Industry 4.0 / Industrial Internet of Things - Related Technologies and Requirements for a Successful Digital Transformation:

An Investigation of Manufacturing Businesses Worldwide

Submitted in partial fulfilment of the requirements of the degree of Master of Science in International Management at The University of Strathclyde

THE UNIVERSITY OF STRATHCLYDE

DEPARTMENT OF STRATEGY & ORGANISATION

Name of authors: Florian Ernst & Patrick Frische

Year of completion: 2015 (Finnieston)

Name of Project Supervisor: Dr Jim Hamill

About the Authors

Florian Ernst

Contact details:

Email: florian.ernst1@gmail.com / florian.ernst.2014@uni.strath.ac.uk

Phone: +49 160 9933 4891 / +44 7767 630 360

LinkedIn: https://uk.linkedin.com/in/florianernst

After finishing his mechanical engineering apprenticeship with Audi AG, Florian Ernst enrolled at the Business College, Soest, Germany where he obtained his Vocational Baccalaureate Diploma in June 2010. Subsequently, he enrolled at the South Westphalia University of Applied Sciences, Soest, Germany, where he graduated with a Bachelor of Engineering and Project Management in February 2014. During his undergraduate studies, he worked as an intern with Mercedes-Benz in Stuttgart/Germany in the Overall Project Management S-Class department, and he worked on his bachelor thesis in cooperation with Mercedes-Benz in the Production & Planning department in Stuttgart/Germany. In September 2014, he enrolled at The University of Strathclyde Business School in Glasgow for the MSc in International Management.

Patrick Frische

Contact details:

Email: mail@patrick-frische.de / patrick.frische.2014@uni.strath.ac.uk

Phone: +49 151 15627429

LinkedIn: https://de.linkedin.com/in/patrickfrische

After finishing his general baccalaureate, Patrick Frische completed a preparatory internship at Behr-Hella Thermocontrol, which was an introductory course in project management. Following this, he studied at the South Westphalia University of Applied Sciences, Soest, Germany and graduated with a Bachelor of Engineering and Project Management in February 2014. During his undergraduate studies, he worked as an intern with Airbus in Hamburg/Germany, and was involved with the project performance management of the aircraft development project A350 XWB; during his tenure, he completed his undergraduate thesis in cooperation with Airbus in its Project & Performance Management department in Hamburg, Germany. In September 2014, he enrolled at The University of Strathclyde Business School in Glasgow for the MSc course in International Management.

STATEMENT OF ACADEMIC HONESTY

We declare that this dissertation is entirely my / our own original work.

We declare that, except where fully referenced direct quotations have been included, no aspect of this dissertation has been copied from any other source.

We declare that all other works cited in this dissertation have been appropriately referenced.

We understand that if any act of academic dishonesty such as plagiarism or collusion is suspected, the awarding of a Masters degree will be disallowed.

Signed ……………………….……… Dated …….……………………

Signed ……………………….……… Dated …….……………………

ABSTRACT

The focus of this research study is in the field of future manufacturing, which is characterized by machine-to-machine communications and virtualized processes along the supply and value chain, in what is also termed digital manufacturing. This form of future manufacturing is called Industry 4.0, or the Industrial Internet of Things, and it presents both enormous business opportunities and challenges. Businesses have to radically change their current processes, procedures, products, and services in order to benefit from this development. The aim of this study is to investigate this current development by considering related technologies, business requirements, and strategic approaches that need to be applied by manufacturing companies to perform this transformation successfully. The research study includes a review of relevant literature, and reports on extensive practical research (based on an inductive qualitative research approach), whereby 40 reports from leading consulting companies were analysed, and semi-structured interviews with 11 industry experts were conducted. According to the research findings, this development is widely seen as an industrial revolution with two groups of identified technology driver: the main driver includes Cyber-Physical Systems, Big Data & Analytics, Cloud Computing, and IT-Security Systems, all of which offer tremendous opportunities for manufacturing businesses; and, the second group comprises technologies including Autonomous Robots, Additive Manufacturing, Augmented Reality, and Simulation (all of which are related to this development in a wider sense). From the findings, 10 generalized business requirements have been identified, the most important of which are a ‘Digital Organisational Mind-Set’, ‘Digital Infrastructure’, ‘Future Workforce’, and ‘Collaboration in the Ecosystem’. The other requirements included ‘Data and Cyber Security’, ‘Smart Innovation Processes’, ‘Digital Value and Supply Chain’, ‘Digital Product and Service Portfolio’, Capitalizing on the Value of Data’, and ‘New Types of Business Models’; these are more specific, and depend on individual company circumstances. Based on this study’s findings, a Digital Transformation Model has been proposed, which builds upon the theoretical framework (which comprises all research findings), and which can be applied by the manufacturing industry in their business practices. The main conclusions drawn from this study are that Industry 4.0 (I40) resp. Industrial Internet of Things (IIoT) present significant opportunities and challenges, not only for individual manufacturing businesses, but also for the entire manufacturing industry as well as the global economy. The means of preparing and transforming businesses to meet the demands of I40 resp. IIoT will inevitably take the form of joint projects, and will not be a ‘one-player game’; collaboration and cooperation amongst businesses and other partners will be fundamental. Manufacturing businesses are recommended to start this transformation immediately, regardless of their size and objectives. Companies should follow a systematic and strategic approach that allows them to exploit the short-term and especially long-term potential benefits of I40 resp. IIoT, whilst still being flexible enough to react quickly and embark on new developments.

Word count: 22,837

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to our mentor, Dr Jim Hamill, for his continuous support during this master's project. Without his excellent supervision, this dissertation project may not have been successfully designed and completed.

We would also like to express our deep gratitude to all interview participants for their time, and for sharing their knowledge during the primary research process. Their support contributed tremendously to the quantity and quality of research results obtained during this research study.

Finally, we would like to thank our families and friends for their support and patience throughout the entire master dissertation project.

Table of Contents

TABLE OF FIGURES

TABLE OF TABLES

ABBREVIATIONS

AM	Advanced Manufacturing
BCG	Boston Consulting Group
CAD	Computer-Aided Design
CPS	Cyber-Physical Systems
e.g.	*exempli gratia* (Latin), meaning “for example”
ERP	Enterprise-Resource-Planning
et al	*et al.* (Latin), meaning “and others”
GDP	Gross Domestic Product
GE	General Electric
HR	Human Resources
I40	Industry 4.0
ibid	*ibidem*, meaning "in the same place"
ICT	Information and Communication Technology
i.e.	*id est* (Latin), meaning “that is to say“
IIoT	Industrial Internet of Things
IoS	Internet of Services
IoT	Internet of Things
IPR	Intellectual Property Rights
IT	Information Technology
NAC	National Absorptive Capacity
OT	Operation Technology
R&D	Research and Development
resp.	Respectively
RI	Re-Industrialisation
SI	Smart Industries
SM	Smart Manufacturing
SME	Small and Medium-sized Enterprises
SMLC	Smart Manufacturing Leadership Coalition
USP	Unique Selling Proposition

1. INTRODUCTION

1.1 Background

Today's manufacturing industry is characterised by highly dynamic and complex competitive structures, whereby businesses are required to be flexible and must rapidly respond to fast changing market conditions (Reeves, Haanaes, and Sinha, 2015). The satisfaction of customer needs requires manufacturers to be far more imaginative than Henry Ford who, when asked for his opinion on product variety, claimed, "The customer can have it painted in any colour he wants, so long as it's black" (Hessmann, 2014). Businesses can no longer achieve market shares and higher profits by producing large quantities of standardized products (Qiao, Lu and McLean, 2006). Successful operations in manufacturing require flexibility concerning procedures in customer-acquisition and order-fulfilment. Manufacturers must be able to manage anticipated change with accuracy, and simultaneously respond quickly and precisely to unanticipated changes (ibid). High customer expectations of product quality, competitive prices, and high labour costs in developed countries altogether pose enormous challenges for today's manufacturing companies (Brettel et al, 2014).

Technologies that have been in the pipeline for a long time, and in which development has significantly accelerated in recent years, are seen as the biggest enabler to overcome such constraints and create new opportunities for business operations (Westerman, Bonnet and McAfee, 2014). The internet broke down the barriers between software and the physical world, and enabled new connections of devices and machines, allowing data generation and control operations to be performed remotely (Bruner, 2013). These network connections enable machines and devices to become a web service, ready to be combined with intelligent software systems that are able to control and optimize operations autonomously. With this development, business processes along the supply and value chain can be virtualized, and relevant product and production information can be accessed in real-time in what is known as 'digital manufacturing' (Brettel et al, 2014). Through these developments, manufacturing businesses have the potential to achieve higher transparencies, flexibilities, and productivities that enable production processes of individualized products on an industrial scale (Lasi et al, 2014).

The initial stages of and the changing conditions caused by this development require considerable changes and consequently present significant business challenges (Sendler, 2013). Changes are required in regard to all forms of business operations: new processes, procedures, products, and services will be required; and consequently, new skills, abilities and working environments are needed (ibid). Businesses have to change their existing operations significantly in order to benefit from the opportunities offered by the new industrial developments.

1.2 Motivation

In view of the authors' backgrounds in business and engineering, and their practical experience of working for leading manufacturing companies, the chosen research topic enabled the authors to apply their existing knowledge and experiences. Since both authors are strongly interested in this area and in pursuing similar career paths (i.e. to become experts in the field of digital manufacturing), they collaborated on the planning of this research study in an effort to maximise the quality of the research project. In addition, both authors aimed to perform a thorough investigation into I40 resp. IIoT in the context of global manufacturing businesses in order to acquire considerable learning experiences, and to contribute new and important knowledge to the development of future manufacturing.

1.3 Aims and Objectives

As mentioned during the background presentation, the future form of manufacturing presents both considerable opportunities and barriers. Since the majority of manufacturing businesses have not started the transformation process and often are not even aware about this development (Capgemini Consulting, 2014a), this research study aims to provide a holistic investigation concerning this form of future manufacturing, to help increase awareness and understanding of this development among manufacturers, as this will be crucial for successful future operations. For this research study, four main research questions were formulated (Table 1):

Table 1: Overview of the research questions

No.	Research Question
1.	What is current state of Industry 4.0 resp. Industrial Internet of Things?
2.	What are major technologies that are integral to Industry 4.0 resp. Industrial Internet of Things, and what potential benefits do they offer for manufacturing businesses?
3.	What requirements need to be accomplished by manufacturing businesses to ensure a successful digital transformation towards Industry 4.0 resp. Industrial Internet of Things?
4.	When and how should manufacturing businesses start the transformation process towards digital manufacturing, and what are potential future development trends of Industry 4.0 resp. Industrial Internet of Things?

In this research study, the current state of this development will be clarified, and the major technologies and main business requirements will be investigated. In addition, strategic implementations and future developments will also be studied to ensure a holistic research study about I40 resp. IIoT in the context of global manufacturing companies.

1.4 Structure of the Report

This research study comprises six chapters including this one: Introduction; Literature Review; Methodology; Findings and Analysis; Derived Digital Transformation Model; and, Conclusions (see Figure 1). The introduction starts with the familiarisation of the topic and the elucidation of its importance, followed the clarification of the main research questions. In the literature review (Chapter 2), the most appropriate literature resources are identified, a theoretical background is provided, and the most important literature is analysed. The third chapter of the research study is the methodology, wherein the research question and objectives are defined; this is followed by the identification of the research study framework and the main research data sources. In Chapter 4, the research results are described, analysed and explained, and are then synthesised and evaluated to test their validity and quality. Chapter 5 consolidates all research findings in the form of a generalized theoretical framework model, which comprises a step-by-step guide for a successful transformation towards digital manufacturing. In the last chapter of this research study, the main research results are summarized, and the wider implications for businesses are revealed.

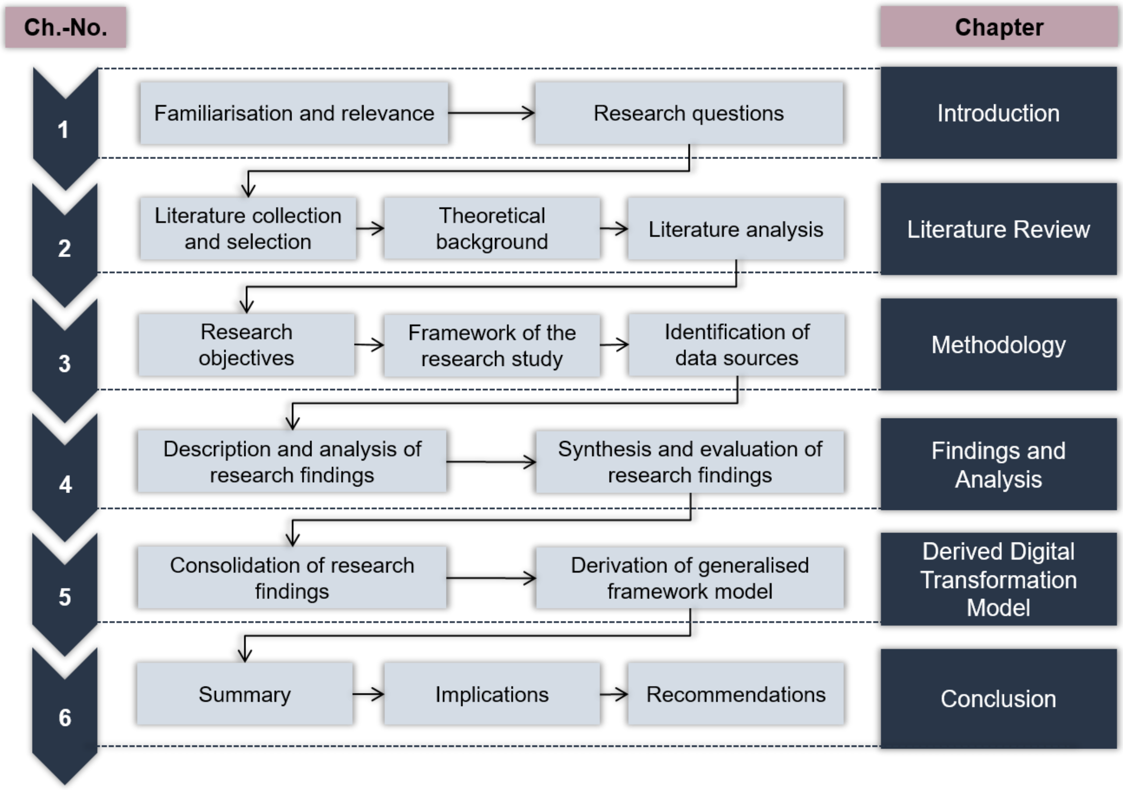


Figure 1: Research study structure

2. LITERATURE REVIEW

2.1 Introduction

This chapter satisfies the second step of the dissertation project (see Figure 1). The aim of the literature review is to provide a comprehensive overview on the status of the emerging industrial revolution by focusing on manufacturing businesses worldwide. A literature review critically explores and evaluates the nature of existing literature in order to identify potential knowledge gaps, and also to ensure that a new research study does not duplicate the work of previous studies (Bryman, and Bell, 2015; Horn, 2009). Section 2.2 in this chapter will describe the literature collecting and selecting process, whereby all available literature was critically collected and evaluated using the academic funnel (Horn, 2009). The collected sources were then subjected to further scrutiny using a literature tree in an effort to identify the most suitable and accurate literature resources, which are later presented and discussed in this chapter. Having identified and selected the most appropriate literature resources, this chapter will then focus on the theoretical background in section 2.3 by defining the current industrial revolution and explaining its general characteristics. Following this establishment of a fundamental understanding of the topic, a deeper investigation will be presented in section 2.4, namely the opportunities being created by the Industry 4.0 (I40) and the Industrial Internet of Things (IIoT), for a wide range of stakeholders. In section 2.5, the advanced technologies will be elucidated; these are seen as the main driver for the current industrial revolution. Following this, section 2.6 details the challenges that need to be overcome by stakeholders, and section 2.7 examines what is required of manufacturing businesses that are intent on expediting the industrial revolution throughout the world. The final section (2.8) summarises the business requirements for I40 resp. IIoT, and provides a literature synthesis, which summarizes the literature review and compares it with the main research objectives.

2.2 Literature Collection and Selection

2.2.1 Synthesised Theory

For the first step of the literature review, the academic funnel was used to systematically collect and select the most appropriate and accurate literature resources. During this process, a wide range of different resources were collected and added to the academic funnel (see Figure 2) whereby mainly books, academic journals, and websites were considered and viewed. Back then, the exact research topic on the current industrial revolution had not yet been selected. This initial literature research therefore produced mostly superficial information with few detailed academic research studies. Following this, a wider range of resources was viewed and added to the academic funnel, including related research studies; business, industry, and consultancy reports; metadata; and, conference transcripts. The purpose behind this more extensive investigation of literature resources was to acquire essential knowledge and identify gaps, and ensure a basic understanding of the fundamentals of the subject before further research was undertaken. The identification and collection of research was mainly performed via search engines and online databases including Google Scholar, Suprimo (University of Strathclyde Library), Google, ScienceDirect, and wiso-net.de, along with other scientific databases. In addition, online news filter services such as Feedly were used to gather information on the latest developments and new publications. For the same reason, specific LinkedIn groups were joined, where relevant reports are published frequently. A second method was to collect information from business-oriented reports, in which the main stakeholders in the topic field were identified. Particular focus was placed on subject areas including the new digital opportunities, and the ways in which the current industrial revolution can provide the best possible support to businesses. Industrial associations conduct research into business capabilities, with the aim of providing first-class support to the companies of the future. Moreover, industrial associations are the major promoters and developers of the revolution as their members are among the main stakeholders (manufacturing companies, policy-makers, academics, and industry organisations). Consequently, their publications are state-of-the-art, and they publish leading articles for businesses. Such reports were systematically collected through searches of consultancies' and associations' websites for publications.

Once the process of collecting suitable literature resources had been completed, all resources were critically evaluated concerning three criteria (see Figure 2).

In the **first step**, each resource was evaluated in terms of its topicality in order to identify the most relevant, up-to-date information. Since the pace of development is fast, and since development is considered to be at an embryonic stage, the cited literature has to be as new as possible to provide qualitative information about the latest state of, and developments in, the industry. As a result, the majority of references for this dissertation have been published between 2013 and mid-2015.

During the **second step**, the trustworthiness of each individual resource was evaluated. It is important that the literature sources are composed by professionals, academics, and experts with sufficient background knowledge and expertise. Consequently, the necessary quality of the information is confirmed.

In the **third step** (and last one), each literature source was assessed regarding its contextual suitability. As the impact of digital and disruptive technologies on different kinds of organisations is very wide field, it is important that the collected resources include specific information in the area of disruptive technologies and the transformation towards digital manufacturing.

These three steps entailed an objective and systematic approach of prioritising and selecting the most appropriate and accurate resources for presentation and discussion of literature findings. In addition, the main subject areas related to the dissertation topic were identified at the end of the literature evaluation process (shown below in Figure 2), and constitute the basis for the literature tree in combination with the prioritised literature resources.

