ I4.0\ concept_{size}]$

Figure 30 graphically illustrates, how the rankings are elaborated, whereby first all the importance values of the Industry 4.0 concepts for the combinations are assessed. Based on those, the rankings can be created for each enterprise size.

		Enterprise size			
		Micro *XS*	Small *S*	Medium *M*	Large *L*
I 4.0 Rank	1	*I4.0 Concept 1*	*I4.0 Concept 1*	*I4.0 Concept 1*	*I4.0 Concept 1*
	2	*I4.0 Concept 2*	*I4.0 Concept 2*	*I4.0 Concept 2*	*I4.0 Concept 2*
	3	*I4.0 Concept 3*	*I4.0 Concept 3*	*I4.0 Concept 3*	*I4.0 Concept 3*
	4	*I4.0 Concept 4*	*I4.0 Concept 4*	*I4.0 Concept 4*	*I4.0 Concept 4*
	5	*I4.0 Concept 5*	*I4.0 Concept 5*	*I4.0 Concept 5*	*I4.0 Concept 5*
	6	*I4.0 Concept 6*	*I4.0 Concept 6*	*I4.0 Concept 6*	*I4.0 Concept 6*
	7	*I4.0 Concept 7*	*I4.0 Concept 7*	*I4.0 Concept 7*	*I4.0 Concept 7*
	8	*I4.0 Concept 8*	*I4.0 Concept 8*	*I4.0 Concept 8*	*I4.0 Concept 8*
	9	*I4.0 Concept 9*	*I4.0 Concept 9*	*I4.0 Concept 9*	*I4.0 Concept 9*
	10	*I4.0 Concept 10*	*I4.0 Concept 10*	*I4.0 Concept 10*	*I4.0 Concept 10*

Figure 30: Graphical representation of the expert survey ranking of I4.0 concepts for each enterprise size.

The ranking is intended to include the ten most important Industry 4.0 concepts for each company size. The last step of the evaluation of the expert survey comprises the graphical representation and preparation of the ranking of the most suitable I4.0 concepts for the categories. Bar charts showing the ten best-rated Industry 4.0 concepts are used for this, with the X-axis showing the average rating and the Y-axis showing the corresponding Industry 4.0 concepts. Subsequently, Figure 31 shows the general top ten ranking for a generic size category by means of a bar chart.

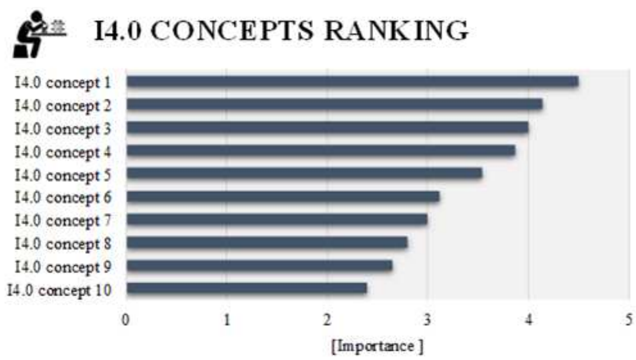


Figure 31. Bar chart for the representation of suitable I4.0 concepts for a generic size-sector combination.

After this sub-section has dealt with the most important elements for the evaluation of the expert survey, the next part is concerned with the procedure for evaluating the enterprise survey.

3.3.2 Evaluation of the enterprise survey

In the enterprise survey, the starting point or initial situation for the survey evaluation is again the Excel file, which is sent back by the participating enterprises. However, it differs slightly with respect to the expert survey. While the experts evaluate only the importance of the Industry 4.0 concepts within the different enterprise size categories, in the enterprise survey maturity, target and importance of all the Industry 4.0 concepts of the participating companies are queried. In a nutshell, in this case much more information is requested and processed, while the experts survey is actually limited to the estimated importance.

The Excel file contains an exact description of the five different levels of maturity of each concept, which considerably simplifies the completion of the survey for the interviewed enterprises and supports them if they do not know a term exactly, e.g. with regard to an Industry 4.0 concept. In addition, by using Excel, graphically appealing incentives can be created to generate a certain added value for the users and thus encourage them to fully complete the survey. Ideally, the companies fill out the Excel forms sent to them completely and then send them back. These completed Excel forms represent the basic starting point for the further evaluation of the results of the enterprise survey.

As in the previous case, once all the forms have been submitted, the first step is to determine the overall response rate by dividing the number of companies participating in the survey by the number of invitations and then multiplying it by 100 to convert it to a percentage, as pointed out subsequently.

$$(1) \quad Enterprise\ Response\ Rate\ [\%] = \frac{Survey\ Participants}{Survey\ Invitations} * 100$$

An important difference between the two types of surveys is the fact that experts assess each of the enterprise sizes while the companies obviously only evaluate the category into which they belong to. For this reason, the number of companies from the respective categories participating in the survey is also examined in this case. For this purpose, a heatmap is made up, which shows the response frequency of the individual categories in a colored way.

The following Figure 32, defines the heatmap colors, whereby depending on the response rate of each combination the color of the field varies according to the frequency of response.

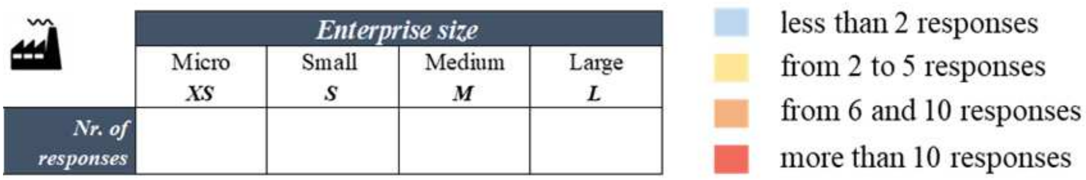


Figure 32. Analysis of response rate by size-sector matrix heatmap.

Accordingly, the colors as known from other applications are classified according to heat, whereby in this case the colors red, orange, green and blue are being selected, with red corresponding to the warmest color and blue the coldest.

As the legend on the right side of Figure 34 clarifies, a field from a category of which there were ten or more answers is therefore colored red in order to graphically represent an increased frequency. In the case of six to ten answers, the field is colored orange, while yellow is used in relevant categories with response rates from two to five. Finally, fields from which there less than two answers are painted blue to visually represent the low frequency of answers through the coldest color. The result of this evaluation is an enterprise size heatmap, which concisely shows the distribution of the answers within the different size categories in the survey. In this case, a reasonable minimum number of responses per company size must be defined to determine the threshold from which a combination is evaluated. It is possible that certain fields only have one or two responses and no average can be considered. Therefore, a minimum number of five returnees is defined for this work in order to ensure a certain statistical significance. Only fields with a response rate of five or more, are evaluated in order to obtain a certain minimal statistical significance.

Once the response rate and its distribution within the size matrix have been analyzed, the central element of the company survey evaluation, namely the processing of the evaluated Industry 4.0 concepts, is then concerned. In contrast to the expert survey, in which the scientists assess exclusively the importance of the individual concepts for the respective combinations, the enterprises evaluate not only the importance, but also the current maturity and the target levels for the individual Industry 4.0 concepts within their organization. That is precisely why it is necessary to evaluate these three parameters, which are summarized and analyzed for each of the size categories.

First of all, the current levels of maturity assessed by the companies are evaluated. For each of the 20 combinations, the progress made by the companies in implementing these concepts is analyzed. For each Industry 4.0 concept, the average degree of maturity is calculated by adding values from the same size categories and then dividing them by the number assigned. This is performed for every Industry 4.0 concept and each combination.

$$(2) \quad Avg.Maturity\ Level\ I4.0\ concept_{size} = \frac{\sum Maturity\ Level\ s}{Number\ of\ answers}$$

Afterwards exactly the same is done for the assessed target levels. For each Industry 4.0 concept and each combination, the objectives pursued by the enterprises for implementation are evaluated.

$$(3) \quad Avg.Target\ Level\ I4.0\ concept_{size} = \frac{\sum Target\ Levels}{Number\ of\ answers}$$

The acquisition and summary of maturity and target level offers the great advantage of being able to evaluate in a second moment for each size category how far the current maturity level and target values differ one from another. As there are numerous data and configurations, it is reasonable to reinforce the whole graphically in order to create a certain clarity. Spider diagrams are deployed to show what the current ratio between maturity level and target values is for each field of the matrix. For this purpose, the calculated average values of maturity and target levels are exploited.

An example of such a representation follows in Figure 33, whereas the orange line represents the average target levels and the blue line the current average maturity of the respective

Industry 4.0 concept for a given combination. This graphic shows five diagrams, which respectively stand for the operational, organizational, socio-cultural as well as data-driven and process-driven technological dimension. These diagrams quickly reveal which Industry 4.0 concepts are already on the right track and which are lagging behind expectations.

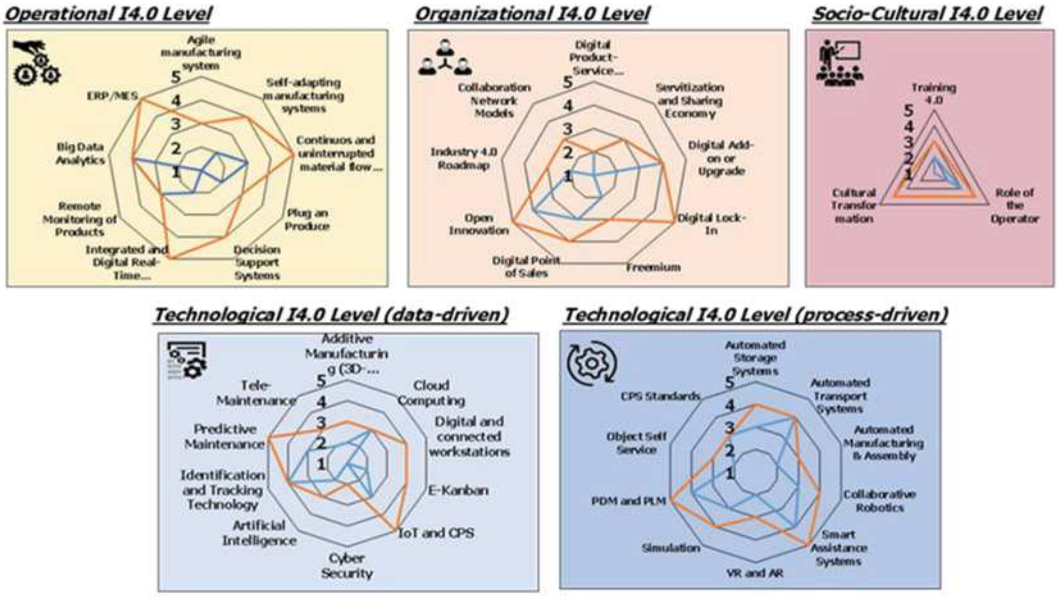


Figure 33. Assessment of actual maturity (blue line) and target levels (orange line).

After the analysis of the as-is and the target situation, the third point to be addressed is the perceived importance of the corresponding Industry 4.0 concepts, as already noted in the expert survey. The aim is to assess which concepts are being perceived most important for companies from the various size classes. To do this, all values must first be calculated and ranked then.

The importance of each concept is calculated for each size class. As previously, the importance values of the same categories and concepts are summed up and the mean value is then computed. This value indicates the average importance of the concepts assessed by the companies in the respective category.

$$(4) \quad Avg. Importance\ I4.0\ concept_{size} = \frac{\sum Importance\ Values}{Number\ of\ answers - "No\ Opinion"}$$

On the basis of these values, a ranking with the ten Industry 4.0 concepts most highly rated by the companies can then be created for each size category.

$$(5) \quad Ranking_{size} = Sort_{descending}\ [Importance\ I4.0\ concept_{size}]$$

Figure 34 illustrates this procedure, which foresees the elaboration of 20 rankings among the size-sector combinations.

I 4.0 Rank		Enterprise size			
		Micro XS	Small S	Medium M	Large L
	1	I4.0 Concept 1	I4.0 Concept 1	I4.0 Concept 1	I4.0 Concept 1
	2	I4.0 Concept 2	I4.0 Concept 2	I4.0 Concept 2	I4.0 Concept 2
	3	I4.0 Concept 3	I4.0 Concept 3	I4.0 Concept 3	I4.0 Concept 3
	4	I4.0 Concept 4	I4.0 Concept 4	I4.0 Concept 4	I4.0 Concept 4
	5	I4.0 Concept 5	I4.0 Concept 5	I4.0 Concept 5	I4.0 Concept 5
	6	I4.0 Concept 6	I4.0 Concept 6	I4.0 Concept 6	I4.0 Concept 6
	7	I4.0 Concept 7	I4.0 Concept 7	I4.0 Concept 7	I4.0 Concept 7
	8	I4.0 Concept 8	I4.0 Concept 8	I4.0 Concept 8	I4.0 Concept 8
	9	I4.0 Concept 9	I4.0 Concept 9	I4.0 Concept 9	I4.0 Concept 9
	10	I4.0 Concept 10	I4.0 Concept 10	I4.0 Concept 10	I4.0 Concept 10

Figure 34. Graphical representation of the enterprise survey ranking of I4.0 concepts per company size.

Finally, these results can be graphically displayed and substantiated. As previously in the expert survey, this is done again using bar charts, which present the Industry 4.0 concepts on the Y-axis and the corresponding mean values of the evaluated importance on the X-axis. In the following Figure 35 an example of such a representation in a ranking order of importance is illustrated.

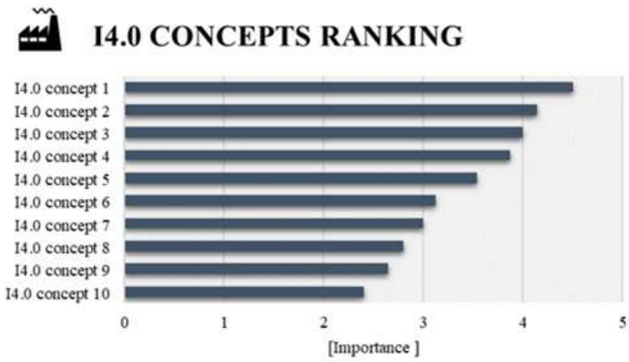


Figure 35. Bar chart representing the most suitable I4.0 concepts for a generic size-sector combination.

After a detailed discussion of how to evaluate the two surveys, the following subchapter deals with how to combine the results of the two surveys in order to derive recommendations for action for the individual size-sector combinations.

3.3.3 Statistical comparison of the experts and enterprise survey results

After the previous two sub-chapters dealt in great detail with the evaluation method of the two typologies of surveys, this final sub-chapter of the methodological part is concerned with the question of how these two can be compared. Previously, it was explained how to proceed in order to evaluate the experts and the enterprise survey individually. So far, however, the interrelation of these two valuable inputs from the various target groups is missing. Exactly this topic will be dealt with in the following. For this purpose, the results of the two surveys are compared statistically for each Industry 4.0 concept.

The statistical parameter which is most appropriate in this case is the standard deviation, which is generally known to describe the scatter range around the mean value. The objective of the statistical comparison is to find out whether the experts and the companies see the importance of an Industry 4.0 concept within a size class as similar or whether there are major differences in the expressed opinions of the two target groups.

Therefore, in a first step, the standard deviations of the importance values of each Industry 4.0 concept are calculated and evaluated within the expert survey, exploiting the following generally known formula for standard deviation.

$$(i) \quad \sigma_{exp.} = \sqrt{\frac{\sum_{n=1}^{i}(x_i - \mu)^2}{n}}$$

$\sigma = \ Standard\ Deviation\ generic\ I4.0\ concept\ Expert\ Survey_{size}$

$x_i = Rated\ Importance\ Value\ generic\ I4.0\ concept\ Expert\ Survey_{size}$

$\mu = Average\ Importance\ Value\ generic\ I4.0\ concept\ Expert\ Survey_{size}$

Once all values for the standard deviation of the individual concepts have been calculated, it is possible to analyze them. To do this, two approaches are considered. First, the calculated standard deviations give an indication whether the evaluation was unambiguous or inconclusive. In this context, a small value for the standard deviation means that the values tend to be close together, whereas a larger value shows a broader dispersion around the mean value. This means that for small values the opinions were of a similar nature, whereas for larger values there was no real agreement. The most understandable form for this is a graphical comparison of the individual rated values within a diagram. This provides a clear indication of the dispersion of the values around the mean values.

Figure 36 shows the two extreme examples mentioned, whereby the values in the left diagram are very close to the mean value and therefore feature a small standard deviation. In the right diagram the other extreme is to be considered, whereby the values here are clearly much more scattered and therefore show a higher standard deviation. The calculated mean values of these two examples, which equal the same value, are interesting to note in this context. It is evident that the mean value alone is not intended as a criterion but should only be used in combination with a scattering parameter. In these diagram blue dots are used which identify the expert opinions.

(i) Expert Survey Results

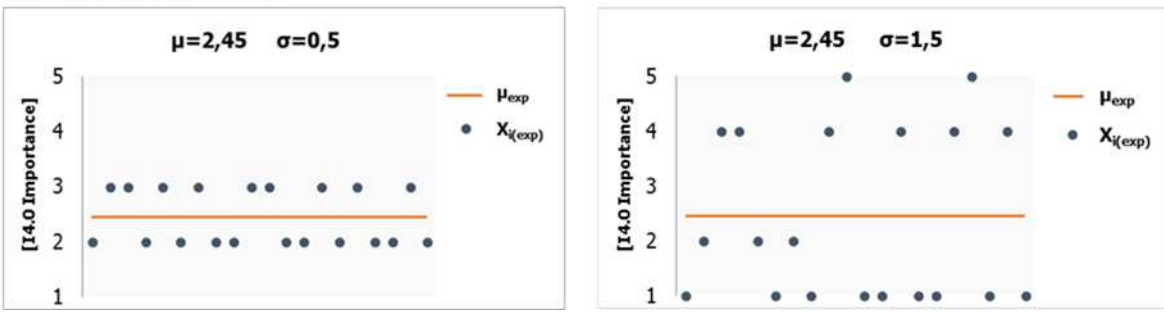


Figure 36. Examples of potential scattering of the results of the Expert Survey (blue dots).

Together with the calculated values, this graph provides an indication of whether the experts' responses to the individual concepts were clearly similar or very different.

The same procedure then follows for the results of the enterprise survey. First and foremost, the standard deviation is calculated numerically for each Industry 4.0 concept per size-sector combination based on the results of the enterprise survey.

$$(ii) \quad \sigma_{ent.} = \sqrt{\frac{\sum_{n=1}^{i}(x_i - \mu)^2}{n}}$$

$\sigma = Standard\ Deviation\ generic\ I4.0\ concept\ Enterprise\ Survey_{size}$

$x_i = Rated\ Importance\ Value\ generic\ I4.0\ concept\ Enterprise\ Survey_{size}$

$\mu = Average\ Importance\ Value\ generic\ I4.0\ concept\ Enterprise\ Survey_{size}$

These results can then be displayed graphically again. Figure 37 illustrates the two extreme examples for the scattering of the results as previously. However, with the difference that the dots here are marked with green color to show that these were opinions of the enterprises. These different colors are then used to overlap the results of the two surveys in the subsequent step.

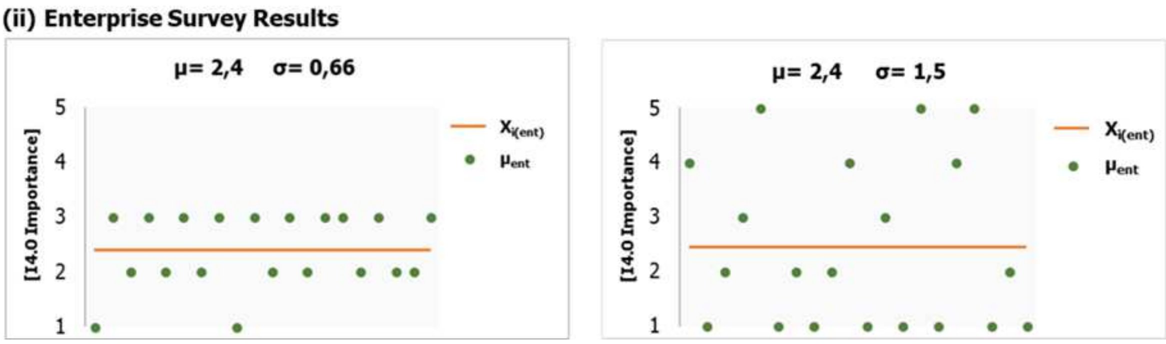


Figure 37. Examples of possible scattering of the enterprise survey results (green dots).

Once the scattering results of the two types of surveys have been individually analyzed, a statistical comparison can now be created with the standard deviation by making a statement as to whether theorists and practitioners see it at once or whether there are differences of opinion and of course analyze what could be the cause of this.

Below, Figure 38 depicts such a comparison of the results of the two surveys. Two extreme cases can occur here, the results of experts and companies being similar in the first case (left diagram). In the other case, opinions differ (right diagram).

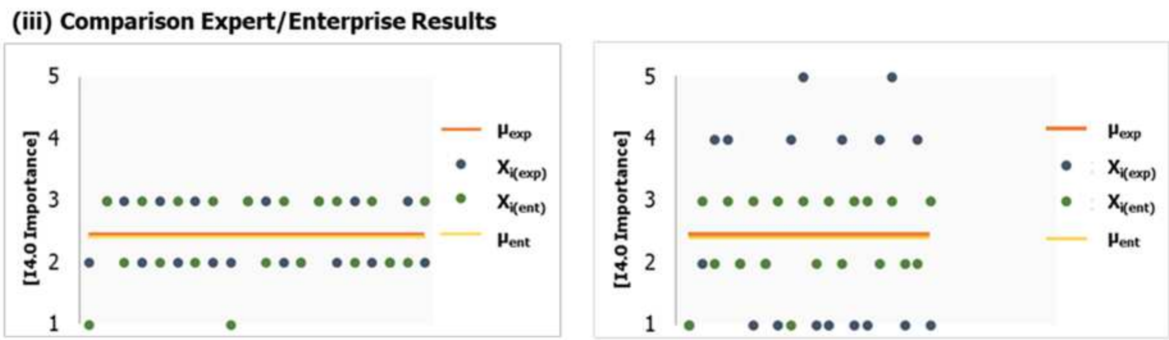


Figure 38. Examples of comparison of the results of expert and enterprise results.

This gives a statement about the importance of Industry 4.0 concepts according to experts (i), enterprises (ii) and both (iii) along with the individual statements of experts and enterprises. To evaluate, classify and rank an Industry 4.0 concept for a certain size category, it is clearly necessary that the results differ not too much.

Relative measure of dispersion

Since the importance of the calculated mean value is generally expressed by the scattered measure (standard deviation), it is advantageous to include another variable in the analysis, the coefficient of variation.

The coefficient of variation (Cv) is the quotient of the standard deviation and the mean value, and is therefore, in contrast to the standard deviation, a relative measure of dispersion. The main reason for the introduction of this variable lies in the fact that higher mean values generally have a larger variance than those with small mean values. This is standardized by the coefficient of variation.

This value is calculated for every Industry 4.0 concept within the two survey forms and company sizes, as pointed out subsequently.

$$(1)\ Cv_{exp./size} = \frac{\sigma_{exp./size}}{\mu_{exp./size}}$$

$Cv_{exp./size} = Coefficient\ of\ variation\ of\ a\ I4.0\ concept\ within\ expert\ survey\ per\ size$

$\sigma_{exp.} = Standard\ deviation\ of\ a\ I4.0\ concept\ within\ expert\ survey\ per\ size$

$\mu_{exp.} = Mean\ value\ of\ a\ I4.0\ concept\ within\ expert\ survey\ per\ size$

$$(2)\ Cv_{ent./size} = \frac{\sigma_{ent.}}{\mu_{ent.}}$$

$Cv_{ent./size} = Coefficient\ of\ variation\ of\ a\ I4.0\ concept\ within\ enterprise\ survey\ per\ size$

$\sigma_{ent.} = Standard\ deviation\ of\ a\ I4.0\ concept\ within\ enterprise\ survey\ per\ size$

$\mu_{ent.} = Mean\ value\ of\ a\ I4.0\ concept\ within\ enterprise\ survey\ per\ size$

The coefficient of variation is expressed as a percentage, which means that it can be rapidly and intuitively ascertained whether the values are scattered or not.

In summary, it can be stated that per Industry 4.0 concept per company size for the expert as well as enterprises survey, the mean values, standard deviations and coefficients of variation are being calculated. The mean value indicates the evaluated importance, the standard deviation and coefficient of variation provide information about the dispersion of the results. Furthermore, it is possible to draw conclusions about whether experts and companies see things similar or not in relation to certain Industry 4.0 concepts.

The combination of the statements of the experts and companies forms the basis for deriving the recommendations for action for companies in the various fields of the size matrix, which follow in chapter 5.

To sum up, the methodical part dealt first and foremost with the actual goal, which is to answer the research question, in a nutshell: is it possible to offer companies recommendations for the introduction of Industry 4.0 concepts based on the enterprise size? To answer this question, the criterion was first of all defined, and the procedure for classifying enterprises was conducted. From there it was possible to derive four different size categories or classes. Subsequently, it was shown how the survey, which serves to collect the necessary data, is structured and designed. Last but not least, as a fundamental step in the concept of this work, the method for the evaluation of this data by which the recommendations will be deducted at a later stage was explained and clarified.

The next chapter is about applying this developed methodology by explaining how the survey is conducted and how the analysis of the results is approached.

4

RESULTS AND DISCUSSION

After the previous chapter dealt in detail with how the survey is structured and how it is subsequently evaluated and analyzed, this fourth chapter is precisely concerned with applying the methodology described in order to evaluate and analyses the results of the survey.

The approach is to describe the survey in a first moment in section 4.1, general aspects, such as participants, geographical distribution, etc. The results of the survey are then presented in section 4.2 followed by a discussion of these findings in section 4.3. The result of this chapter follows in 4.4, which is the core of this work, as it deals with the recommendations for suitable Industry 4.0 concepts for the different enterprise sizes examined.

4.1 General survey analysis

This section gives some general information about the expert first and the enterprise survey in a second moment. In this context, the participants are addressed by explaining the response rate, geographical distribution and research focuses for the experts as well as the field of activity of the enterprises. Therefore, first some general information of the expert survey is provided followed by the enterprise survey.

4.1.1 Expert survey

The expert survey was sent out to 35 researchers involved in the project "Industry 4.0 for SME's", financed by the Horizon 2020 research fund of the European Research MSCA RISE program (grant number 734713), in which besides the Free University of Bolzano nine other universities are involved.

The involved experts, researchers and professors are working on Industry 4.0 for SME's at different universities and research institutions around the globe. In addition, they are increasingly collaborating with enterprises within their research activities in order to support them in their implementation of the digital transformation.

With regard to the main areas of research, these lie at macro level in the two areas of industrial engineering and construction engineering, always related to digitization frameworks. The main research topics of the participants at the micro level are listed subsequently:

- Manufacturing Systems
- Business Model Engineering
- Collaborative Robotics
- Smart Logistics
- Operations Management
- Computational Design
- Smart Logistics
- Manufacturing

- Decision Making
- Industrial Automation

Despite the relatively small number of participants in the expert survey, it can be inferred from the list of research fields that they have many different research focuses and that the field is therefore very broadly diversified. In general, all researchers within this project have an excellent basic education in the field of Industry 4.0 and are therefore well-able to assess concepts which they are not in constant contact with in their daily work.

Figure 39 below sheds light on the geographical distribution of the participants in the expert survey, illustrating it in the context of a map.

Figure 39: Countries of origin of expert survey participants (created with Google MyMaps).

The participating researchers come from five different countries of origin (Italy, Austria, Switzerland, United States of America and Slovakia), with the core concentrated in Central Europe.

Within the investigation period, the survey was sent back by twelve researchers, corresponding to a response rate of approximately 34%. Although this is not a bad value in general, a higher participation rate was expected.

$$(1)\ Response\ Rate_{exp.}[\%] = \frac{Nr.of\ Participants_{\ exp.}}{Nr.sent\ out_{\ exp.}} = \frac{12}{35} = 0{,}342857 \cong 34\%$$

The twelve participating experts were asked to assess the importance from one to five of each Industry 4.0 concepts for the different enterprise sizes for the construction and manufacturing sectors, where one corresponds to a concept which is not at all important and five standing for a very important Industry 4.0 concept for that type of enterprise.

4.1.2 Enterprise survey

The basis for the launch of the enterprise survey was a database with more than 200 contacts containing companies in the province of South Tyrol. In addition, the survey and its objective were also presented in several expert presentations in which several enterprises have participated.

An important criterion that was considered was the fact that the participating companies had their own production, as a large part of the Industry 4.0 concepts in the assessment refer to this. For this reason, companies without their own production were filtered out in advance. Altogether it has been attempted to get feedback for the survey via direct e-mail contact or other channels such as events and lectures. A total of about 300 enterprises were approached.

The companies contacted were from a wide range of sizes (XS, S, M and L) and sectors. A breakdown of the 300 requests sent out into the various size categories was not carried out, solely for the reason of the impossibility of finding data such as number of employees, turnover and balance sheet total of all these enterprises.

Whereas in the expert survey on the means of possible pattern recognition, the macro sectors manufacturing and construction were surveyed, in the enterprise survey micro sectors were also included in order to eventually draw conclusions at a later point in time with these data not only about the size of the company, but also regarding activity sectors in a second moment.

The enterprises were distributed among the following sectors:

- Materials Manufacturing (wood, paper, chemicals, rubber, metal, non-metal)
- Industrial Goods (machinery, equipment, components)
- Textile & Clothing (textiles, clothing, leather)
- Food & Beverages (food, beverages, tobacco)
- Construction (high construction, specialized construction)

What immediately stands out is that in this case the first four sectors belong to the macro sector manufacturing, whereby the macro sector construction is taken over in this way (including high construction and specialized construction), as a low number of returns could already be expected in this case, due to the distribution of enterprises in the province dominated by manufacturing landscape over construction.

A total of 31 companies fully completed the survey, corresponding to a response rate of 10% considering a number of approximately 300 enterprises approached.

$$(2)\ Response\ Rate_{ent.}[\%] = \frac{Nr. of\ Participants_{\ ent.}}{Nr. sent\ out_{\ ent.}} = \frac{31}{300} = 0{,}1033 \cong 10\%$$

The response rate within the individual company categories, micro, small, medium and large was very different. Figure 40 shows the distribution graphically by means of a heat map.

	Enterprise size			
	Micro *XS*	Small *S*	Medium *M*	Large *L*
Nr. of responses	*0*	*8*	*10*	*13*

$\sum$ **30**

Figure 40: Heat-map showing the response rate per company size.

The colors of the individual fields in the matrix similarly to a temperature scale, indicate information about the replies within the company categories, where blue stands for a small number of replies and red for a high number of replies greater than ten.

The most striking features of the chart are the low number of participating companies that fall into the micro (XS) category, corresponding to zero responses, and the high proportion of large (L) companies that comprise thirteen participating companies.

The low number of micro enterprises can probably be explained by the fact that some of these companies are not yet interested in digitalization at all, or do not have the necessary know-how in this field in order to evaluate their enterprise on their own by the means of a self-assessment. Some of these are simple craft businesses such as joineries or locksmiths, with only a few employees, managing their enterprise partly still very traditionally without planning software.

The opposite is the case with large companies. Here there was lively participation and high interest in self-assessment and thus participation in the survey. Most of these companies are already in the process of advancing digitization or are at least already considering incorporating or further developing Industry 4.0 concepts within their environment.

Last but not least, the small and medium-sized enterprises also provide a relatively good participation rate, with eight and nine participants for small and medium sized respectively in the enterprise survey. This indicates that the attention of SME's to digitalization frameworks is also increasing and that they are actually already dealing with it.

All in all, it can be stated that Industry 4.0 concepts seem to already be in a phase of introduction in large companies. Small and medium sized businesses are already considering the topic, whereas micro enterprises apparently are lacking interest in digitization up to now. This is the reason because this work concentrates on the comparison of Industry 4.0 concepts in large, medium and small enterprises, excluding micro enterprises that in this case do not make sense to be analyzed.

Subsequently, Figure 41 shows the geographical distribution of the participating companies in the enterprise survey.

Figure 41: Geographical distribution of enterprise survey participants (created with Google MyMaps).

The participants in the survey came from three different countries, namely Italy, Austria and the United States of America. As can be deducted from the map, the field of participants is concentrated on Central Europe, similar to the expert survey.

4.2 Survey results

After having clarified the key data as well as general information regarding the expert and enterprise survey, this section illustrates the findings of the survey and provides an overview of the survey results.

In the first instance, the reader is given an overview of the results of the experts and enterprise surveys for the different enterprise sizes, followed by a comparison of the results of the two survey forms. However, before proceeding with this, it is of fundamental importance to briefly explain the procedure and methodology of the evaluation in a nutshell.

The evaluations of the two surveys have the same structure and are basically based on the evaluated importance of the individual Industry 4.0 concepts with regard to the different company sizes of the two target groups. Experts and enterprises evaluated on a scale of one to five how important an Industry 4.0 concept is for the respective enterprise category, whereby one stands for a concept that is not at all important and five is rated as very important.

In general, the assessed importance of a single Industry 4.0 concept is characterized by the average value ($\overline{X}$), the respective standard deviation (σ), the coefficient of variation (C_v) as a measure of relative variability of the answers as well as the number of answers (n).

$$(1) \quad \overline{X} = \frac{\sum Importance\ Values}{Number\ of\ answers - "No\ answer"}$$

$$(2) \quad \sigma = \sqrt{\frac{\sum_{n=1}^{i}(x_i - \mu)^2}{n}}$$

$$(3) \quad C_v = \frac{\sigma}{\overline{X}}$$

These values are processed for every Industry 4.0 concept in the expert and enterprise survey and for every size of enterprise.

In the following tables the results of the enterprise and expert survey are reported, by showing the number of answers, the average importance value and the standard deviation of every Industry 4.0 concept for the different enterprise sizes for both survey target groups.

Subsequently, the results of the enterprise and the expert survey for small enterprises, represented by the number of responses (n), the rated average importance values ($\overline{X}$), the standard deviation (σ) and the coefficient of variation (C_v) for every Industry 4.0 concept are illustrated.

Table 1, 2 and 3 show the findings of the enterprise and expert survey results for small, medium-sized and large companies respectively. Within the tables the results of enterprises and experts are confronted. Thereby similarities and possible discrepancies are identifiable quickly. Regarding the ordering of the results, it is of fundamental interest to mention that, as deducible from the tables, the Industry 4.0 concepts were ranked according to the average importance of enterprise survey average importance values opposing the respective expert results.

Table 1: Enterprise and expert survey results for small enterprises.