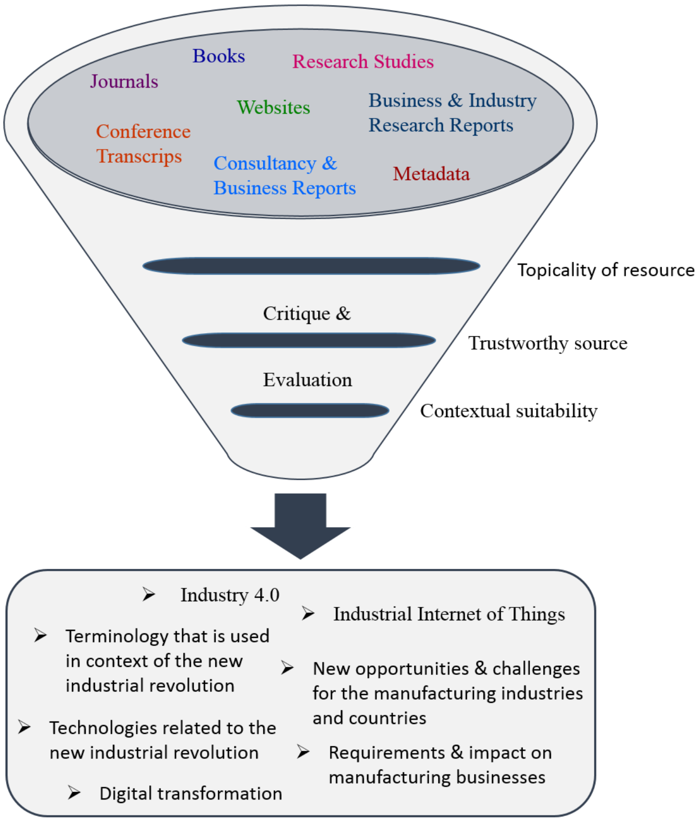


Figure 2: Academic funnel

2.2.2 The Literature Tree

As mentioned in the previous section, a literature tree provides a structured overview of the literature resources that have been reviewed, and which have satisfied the criteria of the academic funnel. The systematically identified areas (or strands) are 'Industry 4.0', 'Industrial Internet of Things', 'Terminology', 'Opportunities', 'Challenges', 'Technologies', 'Requirements' and 'Digital Transformation'. All resources have been categorised according to these areas. It is possible that a resource contains qualitative information in more than one area, and so it was assigned to more than one strand.

The resources for each strand are divided into two groups: main literature, and further literature. Based on the assigned scores and ranking (Figure 2), the literature resources were classified under these categories. Main literature sources are trustworthy, more topical, and contain useful information in the context of this specific study. Therefore, such literature was more heavily referenced during the literature review. Further literature is considered less sophisticated and suitable, but still worth citing in an effort to gain a comprehensive and objective understanding of the topic, and to provide further information for this study.

Industrial Internet of Things

Main references

Accenture	(2014)
Accenture	(2015b)
Accenture and General Electric	(2015)
ARC Strategies	(2014a)
China Materialia (Finland Team)	(2014)
Industrial Internet Consortium	(2014)
Industrial Internet Consortium	(2015)
VINT	(2014)

Further references

ARC Strategies (2014b); Attunity (2014); Bruner (2013); Echelon Corporation (2014); General Electric (2015a); Henning (2015); McRock Capital (2014); McRock Capital (2013); Meltzer (2015); National Instruments (2015); Neosperience Team (2015); RTI (2014); SAP (2014)

Industry 4.0

Main references

Bauernhansl et al	(2014)
Boston Consulting Group	(2015)
Brettel et al	(2014)
Capgemini Consulting	(2014a)
Deloitte	(2014)
Goetzpartners	(2015)
Lasi et al	(2014)
Lee, Bagheri and Kao	(2014)
Plattform Industrie 4.0	(2013)
PwC Strategy&	(2014)
Roland Berger	(2014a)
Roland Berger	(2014b)
VINT	(2014)

Further references

ARC Strategies (2014b); Bertschek (2015); BITKOM and Fraunhofer IAO (2014); Bosch (2014); Buckenhüskes (2015); Dorst (2012); Fallera and Feldmüllera (2015); Feld, Hoffmann, and Schmidt (2012); Hannover Messe (2015); Hinks (2015); McKinsey&Company (2015b); McKinsey&Company (2015c); MHP (2014); Plattform Industrie 4.0 (2015); Plattform-i40.de (2015); Sabo (2015); Schuh et al (2015); Sendle et al (2013); Sohn (2015); Tschöpe, Aronska and Nyhuis (2015); VDMA (2015); Wegener (2015); Heise.de (2015)

Terminology

Main references

Burmeister, Lüttgens and Piller	(2015)
Cognizant	(2014)
Davis et al	(2012)
DKE & VDE	(2014)
Plattform Industrie 4.0	(2013)
Qiming	(2015)
Roland Berger	(2014b)
VINT	(2014)

Further references

Advanced Manufacturing National Program Office (2015); Bryner (2012); Chand and Davis (2010); Goldman Sachs (2014); Kühnle and Bitsch (2015); Luo (2014); Matt, Rauch and Dallasega (2014); Nanry Narayanan and Rassey (2015); Scales (2014); Tschöpe, Aronska and Nyhuis (2015); Vde.com (2015); XMOS (2015)

Challenges

Main references

Accenture	(2014)
Accenture	(2015b)
Dworschak and Zaiser	(2014)
Hartmann and Bovenschulte	(2013)
Lee, Kao and Yang	(2014)
McKinsey&Company	(2015a)
PwC Strategy&	(2014)
Roland Berger	(2014a)
Soley	(2014)
The Economist Intelligence Unit	(2014)
T-Systems	(2014)
Westerman, Bonnet and McAfee	(2014)
World Economic Forum	(2015)

Further references

Accenture (2015a); BITKOM (2015); Botthof and Hartmann (2015); Bryner (2012); Brynjolfsson and McAfee (2014); Fraunhofer IAO (2013); Hannover Messe (2015); Hirsch-Kreinsen and Weyer (2014); Lasi et al (2014); Lass and Kotarski (2014); McKinsey&Company (2013b); McKinsey&Company (2015f); Meyer (2014); O'Brien (2015 Ploss (2014); REFA-Institut e. V. (2015); Tschohl (2014); VDE/VDI & ZVEI (2015)

Industry 4.0 / Industrial Internet of Things - Related Technologies and Requirements for a Successful Digital Transformation: An Investigation of Manufacturing Businesses Worldwide

Challenges

Main references

Accenture	(2014)
Accenture	(2015b)
Dworschak and Zaiser	(2014)
Hartmann and Bovenschulte	(2013)
Lee, Kao and Yang	(2014)
McKinsey&Company	(2015a)
PwC Strategy&	(2014)
Roland Berger	(2014a)
Soley	(2014)
The Economist Intelligence Unit	(2014)
T-Systems	(2014)
Westerman, Bonnet and McAfee	(2014)
World Economic Forum	(2015)

Further references

Accenture (2015a); BITKOM (2015); Botthof and Hartmann (2015); Bryner (2012); Brynjolfsson and McAfee (2014); Fraunhofer IAO (2013); Hannover Messe (2015); Hirsch-Kreinsen and Weyer (2014); Lasi et al (2014); Lass and Kotarski (2014); McKinsey&Company (2013b); McKinsey&Company (2015f); Meyer (2014); O'Brien (2015 Ploss (2014); REFA-Institut e. V. (2015); Tschohl (2014); VDE/VDI & ZVEI (2015)

Technologies

Main references

Bauernhansl et al	(2014)
Boston Consulting Group	(2015)
Brettel et al	(2014)
Capgemini Consulting	(2014b)
China Materialia (Finland Team)	(2014)
Deloitte	(2014)
Germany Trade & Invest	(2014)
Haiping et al	(2014)
Jazdi	(2014)
Kühnle, H. and Bitsch, G.	(2015)
Lasi et al	(2014)
Novak-Marcincin et al	(2013)
Piggin	(2015)
Plattform Industrie 4.0	(2013)
Roland Berger	(2013)

Further references

Bosch (2014); Bruner (2013); Dworschak and Zaiser (2014); Echelon Corporation (2014); Ernst & Young (2015); Filho, Ubelis and Berzina, (2015); Graetz and Michaels (2015); Hessmann (2014); Kracht (2015); Lee Bagheri and Kao (2014); RTI (2014); Sailer (2014); Scales (2014); Shakib (2015); Smith (2015); Vermesan and Friess (2014); Walker (2015); Yen et al (2014)

Requirements

Main references

Brettel et al	(2014)
Davis et al	(2012)
Dworschak and Zaiser	(2014)
Harvard Business Review	(2015)
Lasi et al	(2014)
Lee and Lee	(2015)
McKinsey&Company	(2015a)
Soley	(2014)
Wahlster et al	(2014)

Further references

Binner (2014); Capgemini Consulting, WZA RWTH Aachen and Fraunhofer IPT (2014); Echelon (2013); Hirsch-Kreinsen (2014); Lopez Research LLC (2014); PwC (2013); PwC (2015); Reeves, Haanaes, and Sinha (2015); Sinfield Calder and Geheb (2015)

Digital Transformation

Main references

Capgemini Consulting	(2015)
Caudron and Van Peteghem	(2014)
IBM Institute for Business Value	(2011)
Luo	(2014)
Westerman, Bonnet and McAfee	(2014)

Further references

Capgemini Consulting (2011); De Clerck (2015); Kane et al (2015); McKinsey&Company (2013a); Neosperience Team (2015); OPITZ CONSULTING (2015); Terpitz (2015); The MIT Center for Digital Business (2015)

Figure 3: Literature tree

Overall, approximately 150 literature sources passed the critical evaluation process of the academic funnel. As mentioned above, there was a scarcity of academic publications, and investigations in the form of books, journals and other publications. Therefore, business-oriented reports were targeted in an effort to ensure a fundamental understanding of the topic, a vital underpinning for the later stages of this research project.

2.3 The Industrial Revolution and Digital Manufacturing

2.3.1 Historical Background

Western civilisation has successfully passed through three stages of industrial revolution, and the fourth revolution is in progress (see Figure 4). An industrial revolution can be defined as a disruptive leap in the industrial process (Lasi et al, 2014), a concept and a development that produce fundamental changes in society and the economy (VINT, 2014). The first revolution occurred back in the 18th century due to the mechanical production driven by water and steam, with the development of machine tools, and rapid improvements in their efficiency. At the beginning of the 20th century, the second revolution witnessed the arrival of electricity and mass production (assembly lines). The third revolution was characterised by accelerated automation through the use of electronics and IT in production processes (Bauernhansl, Ten Hompel and Vogel-Heuser, 2014; Brettel et al, 2014). When considering this development on a global perspective, however, it should be recognized that several countries such as the United States see this current industrial transformation, the IIoT, as the third industrial revolution (The Economist, 2012). Since all revolutions result in significantly higher productivity, the current revolution is worthy of being an industrial revolution in itself, in that the internet is being used to integrate physical objects into an information network (ibid; Roland Berger, 2014a).

The current industrial revolution is characterised by the incorporation of intelligent machines, storage systems and production facilities into sophisticated networks, with the aim of merging the real and virtual worlds into what are known as Cyber-Physical Systems (CPS) (Dorst, 2012; Capgemini Consulting, 2014). CPS are combinations of IT with mechanical and electronic components connected to online networks that allow machine-to-machine communication in a similar way to social networks (Lee, Bagheri and Kao, 2014; Deloitte, 2014). These advanced technologies enable factories to become ‘smart’ and act autonomously, resulting in productions of individualised products on an industrial scale, while providing many opportunities for improvements in operational flexibility and efficiency (Capgemini Consulting, 2014).

Even though this technological development is widely seen as a new industrial revolution, it is also considered to be an industrial evolution among many experts. Harald Krüger, Chief Production Offer at the BMW Group, for example, sees this development not as a fundamental revolution taking a huge digital leap forward. He explained this development as a constant developing of technologies that will enable companies to achieve higher productivity, flexibility, as well as enhanced product and service qualities (Roland Berger, 2014a). Roland Berger (2014b) also mentioned that there are slow and steady changes in some areas, and described some evolutionary effects of this development. However, the majority of experts, including those in leading companies such as McKinsey, Boston Consulting Group, Capgemini Consulting, Accenture, and General Electric, have clearly pointed out the fundamental change of this development. They see this transformation towards digital manufacturing as a new and considerable industrial revolution with tremendous effects on countries, economics, businesses and human labour.

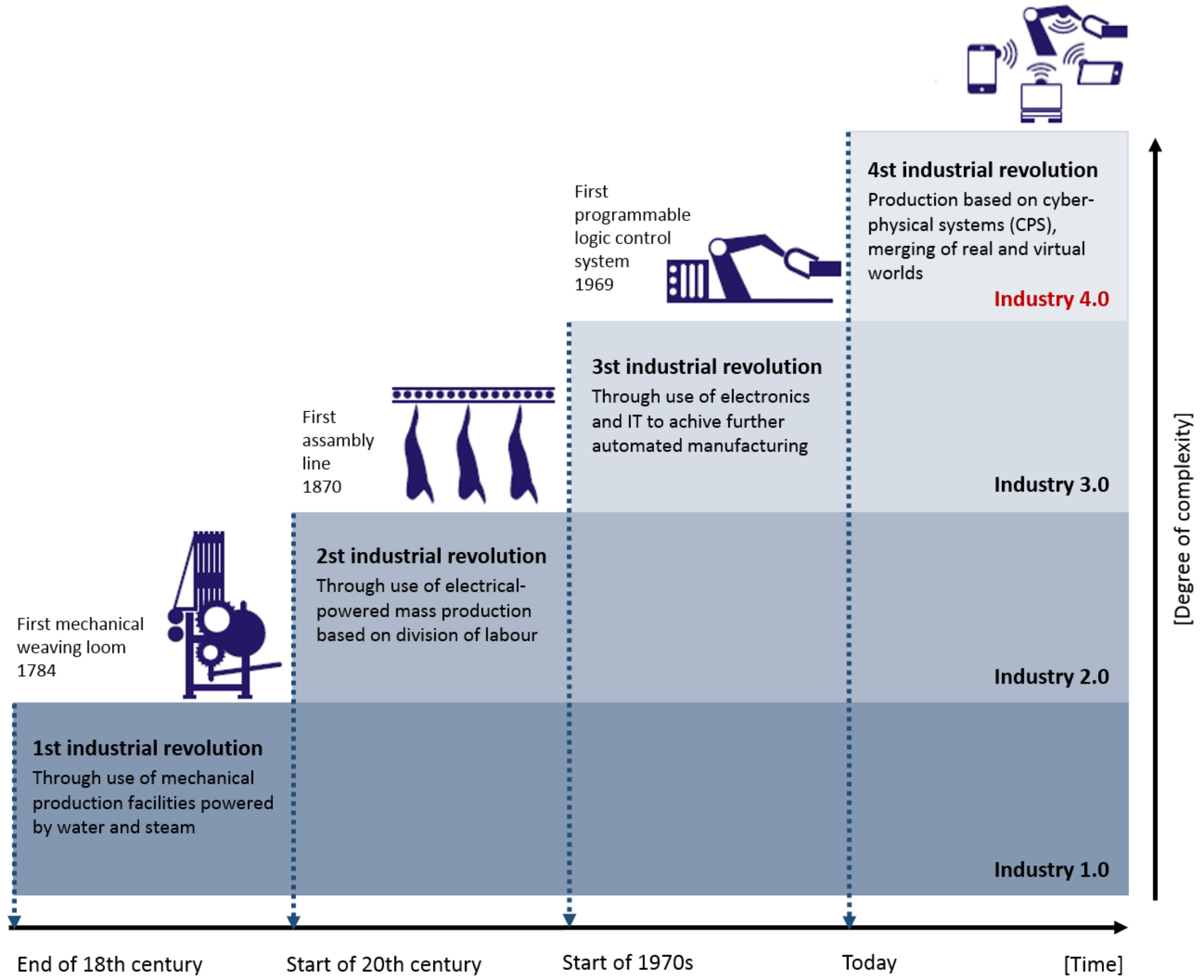


Figure 4: The four industrial revolutions (sourced from Plattform Industrie 4.0, 2013; Deloitte, 2014; Cognizant, 2014; VINT, 2014)

Since there are different views and opinions about the development and the impact of the current industrial revolution, many different terms are being used to describe this development. As illustrated in Figure 4, 'Industry 4.0' (which stands for the fourth industrial revolution) is a widely used term that originated in Germany, and is the same as the 'Industrial Internet of Things', a term which originates from the United States. Therefore, the following sub-section will name and clarify the terms concerning this current industrial revolution.

2.3.2 Terminology

Due to the global implications of the current industrial revolution, many countries have started to establish coalitions and associations to accelerate the progress of the development of industrial technologies. Consequently different terms are being used to describe this development (see Table 2). Since Germany and the United States are the countries playing leading roles in the current industrial revolution (which will be discussed in detail in sub-section 2.3.5), the following terminology has German and American origins:

Table 2: Overview of different terms used for the current industrial development (sourced from Plattform Industrie 4.0, 2013, 2015; Hardy, 2014; Capgemini Consulting, 2014a/b; Qiming, 2015; VINT, 2014; Burmeister et al, 2015; DKE & VDE, 2014; Smartmanufacturingcoalition.org, 2015; Vde.com, 2015; Plattform-i40.de, 2015; Roland Berger, 2014b)

Country	Term	Origin and Meaning
Germany	Industry 4.0 (I40)	In January 2011, 'Industry 4.0' was initiated by the Industry-Science Research Alliance (a group of 19 leading representatives from science and industry) as a future project of the High-Tech Strategy of the German Federal Government. The 'Plattform Industrie 4.0' is the most widely known joint initiative of BITKOM, VDMA, and ZWEI, which today also includes groups of German politicians, unions, and scientists that all collaborate in promoting the current industrial revolution.
United States	Industrial Internet of Things (IIoT)	In March 2014, leading industry players AT&T, Cisco, General Electric, IBM, and Intel announced their collaboration, and founded the Industrial Internet Consortium (IIC), its aim being to promote the development, adaption and use of 'Industrial Internet' technologies.
	Advanced Manufacturing (AM)	In 2011, President Obama launched the Advanced Manufacturing Partnership (AMP), which represents a group of research, business and political communities that aim to invest and further the development of 'Advanced Manufacturing' technologies.
	Smart Manufacturing (SM)	The Smart Manufacturing Leadership Coalition (SMLC) represents U.S. associations and non-profit organizations of different companies (e.g. OEM, suppliers, etc.), which combines different forms of expertise to develop new technologies that enable the application of 'Smart Manufacturing'.
	Re-industrialization (RI)	The term 'Re-industrialization' is also used to label the current industrial revolution, in which smart mechanical components are connected to the internet to perform digital manufacturing.
	Internet of Things (IOT)	The 'Internet of Things' is a more widely used term that represents the status where physical objects will be connected to the internet, which enables them to send and receive data.