SMALL (S)	Enterprise				Expert			
Industry 4.0 Concept	*n*	$\bar{X}$ *Ent*	*σ*	*Cv En*	*n*	$\bar{X}$ *Exp*	*σ*	*Cv Exp.*
Agile Manufacturing Systems	8	4,75	0,66	14%	12	3,58	0,86	24%
Cultural Transformation	7	4,14	0,83	20%	12	3,92	1,26	32%
Continuous material flow models	7	4,00	1,31	33%	12	3,58	1,11	31%
Digital and connected workstations	7	4,00	1,31	33%	11	3,18	0,83	26%
Digital Real-Time Monitoring Systems	8	3,88	0,78	20%	12	2,67	1,31	49%
Role of the Operator	7	3,86	1,36	35%	11	4,00	0,95	24%
Self-adapting manufacturing systems	7	3,71	1,03	28%	12	3,08	1,11	36%
Big Data Analytics	7	3,71	1,39	37%	12	2,50	1,04	42%
Cyber Security	8	3,63	0,99	27%	12	3,75	1,09	29%
ERP/MES	8	3,63	0,99	27%	12	3,25	1,09	34%
Industry 4.0 Roadmap	7	3,57	1,18	33%	12	3,75	1,01	27%
Training 4.0	7	3,57	0,73	20%	12	3,67	0,85	23%
Decision Support Systems	7	3,57	0,90	25%	12	3,00	1,00	33%
PDM and PLM	7	3,43	0,73	21%	11	3,09	1,00	32%
Sustainable Supply Chain Design	8	3,38	0,99	29%	12	3,00	1,00	33%
Collaboration Network Models	8	3,25	0,66	20%	12	3,58	0,86	24%
Digital Product-Service Systems	8	3,25	1,20	37%	11	3,09	1,00	32%
Tele-Maintenance	7	3,14	1,12	36%	12	3,17	1,40	44%
Additive Manufacturing (3D-Print)	8	3,13	1,05	34%	11	2,91	0,67	23%
Predictive Maintenance	7	3,00	1,07	36%	12	3,58	1,04	29%
Open Innovation	8	3,00	0,87	29%	11	3,55	1,37	39%
Cloud Computing	8	3,00	1,12	37%	12	3,17	1,14	36%
E-Kanban	8	3,00	1,32	44%	10	2,90	1,04	36%
IoT and CPS	7	3,00	1,20	40%	12	2,83	1,14	40%
Collaborative Robotics	7	2,86	1,64	57%	12	3,25	1,16	36%
Simulation	7	2,86	0,99	35%	12	3,17	0,90	28%
Automated Manufacturing/ Assembly	7	2,86	1,55	54%	12	2,92	1,04	36%
Object Self Service	7	2,71	0,88	32%	9	2,44	1,17	48%
Identificat. and Tracking Technology	7	2,57	1,18	46%	12	3,42	1,11	33%
Smart Assistance Systems	7	2,57	1,40	54%	11	3,18	1,27	40%
Plug and Produce	7	2,57	0,73	28%	12	3,00	1,41	47%
Automated Storage Systems	7	2,57	0,90	35%	11	2,55	0,89	35%
Freemium	7	2,29	1,28	56%	11	2,64	0,77	29%
Remote Monitoring of Products	8	2,25	0,97	43%	12	2,42	0,49	20%
CPS Standards	7	2,14	1,36	64%	11	3,09	1,24	40%
VR and AR	7	2,14	1,25	58%	12	2,75	0,83	30%
Automated Transport Systems	7	2,14	0,64	30%	11	2,27	0,86	38%
Digital Point of Sales	8	2,13	1,27	60%	12	3,00	0,91	30%
Servitization/Sharing Economy	8	2,00	1,00	50%	8	3,38	1,11	33%
Digital Add-on or Upgrade	8	2,00	1,22	61%	9	2,00	0,47	24%
Artificial Intelligence	7	1,71	1,03	60%	12	2,83	1,14	40%
Digital Lock-In	8	1,25	0,43	34%	8	2,63	1,22	46%

Table 2: Enterprise and expert survey results for medium-sized enterprises.

MEDIUM (M)	Enterprise				Expert			
Industry 4.0 Concept	*n*	*X̄ Ent*	*σ*	*Cv En*	*n*	*X̄ Exp*	*σ*	*Cv Exp.*
ERP/MES	10	4,20	0,98	23%	12	4,00	0,91	23%
Digital Real-Time Monitoring Systems	10	4,20	0,98	23%	12	3,92	0,86	22%
Digital and connected workstations	10	4,20	0,75	18%	11	3,91	0,67	17%
Industry 4.0 Roadmap	10	4,00	0,77	19%	12	4,33	0,75	17%
Cyber Security	10	3,90	0,83	21%	12	4,25	0,92	22%
Cultural Transformation	10	3,70	1,1	30%	12	4,08	0,86	21%
Agile Manufacturing Systems	10	3,70	1	27%	12	3,92	0,76	19%
Cloud Computing	10	3,70	0,64	17%	12	3,42	1,04	30%
Training 4.0	10	3,60	0,66	18%	12	4,42	0,64	14%
Collaboration Network Models	10	3,50	0,81	23%	12	3,67	0,75	20%
Big Data Analytics	10	3,50	1,02	29%	12	3,67	1,43	39%
Automated Storage Systems	10	3,50	0,67	19%	11	3,55	0,89	25%
Predictive Maintenance	10	3,40	1,11	33%	12	4,33	0,47	11%
Identificat. and Tracking Technology	10	3,40	0,8	24%	12	4,33	0,47	11%
Role of the Operator	10	3,40	1,2	35%	11	3,82	0,83	22%
Continuous material flow models	10	3,30	1,1	33%	12	4,17	0,80	19%
PDM and PLM	10	3,30	1,1	33%	11	3,73	0,75	20%
Tele-Maintenance	10	3,10	1,14	37%	12	3,75	0,92	25%
Object Self Service	10	3,10	1,37	44%	9	3,22	1,13	35%
Automated Manufacturing/ Assembly	10	3,00	1,1	37%	12	4,00	0,91	23%
Self-adapting manufacturing systems	10	3,00	0,77	26%	12	3,83	1,14	30%
IoT and CPS	10	3,00	0,89	30%	12	3,67	0,62	17%
Smart Assistance Systems	10	3,00	0,77	26%	11	3,64	0,98	27%
Collaborative Robotics	10	2,90	1,04	36%	12	4,00	0,82	20%
Decision Support Systems	10	2,90	0,94	32%	12	3,92	0,76	19%
Open Innovation	9	2,89	1,2	42%	11	3,18	1,11	35%
Automated Transport Systems	10	2,80	0,87	31%	11	3,45	0,89	26%
VR and AR	10	2,80	0,87	31%	12	3,33	0,85	25%
Simulation	10	2,70	1,27	47%	12	3,92	0,49	13%
Remote Monitoring of Products	10	2,70	1,19	44%	12	3,83	0,80	21%
CPS Standards	10	2,60	1,11	43%	11	3,82	0,83	22%
Digital Point of Sales	10	2,60	1,11	43%	12	3,25	0,83	26%
E-Kanban	10	2,50	1,2	48%	10	3,70	0,78	21%
Digital Product-Service Systems	10	2,50	1,57	63%	11	3,64	1,07	21%
Sustainable Supply Chain Design	10	2,40	1,02	43%	12	3,83	0,90	29%
Artificial Intelligence	10	2,40	0,8	33%	11	3,73	0,96	23%
Servitization/Sharing Economy	10	2,40	1,62	68%	8	3,13	0,93	26%
Plug and Produce	10	2,10	0,7	33%	12	3,42	0,64	30%
Freemium	10	2,10	1,45	69%	11	3,00	0,74	19%
Digital Add-on or Upgrade	10	1,90	1,04	55%	9	2,89	0,74	25%
Additive Manufacturing (3D-Print)	10	1,70	1	59%	11	3,18	0,72	26%
Digital Lock-In	10	1,40	0,49	35%	8	3,25	0,97	22%

Table 3: Enterprise and expert survey results for large enterprises.

LARGE (L)	Enterprise				Expert			
Industry 4.0 Concept	*n*	*$\bar{X}$ Ent*	*σ*	*Cv En*	*n*	*$\bar{X}$ Exp*	*σ*	*Cv Exp.*
Cyber Security	13	4,77	0,42	9%	12	4,50	0,76	17%
ERP/MES	13	4,62	0,62	13%	12	4,25	0,83	20%
Industry 4.0 Roadmap	12	4,33	0,75	17%	12	4,25	0,83	20%
Digital Real-Time Monitoring Systems	13	4,23	0,89	21%	12	4,75	0,43	9%
Cultural Transformation	13	4,23	0,70	17%	11	4,18	0,83	20%
Big Data Analytics	13	4,15	0,77	19%	12	4,25	1,01	24%
Digital and connected workstations	12	4,08	0,86	21%	11	4,09	0,79	19%
Agile Manufacturing Systems	12	4,08	1,19	29%	12	4,08	0,76	19%
Automated Manufacturing/ Assembly	13	4,00	1,18	30%	12	4,33	0,75	17%
Role of the Operator	13	3,77	1,05	28%	11	3,82	1,03	27%
Predictive Maintenance	12	3,75	1,09	29%	12	4,67	0,47	10%
PDM and PLM	12	3,75	0,92	25%	11	4,36	0,77	18%
Automated Transport Systems	12	3,75	1,01	27%	12	4,25	0,83	20%
Collaboration Network Models	12	3,75	0,83	22%	12	3,83	0,90	23%
Training 4.0	13	3,69	0,91	25%	12	4,58	0,64	14%
Cloud Computing	13	3,69	0,99	27%	12	4,00	1,00	25%
Identificat. and Tracking Technology	13	3,62	1,00	28%	12	4,50	0,50	11%
Decision Support Systems	13	3,62	0,92	25%	12	4,33	0,75	17%
Automated Storage Systems	13	3,62	1,00	28%	12	4,25	0,72	17%
Collaborative Robotics	12	3,58	1,19	33%	12	4,17	0,99	24%
E-Kanban	11	3,55	1,30	37%	10	4,20	0,75	18%
Remote Monitoring of Products	12	3,50	1,71	49%	12	4,50	0,65	14%
CPS Standards	12	3,50	0,76	22%	11	4,18	0,72	17%
IoT and CPS	12	3,50	1,38	39%	12	4,08	0,64	16%
Self-adapting manufacturing systems	12	3,50	0,76	22%	12	3,83	0,99	26%
Continuous material flow models	13	3,46	1,01	29%	12	4,58	0,76	17%
Simulation	12	3,42	0,95	28%	12	4,42	0,64	14%
Tele-Maintenance	12	3,42	1,04	30%	12	3,92	0,95	24%
Open Innovation	12	3,42	1,04	30%	11	3,27	1,14	35%
Sustainable Supply Chain Design	13	3,38	0,84	25%	12	4,17	0,90	22%
Digital Point of Sales	11	3,36	1,37	41%	12	3,67	1,03	28%
Smart Assistance Systems	12	3,33	0,75	23%	11	3,91	0,90	23%
Digital Product-Service Systems	12	3,33	1,43	43%	11	3,91	1,24	32%
Artificial Intelligence	13	3,08	1,21	39%	11	4,45	0,78	32%
Servitization/Sharing Economy	11	3,00	1,54	51%	8	3,25	1,20	18%
VR and AR	12	2,92	0,64	22%	12	4,00	1,00	37%
Plug and Produce	11	2,73	0,86	32%	12	3,58	0,86	25%
Digital Add-on or Upgrade	12	2,58	1,26	49%	9	3,44	0,96	24%
Object Self Service	11	2,55	1,50	59%	9	3,78	1,13	28%
Additive Manufacturing (3D-Print)	13	2,54	1,28	50%	11	3,45	0,78	30%
Digital Lock-In	12	2,50	0,96	38%	8	3,38	0,99	23%
Freemium	12	2,50	1,32	53%	11	3,00	1,04	29%

The results presented herein and the comparison between the two survey forms are examined in detail in the following section, the discussion of the results.

4.3 Discussion of results

The following discussion of the results is structured as follows by default. First the expert survey results are discussed followed by the enterprise results. In each case, the conspicuities within the individual size categories are analyzed in detail. Subsequently, the homogeneity of the results is examined, whereby the question arises as to how the respondents agree with regard to the tested Industry 4.0 concepts. Finally, the core of the section follows, which is the comparison of the two target groups, namely the confrontation of the viewpoints of the companies against those of the experts. This involves comparing the results graphically and identifying and interpreting similarities or discrepancies.

Observing the results distribution of the **expert survey** in Table 4, it is immediately striking that the subject of Industry 4.0 is generally approached very positively in this context. The experts do not rate a single Industry 4.0 concept as not at all important on average. They therefore rated all Industry 4.0 concepts for small, medium-sized and large enterprises as slightly important and more. Particularly noteworthy here is the fact that the experts rate Industry 4.0 concepts more important as the size of the enterprise increases. For large companies they actually estimate all 42 Industry 4.0 concepts to be between important and very important classifying as many as 27 concepts as between fairly important and important. The positive tendency towards Industry 4.0 is similar also for medium-sized enterprises, although the distribution of intervals is varying. The majority, 31 of the concepts are rated between important and fairly important and ten between fairly important and very important. One single Industry 4.0 concept is rated with an average importance value less than two. In the case of small companies, the experts generally attach less significance to the importance values than in the case of medium sized and large enterprises. In this context only one Industry 4.0 concept is rated as fairly important to very important. 26 Industry 4.0 concepts are classified as between important to fairly important and 15 between slightly important and important.

Table 4: Distribution of results of in the expert survey.

	Small (S)	Medium (M)	Large (L)
$\bar{X} \geq 4$	1	10	27
$3 \geq \bar{X} < 4$	26	31	15
$2 \geq \bar{X} < 3$	15	1	0
$\bar{X} < 2$	0	0	0

Figure 42 graphically illustrates the described distribution within the intervals very clearly.

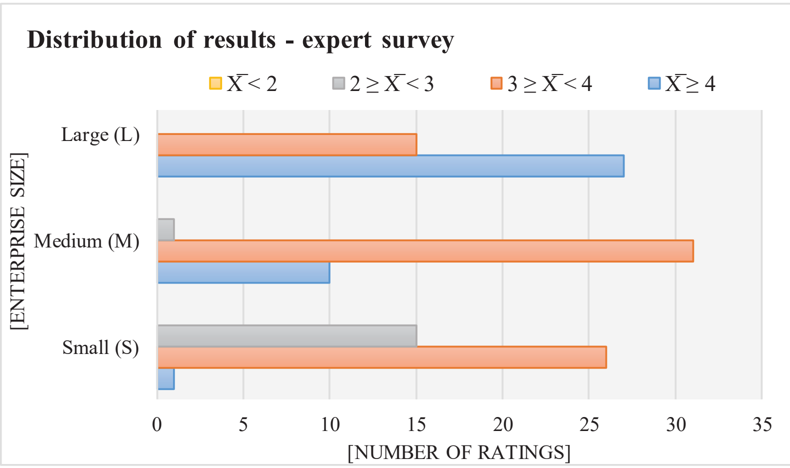


Figure 42: Graphical representation of the distribution of results (expert survey).

In general, it can be deduced here that the experts regard the increased significance of

Industry 4.0 concepts as the size of the company increases.

In the case of the **enterprise survey**, the results were slightly different. As clearly shown in Table 5 at first glance, it is noticeable at this point that differently as for the expert survey certain Industry 4.0 concepts are rated as not important to slightly important. The participating large companies rated nine Industry 4.0 concepts between fairly important and very important, 26 as important to fairly important and seven from slightly important to important. Not a single Industry 4.0 concept was assessed as not at all important within this category. The figures for medium-sized enterprises on the other hand were different. In this category, only four Industry 4.0 concepts were classified as fairly important or very important, with a total of 19 being rated between important and fairly important and 16 as slightly important to important. There were three Industry 4.0 concepts rated as slightly or not at all important. For small enterprises, the distribution of results was once again descending in relation to the other two categories. As with medium sized enterprises, four Industry 4.0 concepts were rated as fairly important to important, 20 between important and fairly important and 16 as slightly important to important. two Industry 4.0 concepts were rated as not at all important to slightly important.

Table 5: Distribution of results of in the enterprise survey.

	Small (S)	Medium (M)	Large (L)
$\bar{X} \geq 4$	4	4	9
$3 \geq \bar{X} < 4$	20	19	26
$2 \geq \bar{X} < 3$	16	16	7
$\bar{X} < 2$	2	3	0

Subsequently, Figure 43 depicts the distribution within the intervals described in Table 11.

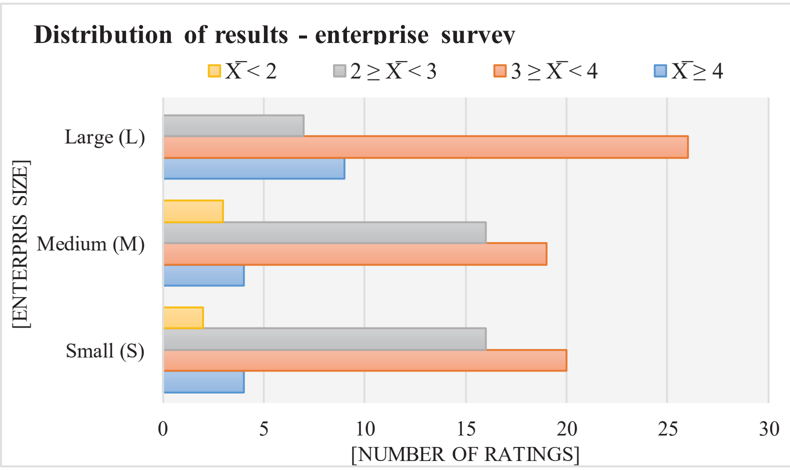


Figure 43: Graphical representation of the distribution of results (enterprise survey).

In general, as with the expert survey, the importance of Industry 4.0 concepts increases proportionally with company size. However, companies rated less Industry 4.0 concepts as very important, the distribution here is denser in the intervals from two to four, i.e. slightly important to fairly important. 104 of 126 Industry 4.0 concepts within the three categories were evaluated in this range, corresponding to a percentage of approximately 83 %. The reason for this different view of the two target groups could possibly be that the experts consider the importance higher, since they possess a more mature know-how about the matter and already adapt very modern future-oriented technologies in research. Nevertheless, practical results should also receive considerable attention, as companies actually apply the new technologies themselves knowing the technologies that are suited to what purpose. However, this knowledge does not yet seem to have been completely transferred to Industry

4.0 throughout.

Following the detailed analysis of the distribution of the results of the two surveys within the stated intervals and the identification of general trends therein, the analysis proceeds one step further by presenting the results of the individual Industry 4.0 concepts. It is particularly interesting to compare the expert opinions and the assessments from the enterprises' practical experience.

In the following, the results of the **evaluations of companies and experts** per enterprise size will be examined and contrasted in order to highlight possible similarities or divergences existing between theoreticians and practitioners. Figure 44 depicts the comparison of the evaluated importance of the individual Industry 4.0 concepts from the perspective of the companies (orange) and the experts (blue) for large companies.

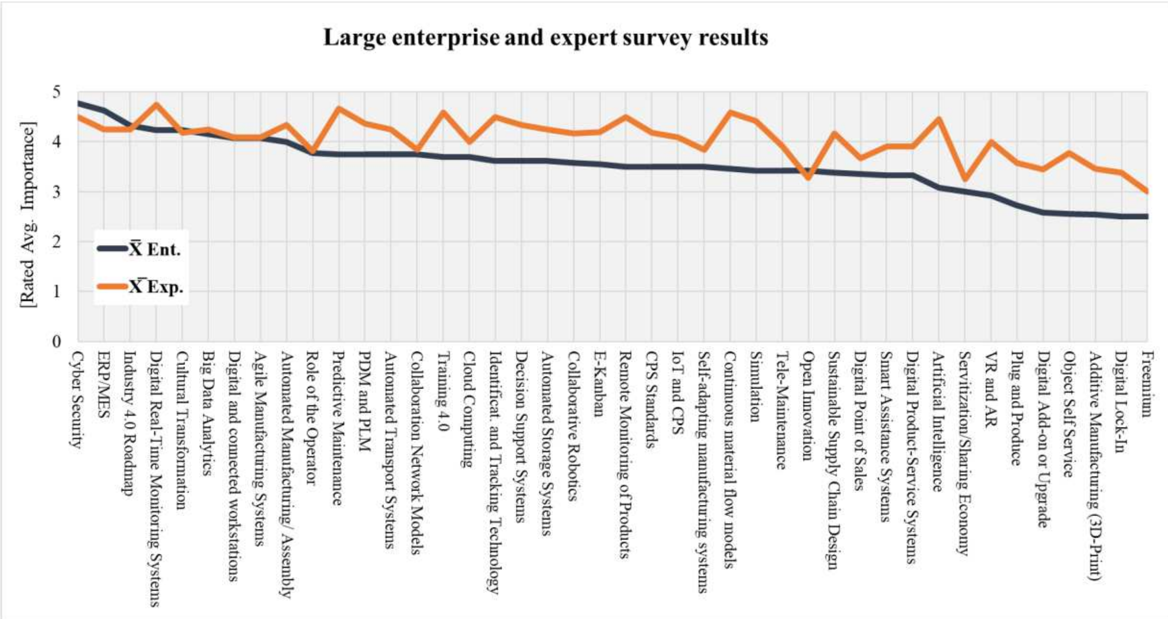


Figure 44: Comparison of rated importance values ($\bar{X}$) in enterprise and expert survey for large enterprises.

This chart shows a lot of interesting findings at a glance. First, the results of the two surveys generally do not seem to be too far apart. In addition, it is immediately noticeable that in almost all Industry 4.0 concepts the importance is rated higher by the experts than by the companies. Exceptions are ‘Cyber Security, ‘ERP/MES’ as well as ‘Open Innovation’. These three are rated more relevant by companies than by experts. Both target groups are completely in agreement at ‘Agile Manufacturing Systems’ and rate this concept identically on average. Similarly, ‘Industry 4.0 Roadmap’, ‘Cultural Transformation’, ‘Big Data Analytics’, ‘Digital and connected workstations’ and ‘Role of the were rated almost equally relevant by enterprises and experts. The largest deviations are recorded in ‘Remote Monitoring of Products’ ‘Continuous material flow models’, ‘Artificial Intelligence’ and ‘Object Self Service’, whereby in each of these cases the experts rate the relevance significantly higher.

Another interesting value to analyze is the **coefficient of variation**. This describes the percentage of dispersion around the average value. Basically, it means that for a small value the respondents were relatively in agreement about the importance of an Industry 4.0 concept and for a large value the opinions were more divided. The following Figure 45 plots the coefficients of variation of the individually evaluated Industry 4.0 concepts of the experts and companies survey in the category of large enterprises.

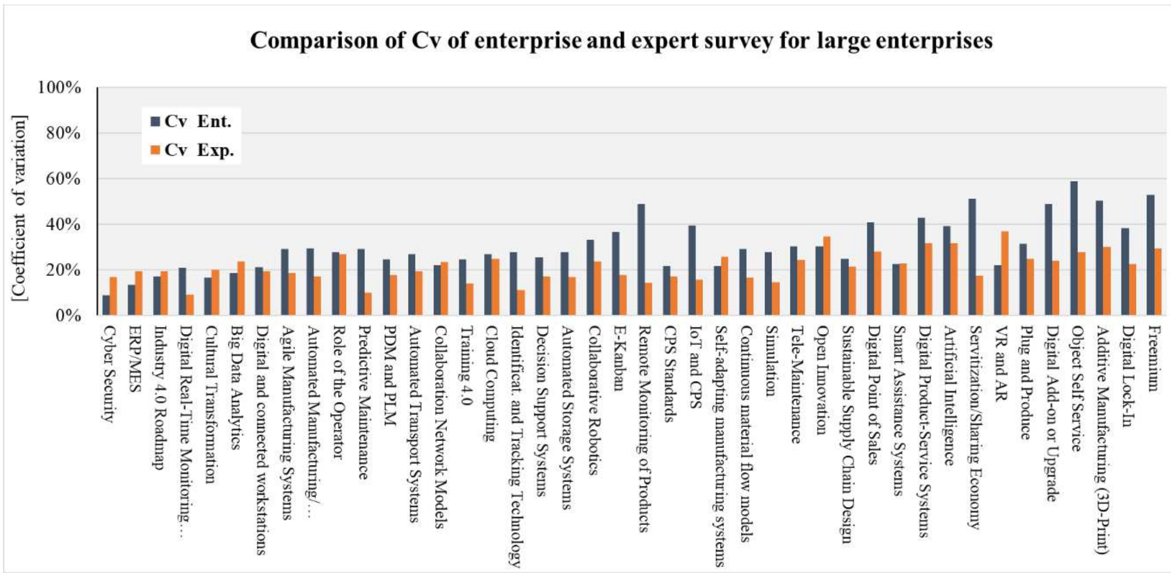


Figure 45: Representation of coefficient of variation (C_v) in enterprise and expert survey for large enterprises.

The diagram unfolds to reveal that the experts, in contrast to the companies, are clearly more in agreement, which corresponds to a smaller coefficient of variation. This is clearly evidenced by the average variation coefficient recorded. In the enterprise survey its rate was 31% whereas in the expert survey approximately 21%. A possible reason for this could be that the experts are at a similar level of education in relation to Industry 4.0, while there are still widely differing views on this in the business world. Exceptions where enterprise judgements are more closely aligned are ‘Cyber Security’, ‘ERP/MES’ and ‘Industry 4.0 Roadmap’. For some Industry 4.0 concepts the coefficients of variation of the two groups are very similar, e.g. ‘Cloud Computing’ and ‘Smart Assistance Systems’.

Next, the focus of attention is the analysis for the category medium-sized enterprises. Figure 46 displays a comparison of the **enterprise and expert evaluations**.

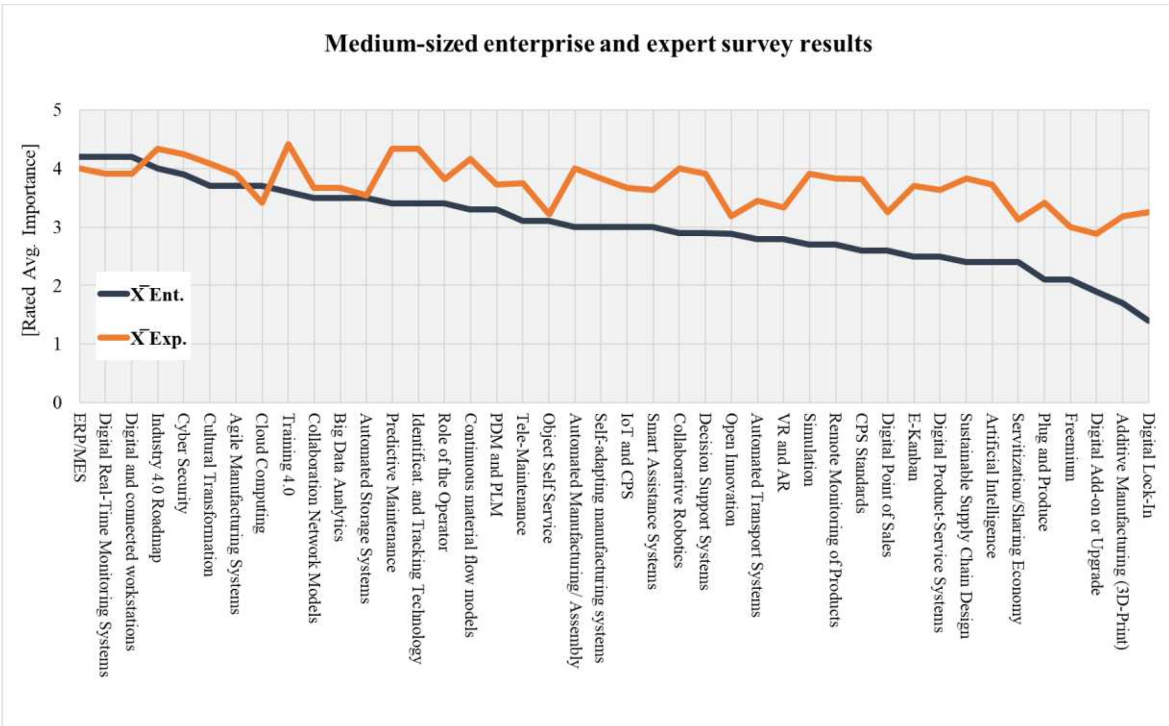


Figure 46: Comparison of rated importance values ($\bar{X}$) in enterprise and expert survey for small enterprises.

The graph shows that the results of the enterprise survey (blue) and expert survey (orange) are further apart than those of the large enterprises. However, the situation is reminiscent of the results in the large companies' category, as in general the experts rate the importance of nearly every Industry 4.0 concept more highly than the enterprises. A hypothesis of these results is the farsightedness of the experts assessing the future benefits of Industry 4.0 concepts, while companies are not yet so aware of the opportunities arising from them. The only exceptions are given by 'ERP/MES', 'Digital Real-time Monitoring', 'Digital and connected workstations' and 'Cloud Computing'. The opinions expressed by both target groups are nearly identical for 'Automated Storage Systems', and 'Object Self-Service'.

Again, a concise examination of the coefficients of variation is provided. Figure 47 illustrates the **coefficients of variation** of the Industry 4.0 concepts resulting from expert and enterprise survey for medium-sized enterprises.

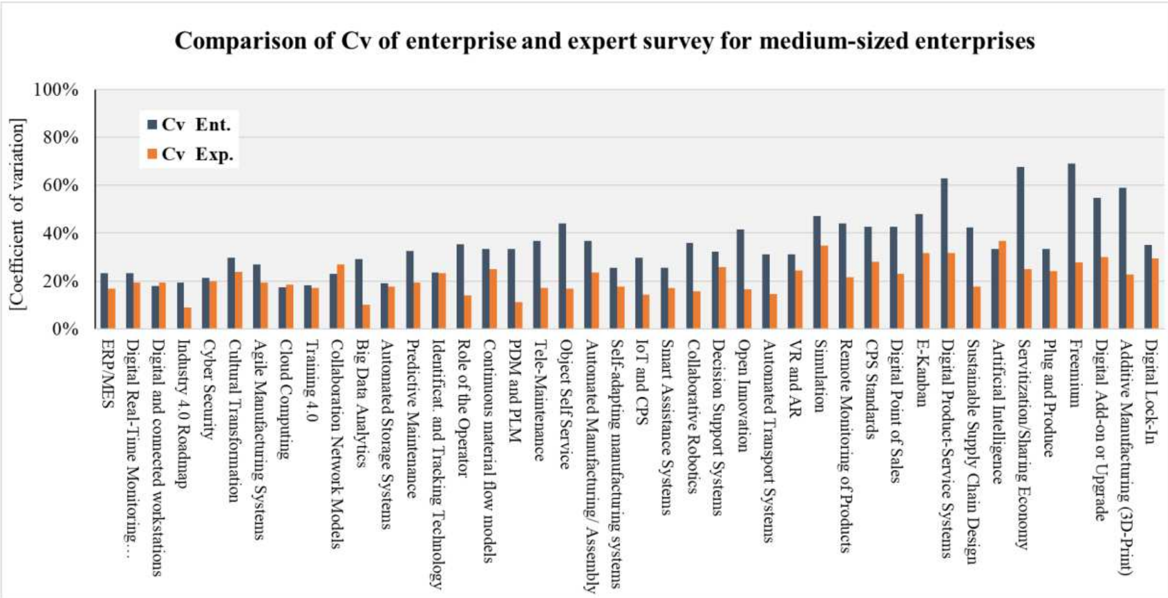


Figure 47: Representation of coefficient of variation (C_v) in enterprise and expert survey for medium-sized enterprises.

As with large enterprises, even in the case of medium-sized businesses the opinions of the companies differ more widely than those of the experts. Exceptions are 'Automated Storage Systems', 'Cloud Computing' as well as 'Artificial Intelligence'. The average values of the coefficients of variation are very similar to those of the large enterprise's category. In the enterprise survey, the average value considering all coefficients of variation is about 35%, while in the expert survey it is approximately 23%. This is a significant difference considering that these values represent averages of 42 values. This substantial gap reveals that the experts are much more agreeable than the enterprises. This may have something to do with the fact that knowledge and experience of digitization differ greatly among companies, while experts have a rather uniform positive opinion. Especially in medium-sized companies there are some very modern, innovative companies while others still operate rather traditionally.

Having analyzed the results of the surveys of large and medium-sized companies, it is now time to scrutinize the lowest category of companies within this analysis, namely the so-called small companies. Finally, Figure 48 displays the results of the **enterprise and expert survey** for the category of small enterprises.

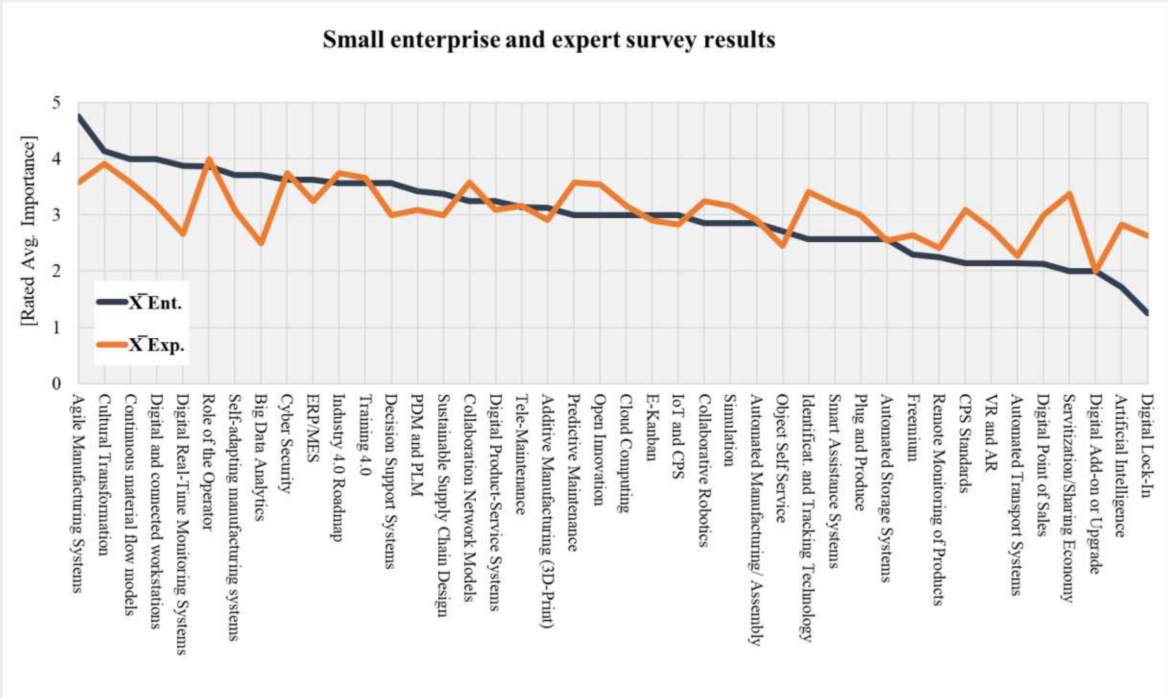


Figure 48: Comparison of rated importance values ($\bar{X}$) in enterprise and expert survey for small enterprises.