Other countries	Industrial Intelligence	'Industrial Intelligence' is a term that is widely used in Japan, and which describes the situation where industrial objects will become smart when connected to the internet, resulting in machine-to-machine communications and autonomously controlled machines in what is known as 'smart manufacturing'.
	Les usines du futur (factories of the future)	This term is used in France and refers to the factories of the future that are characterised by highly autonomous and digital manufacturing operations.
	Made different - factories of the future	The phrase 'Made different – factories of the future' is widely used in Belgium, and constitutes the future form of digital manufacturing.
	Smart Industries (SI)	The term 'Smart Industries' is used in Netherlands, and describes the industry operations that are highly autonomous enough to produce physical industrial objects.

Industry 4.0 is a widely used term around the world, which was coined for a future project that belonged to the German government's High-Tech Strategy of the Internet of Things and Services (Plattform Industrie 4.0, 2013). The German spelling 'Industrie 4.0' set by Angela Merkel is even widely used in English publications, and efforts to strongly promote this 'brand' were made in Germany (Roland Berger, 2014b). The 'Plattform Industrie 4.0' is the most famous joint venture of leading German associations. It was launched at the Hannover Messe 2013, and it acts as a central point of contact for companies, employee representatives, politicians and scientists aiming to continue the Federal Government's future project Industrie 4.0 (German Trade & Invest, 2014). The main objectives of the Plattform Industrie 4.0 collaboration are to develop new manufacturing technologies, standards, and business and organizational models; and to ensure their practical implementation in order to achieve a leading role in digital manufacturing (ibid). The founding of the 'China-German Cooperation' in October 2014 was seen as a strategy by these countries to play a leading role in future manufacturing (Qiming, 2015). China and Germany announced their intention to collaborate, and to make the cooperation a model of future Industry 4.0 manufacturing (ibid).

The **Industrial Internet of Things**, first introduced by General Electric (GE) as the 'Industrial Internet' in 2012, is another term that is widely used regarding the current development of future digital manufacturing (Plattform Industrie 4.0, 2013). In 2014, leading American companies formed the 'Industrial Internet Consortium', the aim of which is to develop advanced manufacturing technologies in order to connect the physical world with the virtual world. Although there are several different terms used in the United States to describe this current industrial revolution, the 'Industrial Internet of Things' is the most common term in relation to this development (ibid).

In this dissertation, the current industrial revolution will be investigated from a global perspective, but only the terms ‘Industry 4.0’ and ‘Industrial Internet of Things’ will be used. Both terms will be seen as synonyms as they are the widely used labels for the current industrial revolution, particularly among the German and American manufacturing industries.

2.3.3 Definition and Characteristics of Industry 4.0 / Industrial Internet of Things

Since the current industrial revolution is expected to inflict fundamental changes in society and the economy, Industry 4.0 (or Industrial Internet of Things) can be understood as a new way of organising and controlling the entire value chain (Plattform Industrie 4.0, 2015). Through this development, the life cycle of products will be increasingly geared towards individualised customer needs (ibid). Fundamentally, this industrial revolution concerns the availability of all relevant information in real time, and the possibility to use gathered data to derive optimal value-added flows at any time (ibid). According to Plattform Industrie 4.0 (2015), this will be ensured by the digital connecting of all instances along the value chain. The connection of humans, physical objects and systems will offer new opportunities of higher flexibility, self-organisation, and optimised value-added processes within and across businesses. This will result in high improvements in expenditure, as well as in availability and consumption of resources.

Therefore, the current industrial revolution presents and abundance of opportunities for improvements in different areas of the value chain. Industry 4.0, or the Industrial Internet of things, possesses four main characteristics (Figure 5).

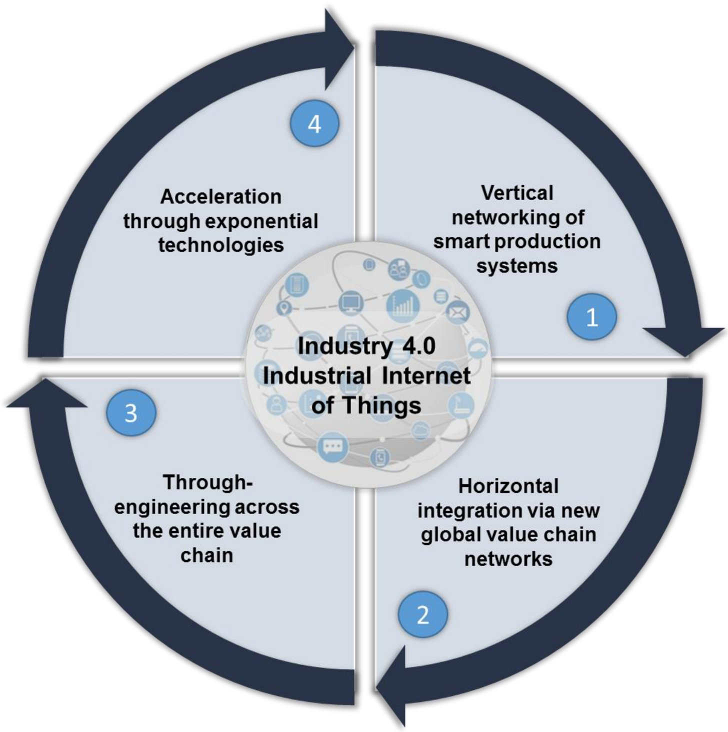


Figure 5: The four characteristics of Industry 4.0 resp. Industrial Internet of Things (sourced from Deloitte, 2014)

The following table provides explanations for each of the four main characteristics presented in Figure 5:

Table 3: Characteristics of I40 resp. IIoT

The four Characteristics of I40 resp. IIoT	
Vertical networking of smart production systems	Vertical networking is where CPS enables factories to become smart and to react rapidly to changes in demand and stock, as well as being able to control themselves concerning customer-specific and individualized productions, based on data that will be communicated during the entire value chain (Deloitte, 2014). Furthermore, CPS not only enables autonomous production management, but also autonomous maintenance management (Brettel et al, 2014), whereby resources and products are controlled by networking, and materials and product parts can be located at any time (Deloitte, 2014). This allows for handling of changes in orders, fluctuations in quality, as well as more rapid responses to machine breakdowns. As a consequence, resources can be used more efficiently, particular in relation to materials, energy, and human labour (ibid).
Horizontal integration via new global value chain networks	With horizontal integration via new global value chain networks, new value-creation networks based on real time data can be used to optimise operational processes that lead to integrated transparency, a higher level of flexibility, and better global optimisation (Deloitte, 2014). These networks will connect the entire value chain from the inbound logistics over the warehouse, through production, marketing and sales, to outbound logistics and frontline services; consequently, the history of the product will be specified and accessible at any time. This will lead to high transparency, flexibility and global optimisation regarding product changes, that not only can be made during the production, but also in the development, ordering, planning, composition and distribution of products (ibid). As a consequence, opportunities for completely new business models will arise, as will new forms of cooperation between customers and business partners (PwC Strategy&, 2014; Accenture and General Electric, 2015).
Through-engineering across the entire value chain	Through-engineering across the entire value chain offers the opportunity of new synergies between product development and production systems (Davis et al, 2012; Deloitte, 2014). Due to the data that will be available during all stages of the product life cycle (Brettel et al, 2014), more flexible processes concerning the product development and manufacturing via modelling to prototypes and the product stage can be realized. This will offer new opportunities for higher flexibility, as well as energy and resource efficiency (Deloitte, 2014).
Acceleration through exponential technologies	Acceleration through exponential technologies is where advanced technologies enable industrial processes to make more use of individualised solutions, flexibility, and cost savings (Lasi et al, 2014; Deloitte, 2014). In this case, artificial intelligence with advanced robotics, sensors, and actor technologies will offer increasingly autonomous processes. This will enable factories to become smart, whereby warehouses will be organized autonomously, production processes performed more reliably, and the interaction between humans and machines is conducted on a new level (Deloitte, 2014; Capgemini Consulting, 2014). All this will result in increasingly higher productivity and efficiency along the entire value chain.

2.3.5 Affected Industries

Since Industry 4.0 will inflict tremendous changes on countries, economics, businesses and manpower (Roland Berger, 2014a), a wide range of industries will be affected by the unfolding effects of this current industrial revolution (Accenture and General Electric, 2014). Figure 6 lists the main industries surveyed by Accenture and General Electric that are expected to be considerable affected by the industrial transformation:

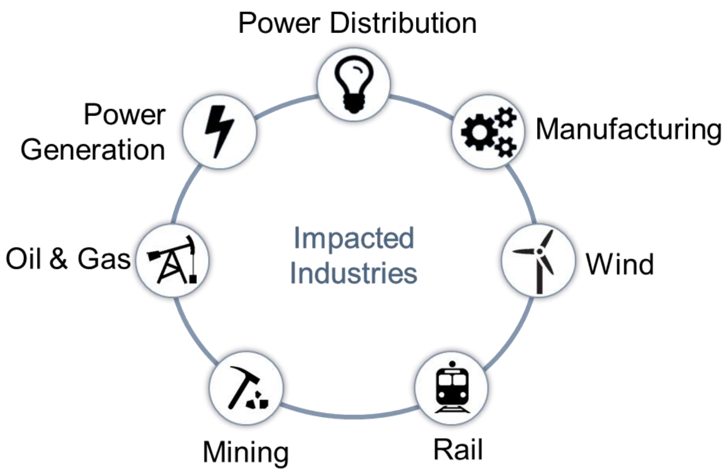


Figure 6: Overview of impacted Industries (sourced from Accenture and General Electric, 2014)

In view of this development, Capgemini Consulting and the MIT Center for Digital Business developed a 'Digital Maturity-Model' that allows for the classification of businesses and industries in terms of their digital maturity, based on their 'digital intensity' and 'transformational management intensity' (further information is provided by Capgemini Consulting, 2014a). This model provides an overview of different industries and shows their digital maturity, as based on a large study of 400 surveyed businesses (Capgemini Consulting, 2014a).

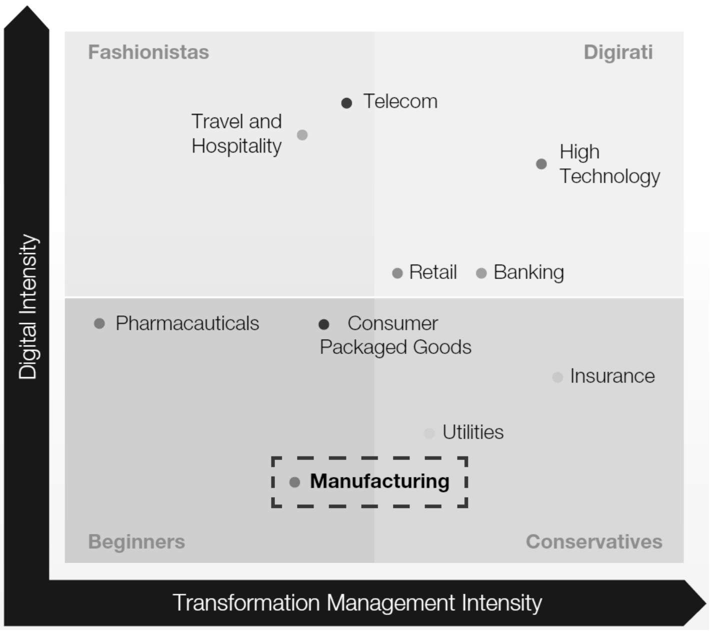


Figure 7: Digital Maturity by industry (sourced from Capgemini Consulting, 2014a)

Since this dissertation focuses mainly on the manufacturing industry, it is important to note that the above figure shows that the digital maturity of manufacturing lags behind that of almost all the other industries (Capgemini Consulting, 2014a). This indicates the necessity for researching disruptive technologies and the transformation towards digital manufacturing.

According to the Capgemini model, the manufacturing sector currently possesses a weaker capacity of driving change in terms of building a clear digital vision and culture. Second, the digital intensity of the sector is less developed, since the majority of manufacturing companies have not started or attempted to implement digital initiatives (e.g. advanced technologies) within their organisations (Capgemini Consulting, 2014a).

This section considers the types of manufacturing businesses that are relevant to this study. The following figure lists the main manufacturing sub-segments, as taken from the research study by BITKOM and Fraunhofer IOA (2014).

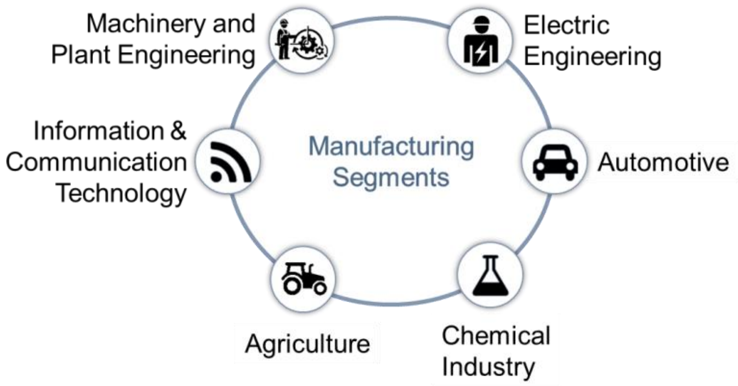


Figure 8: Typical manufacturing segments (sourced from BITKOM and Fraunhofer IOA, 2014)

2.3.6 Readiness of Countries

As illustrated in Capgemini's Digital-Maturity-Model (see Figure 7), the manufacturing industry is characterised by a relatively low readiness in terms of a digital transformation. The comparisons made by Roland Berger (2014b), however, show considerable differences across countries. In his study, Roland Berger compared several European Countries with China, and developed a 'Readiness Index', wherein Germany is classified as a 'frontrunner' and the country with the highest readiness (Figure 9):

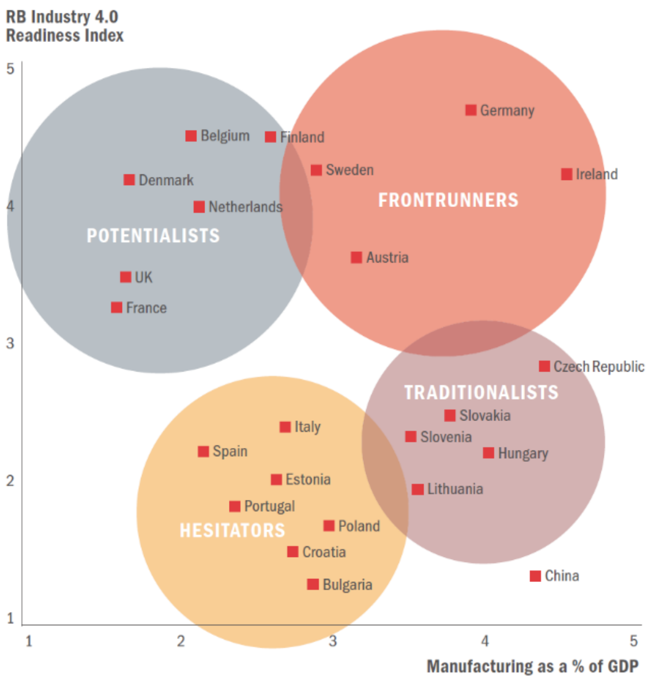


Figure 9: Cross country comparison of Industry 4.0 readiness in relation to the GDP' manufacturing proportion (Roland Berger, 2014b)

Since the United States (USA) and Germany are seen as the leading countries in terms of Industry 4.0 transformations, to date, no comprehensive studies have been conducted with a focus on the USA readiness. However, Goetzpartners (2015) provides a direct comparison between the USA and Germany by investigating criteria such as 'Digital Vision', 'Technology/Data' and 'Transformation Value Chain', and conclude that the USA is the country with higher maturity.

On the basis of these two studies, Germany and the USA are clearly seen as key actors in leading and fostering the transformation towards digital manufacturing.

A further study, albeit one conducted not with a focus on the digital transformation readiness (but which instead considered a country's 'national absorptive capacity' (NAC), or the country's IIoT enabling factors), was performed by Accenture (2015b). This study considered the main manufacturing countries, whereby the USA was ranked first, and Germany was positioned in the middle of the field (see Appendix A: Figure A1).

2.3.7 Key Players and Stakeholders

This study primarily focuses on the manufacturing sector. In addition, important players and stakeholders need to be considered.

Roland Berger (2014a) has identified three main groups of player, which essentially make the Industry 4.0 a reality. These groups are composed of technology suppliers, infrastructure providers, and industrial users. In addition, according to the Boston Consulting Group (2015), and reports by *The Economist* Intelligence Unit (2014), PwC Strategy& (2014) and Plattform

Industrie 4.0 (2013), governments and industry associations also play an important role in overcoming challenges and achieving the full potential of Industry 4.0.

As a result, the following diagram (Figure 10) was created to provide an overview of the main groups of player. The first group of stakeholders consists of government policy-makers and associations, which provide infrastructure, industry standards, and research funding. Another group are the technology providers and suppliers that develop the necessary technology (such as sensor embedded machinery) including infrastructure providers that provide infrastructure and the necessary software (such as Cloud Computing or Big Data Analytics). These technology providers are central to technology implementation and its economic outcomes. The industrial users group includes businesses which utilize the new technologies of Industry 4.0 within their organisation, including manufacturing businesses (which are the subject of investigation in this study).