In this case, the divergence between expert and enterprise opinion is relatively strongly, meaning that the opinions of experts and companies vary widely. The graph indicates that there are some Industry 4.0 concepts that are generally considered to be very important by companies, while they are perceived to be much less important by experts, such as ‘Agile Manufacturing Systems’, ‘Cultural Transformation’, ‘Big Data Analytics’, Digital and connected workstations, ‘Digital real-time Monitoring Systems’, ‘Self-adapting manufacturing systems’ and ‘ERP/MES’. On the other hand, experts consider concepts such as ‘Artificial Intelligence’, ‘Collaboration Network Models’, ‘CPS Standards’, ‘Digital Lock-in’, ‘Digital POS’, ‘Servitization and Sharing Economy’ and ‘Identification and Tracking Technology’ to be much more important than the enterprises.

These fluctuations are a significant difference from the large and medium-sized categories, where the experts had rated the importance higher than the enterprises in most cases. A hypothesis for this behavior is the unexploredness of this category as well as a general unawareness of the firms regarding advantages and disadvantages of the individual Industry 4.0 concepts. However, in this context it is important to note that experts and enterprises were highly in agreement on some Industry 4.0 concepts. Astonishingly often, the two target groups agree on the relevance, starting with ‘Digital Add-on or Upgrade’ over ‘Automated Storage Systems’, ‘Automated Manufacturing and Assembly’ ‘Tele-Maintenance’, ‘Training 4.0’ up to ‘Cyber Security’.

For the purpose of analyzing the consensus of experts and enterprises in this category, the following Figure 49 provides a brief breakdown of the **coefficients of variation**. The coefficients of variation behave very similarly to the average importance values, fluctuating considerably. For some Industry 4.0 concepts companies tend to be more in agreement, for others the experts are and vice versa. Even if the values for the companies, with a maximum value of 66% and a minimum value of 12%, differ more than those of the experts, where they gather closer to the mean, no clear general statement can be formulated in this respect, since the average values of the variation coefficients are very close to each other and amount to about 37% for the companies and approximately 34% for the experts.

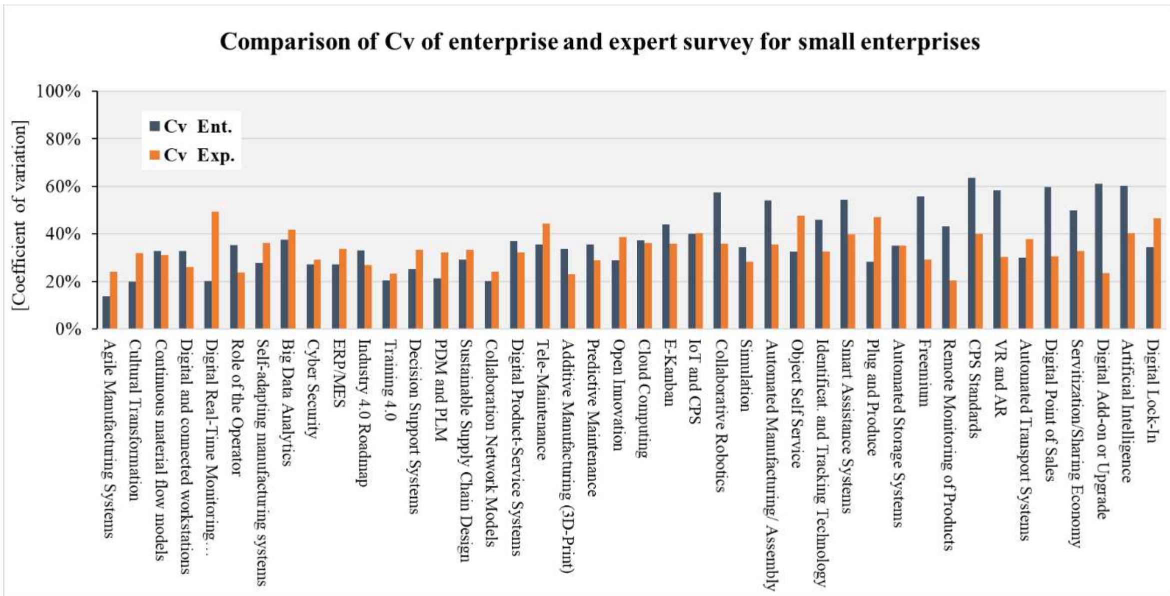


Figure 49: Representation of coefficient of variation (C_v) in enterprise and expert survey for small enterprises.

A very interesting aspect is the view of the slightest deviations in opinions. The enterprises mostly agree on ‘Agile Manufacturing Systems’, ‘Cultural Transformation’, ‘Digital Real-Time Monitoring Systems’, ‘Training 4.0’ as well as ‘Collaboration Network Models’ with coefficients of variation around 20 %. The rest of the values vary greatly, reaching a maximum value of 64% for ‘CPS Standards’. Similarly, for the expert survey the coefficients of variation vary quite strongly reaching a minimum at around 20%. Experts are most agreeable on ‘Additive Manufacturing’, ‘Remote Monitoring of Products’ and ‘Training 4.0’.

As all three categories have now been addressed, some universal conclusions can be drawn from the survey results. In general, Industry 4.0 seems to be a very important subject especially for medium-sized and large companies. Both experts and companies rate the relevance relatively high, with experts within these two categories classifying the majority of Industry 4.0 concepts as more relevant than companies. This can be attributed to the fact that the future significance of these models is perceived more clearly by the experts through their daily work in research than by the companies which tend to be more involved in the here and now and which do not yet consider the advantages of digitization to be as high as the theorists. The importance of small companies is assessed less than that of the other two, both by experts and by enterprises. Contrary to the previous two categories however, there is no clear trend here as to which target group considers digitization models to be more relevant. Significant fluctuations occurred both in companies and in expert opinions. Undoubtedly, this category is still the most unexplored of the three from a research point of view, and even in industry there still seem to be doubts among small companies about useful digitization.

After having investigated general trends from the survey, the next section, building on these results, deals with the core of the whole thesis: which Industry 4.0 concepts are suitable for the three investigated individual enterprise categories?

4.4 Suitable industry 4.0 concepts for different company sizes

In order to do this, the following approach is adopted. First of all, the reader is shown by means of a short overview which Industry 4.0 concepts per company size were rated the most important by the enterprises and the experts. Then the numerical values of these top-rated Industry 4.0 concepts are shown. The section concludes with an evaluation of the suitability of each Industry 4.0 concept per enterprise size. This is depicted in a final summary graphic.

Based on the two survey forms, Tables 6 and 7 in the following summarize the Industry 4.0 concepts per enterprise size that were highly valued within the enterprise and expert survey. These rankings are based on the average importance values and includes the ten highest rated Industry 4.0 concepts for each target group and enterprise size. The bold printed concepts within the two overviews appear in either ranking, be it for the companies or for the experts, and thus seem to have an even increased relevance.

Table 6: Best rated Industry 4.0 concepts for the three enterprise types according to the enterprise survey.

Rank	*Small (S)*	*Medium (M)*	*Large (L)*
1	**Agile Manufacturing Systems**	**ERP/MES**	**Cyber Security**
2	**Cultural Transformation**	Digital Real-Time Monitoring	ERP/MES
3	**Continuous material flow models**	Digital and connected workstations	Industry 4.0 Roadmap
4	Digital and connected workstations	**Industry 4.0 Roadmap**	**Digital Real-Time Monitoring**
5	Digital Real-Time Monitoring	**Cyber Security**	Cultural Transformation
6	**Role of the Operator**	**Cultural Transformation**	Big Data Analytics
7	Self-adapting manufacturing systems	Agile Manufacturing Systems	Digital and connected workstations
8	Big Data Analytics	Cloud Computing	Agile Manufacturing Systems
9	**Cyber Security**	**Training 4.0**	Automated Manufacturing/ Assembly
10	ERP/MES	Collaboration Network Models	Role of the Operator

Table 7: Best rated Industry 4.0 concepts for the three enterprise types according to the expert survey.

Rank	*Small (S)*	*Medium (M)*	*Large (L)*
1	**Role of the Operator**	**Training 4.0**	**Digital Real-Time Monitoring**
2	**Cultural Transformation**	**Industry 4.0 Roadmap**	Predictive Maintenance
3	**Cyber Security**	Predictive Maintenance	Training 4.0
4	Industry 4.0 Roadmap	Identificat. and Tracking Technology	Continuous material flow models
5	Training 4.0	**Cyber Security**	**Cyber Security**
6	**Agile Manufacturing Systems**	Continuous material flow models	Identificat. and Tracking Technology
7	**Continuous material flow models**	**Cultural Transformation**	Remote Monitoring of Products
8	Collaboration Network Models	**ERP/MES**	Artificial Intelligence
9	Predictive Maintenance	Automated Manufacturing/ Assembly	Simulation
10	Open Innovation	Collaborative Robotics	PDM and PLM

In the following, the importance scores of the top-rated Industry 4.0 concepts per company size are illustrated. Therefore, three figures are elaborated, which confront the resulting most promising Industry 4.0 concepts according to enterprises and experts. Figure 50 compares the most important Industry 4.0 according to enterprises and experts for large enterprises, whereas ‘Digital Real-Time Monitoring Systems’ and ‘Cyber security’ appear in both of the rankings and therefore seem to be of increased importance.

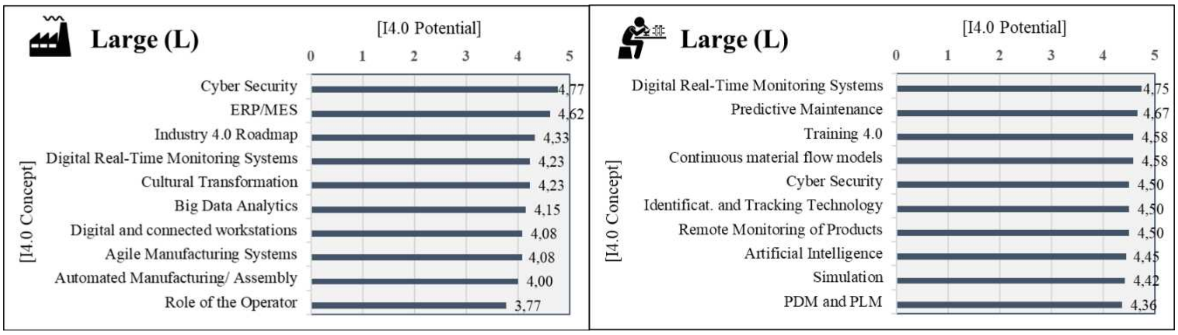


Figure 50: Top-rated Industry 4.0 concepts of enterprise (left) and expert (right) survey for large companies.

Similarly, Figure 51 shows the ranking for medium-sized enterprises. In this case the Industry 4.0 concepts that attract most attention are ‘Training 4.0’, ‘Industry 4.0 Roadmap’, ‘Cyber security’, ‘Cultural Transformation’ and ‘ERP/MES’.

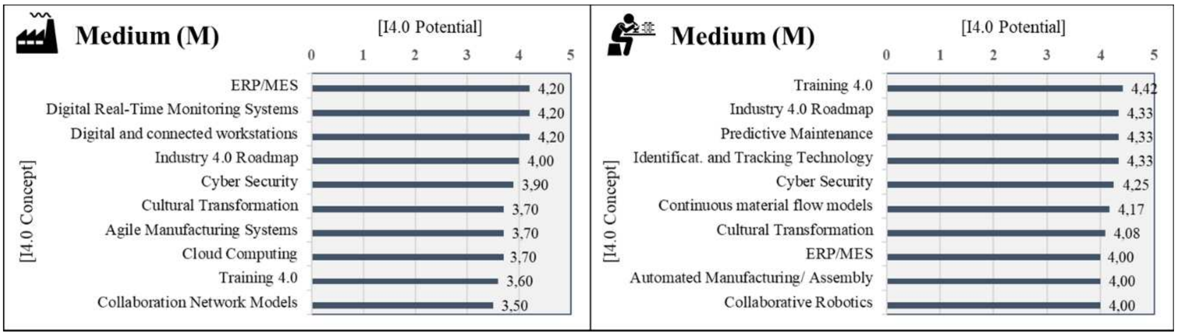


Figure 51: Top-rated Industry 4.0 concepts of enterprise (left) and expert (right) survey for medium-sized companies.

Finally, Figure 52 gives the rankings of the most suitable Industry 4.0 concepts for small companies, according to enterprises and experts. Within this evaluation a total of five concepts appear in both rankings: ‘Agile Manufacturing Systems’, ‘Cultural Transformation’, ‘Continuous material flow models’, ‘Role of the Operator’ and ‘Cyber Security’.

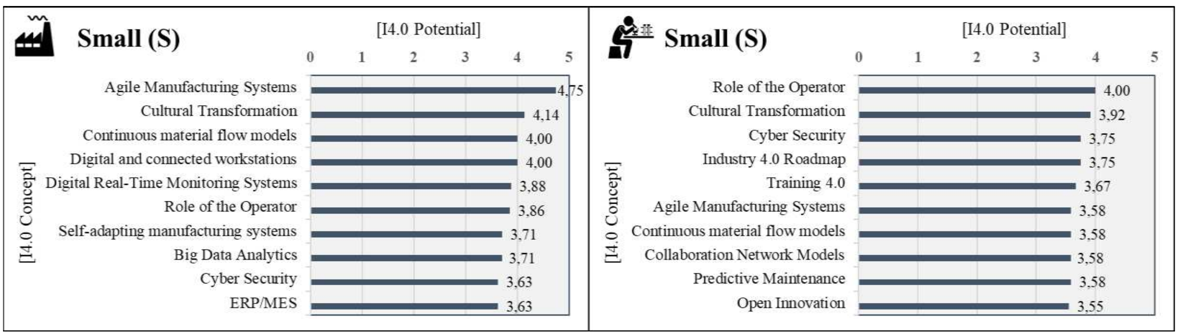


Figure 52: Top-rated Industry 4.0 concepts of enterprise (left) and expert (right) survey for small companies.

Observing these results, it quickly becomes apparent that the importance values are generally very high for all company types, particularly considering that these are mean values. It is further interesting that the experts generally rate the importance of Industry 4.0 concepts higher than the companies concerned. An example for this is given by the comparison of the survey results for large enterprises. While the tenth-best Industry 4.0 was rated with a value of 3.77 among the companies, this is rated with 4.36 among the experts. For small enterprises instead, the opposite is the case, whereby enterprises rate the higher importance values as experts. Subsequently, Table 13 gives an overview of the suitability of all Industry 4.0 concepts considered according to experts and enterprises. In order to determine the suitability, for each Industry 4.0 concept, average values of the importance rated by experts and enterprises were computed.

Table 8: Overview of suitability of Industry 4.0 concepts per enterprise size and Industry 4.0 dimension.

	INDUSTRY 4.0 CONCEPT	Small (S)	Medium (M)	Large (L)
Operational	Agile manufacturing systems	●	◕	●
	Self-adapting manufacturing systems	◕	◕	◕
	Continuous material flow models	◕	◕	●
	Plug and Produce	◑	◑	◕
	Decision Support Systems	◕	◕	◕
	Digital Real-Time Monitoring Systems	◕	●	●
	Remote Monitoring of Products	◑	◕	●
	Big Data Analytics	◕	◕	●
	ERP/MES	◕	●	●
Organizational	Digital Product-Service Systems	◕	◕	◕
	Servitization/Sharing Economy	◑	◑	◕
	Digital Add-on or Upgrade	◑	◑	◕
	Digital Lock-In	◔	◑	◑
	Freemium	◑	◑	◑
	Digital Point of Sales	◑	◑	◕
	Open Innovation	◕	◕	◕
	Industry 4.0 Roadmap	◕	●	●
	Sustainable Supply Chain Design	◕	◕	◕
	Collaboration Network Models	◕	◕	◕
Socio-cultural	Training 4.0	◕	●	●
	Role of the Operator	◕	◕	◕
	Cultural Transformation	●	◕	●
Technological (data-driven)	Additive Manufacturing (3D-Print)	◕	◑	◑
	Cloud Computing	◕	◕	◕
	Digital and connected workstations	◕	●	●
	E-Kanban	◑	◕	◕
	IoT and CPS	◑	◕	◕
	Cyber Security	◕	●	●
	Artificial Intelligence	◑	◕	◕
	Identificat. and Tracking Technology	◑	◕	●
	Predictive Maintenance	◕	◕	●
	Tele-Maintenance	◕	◕	◕
Technological (process-driven)	Automated Storage Systems	◑	◕	◕
	Automated Transport Systems	◑	◕	●
	Automated Manufacturing/ Assembly	◑	◕	●
	Collaborative Robotics	◕	◕	◕
	Smart Assistance Systems	◑	◕	◕
	VR and AR	◑	◕	◕
	Simulation	◕	◕	◕
	PDM and PLM	◕	◕	●
	Object Self Service	◑	◕	◕
	CPS Standards	◑	◕	◕

○ unsuitable ◔ less suitable ◑ suitable ◕ well suitable ● very suitable

The circular symbols within Table 8 indicate the degree of suitability of the single Industry 4.0 concepts for the various company types. The extent of the filling of the circles is proportional to the suitability of the concepts for the particular company type. This table combines the experts and enterprise judgements from the survey and assesses each Industry 4.0 concept according to suitability per enterprise category. In general, aptitude increases continuously with company size, according to experts and companies. However, there are also some exceptions, as can be seen very clearly in the table.

In summary, in this chapter the results of the survey were analyzed and presented both numerically and graphically. First, general aspects of the experts and enterprise survey were discussed. The results of the surveys were then clearly listed, with the focus always on the comparison of experts and company survey results. The subsequent comparison was made by contrasting the results numerically and graphically trying to interpret similarities or differences in the evaluations. In addition, an attempt was made to explain which differences occurred between the company typologies and why this might be the case. Finally, the suitability of Industry 4.0 concepts for each company category was derived and graphically presented to the reader. Particular attention was paid to concepts that were considered suitable in both target groups. The chapter concludes with an overview of all Industry 4.0 concepts per company typology which reflects the suitability of these in the opinion of the experts paired with that of the companies themselves.

5

FINAL REMARKS AND OUTLOOK FOR FURTHER RESEARCH

The fifth and penultimate chapter of this thesis is about drawing the most important conclusions from the analysis and laying a foundation for further future research. In the previous chapter, suitable Industry 4.0 concepts were examined for the various categories of enterprises, which differ in size (S, M, L). Enterprises from a wide variety of sectors were used and examined. However, the focus has always been on identifying patterns that can be attributed to enterprise size. This chapter deals with this topic as well, but the approach differs by attempting not only to analyze possible patterns per enterprise size, but also to include the criteria activity sector in the analysis and therefore provide a two-dimensional assessment procedure for the suitability of Industry 4.0 concepts. This should above all serve as an impetus for future research.

The chapter will be structured as follows. First, the sector analysis in 5.1 deals with which operational sectors are examined and which patterns were recognizable within the surveys. In a second moment, in 5.2, possible future research will be raised, and it will be mentioned which prerequisites are necessary for this.

5.1 Sector analysis

After a clear definition and delineation of the investigated sectors, the objective of the sector analysis is to examine them and to derive possible suitable Industry 4.0 concepts per size and sector in this context. First of all, it is briefly illustrated how the sectors are selected. This distinction after the classification according to company size will represent the second dimension in the evaluation of suitable Industry 4.0 concepts for different companies.

For the classification of sectors, NACE and ISIC codes can be considered the most common standards and are traditionally referenced in the literature. For this reason, these databases are also consulted as a basis for further analysis, whereby in a second moment the sectors relevant for this evaluation approach are selected and if appropriate clustered to groupings of similar sectors. A distinction is made between two basic sector subdivisions in this context.

The two NACE macro groups relevant to this work, manufacturing, abbreviated as “MF” and construction, shortened with “CO”, are consulted. Table 9 illustrates the two groups, specifying the micro sectors included within them.

Table 9: Sectors classified by NACE and ISIC macro groups.

Sector Naming	Abbre-viation	Specifications
Manufacturing	*MF*	materials, industrial goods, textile & clothing, food & beverages, others
Construction	*CO*	high construction, specialised construction

The manufacturing macro sector is made up by many micro manufacturing sectors. Within this classification the most relevant micro sectors are mentioned. The materials sector comprises enterprises which produce wood, plastic, rubber or non-metallic mineral as well as primary and processed metals. Second, the industrial goods sector comprises manufacturers of machinery, electrical equipment, other components, appliances and transportation equipment (e.g. automotive). The next sector consists of textile and clothing producers. It also includes leather products. Food and beverages represent the fourth micro sector within manufacturing including also tobacco products in addition to food and beverages. Finally, the second macro sector, namely construction, which mainly includes building construction.

The nature of the two surveys is known to be very different. While the theorists within the expert survey should evaluate companies from the macro sectors manufacturing and construction from the outset, the companies within the enterprises survey were asked for a more precise assignment of their businesses to micro sectors. This was done mainly for data collection purposes, but from the outset the focus was on collecting data to distinguish differences across company sizes. The experts are asked to evaluate all sector size combinations by assessing the importance of the single Industry 4.0 concepts within the different company categories. In the assessment, they should do this for manufacturing companies and, in a second moment, for construction firms. Enterprises obviously assess their own organization and therefore only deal with the size sector combination in which their company is located within the matrix.

Since the two criteria, company size and activity sectors, are to be considered, it is henceforth possible to combine these two aspects. The objective is to unite the two criteria and to categorize or cluster enterprises according to those criteria in order to then permit the evaluation of these individual combinations in a second step. Since these are two criteria, this can be displayed using 2D matrices. The combination and the configuration of the two axis enables the derivation of two matrices, where in this case the x-axis generally represents the enterprise size and the y-axis the operating sector.

Considering only the two macro sectors a matrix consisting of two rows and four columns comes along. In this case, that results in eight fields corresponding to eight different size-sector combinations. Figure 53 illustrates the matrix of the enterprise survey, where the fields provide information about the response rate of the expert survey.

			Enterprise size			
			Micro XS	Small S	Medium M	Large L
Sector	Manufacturing	MF	*8 to 12*	*9 to 12*	*9 to 12*	*8 to 12*
	Construction	CO	*7 to 11*	*8 to 11*	*6 to 11*	*6 to 11*

Figure 53: Matrix representing the amount of responses within the expert survey per size-sector combination.

The presentation of the results is based on intervals. Considering the fact that the experts did not always evaluate all Industry 4.0 concepts, the returns vary. In this case the lower limit represents the minimum number of responses within a category for a given Industry 4.0 concept and the upper limit the maximum. Accordingly, the colors as known from other applications are classified according to heat, whereby for this application the colors red, orange, yellow and blue are being selected, with red corresponding to the warmest color and blue the coldest. This results in a size-sector matrix heatmap, which concisely shows the distribution of response rates within the different combinations in the expert survey. The heatmap shows very clearly that the response rate in the field of manufacturing was generally higher than for the construction sector. This is interpreted mainly by the fact, that the majority of the researchers focus lies in manufacturing and henceforth some did not evaluate Industry 4.0 for construction.

In the case of the enterprise survey, a larger matrix could be considered since companies were asked to specify the micro sector within the survey. Including micro sectors would allow the derivation of a matric with five rows and four columns, however, some of the size-sector combination fields would contain none to only a few returns, as illustrated in Figure 54, from which it would be impossible to draw statistically meaningful conclusions.

		Enterprise size			
		Micro XS	Small S	Medium M	Large L
Sector: Materials Manufacturing	MA	*0*	*3*	*1*	*0*
Industrial Goods	IG	*0*	*3*	*3*	*9*
Textile & Clothing	TC	*0*	*0*	*0*	*0*
Food & Beverages	FB	*0*	*0*	*2*	*1*
Other Sector	OS	*0*	*0*	*2*	*2*
Construction	CO	*0*	*2*	*2*	*1*

Figure 54: Size-sector matrix including micro sector distribution.

In any case, a reasonable minimum number of responses per size sector combination must be defined to determine the threshold from which a combination is evaluated. It is possible that certain combinations only have one or two responses and no average can be taken into account. Therefore, a minimum number of five returnees is defined for this work in order to ensure a certain statistical significance. Only fields with a response rate of five or more are evaluated, meaning that for the heatmap above only the sector size combination Industrial Goods – L could be evaluated.

This is the main reason why also in this case only the macro sectors are consulted like in the expert survey. Moreover, the comparison between expert and enterprise survey is simplified. Within this work, for reasons of simplicity the main sector classification is made according to macro sectors, namely manufacturing and construction. The companies from the different micro sectors are divided into these two groups according to their activity.

Figure 55 shows the resulting heatmap of responses within the reduced macro sector – size combinations in the enterprise survey.

		Enterprise size			
		Micro XS	Small S	Medium M	Large L
Sector: Manufacturing	MF	*0*	*6*	*7*	*12*
Construction	CO	*0*	2	2	1

Figure 55. Size-sector matrix representing the sector-size distribution of participating enterprises.

The enterprise response heatmap similarly as the expert survey heatmap indicates the strongest response rates within manufacturing (especially for S, M and L) and a very weak participation of construction companies on the other hand.

Observing this heatmap it quickly becomes apparent that it makes little sense to evaluate the construction sector at all. There are some opinions among the experts, but there is a maximum of two registered opinions per field among the companies, which is statistically far from the minimum of necessary returns. This would make it possible to evaluate only the expert survey for construction, but the basic idea behind this work is to compare the two target groups in order to see what is similar and what is perceived in a different way. It is therefore decided to perform this analysis only for the manufacturing sector and the company sizes S, M and L.

By standardizing the two surveys, a certain comparability is given. The aim is to examine per sector how experts and enterprises perceive the importance of Industry 4.0 concepts depending on the criteria company size and sector. This is merely intended as an initial stimulus for further research in this regard.

To sum up, four different sizes and two sector result in eight size-sector combinations. For all these configurations, the response rate of expert and enterprise survey was analyzed. For combinations with enough returns in both surveys, the next section considers which Industry 4.0 concepts researchers and companies consider appropriate for the respective size-sector category.

5.1.1 Analysis of suitable industry 4.0 concepts for manufacturing

From the return numbers indicated in the above heatmaps it follows that in this case it only makes sense to analyze the combinations S, M and L of the manufacturing sector. Within this survey, there were few returns for construction, mainly for the reason that this thesis had the main objective to analyze the differences in the size of a company and therefore not targeted companies from specific sectors but selected based only on the criterion size. The manufacturing sector had enough returns, so this subsequent analysis should be used as a general framework and impetus for future research of suitable Industry 4.0 concepts in different sectors.

The objective is to identify a ranking, describing which Industry 4.0 concepts are suitable for the relevant size-sector combination. This is to be done by combining surveys of experts as well as enterprises themselves from the different sizes of manufacturing in order to include both Industry 4.0 experts who deal with the topic on a daily basis in their scientific environment and industrial partners from practice.

Figure 56 highlights the size-sector combinations discussed in this analysis, comparing experts and company ratings for each of them.

			Enterprise size			
			Micro XS	Small S	Medium M	Large L
Sector	Manufacturing	MF				
	Construction	CO				

Figure 56: Size-sector combinations discussed within this analysis.

In the following, the results of the individual combinations are shown first, whereby the number of responses (n), the average importance rating ($\bar{X}$), standard deviation (σ) and the coefficient of variation (C_v) are displayed for each Industry 4.0 concept.

Tables 10, 11 and 12 compare enterprise and expert survey results. From the tables it can be deduced that Industry 4.0 concepts are ranked in descending order according to the importance assigned by the enterprises.

Table 10: Enterprise results for large enterprises within manufacturing sector.

LARGE - MANUFACTURING	Enterprise				Expert			
Industry 4.0 Concept	*n*	*X̄ Ent*	*σ*	*Cv En*	*n*	*X̄ Exp*	*σ*	*Cv Exp.*
Cyber Security	12	4,83	0,37	8%	12	4,50	0,76	17%
ERP/MES	12	4,75	0,43	9%	12	4,25	0,83	20%
Industry 4.0 Roadmap	11	4,45	0,66	15%	12	4,25	0,83	20%
Digital Real-Time Monitoring Systems	12	4,33	0,85	20%	12	4,75	0,43	9%
Big Data Analytics	12	4,33	0,47	11%	12	4,25	1,01	24%
Cultural Transformation	12	4,25	0,72	17%	11	4,18	0,83	20%
Agile Manufacturing Systems	11	4,18	1,19	29%	12	4,08	0,76	19%
Digital and connected workstations	11	4,09	0,90	22%	11	4,09	0,79	19%
Automated Manufacturing/ Assembly	12	3,92	1,19	30%	12	4,33	0,75	17%
Role of the Operator	12	3,92	0,95	24%	11	3,82	1,03	27%
Cloud Computing	12	3,83	0,90	23%	12	4,00	1,00	25%
Automated Transport Systems	11	3,82	1,03	27%	12	4,25	0,83	20%
E-Kanban	10	3,80	1,08	28%	10	4,20	0,75	18%
Training 4.0	12	3,75	0,92	25%	12	4,58	0,64	14%
Predictive Maintenance	11	3,73	1,14	30%	12	4,67	0,47	10%
Remote Monitoring of Products	11	3,73	1,60	43%	12	4,50	0,65	14%
PDM and PLM	11	3,73	0,96	26%	11	4,36	0,77	18%
Collaborative Robotics	11	3,73	1,14	30%	12	4,17	0,99	24%
IoT and CPS	11	3,73	1,21	33%	12	4,08	0,64	16%
Collaboration Network Models	11	3,73	0,86	23%	12	3,83	0,90	23%
Decision Support Systems	12	3,67	0,94	26%	12	4,33	0,75	17%
Automated Storage Systems	12	3,67	1,03	28%	12	4,25	0,72	17%
Identificat. and Tracking Technology	12	3,58	1,04	29%	12	4,50	0,50	11%
CPS Standards	11	3,55	0,78	22%	11	4,18	0,72	17%
Digital Product-Service Systems	11	3,55	1,30	37%	11	3,91	1,24	32%
Self-adapting manufacturing systems	11	3,55	0,78	22%	12	3,83	0,99	26%
Continuous material flow models	12	3,50	1,04	30%	12	4,58	0,76	17%
Digital Point of Sales	10	3,50	1,36	39%	12	3,67	1,03	28%
Tele-Maintenance	11	3,45	1,08	31%	12	3,92	0,95	24%
Open Innovation	11	3,45	1,08	31%	11	3,27	1,14	35%
Simulation	11	3,36	0,98	29%	12	4,42	0,64	14%
Smart Assistance Systems	11	3,36	0,77	23%	11	3,91	0,90	23%
Sustainable Supply Chain Design	12	3,33	0,85	25%	12	4,17	0,90	22%
Artificial Intelligence	12	3,25	1,09	34%	11	4,45	0,78	22%
VR and AR	11	3,00	0,60	20%	12	4,00	1,00	18%
Plug and Produce	10	2,80	0,87	31%	12	3,58	0,86	25%
Servitization/Sharing Economy	10	2,80	1,47	52%	8	3,25	1,20	24%
Object Self Service	10	2,70	1,49	55%	9	3,78	1,13	37%
Additive Manufacturing (3D-Print)	12	2,67	1,25	47%	11	3,45	0,78	30%
Digital Lock-In	11	2,64	0,88	33%	8	3,38	0,99	23%
Freemium	11	2,64	1,30	49%	11	3,00	1,04	29%
Digital Add-on or Upgrade	11	2,55	1,30	51%	9	3,44	0,96	35%

Table 11: Enterprise results for medium-sized enterprises within manufacturing sector.

MEDIUM-MANUFACTURING	**Enterprise**				**Expert**			
Industry 4.0 Concept	*n*	*X̄ Ent*	*σ*	*Cv En*	*n*	*X̄ Exp*	*σ*	*Cv Exp.*
Digital and connected workstations	8	4,38	0,70	16%	11	3,91	0,67	17%
ERP/MES	8	4,13	1,05	26%	12	4,00	0,91	23%
Digital Real-Time Monitoring Systems	8	4,13	1,05	26%	12	3,92	0,86	22%
Industry 4.0 Roadmap	8	4,00	0,87	22%	12	4,33	0,75	17%
Cyber Security	8	4,00	0,87	22%	12	4,25	0,92	22%
Training 4.0	8	3,75	0,66	18%	12	4,42	0,64	14%
Cultural Transformation	8	3,75	1,20	32%	12	4,08	0,86	21%
Agile Manufacturing Systems	8	3,63	1,11	31%	12	3,92	0,76	19%
Big Data Analytics	8	3,63	0,99	27%	12	3,67	1,43	39%
Cloud Computing	8	3,63	0,70	19%	12	3,42	1,04	30%
Predictive Maintenance	8	3,50	1,22	35%	12	4,33	0,47	11%
Continuous material flow models	8	3,50	1,12	32%	12	4,17	0,80	19%
Collaboration Network Models	8	3,50	0,87	25%	12	3,67	0,75	20%
Automated Storage Systems	8	3,50	0,71	20%	11	3,55	0,89	25%
Role of the Operator	8	3,38	1,32	39%	11	3,82	0,83	22%
Identificat. and Tracking Technology	8	3,25	0,83	26%	12	4,33	0,47	11%
Smart Assistance Systems	8	3,13	0,78	25%	11	3,64	0,98	27%
Self-adapting manufacturing systems	8	3,00	0,87	29%	12	3,83	1,14	30%
Tele-Maintenance	8	3,00	1,22	41%	12	3,75	0,92	25%
PDM and PLM	8	3,00	1,00	33%	11	3,73	0,75	20%
Object Self Service	8	3,00	1,32	44%	9	3,22	1,13	35%
Automated Manufacturing/ Assembly	8	2,88	1,17	41%	12	4,00	0,91	23%
Collaborative Robotics	8	2,88	1,05	37%	12	4,00	0,82	20%
IoT and CPS	8	2,88	0,93	32%	12	3,67	0,62	17%
Open Innovation	7	2,86	1,25	44%	11	3,18	1,11	35%
Decision Support Systems	8	2,75	0,97	35%	12	3,92	0,76	19%
Automated Transport Systems	8	2,75	0,97	35%	11	3,45	0,89	26%
Remote Monitoring of Products	8	2,63	1,32	50%	12	3,83	0,80	21%
VR and AR	8	2,63	0,86	33%	12	3,33	0,85	25%
Digital Point of Sales	8	2,63	1,22	46%	12	3,25	0,83	26%
Simulation	8	2,38	1,22	51%	12	3,92	0,49	13%
CPS Standards	8	2,38	1,11	47%	11	3,82	0,83	22%
Artificial Intelligence	8	2,38	0,86	36%	11	3,73	0,96	26%
Digital Product-Service Systems	8	2,25	1,64	73%	11	3,64	1,07	26%
Sustainable Supply Chain Design	8	2,13	0,93	44%	12	3,83	0,90	29%
E-Kanban	8	2,13	1,05	50%	10	3,70	0,78	23%
Servitization/Sharing Economy	8	2,13	1,54	72%	8	3,13	0,93	21%
Plug and Produce	8	2,00	0,71	35%	12	3,42	0,64	30%
Digital Add-on or Upgrade	8	1,88	1,17	62%	9	2,89	0,74	19%
Freemium	8	1,75	1,39	80%	11	3,00	0,74	26%
Additive Manufacturing (3D-Print)	8	1,38	0,70	51%	11	3,18	0,72	25%
Digital Lock-In	8	1,25	0,43	35%	8	3,25	0,97	22%

Table 12: Enterprise results for small enterprises within manufacturing sector.