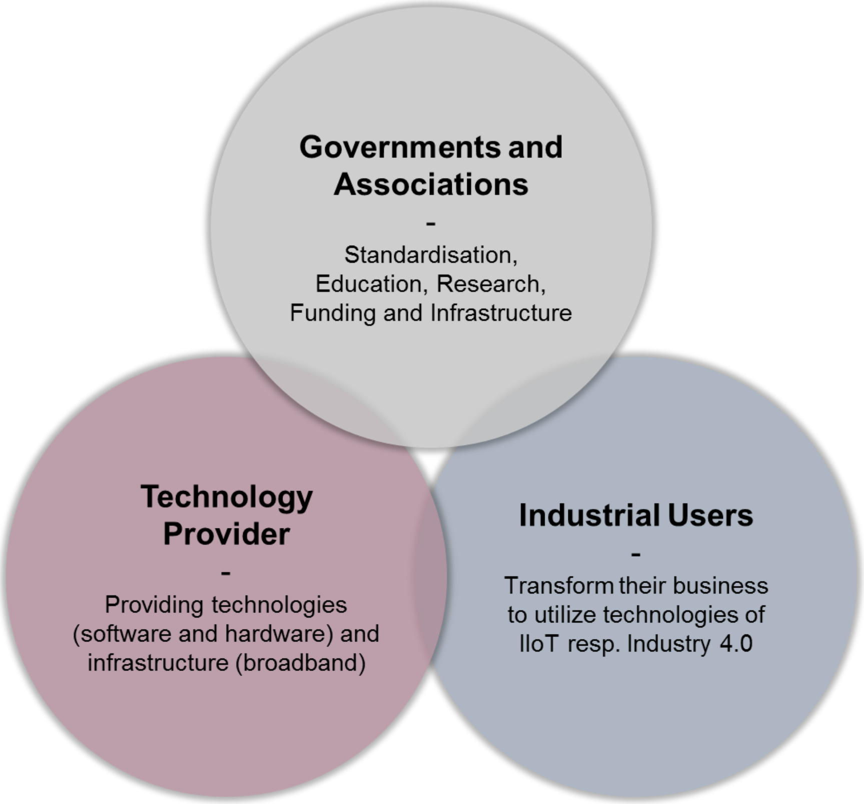


Figure 10: Three main groups of I40 (resp. IIoT) players (sourced from Roland Berger, 2014a; Boston Consulting Group, 2015)

2.4 General Opportunities in the Manufacturing Industry

2.4.1 Economic Opportunities

The benefits of Industry 4.0 are wide ranging, and influence entire economies and countries. Several studies and figures have been published during recent years that illustrate the value of these new developments. A study by Accenture (2015b) forecasts the value of IIoT for countries including the United States, China, Germany, and United Kingdom, by 2030. The United States will probably gain the greatest benefits (US$7.1 trillion) followed by China (with US$1.8 trillion), Germany (with US$700 billion), and the UK (with US$531 billion) (Figure 11).

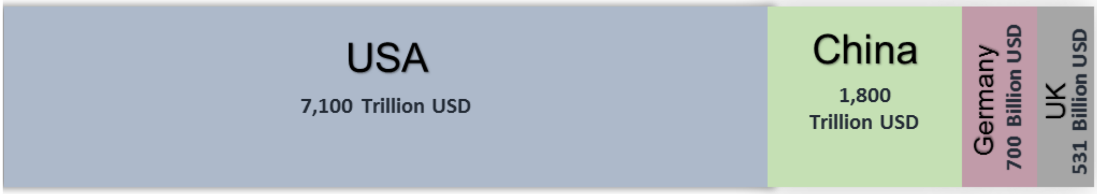


Figure 11: Worth of IIoT by 2030 for selected countries (Self-creation based on Accenture, 2015b)

Such speculated figures vary among several institutes and consultancies, with McKinsey Global Institute predicting a windfall of US$2.7 trillion to US$6.2 trillion by 2025, and General Electric predicting that the industry will contribute between US$10 trillion and US$15 trillion to global GDP over the next 20 years (Industrial Internet Consortium, 2014). Indeed, these figures underscore the tremendous opportunities offered by the I40. The significance becomes even more obvious in consideration of the value added to the GDP by the manufacturing sector in several countries. For instance, manufacturing contributed 22% to the GDP of Germany in 2013, and 12% of the GDP of the USA in 2013 (see Appendix A: Figure A2, and Figure A3) (The World Bank, 2015).

Another great opportunity being created by I40 is the strengthening of domestic production in Europe and North America. As a consequence, it could even send the trend of outsourcing industry to low-cost, low-wage countries into reverse, because of the changing requirements and factors in manufacturing (Deloitte, 2014; Gneuss, 2014).

2.4.2 Business Opportunities

In order to gain economic opportunities on a national level, industrial users, i.e. the manufacturing businesses, need to acknowledge the new possibilities I40 offers to businesses. According to Lasi et al (2014), these possibilities exist in different areas such as efficiency, productivity, flexibility, short development periods, individualisation on demand, and decentralisation. König (2014) also mentions the enablement of new innovative business models.

It is important to understand these opportunities, and so Figure 12 provides an explanation of, and examples within, the previously mentioned areas:

Business opportunity areas	Further details
Efficiency	▪ Savings of raw materials and energy
Productivity	▪ Intelligent technologies (e.g. robots and devices) increase prodcutivity and enable worker to be more productive
Flexibility	▪ Production becomes more flexible through connectivity (e.g. CPS) ▪ Increased transparency in manufacturing enables to react faster and change production procedures
Short development periods	▪ Advanced technologies allow shorter product development processes and production processes (shorter lead time to customer)
Individualisation on demand	▪ Integration of customer through networks (CPS) ▪ Mass customisation through new additive manufacturing technologies ("batch size one")
Decentralisation	▪ Faster and data driven decision-making (based on manufacturing data)
Innovative Business models	▪ Connectivity (IoT and IoS) combined with Big Data enable new hybrid business models

Figure 12: Business opportunities (sourced from Lasi et al, 2014 and König, 2014)

2.5 Advanced Technologies Enabling New Opportunities

This section outlines the advanced technologies that are integral to I40. As mentioned in the previous section, great business potential for manufacturing businesses can be realised through advanced technologies.

The main driver that is mentioned in almost all the cited literature is that of **Cyber-Physical Systems (CPS)** (Germany Trade & Invest, 2014; Plattform Industrie 4.0, 2013). This is not a single technology, but is the integration, co-operation and interaction of a range of technologies. However, before explaining its specific elements and components in detail, it is necessary to specify what CPS represents (Bauernhansl, ten Hompel and Vogel-Heuser, 2014).

Cyber-Physical Systems (CPS) are networks that combine the physical world with the virtual world. The physical states of machines and other physical objects are communicated into the virtual and connected network (Germany Trade & Invest, 2014). Thus, CPS enables the communication of physical objects like machines or robots among themselves, and also with humans. Since the objects are smart and connected, they are able to acquire and process data on their own, and so become self-controlled in some task, and can even become self-learning in the future (Brettel et al, 2014).

As shown in Figure 13, CPS is a combination of convergent technologies over the time. According to Jazdi (2014), CPS, when connected with the internet, is often referred to as the 'Internet of Things'. Machines and other physical devices are embedded with sensors that provide data (Germany Trade & Invest, 2014), and with actuators that can control the machines (China Materialia - Finland Team, 2014). When combined with small embedded computers and software, the objects become intelligent (Brettel et al, 2014). However, the real enabler is the integration in networks and connectivity to the internet, which makes the objects truly smart. As mentioned, this enables physical objects such as machines to communicate with plants, fleets, networks, and humans, and also to network socially (ibid).

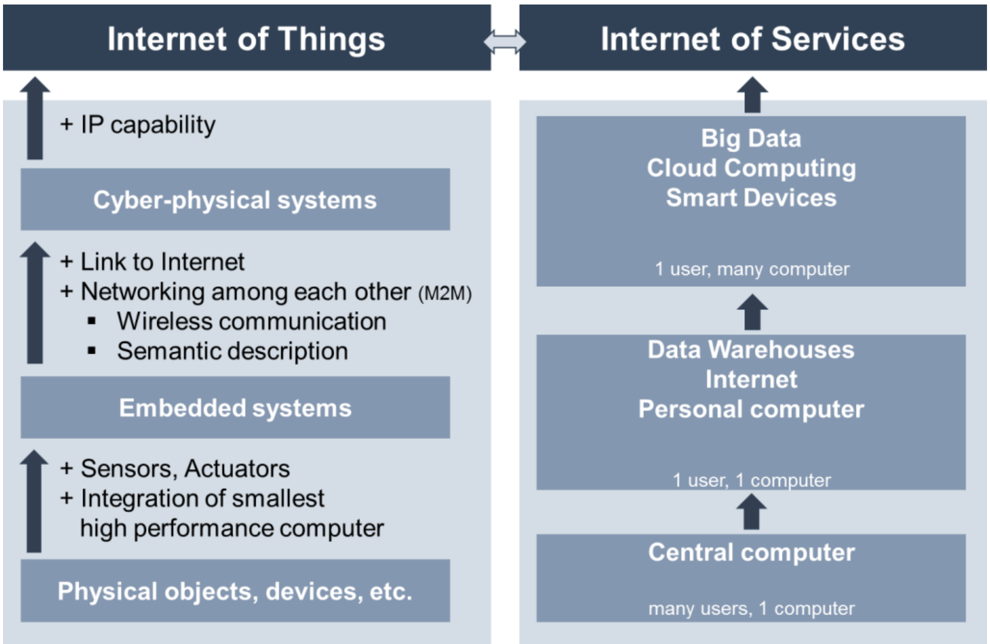


Figure 13: Convergent technology development (illustration of CPS) (translated and modified information sourced from Bauernhansl, ten Hompel and Vogel-Heuser, 2014)

Moreover, as shown on the right half of Figure 13, there are accompanying technologies that are integral to I40. These technologies form the 'Internet of Services and Data', which represents the connectivity, collection and processing of all data that is available, and which can be utilized in the business context.

Big Data is the collection, processing and analysis of large reams of structured and unstructured data with intelligent algorithms. It has recently become a widely discussed topic in business and academia, as it provides a range of new opportunities for businesses. The large quantities of diverse data in business emerge from different systems and sources, including manufacturing, as illustrated in Figure 14 (Plattform Industrie 4.0, 2013):

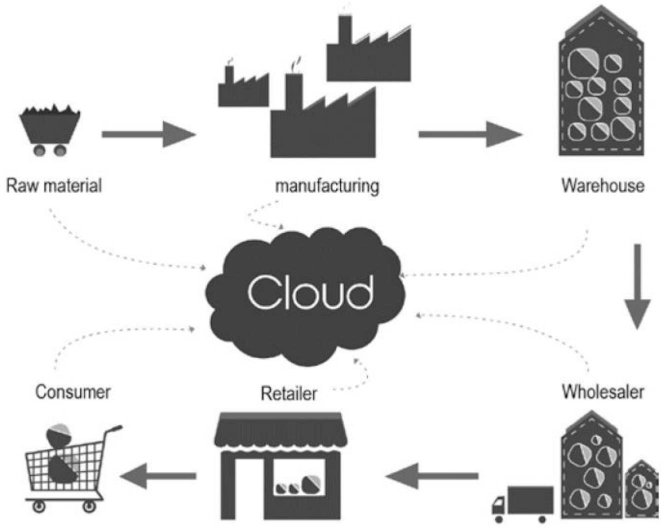


Figure 14: Data of entire supply chain is accessible in the Cloud (Kühnle and Bitsch, 2015)

The **Cloud** is the place in which all the collected data can be stored and processed (also see Figure 14). It provides the necessary computing power, intelligent software and algorithms (Big Data Analytics) to analyse and to visualize the information in real-time. Cloud computing allows access to information from anywhere around the globe at any time, thus increasing flexibility (Haiping et al, 2014).

A good illustration of the interaction and interdependencies of all the above described technologies in the value and supply chain is provided in Figure 15. All information from several stations of the value and supply chain can be fed together into the CPS. This allows, for example, the provision of various automated services and actions independent of location, and widespread integration and collaboration within the value chain (Lasi et al, 2014).

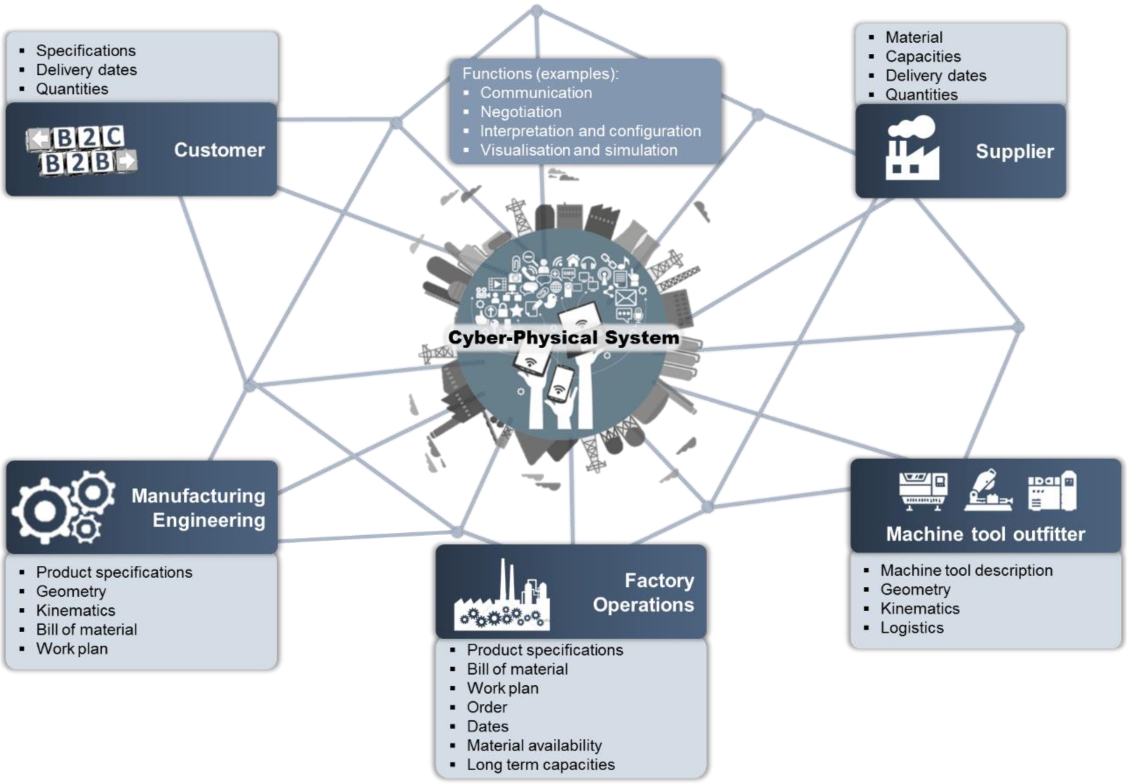


Figure 15: Illustration of a Cyber-Physical System (sourced from Lasi et al, 2014)

Beside these main technologies, researchers including Kühnle and Bitsch (2015), Bauernhansl, ten Hompel and Vogel-Heuser (2014), Bruner (2013), Kracht (2015), Novak-Marcincin et al., (2013) and Piggin (2015) have marginally mentioned other supportive technologies. These include IT-security systems, autonomous robots, additive manufacturing, and augmented reality and simulation. Since the academic literature does not provide information about these technologies in relation to I40 resp. IIoT, the following figure (16) has been produced using information from business-oriented reports. The top half of the graphic illustrates the CPS and the main technologies related to I40 resp. IIoT. The bottom half details other, less-related technologies.

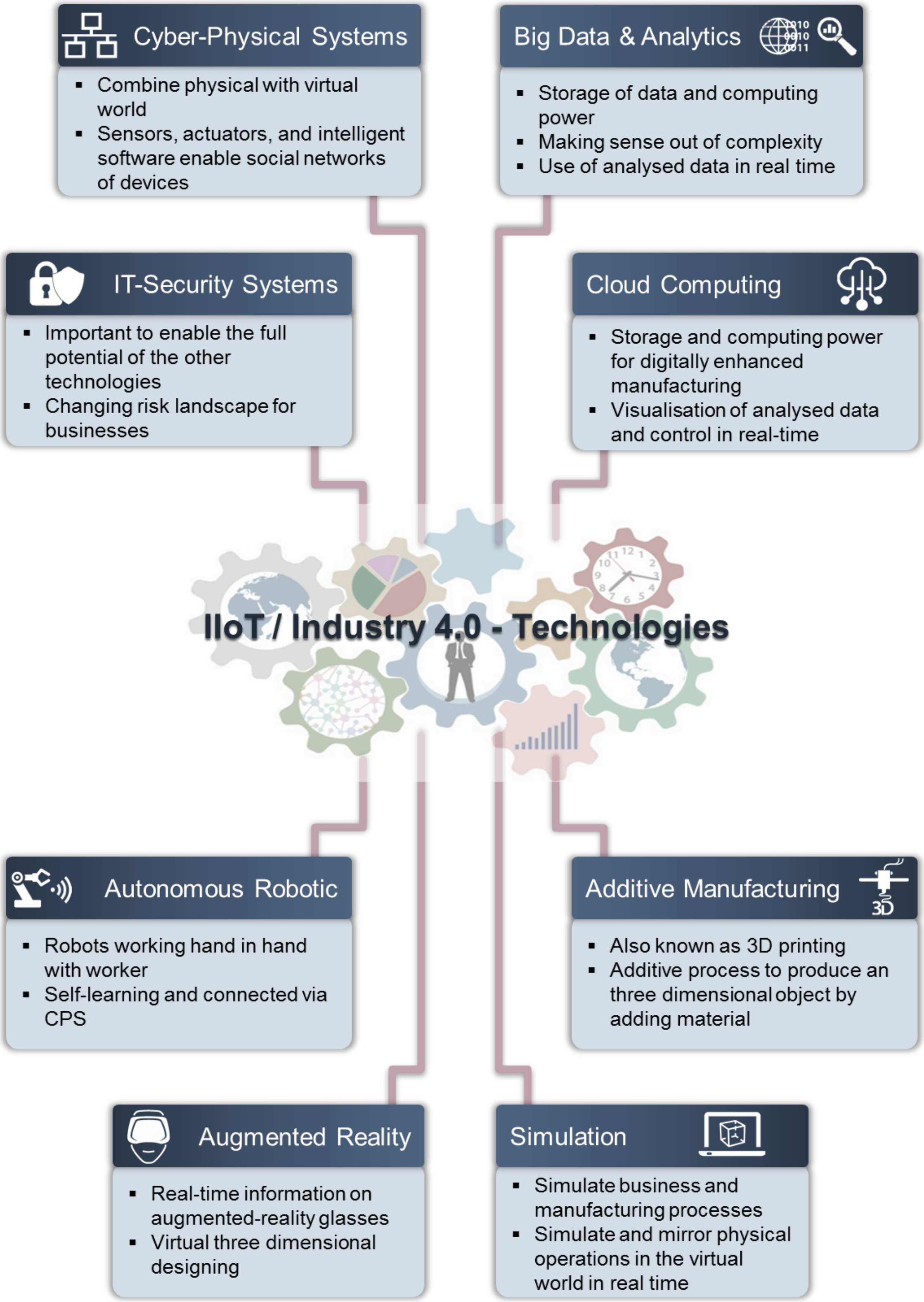


Figure 16: Overview of advanced technologies (sourced from Deloitte, 2014; Germany Trade & Invest, 2014; Bauernhansl, ten Hompel and Vogel-Heuser, 2014; Accenture, 2014; Lee, Kao and Yang, 2014; Capgemini Consulting, 2014b; Haiping et al, 2014; Roland Berger, 2014a; Metz, 2014; Novak-Marcincin, 2013; Boston Consulting Group, 2015; Kühnle and Bitsch, 2015)

2.6 Challenges Posed by Digital Manufacturing

2.6.1 General Challenges facing Governments and Associations

In order to gain the economic advantages that have been described earlier in this chapter, governments and other public policy makers need to overcome certain challenges. According to the World Economic Forum (2015), they need to re-examine and revise data protection and liability policies, and industry regulations. The data protection policies are important for multinational businesses as they regulate transnational data flow, data ownership, and data usage. To support investment in digital processes and transformation of business in several industries, governments need to revise industry regulations affecting industries such as utilities and healthcare. Since these are global challenges, governments need to cooperate and harmonise their policies and regulations, which will benefit large and global enterprises.

Another important task is for governments to expedite the developments in, and to promote I40 resp. IIoT, so that stakeholders (including policy makers, technology providers, and industrial users) are aware of latest developments and specific opportunities (ibid).

Countries should also invest in more digital infrastructure, so that their industries become more robust and ready to utilise the full potential of smart connectivity in business. This could include investment in broadband connectivity and sensors (PwC Strategy&, 2014; World Economic Forum, 2015).

The new industrial and digital revolution requires different skills in the future, according to Hartmann and Bovenschulte (2013) and, therefore, the governments need to foster education in those areas. The changing demography in some countries is an important factor, but the industry revolution can also provide economic opportunities for older workers.

A main challenge that is also discussed by various experts is establishing standards and references for networked manufacturing. Setting such standards and references cannot be achieved by one stakeholder group alone (e.g. the government, or businesses). These are joint tasks, which should be led by governments in cooperation with companies, industry associations, technology providers, and industrial users. One example is the Advanced Manufacturing National Programme Office at the National Institute of Standards and Technology in the US, which collaborates with industry to develop and set standards. The German approach is to initiate a joint forum of government, industry, academia, and three different Fraunhofer institutes, which addresses these challenges (The Economist Intelligence Unit, 2014).

Further associations with partners in industry, academia, and other research and development units should be founded and supported by governments, which in turn fund and foster the research and development of advanced I40 resp. IIoT technologies (World Economic Forum, 2015).

2.6.2 Requirements of Technology Suppliers

As mentioned in the previous section, a key challenge for technology suppliers are industry standards, as technology supplies need to develop new technologies and sell tried and tested equipment, which are interconnected and communicate in the same language. If the standards (including the compatibility of machines, robots, and further devices supplied by other vendors) are not specified, this can undermine industrial advancement and success (Soley, 2014).

Furthermore, technology suppliers need to illustrate the viability of their smart machines and technologies and produce convincing evidence, as manufacturers are still hesitant to invest in them. Therefore, technology suppliers need to develop real test beds to demonstrate the viability and the potential of their advanced equipment and technologies (World Economic Forum, 2015). Additionally, they can support industrial user by identifying opportunities, helping them to overcome barriers, and by sharing best practices (ibid).

Another challenge confronting technology providers is the rapid change in requirements of machinery, which requires a change in the mind-set. Until recently, products and equipment were built to last for several years; however, in the future the product lifecycle of such devices will have changed, and devices have to be changeable and flexible. One example is a machine that accommodates supportive devices or sensors (ibid).

2.6.3 Challenges for Manufacturing Businesses

The industrial revolution towards digital manufacturing poses various challenges for trade associations, policy makers, and technology suppliers, and manufacturing companies are no exception. Despite the opportunities being created, companies will have to solve various challenges before they can benefit from the current industrial revolution. According to Roland Berger (2014a), businesses have to change their organizations, processes, and capabilities – entirely in some cases, and partially in other cases – in order to capture the full potential benefits under I40.

The first and most crucial challenge is to seize the **attention of those at the top tier of management** (Westerman, Bonnet and McAfee, 2014). As the industrial internet comprises a digital transformation of important business processes (including changes in value and supply chains, revolutions of product and service portfolios, as well as new and disruptive business models), high investment will be needed to push the implementation of this development (PwC Strategy&, 2014). However, as well as high investment, strong leadership practices have to be applied to foster a learning organization (Westerman, Bonnet and McAfee, 2014). An organization that is shaped by openness, readiness for change, and new knowledge will undergo a successful transformation. These issues therefore need to feature in a CEO's agenda, as top management is the only force that can drive such fundamental changes (ibid).

Tremendous investment will be needed, but it might not be possible to accurately calculate the return on investment, and such **unclear economic benefits** present further challenges to companies (PwC Strategy&, 2014). According to McKinsey & Company (2015a), considerable investment is needed to build up a smart factory with a connected supply and value chain via CPS, and this constitutes a high barrier for many manufacturing businesses. Furthermore, the predicted opportunities such as higher productivity, efficiency, and flexibility are often too vague, and it can be difficult to clearly predict the benefits of the I40 resp. IIoT development (PwC Strategy&, 2014).

According to Accenture and General Electric (2015), another main challenge is that of **Big Data analytics**. As operations will be driven by data produced by sensors placed inside machines, robots, and products along the entire supply and value chain, companies have to figure out how to gather data appropriately. Companies can struggle with collecting and correlating data sourced from different systems and departments that have different responsibilities (Lee, Kao and Yang, 2014). Moreover, businesses are often incapable of consolidating different types of data and using results achieved from such data analyses properly. This arises from a lack of advanced technologies and high performance software, as well as shortages in skills and relevant experiences among staff (Accenture and General Electric, 2015).

Further challenges will arise alongside **opportunities for new and disruptive business models.** Due to the application of CPS in highly digitalized supply and value chains, as well as in complex manufacturing networks (including changing the roles of designers, physical product suppliers, and the means of interfacing with the customer or contractor), new ways of doing business shall emerge (Roland-Berger, 2014a). As a result, businesses have to overcome the challenges involved in transforming their business models towards a more hybrid, product and service approach-based model (Burmeister, Lüttgens and Piller, 2015; Accenture, 2014). Companies need to exploit the opportunities offered by highly connected CPS to generate additional value from gathered data in an effort to improve customer benefits (PwC Strategy&, 2014).

Digital manufacturing will also present challenges to companies through a rising demand for **new skills among employees** (Dworschak and Zaiser, 2014). Since I40 resp. IIoT involves the digital transformation of linking information technology (IT) with operation technology (OT), new skillsets in different functions shall be needed (Accenture, 2014). Engineers, for example, need to possess more IT skills, and must think about product function rather than just technical features, as software becomes a crucial part of manufacturing products (Capgemini Consulting, 2014). In this case, the main challenge for manufacturing companies is to appropriately implement training and development programmes to ensure that employees possess the appropriate skills during a successful transformation (ibid).

Since digital manufacturing will require highly connected supply and value chains between all parties (including autonomously controlled machines), **associated standards** and **IT security** present further challenges to companies (PwC Strategy&, 2014). Standards will be needed to ensure machine-to-machine communications as well as communications between different departments and companies. These challenges are mainly facing technology suppliers and policy-makers (refer back to sections 2.6.1 and 2.6.2), but these also exist in the manufacturing sector (ibid). IT security is also a crucial issue since intelligent networking will create a surge in business opportunities (refer back to sub-section 2.4.2), but at the same time increases the scope for cyber-attacks (T-systems, 2014). Companies have to face the challenge of ensuring that their operations are secure so as to avoid data losses, which could undermine their competitive advance, and include the leaking of sensitive information concerning important customers. Organisations may become more susceptible to losing private customer data (ibid).

2.7 Requirements of Manufacturing Businesses

This chapter has provided a detailed list of the challenges that I40 resp. IIoT presents to policy-makers, technology firms, and other businesses. The following chapter therefore will examine the requirements that manufacturing companies worldwide must satisfy to ensure a successful transformation towards digital manufacturing.

According to primary market research by McKinsey & Company (2015a) in the United States, Germany, and Japan, manufacturing companies in general have to increase their performance along these three dimensions: (1) drive the next horizon of operational effectiveness, (2) adapt business models to capture shifting value pools, and (3) build the foundations for digital transformation (Figure 17). Since these three dimensions envelop the fundamental requirements of businesses performing a digital transformation, the following sub-sections will focus on these three dimensions in more detail.

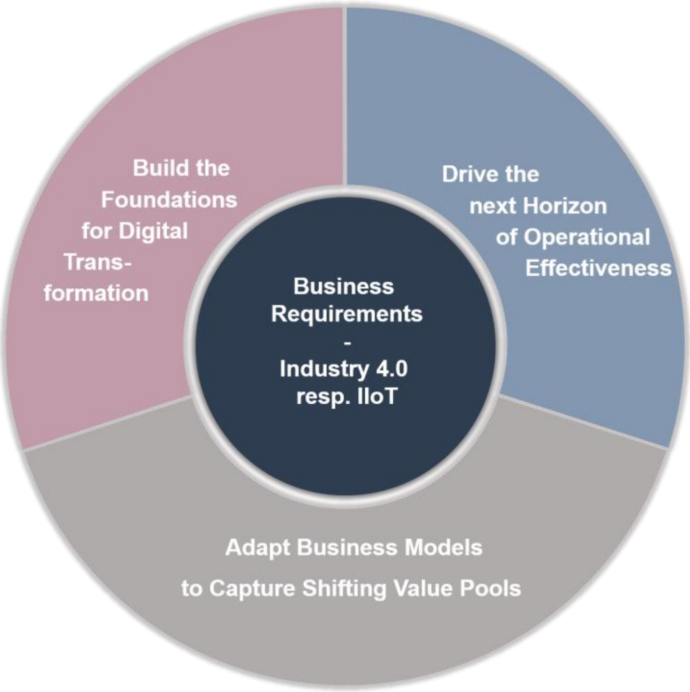


Figure 17: The three dimensions of manufacturing business requirements (sourced from McKinsey & Company, 2015a)

2.7.1 Drive the next Horizon of Operational Effectiveness

McKinsey & Company (2015a) describes the first main dimension as a need for higher operational effectiveness during business operations. In general, this dimension requires the efficient use of information that emerges through digital connections, by using information appropriately, and by sharing it among parties of the value chain, while eliminating inefficiencies caused by missing information during communications among functions, departments, and companies (ibid).

According to Lasi et al (2014), companies need to create intelligent products that are attuned to their manufacturing process and customer applications, as well as being able to generate and share information along the value chain. At the same time, products need to be customized to satisfy individual needs. Businesses therefore need to ensure increased flexibility within complex product development and manufacturing processes. Brettel et al (2014) argue that one way of reducing complexity of coordination whilst increasing flexibility is to divide the manufacturing process into smaller, single value-oriented units. In this case, information will only be shared during each consecutive step in the process (ibid).

As standardization decreases and products become highly individualized, control procedures need to be adapted down to the shop-floor level, and be performed by people with product and process-specific knowledge (ibid). Companies therefore need to apply high decentralized operations to be able to handle specific conditions in the most efficient ways, including fast decision-making procedures, which in turn require changes towards flatter organizational hierarchies (Lasi et al, 2014).

Brettel et al (2014) mention that companies need to centralize information and data collecting, and also model processes throughout the industry to achieve the most efficient synergy. Due to the need for cooperation and information sharing between departments, businesses, and even industry players (Lee and Lee, 2015), companies can complement each other where a potential solution for a unit in one company allows a solution in another (Brettel et al, 2014). This trend needs to be understood by a company's management board, which in turn must analyse the company's current and future operations, consider potential synergy effects, and recognise competencies that can be gained though collaboration with other companies (Soley, 2014).

2.7.2 Adapt Business Models to Capture Shifting Value Pools

The need for changing a company's business models to capture shifting value pools is the second dimension of business requirements (McKinsey & Company, 2015a). Companies need to adapt their business models towards more service-oriented ones. Those will be based on collected and shared data that offer new value pools in existing value chains.

Brettel et al (2014) argues that increased collaborations enabled by shared data will offer companies new opportunities to optimize their operations in factories and even outside company boundaries. Businesses therefore need to focus mainly on their core competencies while outsourcing other activities to partners in order to ensure optimized operations and a sustainable competitive advantage. This will potentially require changes to existing business models, whereby manufacturing companies need move away from merely offering a single physical product, towards the offering of bespoke products; manufacturing, in terms of its capability, will change from the restricted means of product design into almost a service industry (ibid).

According to Soley (2014), companies have to develop and adapt new ways of thinking, and understand that value is not so much created by physical products, than by the capacity of a firm to collaborate with partners, and to concentrate on individual, unique competencies. Since changes and adaptations to business models often require considerable transformations in business operations, it will be the duty of senior management to identify potential opportunities (Davis et al, 2012), and to invest strategically in operations that create new business value (Lee and Lee, 2015).

2.7.3 Build the Foundations for Digital Transformation

Since a transformation towards digital manufacturing requires fundamental changes, the creation of a stable foundation for a successful transformation is the third dimension (McKinsey & Company, 2015a). As I40 resp. IIoT disrupts the supply and value chain, companies have to change significantly the way they do business. Manufacturing businesses therefore need to build up digital capabilities (e.g. by attracting digital talent); enable collaborations (e.g. alliances and strategic partnerships); treat data as a valuable business asset; and, manage cybersecurity, proprietary data, and data architectures in an effort to enhance their business operations (ibid).

As noted by Dworschak and Zaiser (2014), digital manufacturing involves fundamental changes in business operations that require a transformation of a firm's workforce through acquiring new skills and experiences. Products need to be smart by possessing information on the manufacturing process as well as customer applications (Brettel et al, 2014); production processes will be increasingly automated (including machine-to-machine communications); and, employees need to possess more technical skills and IT knowledge (Dworschak and Zaiser, 2014). In view of all this, companies need to provide employees with new training and development programmes to acquire skills in the fields of electronics and mechanical systems, and in the programming and use of specific software.

Moreover, companies need to establish collaborations with partners along the supply and value chain as the margin of added value within a company decreases when product and process complexity increase (Brettel et al, 2014). These trends compel companies into creating platforms that connect with partners and enable firms along the supply and value chain to collaborate with them (Wahlster, 2014). Innovation platforms are a good example of when a firm involves collaborators and customers in the innovation process (ibid). These platforms need to combine smart products, data and services, and make them accessible to all involved parties in order to use and combine different expertise during innovation processes. Within collaborative networks, companies can share risks and combine resources, which is crucial in a highly dynamic and complex digital manufacturing environment (Brettel et al, 2014).

As the trend towards networked manufacturing increases connectivity between companies, machines, and operational processes, companies have to create systems that are dependable, reliable, safe, and secure (Soley, 2014). Since the rate of cyberattacks has increased substantially, businesses have also had to apply systematic security procedures (Harvard Business Review, 2015). Companies therefore need to develop security systems that constantly measure potential risks accompanying existing and future technologies of the industrial internet, as well as constantly and automatically identifying gaps and threats to ensure secure operations (Soley, 2014). Due to the very dynamic development and change in cybersecurity requirements, the industry as a whole should address this need by developing architectural frameworks and standards that can be used by businesses across the industry (ibid).

2.8 Conclusion

In this final section of the literature review, the analysed literature will be summarized and synthesized, and critical gaps in the literature will be identified. During the critical literature resource evaluation (refer back to section 2.2), it was found that academic literature provided only superficial research in the area of I40 resp. IIoT, mainly due to the novelty of this phenomenon. This was strengthened with a deeper literature analysis of the theoretical background of I40 resp. IIoT. Therefore, non-academic literature resources were used to fill these significant literature gaps, to ensure a fundamental understanding of the dissertation subject. The synthesis below focuses solely on literature, and not on the wider range of business-oriented reports. Table 4 provides a comprehensive overview of the literature status and identified knowledge gaps in the literature:

Table 4: Literature synthesis and identified literature gaps

Objective	Literature Synthesis	Literature Gaps
Research Objective 1	According to Platform Industrie 4.0 (2013), the term I40 was coined for a future project that belongs to the German government High-Tech Strategy of the Internet of Things and Services, the aim of which is to development new manufacturing technologies and procedures, and achieve a leading role in digital manufacturing. Hardy (2014) describes a similar development in the USA, which is called the IIoT. According to Dorst (2012), I40 resp. IIoT can be explained as an industrial revolution of incorporating intelligent machines, storage systems and production facilities to build sophisticated networks, with the aim to merge the real and virtual worlds. Cyber-physical systems (CPS) are seen as the main enabler of this development, which can be explained as a combination of IT with mechanical and electronic components, which are connected to online networks that allow new ways of operations (Brettel et al, 2014; Dorst, 2012; Bauernhansl, Ten Hompel and Vogel-Heuser, 2014. Brettel et al (2014) described I40 resp. IIoT as being characterised by autonomous production and maintenance management. Davis et al (2012) notes the opportunity of new synergies between product development and production systems, whereas Lasi et al (2014) sees the main benefits of advanced technologies enabling companies to make more use of individualised solutions as being flexibility and cost savings. According to The Economist Intelligence Unit (2014), governments and industry associations play an important role in overcoming challenges of, as well as in achieving the full potential of I40 resp. IIoT. Moreover, the Deutsche Bank Research (2014) predicts huge economic opportunities and considerable future changes to the labour market.	The literature provides a very general view on the topic of mains development, and no specific research into major and often fundamental areas of the current industrial revolution was found. There exist fundamental knowledge gaps on the issues facing stakeholders (such as technology and infrastructure providers, industry associations, academia, and governments). Similarly, no information was found on the relative importance of these key stakeholders on driving the current development. In addition, the literature provides only superficial information about the tremendous challenge of setting industry standards, which are required to make this revolution happen, and it provides no specific information about which party or parties should drive this process of standardisation. Moreover, information on the opportunities and challenges for businesses were also superficial; the literature only