SMALL - MANUFACTURING	**Enterprise**				**Expert**			
Industry 4.0 Concept	*n*	*X̄ Ent*	*σ*	*Cv En*	*n*	*X̄ Exp*	*σ*	*Cv Exp.*
Agile Manufacturing Systems	6	5,00	0,00	0%	12	3,58	0,86	24%
Cultural Transformation	5	4,20	0,75	18%	12	3,92	1,26	32%
Continuous material flow models	6	4,00	1,41	35%	12	3,58	1,11	31%
Role of the Operator	6	3,83	1,46	38%	11	4,00	0,95	24%
Digital and connected workstations	6	3,83	1,34	35%	11	3,18	0,83	26%
Self-adapting manufacturing systems	6	3,83	1,07	28%	12	3,08	1,11	36%
Digital Real-Time Monitoring Systems	6	3,83	0,69	18%	12	2,67	1,31	49%
Cyber Security	6	3,67	1,11	30%	12	3,75	1,09	29%
Training 4.0	6	3,67	0,75	20%	12	3,67	0,85	23%
Decision Support Systems	6	3,67	0,94	26%	12	3,00	1,00	33%
Big Data Analytics	6	3,67	1,49	41%	12	2,50	1,04	42%
Industry 4.0 Roadmap	6	3,50	1,26	36%	12	3,75	1,01	27%
ERP/MES	6	3,50	0,96	27%	12	3,25	1,09	34%
Digital Product-Service Systems	6	3,50	1,26	36%	11	3,09	1,00	32%
PDM and PLM	6	3,33	0,75	22%	11	3,09	1,00	32%
Sustainable Supply Chain Design	6	3,33	1,11	33%	12	3,00	1,00	33%
Additive Manufacturing (3D-Print)	6	3,33	1,11	33%	11	2,91	0,67	23%
E-Kanban	6	3,33	1,25	37%	10	2,90	1,04	36%
Collaboration Network Models	6	3,17	0,69	22%	12	3,58	0,86	24%
Collaborative Robotics	6	3,17	1,57	50%	12	3,25	1,16	36%
Open Innovation	6	3,00	1,00	33%	11	3,55	1,37	39%
Tele-Maintenance	6	3,00	1,15	38%	12	3,17	1,40	44%
Automated Manufacturing/ Assembly	6	3,00	1,63	54%	12	2,92	1,04	36%
IoT and CPS	6	3,00	1,29	43%	12	2,83	1,14	40%
Predictive Maintenance	6	2,83	1,07	38%	12	3,58	1,04	29%
Cloud Computing	6	2,83	1,21	43%	12	3,17	1,14	36%
Simulation	6	2,83	1,07	38%	12	3,17	0,90	28%
Smart Assistance Systems	6	2,67	1,49	56%	11	3,18	1,27	40%
Plug and Produce	6	2,67	0,75	28%	12	3,00	1,41	47%
Object Self Service	6	2,67	0,94	35%	9	2,44	1,17	48%
Identificat. and Tracking Technology	6	2,50	1,26	50%	12	3,42	1,11	33%
Automated Storage Systems	6	2,50	0,96	38%	11	2,55	0,89	35%
CPS Standards	6	2,33	1,37	59%	11	3,09	1,24	40%
VR and AR	6	2,33	1,25	53%	12	2,75	0,83	30%
Freemium	6	2,17	1,34	62%	11	2,64	0,77	29%
Remote Monitoring of Products	6	2,17	1,07	49%	12	2,42	0,49	20%
Automated Transport Systems	6	2,17	0,69	32%	11	2,27	0,86	38%
Servitization/Sharing Economy	6	2,00	1,00	50%	8	3,38	1,11	33%
Digital Add-on or Upgrade	6	2,00	1,41	71%	9	2,00	0,47	24%
Artificial Intelligence	6	1,83	1,07	58%	12	2,83	1,14	40%
Digital Point of Sales	6	1,67	1,11	66%	12	3,00	0,91	30%
Digital Lock-In	6	1,00	0,00	0%	8	2,63	1,22	46%

Once the results of the manufacturing sector survey for the company sizes L, M and S have been presented within these tables, the following diagrams are used to illustrate this in more detail by proceeding in the same order, from L to M to S.

Subsequently, Figure 57 displays the survey results for large manufacturing enterprises.

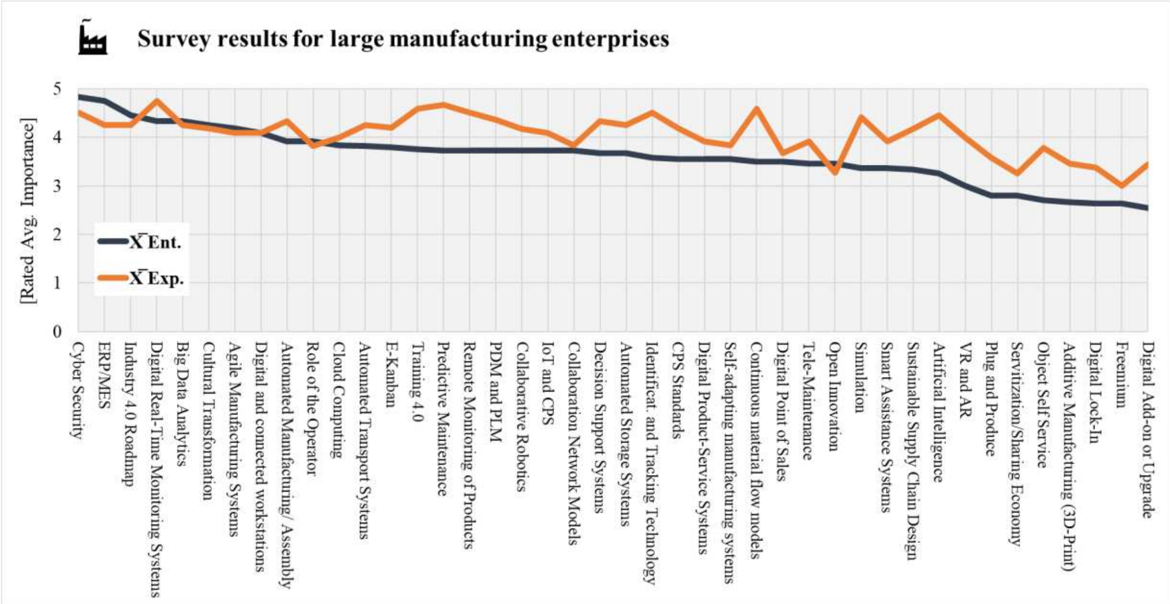


Figure 57: Comparison of rated importance values of enterprises and experts for large manufacturing companies.

In general, it can be very clearly seen that experts consider the importance of Industry 4.0 concepts for large manufacturing companies more important than the companies themselves, even if the results are quite nearby. Exceptions are 'Cyber Security', 'ERP/MES', 'Role of the Operator' and 'Open Innovation', which are rated more important or equal by enterprises. Figure 58 below juxtaposes the resulting coefficients of variation in enterprise and expert survey for the large manufacturing company category.

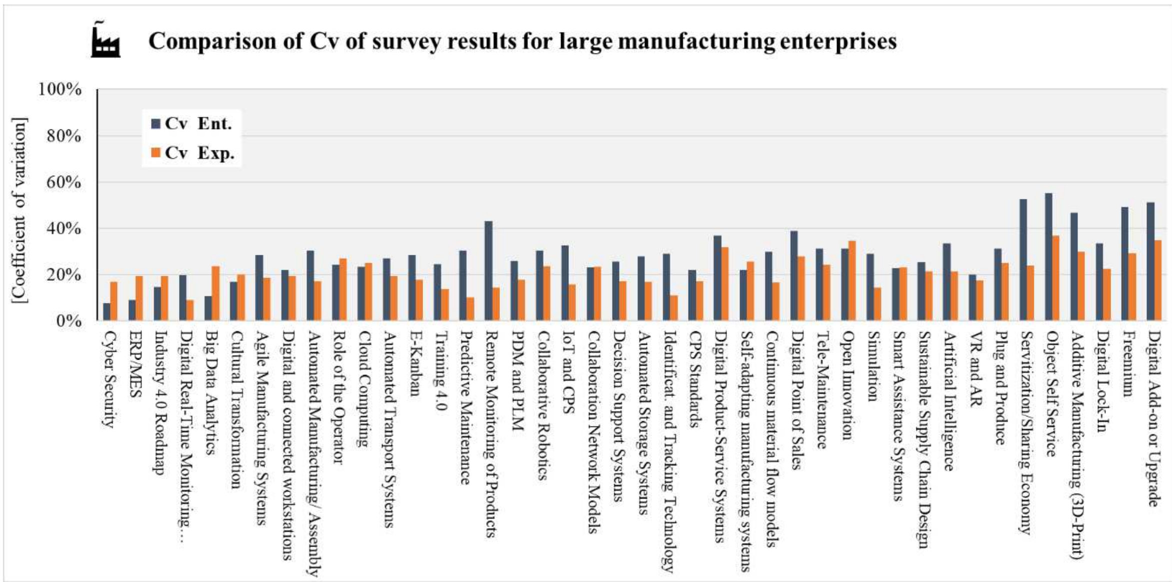


Figure 58: Comparison of coefficients of variations of enterprises and experts for large manufacturing enterprises.

In this context, deviations in the coefficients of variation are generally more pronounced among companies than among experts. This means that experts are generally more in agreement on the importance of Industry 4.0 than companies in this category. This fact is also supported by the figures. While the average coefficient of variation for enterprises is around 29%, it is of only 21% for enterprises.

Figure 59 graphically depicts the results of the enterprise and expert survey for medium-sized manufacturing companies.

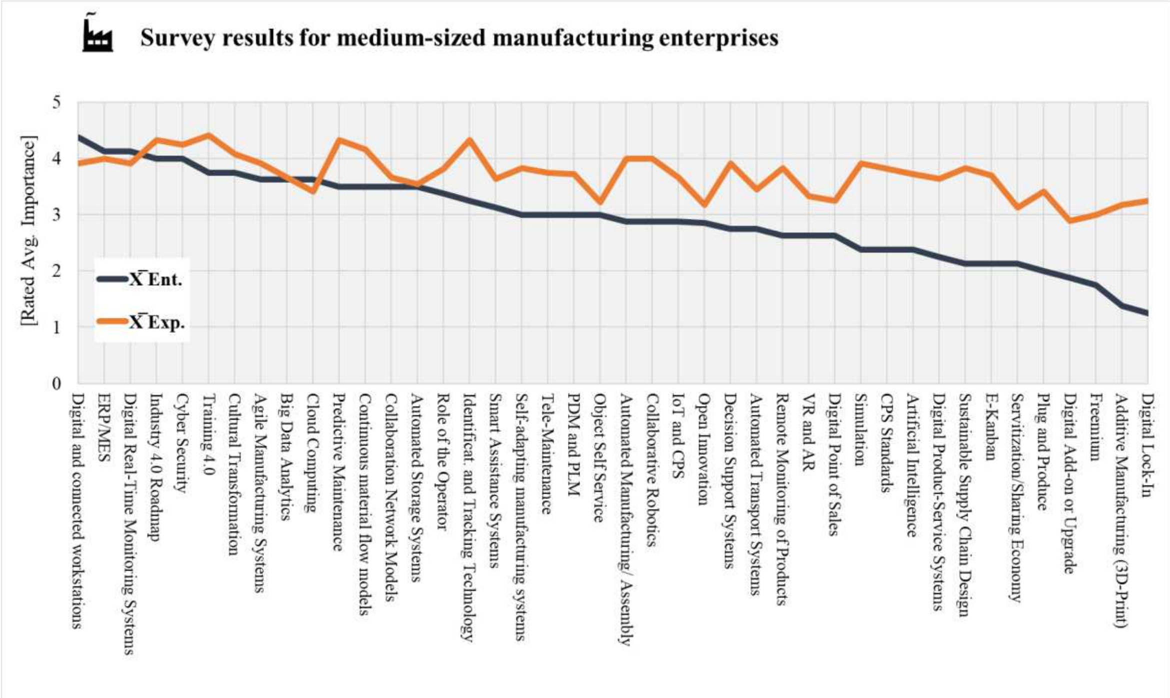


Figure 59: Comparison of rated importance values of enterprises and experts for medium-sized manufacturing companies.

Again, industry experts generally rate Industry 4.0 concepts higher, i.e. more important, with a few exceptions: 'Digital and connected workstations', 'ERP/MES', 'Digital Real-Time Monitoring' as well as 'Cloud Computing' are rated more important or equal by enterprises. Figure 60 compares the agreement in the answers of experts and companies in this category.

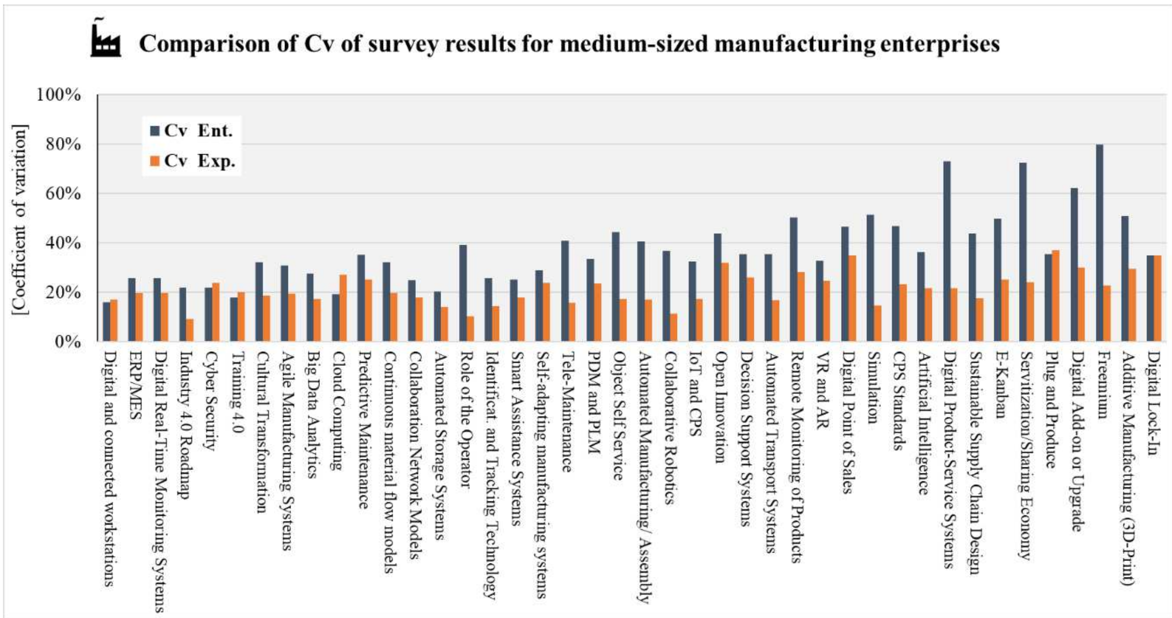


Figure 60: Comparison of coefficients of variations of enterprises and experts for medium-sized manufacturing enterprises.

There are some significant peculiarities here. While the average values of the coefficients of variation, amounting to 37% for the companies as opposed to 23% for the experts, are already very different, the very large differences in the company opinions are striking. There is complete disagreement among companies regarding the industry 4.0 concepts 'Digital Product-Service Systems', 'Servitization/Sharing Economy' and 'Freemium', which is reflected in coefficients of variation greater than 70%.

In the following, Figure 61 deals with the survey results of the last category, namely that of small manufacturing companies.