	Also, Lasi et al (2014) claims that I40 resp. IIoT is a development that offers huge opportunities, whereby businesses can benefit from higher efficiency, productivity, flexibility, short development periods, individualisation on demand, and decentralisation. König (2014) also notes the enablement of new innovative products and business models.	contained general views of the development for businesses, with no detailed research regarding the potential business implications.
Research Objective 2	According to Brettel et al (2014), most experts from industry and research agree that the internet in combination with Cyber-Physical Systems (CPS) form a main driver of the industrial revolution. CPS compromises a range of technologies such as sensors, actuators and small computers, which are embedded in physical objects such as machines, robots, or other devices (Bauernhansl, ten Hompel and Vogel-Heuser, 2014). The internet and CPS allow humans and machines to communicate among themselves. The physical states of the objects are translated into the virtual world through large networks and the internet. Brettel et al (2014) even argue that smart objects will soon be able to acquire and process data on their own, and become self-learning and self-optimizing. Jazdi (2014), and Bauernhansl, ten Hompel and Vogel-Heuser (2014) present further technologies that are closely related to CPS and that are interconnected (such as Cloud Computing, and Big Data & Analytics). The Cloud is described as a form of storage and computing power which provides information and visualisation of analysed data, but also a platform for communication and control systems (Haiping et al, 2014; Jazdi, 2014). Big Data is the management and analysis of unstructured and structured data collected from different systems and functions along the value and supply chain to enable new potential (Lee, Kao and Yang, 2014). The potential offered by these novel advanced technologies in manufacturing are extensively discussed in the literature (such as Jazdi (2014), Lasi et al (2014), and Bauernhansl, ten Hompel and Vogel-Heuser (2014)). Potential benefits include increases in efficiency, productivity, flexibility, safety, and the integration of customers and innovative business models. Other technologies that are mentioned in some literature alongside I40 resp. IIoT include IT-security systems, simulation, augmented reality, additive manufacturing, and autonomous robotics. Bauernhansl, ten Hompel and Vogel-Heuser (2014) define augmented reality and 3D-simulation as a technology for enhancing the human-machine interface. Kühnle and Bitsch (2015) mention the novel manufacturing technology of additive manufacturing, which allows for the shift of manufacturing activities into the design process, through the production of more complex parts or products even in very small batches. According to The Economist Intelligent Unit (2014), in the future, advanced robots	Again, the literature lacks comprehensive information of the technologies and their individual importance in this current industrial revolution. The literature only mentions some technologies such as CPS and Big Data, but contains no thorough descriptions of their potential uses or on how they meet business objectives. Where technologies are outlined individually in detail, no mention is made of their connection with other technologies and necessary standards and references, which are important for the interconnectivity of the technologies. The potential benefits identified in the literature are not related to individual technologies, but rather to the combinations of several technologies. It appears that previous research studies have not identified the individual potential of each technology in line with manufacturing objectives and overall business objectives. Moreover, the literature does not provide concrete information about the practical applicability and maturity of combined technologies. Further technologies such as Simulation, Augmented Reality and Additive Manufacturing are very rarely and superficially discussed. In addition, the literature provides no discussion about

	will become more intelligent and common in the manufacturing sector.	autonomous robotics in relation to I40 resp. IIoT.
Research Objective 3	Lasi et al (2014) state that companies need to create intelligent products that possess information on their manufacturing process and customer applications, as well as being able to generate and share information along the supply and value chain. According to Brettel et al (2014), businesses have to ensure increased flexibility during complex product development and manufacturing processes, whilst Lasi et al (2014) sees the need to apply high, decentralized operations for handling specific conditions most efficiently. Soley (2014) identifies the need for senior management to understand the rising trend towards greater collaboration with other companies. Lee and Lee (2015), and Brettel et al (2014) identify the need to centralize information and data, as well as modelling processes across industry to improve synergy effects. The increased need for collaboration will bring new opportunities for optimizing operations across factories and even out with company boundaries (Wahlster, 2014), but these require changes to existing business models (Davis et al, 2012; Brettel et al, 2014). Soley (2014) therefore identifies the need for developing and adapting a new way of thinking in order to understand new value propositions, and this needs to be driven by senior management. Dworschak and Zaiser (2014) add the requirement for transforming the firm's workforce through gaining new skills and experiences. Harvard Business Review (2015) also mentions that enhanced applications of systematic cybersecurity procedures are essential.	The main knowledge gap identified in the literature (concerning this research objective) is the very superficial information concerning the business requirements. The literature again provides only general views on this topic, and often presents only scattered company requirements without focusing on an organization as a whole. Although some business requirements are explained, no evaluative information was found on exactly how important and crucial different requirements are when it comes to performing a successful transformation. In addition, the literature contains no information on the consideration of relationships between different business requirements, and does not provide strategic approaches or recommendations according to what businesses need to consider, or on what order requirements need to be accomplished.
Research Objective 4	The World Economic Forum (2015) forecasts a massive change in digital infrastructure due to increased connectivity and more smart devices in various industries using the internet. Lasi et al (2014) sees tremendous changes in technologies that will become increasingly advanced in the future (e.g. intelligent and self-controlled machines). In addition, Hartmann and Bovenschulte (2013) express the considerable need for changes in education systems, since I40 resp. IIoT requires new skills and capabilities in the future, which in turn must be considered by governments, companies, and universities.	Again the literature provides scant information, with only superficial research on potential future development needs, and no generalized strategic approaches nor explanations of when and how manufacturing businesses can and should start the transformation process towards digital manufacturing.

3. METHODOLOGY

3.1 Introduction

This chapter covers the third step of this research study (see Figure 1), in which an appropriate research methodology was chosen in accordance with the formulated research question and objectives. According to Easterby-Smith, Thorpe, and Jackson (2012), a research design, which comprises the process of data collection and analysis, needs to be systematically planned so that the researchers' objectives are achieved. A research design is based on the research philosophy and objectives, as well as existing theoretical knowledge identified during the literature review (Saunders, Lewis, and Thornhill, 2009). This chapter commences with a section, in which research questions and related objectives are clarified. Following these, an explanation of the research strategy is provided, followed by descriptions of the applied research philosophy, the data collection methods, and the data analysis process. Following this, the validity of collected data will be considered, as well as the ethical standards of the research, and also anticipated research problems and limitations.

3.2 Research Questions

Since the research questions were briefly mentioned in section 1.3, this section will clarify these by considering the identified knowledge gaps detailed in the previous chapter (refer back to section 2.8). According to Bryman and Bell (2015), the formulation of clear and specified research questions is crucial for a successful research study. Four main research questions and objectives were formulated (see Table 5):

Table 5: Research questions and objectives

Mapping and explanation of research questions and objectives	
1. Research Question	What is current state of Industry 4.0 (I40), or Industrial Internet of Things (IIoT)?
1. Research Objective	To assess the current state and the current development of Industry 4.0 resp. IIoT.
Explanation	According to the first research question, the aim is to investigate the current state of I40 resp. IIoT. Since this revolution is progressing at a high pace, the literature comprises considerable knowledge gaps, which make it difficult to satisfy the research study aim of gathering information on the latest and current state of I40 resp. IIoT.

2. Research Question	What are major technologies that underpin I40 resp. IIoT, and what potential benefits do they offer for manufacturing businesses?
2. Research Objective	The main technologies that drive I40 resp. IIoT, and the potential opportunities and benefits they offer for manufacturing businesses worldwide.
Explanation	The second research question considers the main technologies that underpin I40 resp. IIoT, and the opportunities and benefits they offer for manufacturing businesses. Since the literature contains only superficial research in this area, the aim in this study is to provide a comprehensive overview and explanation of the main technologies, in terms of their individual importance in the new industrial revolution, their individual benefits they offer in connection with business objectives. The practical applicability and maturity of combined technologies in manufacturing will also be investigated.
3. Research Question	What requirements need to be accomplished by manufacturing businesses to ensure a successful I40 resp. IIoT digital transformation?
3. Research Objective	Investigate the requirements that need to be accomplished by manufacturing businesses worldwide to perform a successful transformation towards digital manufacturing (I40 resp. IIoT).
Explanation	The third research question considers the requirements that need to be accomplished by businesses to perform a successful transformation towards digital manufacturing. Again, the existing literature contains only superficial research and provides only a general view on this topic. Therefore, this research study aims to provide a more comprehensive presentation of prioritized requirements that need to be accomplished to ensure a successful transformation towards I40 resp. IIoT, with considerations of company sizes and overall business objectives.
4. Research Question	When and how should manufacturing businesses start the transformation process towards digital manufacturing, and what are potential future development trends of I40 resp. IIoT?
4. Research Objective	To identify when and how manufacturing businesses can best start the transformation process towards digital manufacturing, and to consider potential future development trends of I40 resp. IIoT.
Explanation	This is the fourth research question, which considers when and how businesses can start best the transformation process towards I40 resp. IIoT, and what potential future development trends can be expected. As the existing literature provides almost no information concerning these aspects, this dissertation aims to prescribe a general approach for when and how businesses can best start this process, with considerations and explanations of potential future devolvement trends of I40 resp. IIoT.

3.3 Research Strategy

A fundamental distinction needs to be made between quantitative and qualitative research studies. Quantitative research involves the collection and analysis of quantitative data (i.e. numbers), while qualitative research is the collection and analysis of words and sentences (Bryman and Bell, 2015). A qualitative research approach is the clarification about how (process) and why (meaning) things happen (Cooper and Schindler, 2014), whereby the researcher considers different people's perceptions of the world's reality (Bryman and Bell, 2015). Qualitative research therefore is seen as a valuable approach for international business studies, as data in the form of real phenomena instances can contribute to theory building and reflection (Doz, 2011). One form of qualitative research is interpretive qualitative research, whereby prevailing complex phenomena are identified using a process of considering subjective perceptions of different phenomena in the social world (Lee and Lings, 2008). However, quantitative researchers consider the world as an objective construct (Baker and Foy, 2012), and they may hold sceptical views on qualitative research, citing the potential influence of the researcher's subjectivity during qualitative data collection and analysis, and the generalisation of what may be limited research results (Cooper and Schindler, 2014). On the other hand, quantitative researchers collect and analyse data from a population to explain their general characteristics; the danger here is that individual elements may be ignored during the investigation (Hyde, 2000). Single data elements may therefore not match up with the generalized character of the investigated population, as quantitative research may solely investigate the general, rather than the particular, aspects. Qualitative research, however, can allow for a deep investigation of a phenomenon, and a ream of detailed data on an individual scale can be collected and analysed (ibid). The critical incident research approach comprises the collection of data on a particular phenomenon, rather than the collection of large reams of data that may not be directly relevant to the research study (Easterby-Smith, Thorpe, and Jackson, 2012). An exploratory qualitative research approach is seen as being more appropriate to this research study, as it allows for a deep and individual investigation of I40 resp. IIoT development, including its current state, the necessary technologies and business requirements, as well as potential future developments and trends (Lee and Lings, 2008). This research was performed using a multiple data collection and analysis method including document analysis and individual in-depth interviews (Cooper and Schindler, 2014). Through this method, existing expert documents in the form of consultancy reports were analysed, and semi-structured interviews with experts were conducted in an effort to satisfy the research questions and objectives (Bryman and Bell, 2015).

A further distinction needs to be made between inductive and deductive research studies (Lee and Lings, 2008). Qualitative research studies generally follow an inductive process (Hyde, 2000) whereby collected data in the form of specific views is used to build generalised theories (Lee and Lings, 2008). A deductive process goes in the opposite direction, whereby existing generalized theories are used and tested through specific instances in order to draw conclusions about their validity (ibid). Since existing literature provides only superficial theories about I40 resp. IIoT, an inductive approach has been applied that may allow for generalized theory building on the basis of collected and analysed secondary and primary data gathered during the research study (Bryman and Bell, 2015).

3.4 Research Philosophy

Research philosophies include ontology and epistemology research approaches. An ontology approach is a study about the nature of reality and existence, whereas an epistemology approach considers the most appropriate ways of enquiring into the nature of the world (Easterby-Smith, Thorpe, and Jackson, 2012). As qualitative researcher tends to apply interpretations by analysing the interrelation between different people's perceptions and the social world, an epistemological interpretivist research philosophy that has been used in this research study (Bryman and Bell, 2015). Moreover, an ontological subjectivist research approach has been applied to comprehend different realities during the process of analysing subjective perceptions about these realities made by different individuals in the nature of reality (Creswell, 2012). With the strategic selection and analysis of existing documents, and the conducting of semi-structured expert interviews, an investigation into the subjective perceptions of different individuals was performed, which is considered a valuable research method that can satisfy the research questions and objectives (Cooper and Schindler, 2014).

Since the conducted research was built upon the researcher's own nature of reality, an empirical phenomenology approach was also applied during the research study (Bryman and Bell, 2015). In an investigation of subjective individual views on the nature of reality, an empirical phenomenological research approach considers all individual interpretations, and leads to the acquisition of new insights concerning the world's reality (Aspers, 2009). This approach was used to gain an insight into the knowledge and experiences of different experts (ibid). Through this, a researcher acquires a deeper understanding during the collection and analysis of data concerning other people's expertise, and a more universal perception of the research topic in the nature of reality is formed (Bryman and Bell, 2015). Therefore, this research study was conducted by applying two different forms of data collection and analysis: professional documents (secondary data) were analysed; this was followed by semi-structured expert interviews (primary data). The aim was to maximize the researcher's understanding and experience, with the intention of developing a more generalized perception of the research topic.

3.5 Secondary Data Collection

Secondary data comprises previously collected and analysed information, which can be used to complement primary data sources such as interviews (Easterby-Smith, Thorpe, and Jackson, 2012). According to Sekaran and Bougie (2010), secondary data can be gathered from a wide range of different sources such as company reports, government publications, and statistical abstracts. Farquhar (2012) adds that consultancy reports in particular are a useful and valuable secondary data source, as they consider specific business issues. Therefore, reports from leading consultancies (which often conduct large surveys with global manufacturing companies, and therefore possess considerable expertise concerning I40 resp. IIoT) were identified as a valuable source of secondary data.

Bryman and Bell (2015) state that a systematic approach is needed for the appropriate collection of such documents. The internet was visited first, since it comprises a vast resource (Lee and Lings, 2008); around 40 appropriate consultancy reports were sourced. The four criteria (authenticity, credibility, representativeness, and meaning) proposed by Bryman and Bell (2015) were used for the evaluation of documents, and are integral to the purpose of this research study. Therefore, all selected reports were evaluated (refer back to sub-section 2.2.1) to ensure the collection of the most appropriate documents for data analysis later on in the study.

3.6 Primary Data Collection

Primary data contains new data that has been collected directly by the researcher from original sources (Easterby-Smith, Thorpe, and Jackson, 2012). The most common sources of primary data during qualitative research studies include individual in-depth interviews, participant observation, films, photographs, and case studies (Cooper and Schindler, 2014). Individual in-depth interviews with various experts (who were economists and scientists, and who possessed considerable knowledge and expertise regarding I40 resp. IIoT) were conducted, as in-depth interviews were considered a valuable method for the primary data collection for this research study.

3.6.1 Interviews

In-depth interviews are a common method of conducting qualitative research studies, and they take the form of either unstructured or semi-structured interviews (Lee and Lings, 2008). Whereas unstructured interviews provide no specific questions or contain a strict order of the topics being discussed, semi-structured interviews usually start with a few specific questions, after which the interviewees are given more freedom to talk about their individual thoughts and ideas about the research topic (Cooper and Schindler, 2014). Since the aim of this research study was to investigate I40 resp. IIoT technologies and business requirements (which is considered a broad topic), semi-structured interviews were used since they are commonly applied in phenomenology research studies. Semi-structured interviews therefore underpin the chosen research philosophy in this study (Lee and Lings, 2008). The semi-structured interview format enabled the researchers to gently guide the interviewees through the interview process, with the intent of gathering relevant data in order answer the research questions in this study (Bryman and Bell, 2015).

Experienced senior consultants, managers, scientists, and researchers from leading companies and institutes worldwide were considered to be suitable candidates for primary data collection (see Figure 18). All interviewees in these categories were chosen in accordance with their background, expertise, and current field of working. In view of the sophisticated nature of digital manufacturing, a diverse group of 11 different experts were interviewed, all of whom possessed profound knowledge and considerable expertise in various areas of I40 resp. IIoT. During the interviewing stage of this study, 9 experts were interviewed via online meetings and by telephone; each interview lasted 30 minutes, resulting in 4.5 hours of total interviewing time. In addition, 2 experts were interviewed via email by using the same interview question procedure.

All interviews were conducted by both researchers, whereby every expert was asked the same questions in the same order. Since phenomenological interviews tend to be more like dialogues between interviewer and interviewee (Bryman and Bell, 2015), questions were also added or skipped, depending on the interviewees' answers, and a wealth of detailed and high quality data on individual experts' perceptions in relation to the research questions and objectives were collected.

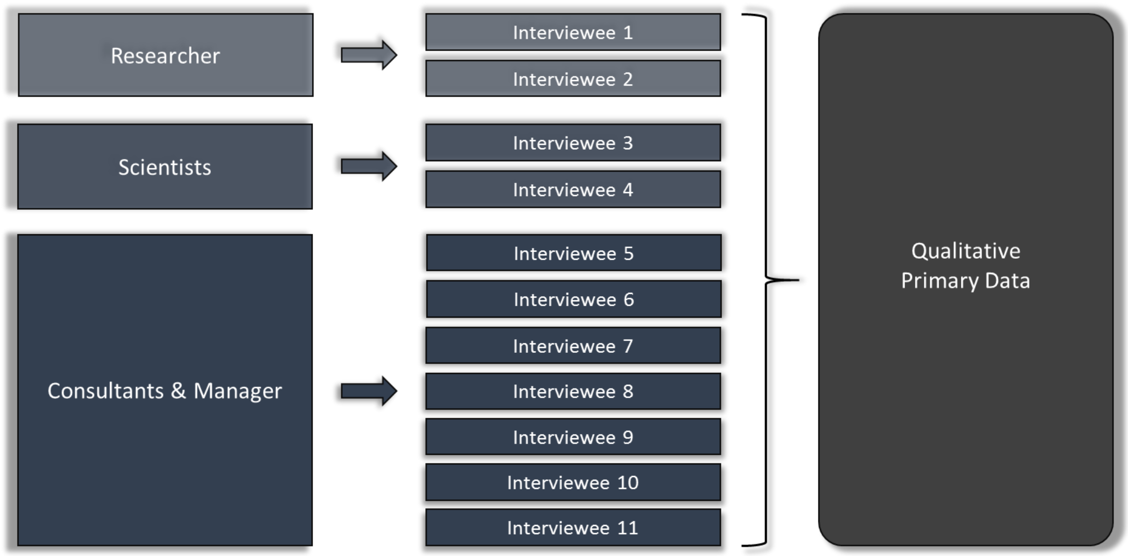


Figure 18: Overview interview process

3.6.2 Questionnaire

According to Bryman and Bell (2015), interview questions need to be developed specifically for the research study to ensure an appropriate satisfaction of the research objectives. Therefore, the interview questions were created on the basis of identified knowledge gaps in the literature review, as well as in regard to the research objectives of this study. Since semi-structured interviews were conducted, questions were mainly used as an interview guide. The questionnaire therefore contained 7 open questions, which were divided into three main categories in accordance with the research objectives.

Appendix B contains a template of the semi-structured interview questionnaire, which was used as an interview agenda at the same time (Figure B1). All 9 interviewees who were interviewed via online meetings or telephone were provided with this agenda in advance; this enabled all interviewees to familiarise themselves with the interview content, and gave them enough time for interview preparation. The 2 interviewees who were interviewed via email were also provided with the same questions, albeit in a different word format, which enabled all participants to answer the questions more easily in written form.

3.6.3 Sampling Method

For this research study, appropriate sampling methods were applied to select suitable participants for the semi-structured interviews. The first was purpose sampling, whereby participants were selected in regard to their background, expertise, and current field of employment, in an effort to contact the most suitable participants, in terms of the research objectives (Cooper and Schindler, 2014). Potential participants were kindly asked if they were interested in participating in the research study (Bryman and Bell, 2015). As soon as participants agreed, they were included in the sample population; appointments were scheduled, and all interview instructions were clarified. Furthermore, snowball sampling was applied, whereby participants who signed up were asked to name further potential participants who were eligible candidates for this research study (Easterby-Smith, Thorpe, and Jackson, 2012). Since the first applied sampling method resulted in 10 participants signing up, the second sampling method was rarely used. Therefore, the majority of participants were selected by purpose sampling to ensure selection of the most suitable interviewees for this research study.

3.7 Data Analysis

Qualitative research studies generate a wealth of detailed data that needs to be analysed systematically so that the most appropriate research results can be presented (Bryman and Bell, 2015). According to Easterby-Smith, Thorpe, and Jackson (2012), qualitative data analysis can be either a content analysis, or a grounded analysis. The purpose of content analysis is to analyse data in order to test previously defined constructs and ideas in form of hypotheses. The purpose of ground analysis is to focus more heavily on the data itself and let it ‘speak’ in order to understand different contexts (ibid). Since the aim of this research study is to understand the development of I40 resp. IIoT, including its technologies, challenges and requirements, as well as potential future trends, grounded analysis was identified as a more valuable approach for this dissertation.

A sequential data analysis approach was applied in a systematic analysis of the collected secondary and primary data. 40 consultancy reports were analysed as secondary data, followed by primary data analysis of the 11 semi-structured interviews. During both analysis procedures, a grounded analysis approach was applied, as this fits in with empirical research (Bryman and Bell, 2015); the analysis comprised a 7-step process (see Figure 19):

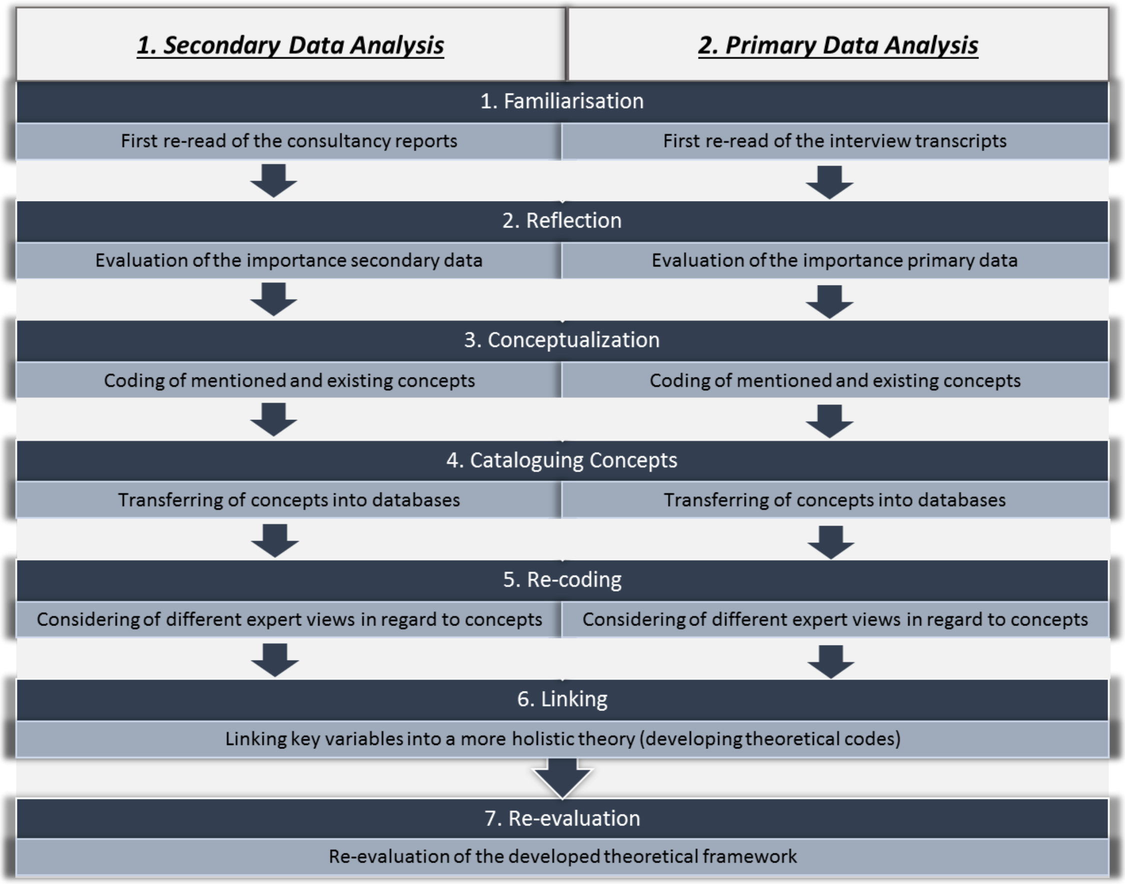


Figure 19: Grounded data analysis (based on Easterby-Smith, Thorpe, and Jackson, 2012)

Both processes of data analysis were conducted independently. Using the phenomenological research approach, the research analysis commenced as soon as the researchers embarked on the literature review (by which a comprehensive understanding and knowledge is acquired, in this case through the analysis of consultancy reports), prior to conducting the semi-structured expert interviews (Bryman and Bell, 2015). In this study, the sequential data analysis approach was applied through 7 steps. The first was a familiarization of collected secondary and primary data (step 1). This is followed by data reflection, whereby all collected data is evaluated and prioritized (step 2). In view of the research questions and objectives, the data was categorized and coded in order to build relationships between data and to yield important information (step 3). The information was transferred onto databases (step 4). Since experts expressed different views about similar concepts, their different perceptions were compared, whereby data units were re-coded to refine the stability, quality, and value of all data (step 5).

The entire data analysis process was conducted via an inductive process (see Figure 20), whereby analysed secondary and primary data were combined and transferred into theory by developing theoretical codes (step 6). During this process, the data was generalized by conceptualizing the ways in which different codes related to one other, in the form of hypotheses, which then were used for theory building (Easterby-Smith, Thorpe, and Jackson, 2012). In the final step, the developed theory was re-evaluated by critically evaluating and testing the developed theoretical framework, with the aim of ensuring that this study would make a substantial and valuable contribution to the canon of knowledge

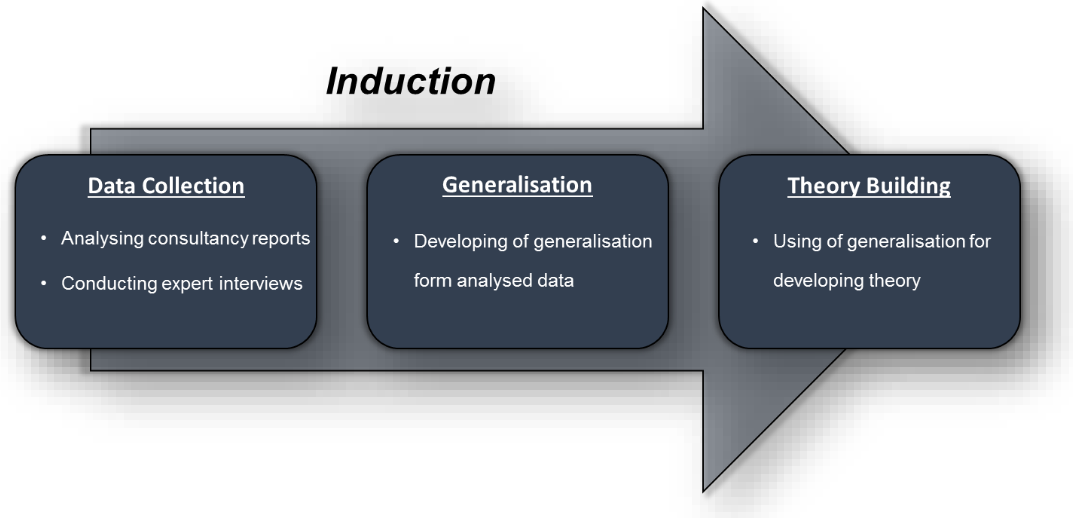


Figure 20: Induction process (sourced from Lee and Lings, 2008)

3.8 Trustworthiness

The trustworthiness of qualitative research is often criticised by other researchers, namely positivists; such criticisms can arise due to the limited consideration of validity and reliability during naturalistic work (Shenton, 2004). According to Saunders, Lewis and Thornhill (2009), and Bryman and Bell (2015), trustworthiness can be increased by considering and addressing the credibility, transferability, dependability, and confirmability of data. Table 6 details how these criteria have been addressed and considered in this research study:

Table 6: Trustworthiness

Quality Criteria	Provisions to address the criterion
Credibility	The credibility of the qualitative research was guaranteed by considering triangulation, whereby two methods - the analysis of consultancy reports, and the conducting of semi-structured expert interviews - were applied. Regarding the analysis of consultancy reports, the secondary data is considered credible and trustworthy since all considered documents are accessible online and they provided comprehensive information for this research study. As per the interviewing of experts, the primary data is also considered as credible since all experts participated voluntarily, and a reflective commentary approach was used, which allowed for a collection high quality, reliable data (Shenton, 2004). Moreover, a brief introduction on the participants is provided at the beginning of the next chapter; this covers the background, qualifications, and experiences of each interviewed expert. In addition, all recordings and transcripts were passed over to the dissertation supervisor, who doubled-checked the credibility of the research results.
Transferability	The transferability was assured by analysing business reports from leading consulting companies worldwide, which conducted large international surveys concerning I40 resp. IIoT. For the interviews, experts from different countries and organisations were interviewed, and therefore the research results are based on a broad population.
Dependability	The dependability of the research study is acceptable, as this dissertation provides an in-depth explanation of the research methodology (including a research design), which enables the reader to repeat this study. However, this research study can only be repeated under the same social circumstances since it is qualitative research, in which different subjective perceptions of individuals are investigated.
Confirmability	Since the study was conducted by two researchers, and since two independent methods were applied, the confirmability of this study is assured. Hence, potential subjective influences of the researchers were minimized by developing a generalized perception of the research topic, so that the research results have not been purposely influenced by subjectivity (refer back to section 3.4).

3.9 Ethical Considerations

3.9.1 Anonymity

All interview research results have been entirely anonymised. References to interview results and quotations are solely based on codes, with no inferences of the names or information about the individual participants in this study. The introduction on the participants contains sufficient contextual information (for the sake of trustworthiness of the study). All the participants were given the option of authorising the usage of their names, positions, professions and/or employing organisations by signing an additional permission form (see Appendix B: Figure B2). This permission was completely voluntary, and the names of participants who did not fill out the form are anonymised. The main permission form specified that in the presentation and discussion of all research results, their names would remain confidential. Through this procedure, the privacy of all participants was maintained, and only the information that was authorised by participants is provided in this dissertation (Bryman and Bell, 2015).

3.9.2 Participation Information Sheet and Consent Form

In addition to the permission forms (sub-section 3.9.1), every participant was provided with a participant information sheet and a consent form, which they completed prior to interview. Hence, the participants received all the relevant information in advance, and they volunteered to participate. This was to ensure that the interview process was accurate and ethically acceptable. Furthermore, the participant information sheet clarified the ethical codes of the University of Strathclyde Business School, since research involving the interviewing of participants must satisfy ethical standards. In addition, the consent form specified that participants could volunteer to participate, and that they had the right to withdraw their participation at any time; this also ensures that the interview process is both accurate, and satisfies ethical considerations. Throughout the complete primary data collection process, care was taken so that participants were not stressed, discomforted, harmed, or embarrassed in any way (Bryman and Bell, 2015). These standards will be considered during the presentation and discussion of the research results in the next chapter.

3.9.3 Reflexivity

According to Alvesson and Sköldberg (2009), reflexivity is a complex relationship between procedures of knowledge generation, the different concepts used for these procedures, and the actual knowledge generator(s). Bryman and Bell (2015) describe a deconstructive reflexivity as a method associated with an interpretive epistemology research approach, whereby the social phenomena study aims to comprehend specific social phenomena through the understanding of social actors and their perceptions about the specified phenomena. Malterud (2001) suggests that researchers need to be wary when conducting studying specific incidents from different positions and perspectives, and explaining them through different beliefs, values, biases and experiences, which consequently may can lead to differences in research results. Therefore, reflexivity is often widely discussed in qualitative research studies, in which the researcher is seen as a considerable part of the research instrument (Qualres.org, 2015).

For this study, reflexivity should be considered in regard to the conducting of the semi-structured interviews, in which both researchers held deep conversations with all interviewees. Due to the different experiences, backgrounds, beliefs, and values of the researchers, different perceptions about social phenomena may have arisen. However, Saunders, Lewis and Thornhill (2009) argue that researchers who are more familiar with the research topic will be more knowledgeable about the investigated social phenomena, especially if they have performed an extensive academic study in advance, and possess different experiences in relation to the research topic. Potential threats still occur though, as research may rely on existing knowledge, and consequently, new concepts and relationships between frameworks may be overlooked or ignored (ibid).

Malterud (2001) advises the use of a recording device for interviews, since transcription of the gathered primary data will improve the reflexivity, during when a researcher may reconsider one's perceptions. Since in-depth interviews were performed by two independent researchers for this study, it can be argued that the level of reflexivity is appropriate. In addition, Bryman and Bell (2015) state that reflexivity is also related to postmodern thinking, which in turn embraces multiple perceptions about the world reality. Researchers therefore need to take a central and leading role within their studies, and must be aware of their influences on the actual research study by different values, beliefs, bias, and experiences (ibid).

3.10 Anticipated Problems

Prior to data collection, potential problems, particularly those arising during primary data collection, were considered. In order to overcome these obstacles, several measures were planned in an effort to ensure an adequate completion of the research process.

The limited time frame available for the primary research intensified the likelihood of problems occurring. Therefore, the authors meticulously planned the primary data collection process, and identified potential participants at the beginning of the research study. Several distinguished economists and scientists were contacted in order to maximise the number of participants in the research study.

However, due to the limited availability of many experts in July (a month when professionals often go on vacation) it was a challenge to find suitable timeframes. The authors were flexible in their scheduling of interviews, so that all interested experts could participate in the study.

Since the research was conducted as a global investigation, experts from different nations were interviewed, and time zone differences had to be considered (a factor that might have further limited the number of participants). Through appropriate interview scheduling and coordination with the participants, however, this problem was minimised.

Finally, this dissertation study was conducted by two students. Teamwork can be affected by problems relating to cooperation, coordination and project management. Since both researcher possessed group-working experience and held similar objectives and ambitions for this dissertation project, successful collaboration continued throughout the project.

3.11 Limitations

Since the study was conducted in a limited time frame, and since a qualitative research approach was applied, limitations need to be considered. The qualitative research findings in this report may be affected by the generalisability of the results. This is due to the exploratory research approach used, and also because the study is tailored to the needs of one population. Conclusions on, and generalisations of, the research findings may therefore be limited.

Furthermore, the restricted time timeframe is in itself a limitation. Since the primary research had to be conducted within a time period of one month, only a limited number of experts could be interviewed. In addition, due to the limited time and restricted budget, the researchers were unable to conduct face-to-face interviews, but could only perform online meeting interviews or interviews via telephone – this might have deterred some potential participants, and the interview styles have their limitations.

3.12 Conclusion

The aim of a qualitative research study is to investigate a specific phenomenon by considering different perceptions of actors in the social environment concerning this phenomenon (Bryman and Bell, 2015). For this research study, existing documents written by experts (in the form of consultancy reports) were analysed, and different expert views on I40 resp. IIoT were recorded via semi-structured interviews concerning. Both methods were chosen to provide deep insights into this topic, with considerable new information and concepts that will contribute to the canon of knowledge. As changes in the social environment will consequently lead to changes in the subjective perceptions of actors within the social environment, the exact same social conditions might not exist if this research study method is to be repeated (ibid).

4. FINDINGS AND ANALYSIS

4.1 Introduction

This chapter marks the fourth step of this research study (see Figure 1), the purpose of which is to accurately answer the research questions on the subject of I40 resp. IIoT. This chapter therefore provides the primary and secondary data that were gathered in this research. In addition, the data will be discussed, and the aspects of primary and secondary data-based research will be examined. This chapter is divided into five main sections and follows a systematic structure in accordance with the research objectives. Section 4.2 provides an introduction to the participants who were interviewed during the qualitative primary research study. This section is followed by description, analysis, synthesis, and evaluation of the research findings, as based on a process proposed by Biggam (2008) which is shown in Figure 21 below:

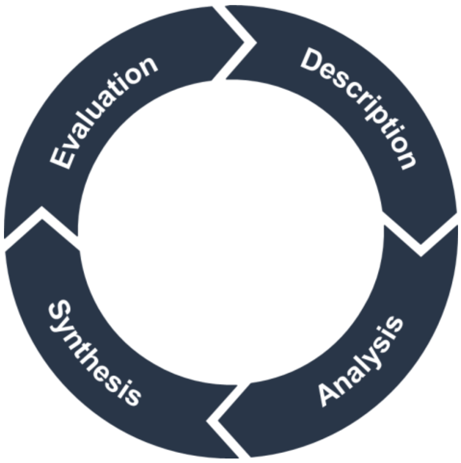


Figure 21: Process of investigation of findings and presentation of results (based on Biggam, 2008)

The findings and results are structured in relation with each research objective, and contained in tables that provide a structured and systemic overview. The tables contain a description and analysis of the research findings, and results in the tables are divided into primary and secondary data to allow for a clear distinction between the two research methods. In addition, the findings and information gained in the literature review are synthesised, and research results will be evaluated in a sub-section at the end of each section (titled 'Discussion') for all the research objectives.

4.2 Introduction to the Participants

This section provides an overview about each interviewee's background and areas of expertise, partly to illustrate the quality and relevance of the conducted research. However, during the presentation and discussion of the research findings in later sections of this chapter, participants are *not* named wherever their statements are quoted. For the sake of clarity and to preserve their anonymity, different alphabetic letters have been ascribed randomly to the interviewed experts. Throughout the following sections, these initials will be used so that specific statements cannot be attributed to individual experts. The interviewees were as follows:

Prith Banerjee

Managing Director of Global Technology Research & Development at Accenture

Prith Banerjee's role is overseer of the Accenture Technology Labs, the global technology R&D organization within Accenture that explores new and emerging technologies. This also includes technologies in the context of the Industrial Internet, and he had written significant contributions in several professional publications in this field.

Max Blanchet

Global Head Operations Strategy Competence Center (OpS CC), Partner

Roland Berger

Specializing in automotive, process and other manufactured products industries, Max Blanchet has carried out many projects for strategic repositioning and improving operational efficiency with top industrial and global groups. His areas of activity cover R&D issues, purchasing, supply chain and manufacturing.

Christian Burmeister

Senior Consultant and Doctoral Researcher

RWTH Aachen - Technology and Innovation Management Group

Christian Burmeister holds a degree in Business Administration, and International Management & Accounting. He is currently completing his doctorate at RWTH Aachen, and conducts research in the field of business modelling, and in business model innovation under Industry 4.0.

Christian Gülpen

Head of Company Cooperations and Devision Manager Digitalisation / Industry 4.0

RWTH Aachen - Technology and Innovation Management Group

Christian Gülpen holds a degree in Business Administration, and conducts research in the areas of digitalisation / Industry 4.0, business models for the IoT and IoS, and business model innovation. He has written significant contributions in various publications in these subject areas.