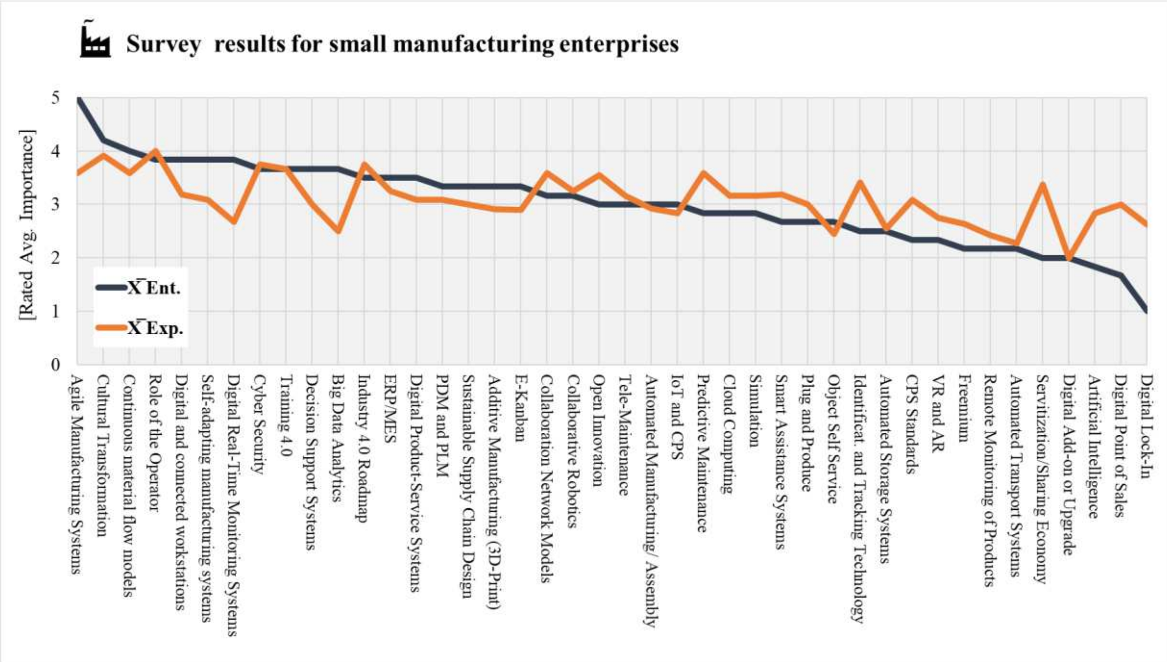


Figure 61: Comparison of rated importance values of enterprises and experts for small manufacturing companies.

Here the results are slightly different from the previous two categories. It is no longer the case that experts generally rate the importance more strongly than companies. In this category, Industry 4.0 concepts are interpreted very differently. Strong fluctuations occur, with in some cases Industry 4.0 concepts rated more important by the companies while in others by the experts. This may have to do with the fact that the category has not yet been researched very much, as research has so far concentrated on large to medium-sized enterprises. Finally, Figure 62 compares the resulting coefficients of variation for small manufacturing enterprises within expert and enterprise survey.

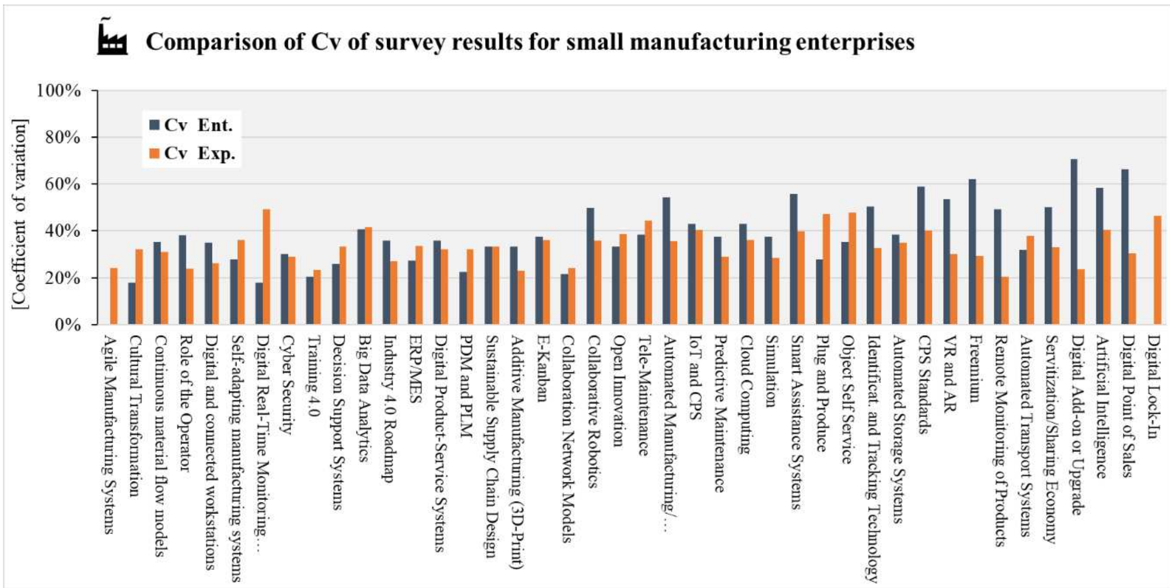


Figure 62: Comparison of coefficients of variations of enterprises and experts for small manufacturing enterprises.

The fluctuations substantiated above are also reflected in the coefficient of variation. The average values are very close in this category, with 38% for companies and 34% for experts.

Here, too, there is again very great disagreement among individual Industry 4.0 concepts, whereby in contrast to the other categories, the disagreement between the experts stands out above all. This is interpreted by the fact that this field has not yet been sufficiently researched.

Now that the results of the experts and company evaluations with regard to different size sector combinations in manufacturing have been compared, the best rated Industry 4.0 concepts are presented below. While Table 13 shows the most suitable Industry 4.0 concepts for small, medium and large companies in the manufacturing sector according to expert opinion, Table 14 shows the top-rated Industry 4.0 concepts for the corresponding categories rated by the companies themselves. The bold Industry 4.0 concepts are those that appear in both top lists and should therefore be given particular consideration.

Table 13: Top rated Industry 4.0 concepts within manufacturing per size of experts.

Rank	*Small (S)*	*Medium (M)*	*Large (L)*
1	**Role of the Operator**	**Training 4.0**	**Digital Real-Time Monitoring**
2	**Cultural Transformation**	**Industry 4.0 Roadmap**	Predictive Maintenance
3	**Cyber Security**	Predictive Maintenance	Training 4.0
4	Industry 4.0 Roadmap	Identificat. and Tracking Technology	Continuous material flow models
5	**Training 4.0**	**Cyber Security**	**Cyber Security**
6	**Agile Manufacturing Systems**	Continuous material flow models	Remote Monitoring of Products
7	**Continuous material flow models**	**Cultural Transformation**	Identificat. and Tracking Technology
8	Collaboration Network Models	**ERP/MES**	Artificial Intelligence
9	Predictive Maintenance	Automated Manufacturing/ Assembly	Simulation
10	Open Innovation	Collaborative Robotics	PDM and PLM

Table 14: Top rated Industry 4.0 concepts per enterprise size rated by manufacturing companies.

Rank	*Small (S)*	*Medium (M)*	*Large (L)*
1	**Agile Manufacturing Systems**	Digital and connected workstations	**Cyber Security**
2	**Cultural Transformation**	**ERP/MES**	ERP/MES
3	**Continuous material flow models**	Digital Real-Time Monitoring Systems	Industry 4.0 Roadmap
4	**Role of the Operator**	**Industry 4.0 Roadmap**	**Digital Real-Time Monitoring**
5	Digital and connected workstations	**Cyber Security**	Big Data Analytics
6	Self-adapting manufacturing systems	**Training 4.0**	Cultural Transformation
7	Digital Real-Time Monitoring	**Cultural Transformation**	Agile Manufacturing Systems
8	**Cyber Security**	Agile Manufacturing Systems	Digital and connected workstations
9	**Training 4.0**	Big Data Analytics	Automated Manufacturing/ Assembly
10	Decision Support Systems	Cloud Computing	Role of the Operator

It is remarkable that six of the 42 Industry 4.0 concepts appear in both top ten lists for the small manufacturing combination. Agile Manufacturing Systems', 'Cultural Transformation', 'Continuous material flow models', 'Role of the Operator', 'Cyber Security' and 'Training 4.0' are chosen by companies as well as by experts on average among the most suitable Industry

4.0 concepts. For medium sized manufacturing companies, five Industry 4.0 concepts appear in both rankings, namely 'ERP/MES', 'Industry 4.0 Roadmap', 'Cyber Security', 'Training 4.0' and 'Cultural Transformation', while for large manufacturing companies, astonishingly enough, only two occur least in both rankings, namely 'Cyber Security' and 'Digital Real-Time Monitoring'.

Finally, Table 15 gives an overview of all Industry 4.0 concepts and their suitability for the analyzed combinations S, M and L in manufacturing respectively.

Table 15: Overview of suitability of Industry 4.0 concepts for different enterprise sizes within manufacturing:

	INDUSTRY 4.0 CONCEPT	Small (S)	Medium (M)	Large (L)
Operational	Agile manufacturing systems	●	◕	●
	Self-adapting manufacturing systems	◕	◕	◕
	Continuous material flow models	◕	◕	●
	Plug and Produce	◑	◑	◕
	Decision Support Systems	◕	◕	●
	Digital Real-Time Monitoring Systems	◕	●	●
	Remote Monitoring of Products	◑	◕	●
	Big Data Analytics	◕	◕	●
	ERP/MES	◕	●	●
Organizational	Digital Product-Service Systems	◕	◑	◕
	Servitization/Sharing Economy	◑	◑	◕
	Digital Add-on or Upgrade	◑	◑	◑
	Digital Lock-In	◔	◑	◕
	Freemium	◑	◑	◑
	Digital Point of Sales	◑	◑	◕
	Open Innovation	◕	◕	◕
	Industry 4.0 Roadmap	◕	●	●
	Sustainable Supply Chain Design	◕	◑	◕
	Collaboration Network Models	◕	◕	◕
Socio-cultural	Training 4.0	◕	●	●
	Role of the Operator	◕	◕	◕
	Cultural Transformation	●	◕	●
Technological (data-driven)	Additive Manufacturing (3D-Print)	◕	◑	◕
	Cloud Computing	◕	◕	◕
	Digital and connected workstations	◕	●	●
	E-Kanban	◕	◑	●
	IoT and CPS	◑	◕	◕
	Cyber Security	◕	●	●
	Artificial Intelligence	◑	◕	◕
	Identificat. and Tracking Technology	◑	◕	●
	Predictive Maintenance	◕	◕	●
	Tele-Maintenance	◕	◕	◕
Technological (process-driven)	Automated Storage Systems	◑	◕	◕
	Automated Transport Systems	◑	◕	●
	Automated Manufacturing/ Assembly	◑	◕	●
	Collaborative Robotics	◕	◕	◕
	Smart Assistance Systems	◑	◕	◕
	VR and AR	◑	◑	◕
	Simulation	◕	◕	◕
	PDM and PLM	◕	◕	●
	Object Self Service	◑	◕	◕
	CPS Standards	◑	◕	◕

○ unsuitable ◔ less suitable ◑ suitable ◕ well suitable ● very suitable

As before, this table combines the assessments of experts and companies and thus determines the suitability of the individual Industry 4.0 concepts for small, medium and large enterprises from the manufacturing sector. The filling of the circles describes the suitability of the concepts. Even within the macro sector of manufacturing, suitability generally increases with increasing company size, but there are a few exceptions.

In summary, in this chapter, an impulse for the inclusion of the operating sector as an element to be considered in the analysis was provided. To this end, the first step was to analyze which areas the participating companies originate from and whether there were enough returns for a statistical evaluation of the individual size-sector combinations. Since most of the returns came from the manufacturing sector and the company typologies S, M and L, the decision was taken to analyze them, always comparing the company assessment with the expert opinions. Interesting insights were gained, but this should serve as a framework for future initiatives. In particular, the more specific sectors could be addressed. Finally, as in the previous chapter, the suitability of Industry 4.0 concepts for each company size in manufacturing was analyzed and graphically presented. In the end, an overview of all concepts with their suitability for small, medium-sized as well as large companies in manufacturing was presented, including a combination of experts and company opinions.

5.2 Outlook for further research

The analysis has shown that the importance of Industry 4.0 is perceived very differently, both between different forms of enterprises and between experts and researchers in the field. In most cases, large and medium-sized enterprises are already more advanced with digitization and consider it to be of great importance for their future success.

Furthermore, experts and companies in these categories seem to agree on the relevance, even though experts generally rate the importance higher. This can be interpreted by the fact that the researchers estimate the future potential higher because they are confronted with it in their daily work, while companies sometimes find it difficult to estimate the potential of individual concepts. Opinions differ more among small companies. Although they regard individual Industry 4.0 concepts as very relevant, opinions between experts and companies vary greatly.

In fact, the introduction of Industry 4.0 is an enormous challenge for all type of enterprises but seems especially huge for small companies. There is certainly a need to catch up here. Future research efforts should therefore focus on why experts generally see Industry 4.0 concepts as more relevant than companies and why the theoretical concepts from research have so far only partially been successfully implemented in practice. In addition, a more detailed analysis of the category of small enterprises would be very interesting and also necessary. So far, research on Industry 4.0 has mainly focused on large enterprises, but there is a need to make up ground in the area of small enterprises, which form the backbone of today's economy.

The analysis within this work was generally focused only on the differences within the different company sizes, whereby the comparison of theoretical and practical know-how in particular gave some interesting insights into the perception of Industry 4.0. This should only be the impetus for more research in the field. In the future, several companies and researchers should be included in the analysis, which should be possible with the growing interest in the subject. In addition, the fifth chapter has already begun to find possible patterns from the various operating sectors. Future research might also proceed in this direction, although a much larger database is needed and companies from all the sectors concerned would have to be involved.

In particular, in this context, it would be very beneficial both to analyze the macro-sectors as in this paper and to address the micro-sectors, thus providing even more appropriate guidelines for enterprises from different sectors and enterprise sizes for the introduction of suitable Industry 4.0 concepts, based on the opinions of leading experts and similar enterprises from the same category in terms of sector and size.

6

CONCLUSION

The final sixth chapter is intended to reflect the contents of the thesis as a whole, to review it chronologically, and to summarize the most important points for the reader, by emphasizing the most important insights.

The first chapter addressed the current situation in the industrial environment, dominated by uncertainty concerning the digitalization process. Difficulties and problems this development poses for companies nowadays were pointed out. This resulted in the motivation of the work, which consists in supporting companies in selecting and implementing suitable Industry 4.0 concepts for their businesses.

In the second chapter the most important terms within the field of Industry 4.0 were clarified, the historical development followed as well as the definition of Industry 4.0 concepts, which are regarded as basis for the later evaluation within the Assessment Tool I4.0. In addition, already existing models for the implementation of Industry 4.0 were mentioned, from which the formulation of the research question was derived. Which Industry 4.0 concepts are suitable for a given company based on its size? Various hypotheses have been formulated in which the core message is that Industry 4.0 concepts can be evaluated and ranked on the basis of company size. This approach should not be time-consuming for enterprises but should guide them through their digital transformation process by introducing Industry 4.0 more quickly and easily.

On this basis, a concept was developed in the third chapter to create a database by involving companies and experts to assess which Industry 4.0 can be suitable for certain company sizes. The companies were first suitably classified. Subsequently, the surveys were defined to collect the data. The target groups and the contents of the surveys were defined. Furthermore, the method for evaluating the survey was recorded here in detail.

Subsequently, in the fourth chapter, the results of the survey were processed and analyzed. This revealed some interesting aspects. The results of the various categories and target groups were then compared and interpreted. Building on this, the suitability of the defined Industry 4.0 concepts per company category and per target group was explained.

The fifth chapter provided an idea for further research by including the criterion sector in the analysis. In the future, the evaluation could be extended to examine so-called size-sector combinations of companies instead of focusing only on the size of the enterprise.

The concluding sixth chapter serves to give the reader an overview of the thesis, to recall the logical thread and to deal with the most important findings.

Within Hypothesis 1 (H1) it was stated that Industry 4.0 concepts can be ranked based on enterprise size. This statement was confirmed, as in the fourth chapter a ranking of the best rated Industry 4.0 concepts per company typology was provided.

The second Hypothesis (H2) stated that companies with this method can be offered recommendations for the introduction of Industry 4.0 without much effort. This is true, but it should be emphasized that these are only recommendations. Each company should analyze the situation for its specific business case and implement appropriate measures. The recommendation can, however, be a very valuable first point, showing enterprises exactly where other enterprises are in the category and what research experts consider important for a successful future.

Hypothesis 3 (H3) argued that this approach makes the introduction of digitization easier and swifter for companies. In any case, this is the case, because especially companies that deal with the I4.0 Assessment tool themselves not only acquire important knowledge from the field of Industry 4.0, but also subject their business to a self-analysis consisting of current-state analysis and target setting. This, coupled with the results of the study, is a promising start into a successful digital transformation process.

All in all, it can be stated that digitization is a major challenge for companies, regardless of their size. However, large and medium-sized enterprises apparently have more resources available to deal with Industry 4.0 than small enterprises. The aim of this thesis was to gather data from different companies and expert opinions based on an existing I4.0 Assessment Tool to identify promising Industry 4.0 concepts for various enterprise sizes. The general results of the study were highly revealing, with large and medium-sized enterprises generally finding the importance of Industry 4.0 higher than small enterprises. However, it was very noticeable in almost all categories that the experts from the research sector generally regarded the importance of Industry 4.0 in the individual company typologies as being more important than the companies themselves. The largest convergence of the two target groups can be observed in the area of large enterprises, although they are much divided among the small enterprises. This clearly shows that research and practice are still far apart and that there is a need to catch up in this divergence.

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