DDr. Michael Harnisch Consultant The Boston Consulting Group	DDr. Michael Harnisch is a consultant at The Boston Consulting Group, and has written several publications including 'Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries'.
PD Dr. Ernst Andreas Hartmann Director of the Institut für Innovation und Technik (iit) der VDI/VDE Innovation + Technik GmbH	Dr. Hartmann holds a degree in Psychology, and specialises in work and organisation psychology. He obtained his doctorate at the Faculty of Mechanical Engineering, at RWTH Aachen. He recently published a book, entitled 'Zukunft der Arbeit in Industrie 4.0 – Neue Perspektiven und offene Fragen', which deals with the impact of Industry 4.0 on working perspectives in the future.
Andreas Kern Central European Manufacturing Sector Capgemini Consulting	Andreas Kern is a consultant in the industrial manufacturing sector. His core interest lies in the areas of digitising added industrial value, and in the related development and implementation of profitable strategies for manufacturing companies.
Markus Koch Consulting Partner Deloitte	Markus Koch has more than 20 years' experience in consulting and restructuring. He has led strategy, cost reduction, supply chain, and restructuring projects on five continents. As an expert in Industry 4.0, he has participated in several interviews on this subject, and has published business reports.
Georg Kube Global Vice President, Industrial Machinery & Components SAP SE	Georg Kube holds a degree in Mechanical Engineering and an MSc in Business Marketing. At SAP he is responsible for defining industry-relevant solutions based on SAP's complete portfolio of products and technologies, bringing them to market, and driving businesses in the regional units. He is a frequent speaker on the topics of the Internet of Things and Industry 4.0.

Dr. -Ing. Sebastian Schlund Head of Competence Center Production Management Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO	In his position at Fraunhofer, Dr.-Ing. Sebastian Schlund specialises in the fields of lean management, integrated planning and optimisation, as well as the future of work and productivity under Industry 4.0. In this context he has written significant contributions to several publications.
Jan Veira Associate Principal McKinsey & Company, Inc.	Jan Veira holds a diploma in physics, and completed his MBA in the USA. His industry focus is in the technology sector, and he focuses on strategy and innovation engagements with a particular focus on Industry 4.0. At McKinsey & Company, he has focused on the semi-conductor industry.

4.3 Objective 1 – Current Development Trends

The first research objective was to research the current state of I40 resp. IIoT developments. It can be considered as the prime objective, from which the other three objectives follow. The literature review provided a comprehensive overview of the latest developments, to demonstrate the necessary understanding of the subject. Therefore, the presentation and discussion of secondary and primary information has partly been covered by the literature review. Nevertheless, the primary and secondary data collection and analysis contributes important findings, which meet the research objectives.

4.3.1 Status Quo

Table 7 provides descriptions and analyses of the secondary and primary data concerning the status quo of I40 resp. IIoT:

Table 7: Findings - Status Quo

Status Quo	
Secondary Data	
Revolution versus evolution	Whether I40 resp. IIoT will occur as a revolution or an evolution (from the consultancies' point of view) has been already discussed in the literature review, which stated that most of the consultancies/consultants (including McKinsey, Boston Consulting Group, Capgemini Consulting, and Roland Berger) see I40 resp. IIoT as a revolutionary change in manufacturing.
Main stakeholders and players	The I40 resp. IIoT development do not merely concern manufacturing businesses that will utilize the emerging technologies, but also technology and infrastructure providers, industry associations, academics and governments (as outlined by several consultancies/consultants such as Roland Berger (2014a), Boston Consulting Group (2015), PwC Strategy& (2014) and the World Economic Forum (2015; in collaboration with Accenture)). These key groups play an important role in fostering developments in, and the migration to, I40 resp. IIoT by manufacturing businesses. PwC Strategy& outlines, for example, that policy-makers and industrial associations can support the companies by helping them master the challenges posed by I40 resp. IIoT. The specific challenges will be discussed further on in this dissertation, but to provide an idea, they include challenges such as insufficient skills, high investment, and unclear business goals, as well as toughening standards for communication, data exchange and IT security.
Significant opportunities	Since they have analysed the revolution from the beginning, some consultancies such as Accenture and McKinsey have also identified the opportunities being created by I40 resp. IIoT for businesses (i.e. technology and infrastructure), and even for entire countries (refer back to section 2.4).

Primary Data	
Tremendous opportunities	All interviewed experts were enthusiastic about I40 resp. IIoT developments, and see them offering great opportunities for businesses in the future in many ways. More than 80% (9 of 11) of the interviewed experts outlined opportunities that could increase operational efficiency and flexibility, and even generate new hybrid business models and other top line growth potentials.
Revolution versus evolution	There was no clear consensus among the interviewed experts as to whether I40 resp. IIoT constitute a revolution or an evolution. Four of the experts perceived the development and change as being more evolutionary than revolutionary. Expert D claimed it as an accelerated evolution rather than a revolution. Expert C claimed it is a revolution that follows an evolutionary process. Expert B elucidated that the technologies of I40 resp. IIoT are not new, and had been developing during the past few years in an evolutionary process, reaching a level of maturity where they can be utilised in everyday business. In addition to this, Expert E outlined that one technology on its own is not revolutionary, even if it makes an industrial revolution happen; rather, the group and the interconnection of technologies can be considered revolutionary.
Standards and associations	Five of the twelve experts argued that in order for I40 resp. IIoT to proceed, standards must be established for the transfer and exchange of data, as well as for machine communication. Expert B described the approach taken by Germany, which cooperates with China, as being different from that by the USA. As expert B explained, in Germany, associations like 'Plattform Industrie 4.0' include representatives of industries, along with researchers and policy makers, all of whom want to set the necessary standards. Whereas in the USA, international associations such the 'Industrial Internet Consortium' do not set the standards directly, but believe that the standards are formulated from best approaches. The American approach could be more risky but on the other hand it could accelerate the transformation. Five of twelve experts (B, E, F, H and I) mentioned also the importance of the associations, which not only set standards, but also provide the latest information about developments and trends (including case studies of businesses) to foster the transformation.

4.3.2 Discussion

As mentioned in the literature review, some academic literature (e.g. by Bauernhansl, Ten Hompel and Vogel-Heuser (2014), Lasi et al (2014), Bruner (2013), and Kühnle and Bitsch (2015)) outline the importance of I40 resp. IIoT, and their wide-ranging implications on the manufacturing businesses in the future.

The importance and relevance of this topic was clearly emphasised by the interviewees, as they all expressed enthusiasm about development, and possess a strong personal interest. Whereas the academic literature only vaguely discusses I40 resp. IIoT, the business reports from consultancies, industry and research associations detailed the tremendous opportunities, and implications for the future.

Whereas the academic literature still reveals several knowledge gaps, the business (especially consultancy) reports provide more sophisticated information about the next industrial era. Thus, it is not possible to synthesise, discuss, or critically compare information gained in both the literature review and by primary and secondary research.

The analysis of the information gained in the literature, and from secondary and primary research shows that there is a broad agreement that I40 resp. IIoT are important for the entire manufacturing industry, and even economically for countries. The key issue that was unearthed through all three research strands was the need for cooperation and collaboration in associations and with partners, since I40 resp. IIoT runs on connectivity, and it is not a one-player game. Another issue is standards, which are still being developed, and are the subject of heated debate.

Neither the secondary findings nor the primary findings clearly indicate whether I40 resp. IIoT will occur as a revolution or as an evolution; nevertheless, all the findings point to their enormous impact and opportunity creation.

The following sections contain a deeper synthesis of the literature and findings of the secondary and primary research regarding the technologies, requirements, and further implications of I40 resp. IIoT.

4.4 Objective 2 – Related Technologies

The second research objective was to investigate the technologies relating to I40 resp. IIoT, and which are the main driver of the current industrial revolution. The potential opportunities offered by these technologies shall be outlined. Since these technologies have already been described in the literature review, this chapter shall consider the importance of each technology based on its potential benefits in relation to I40 resp. IIoT. The collected and analysed secondary and primary data included the following:

The **secondary data** included consultancy and business reports, which outlined a variety of technologies that are integral to the new industrial revolution. None of the reports provided a comprehensive study of all technologies, but tended to concentrate on the nature of selected Industry 4.0 technologies. They can be categorised into two main groups:

Cyber-Physical Systems (CPS) are mentioned in every report (including those by Accenture, Capgemini, Deloitte, Boston Consulting Group, Deloitte, Germany Trade & Invest, and McKinsey). The acronym itself is not mentioned in every report, but every report mentioned that physical objects embedded with sensors, actuators and small computers will become smart and interconnected with some kind of network, including the internet or the Internet of Things (e.g. by Accenture and General Electric (2015)). This idea of transferring physical states to the virtual world, as well as connecting all objects to networks and the internet is central to the definitions of I40 resp. IIoT used in the reports. The reports also mentioned closely related technologies, including Big Data & Analytics, Cloud Computing, and IT security (see sub-section 4.4.1), which are explained in more detail by Roland Berger (2014a), Accenture (2014), Accenture and General Electric (2015), and Capgemini Consulting (2014b).

However, not all these technologies were mentioned in the analysed reports. Some reports outline further technologies in the contexts of digital manufacturing and smart manufacturing. Consequently, these reports classify these under the terms Autonomous Robots, Additive Manufacturing, Augmented Reality, and Simulation (see sub-section 4.4.2). Reports by McKinsey & Company (2015a), Deloitte (2014), The Boston Consulting Group (2015), and Capgemini Consulting (2014b) outline these technologies as I40 resp. IIoT enablers, and as growing innovations that will change the industrial processes.

In the **primary research**, the interviewed experts have answered on the question regarding the main technological drivers of I40 resp. IIoT. Their answers varied widely, which partly reflects a similar pattern in the secondary research. Not every technology was equally discussed in the interviews. Just as in the secondary research findings, CPS and Big Data & Analytics were mentioned by every expert in the interviews. The other technologies were discussed in less detail. Table 8 shows the number of interviews in which each of the technologies was mentioned.

However, this table does not strictly provide any measure of the importance of the technologies; their importance and maturity will be analysed in later sections.

Table 8: Findings - Overview Technologies

Technologies	Number of interviews in which the technologies were discussed
CPS	11
Big Data & Analytics	11
IT-Security Systems	7
Cloud Computing	6
Autonomous Robots	4
Additive Manufacturing	4
Augmented Reality	2
Simulation	2

Since the research objective is to examine the potential opportunities that all these technologies offer for businesses worldwide, the following tables provide descriptions of the secondary and primary data for each technology in a structured manner.

4.4.1 Main Technological Drivers

The first technology is the **CPS**, and the findings are provided in Table 9. As noted earlier, this technology is mentioned in almost every report, and was also discussed during each interview.

Table 9: Findings - Cyber-Physical Systems

Cyber-Physical Systems	
Secondary Data	
Decision-making	Capgemini Consulting (2014b) outlines the capabilities of CPS, whereby smart objects that are embedded with small computers and intelligent software process received data and make decisions locally. Thus, CPS enables physical objects such as machines to link with plants, fleets, networks, and human beings, as well as to network socially (Deloitte, 2014).
Flexibility	According to the Deutsche Bank Research (2014), the networking enables more dynamic organisation of business, as well as production processes and procedures. The production can react more flexibly to changing demands or breakdowns. The intelligent CPS organises production lines according to demand, which makes production more flexible, but also more efficient and productive.

Working conditions and employment	The Plattform Industrie 4.0 (2013) presents opportunities and improvements in working conditions. Through the use of CPS, more flexible work organisation models with a better work-life balance for employees can be attained. Additionally, in countries like Germany with issues of demographic change and an aging population, these new CPS will enable diverse and flexible career paths that will allow people to keep working and remain productive for longer (ibid).
Further potentials	The German Trade & Invest agency (2014) points to potential increases in human security, efficiency and productivity.
Primary Data	
Importance / Potential benefits	Almost half of the experts (A, B, D, E and L) stated that CPS is a main technology and driver, but mostly in combination with further technologies (of which different examples were named by different experts - see discussion for deeper analysis). Expert H described the main feature of CPS as machines and equipment that become smart and that can make decentralised and local decisions on their own. The intelligent objects can communicate with each other autonomously without human interaction. In addition to this, Expert H added that CPS solutions are now affordable for businesses. Machines have become intelligent and social, and can be implemented easily as plug and produce solutions. However, he mentioned the issue of determining which physical objects need to be connected to which drive values. According to him, the next step in the future will be the smart factory, which also offers new human-machine interactions. The other experts (D, A, E, G, I and J) described the major characteristics, but did not detail the potential benefits of these technologies.
Maturity	Most of the experts (e.g. B and D) agreed that elements of CPS such as sensors, actuators, small computers already exist, and already communicate with ships and the internet. Expert B stated that the technological combination is mature enough for practical application in industry. However, he also mentioned that the complete networking of the value chain is still unresolved. By contrast, Expert H asserted that CPS is almost ready, but the interoperability of machines needs to be improved so that plug and play solutions are available. This is a challenge in relation to standards and references. The formulation of standards was also mentioned by Expert A. He explained that the new standards and protocols are necessary for enabling new networks, and that they are almost ready.
Terminology	Seven out of the ten experts called the technology CPS, but the other three used different terms, e.g. Expert G, who described the same characteristics and used the term IoT, or Expert I who used the term IIoT. In the context of CPS, smart factories, intelligent machines, and machine-to-machine communication were also mentioned (e.g. by Expert C), which are relevant and related topics.

Further aspects	A very interesting and important explanation was given by Expert D, who provided a better understanding and differentiation between smart and intelligent physical objects, and the central systems (e.g. Big Data Analytics). Expert D called CPS a system of systems, in which the smart objects are intelligent and can make decentralised and local decisions on their own, but that there is also a superior system, which in turn connects all the objects, provides data, and processes data centrally, and so can also control centrally.

Big Data & Analytics is also an important technological driver of I40 resp. IIoT, and the findings are presented in Table 10 below. Since it is closely interconnected to CPS, some of the potential benefits are quite similar to those mentioned in Table 9.

Table 10: Findings - Big Data & Analytics

Big Data & Analytics	
Secondary Data	
Decision-making	The Big Data and its advanced analytics enable data-driven decision-making, or even decentralized decision-making by the CPS itself (Capgemini, 2014b; Capgemini, 2011).
Results out of complexity	The advanced analytics are intelligent software solutions, which use smart algorithms to analyse and process the data (Capgemini, 2014b; Capgemini, 2011).
Ability of analysing all kinds of data	The Big Data in manufacturing will mainly be collected from the embedded sensors in CPS, and other sensors that monitor the environment. The sources of Big Data in an organisation extend beyond manufacturing, and will include further business data such as customer data (Accenture, 2014).
Transparency	Such available real time data creates an end-to-end transparency, and opens new opportunities for the manufacturing (Capgemini, 2014a).
Productivity	Another application of analytics is to identify defects, faults, and shortcomings in the production process, which allows for an early correction (Deloitte, 2014). As an example, the analytics enables predictive maintenance, which prevents downtime and production losses. In other words, the intelligent software identifies and informs proactively about equipment issues so that they can be repaired directly without any unplanned and unnecessary shutdowns (Accenture, 2014; Accenture and General Electric, 2015).
Efficiency and product quality	McKinsey & Company (2014) reports that the early detection of defects and faults in products increases the product quality and saves resources.

Primary Data	
Importance / Potentials	The importance of Big Data Analytics was emphasised by all experts: Expert E claimed that the real worth and value of the revolution lies in the collection, analysis, and use of data. This was validated by Expert D and Expert L, who stated that Big Data capabilities are important for generating results from structured and unstructured mass data. In addition to this, Expert A added the increased transparency in production. Expert L explained that the data could be flexibly filtered and analysed to meet individual needs and to discover complex interrelationships. A slightly different explanation was given by Expert B who described Big Data & Analytics as a model consisting of layers. The first is the data layer, where the main software collects and analyses the mass data. The next is the application layer, wherein applications allow access to, and use data from everywhere, and even perform control commands in the production. Another potential benefit that was outlined by many experts including B, H and I is the enablement of new business models, with additional services alongside the companies' products. Expert I even outlined that completely new products and production processes based on Big Data are possible.
Maturity	There is no clear consensus regarding the maturity of Big Data & Analytics among the interviewed experts. Several experts (such as A, B and D) argued that it is to some extent ready. Other experts (C, E and F) stated that neither the technology is mature nor are companies ready for the implementation. Expert A commented that 'quasi' real time data analysis is mature, and can be applied to collect data and make decisions in manufacturing. However, the data quality needed for production control, process transparency, tracking and predictive maintenance is not adequate at the moment, but will be mature in approximately 5 years. Experts B and D believed that Big Data Analytics is mature and businesses can start now to implement it (e.g. SAP Hana). However, Expert B also bemoaned the lack of standards, which can limit the applicability. By contrast, experts C, E and F argued that there are some limitations. According to Expert C, Big Data / Smart Data is not common in production processes at the moment, but is more of a vision. He thought that Big Data will be commonly used within the next 2 years, or within a decade. As described by Expert E, the objective is to automate data collection and analysis, but to date this has not matured, and it remains a goal in manufacturing. Expert E argued that even if the technology had matured, many manufacturers are unable to utilise Big Data because their heterogeneous ERP-Systems do not work together. This opinion is quite similar to Expert I's view, who stated that all technologies are available and practically applicable. However, the question is if companies are ready to implement them. In terms of Big Data, he thought that large companies develop faster than SMEs, which do not have the capabilities.

Cloud Computing offers some interesting potential benefits, which are not just related to manufacturing but can also be utilized in other areas. Their main features include the handling and management of data (storage and computing power), and the exchange of information, i.e. communication (Capgemini Consulting, 2014b).

Table 11: Findings - Cloud Computing

Cloud Computing	
Secondary Data	
Storage	Capgemini Consulting (2014b) describe Cloud Computing as an important technology for storing and processing a huge of amount of data in business, and especially from the CPS.
Accessibility and borderless flow of data	The Cloud enables the borderless flow of data and access to analysed results from anywhere around the world, which greatly increases data flexibility and transparency (Capgemini Consulting, 2014b).
Collaboration	Further potential opportunities include Cloud-based collaboration platforms. Capgemini Consulting, WZA RWTH Aachen and Fraunhofer IPT (2014) and Capgemini Consulting (2014b) outline several kinds of platforms such as a knowledge exchange platform, a supplier collaboration platform, a collaborative manufacturing enterprise system, or co-innovation platforms. The main objective and value of these platforms is to enable new forms of collaboration and coordination. Employees can communicate and collaborate more efficiently and dynamically on platforms, which allow content-rich interactions through other integrated platforms and systems. The full potential of these platforms is realised in cross-company collaboration, and coordination with suppliers, customers and other partners. (For a deeper insight in community platforms, please refer to Capgemini Consulting (2014b), and Capgemini Consulting, WZA RWTH Aachen and Fraunhofer IPT (2014).)
Primary Data	
Importance / Potentials	According to Expert A, Cloud Computing is affordable for businesses and does not need high investment. This was validated by the statement of Expert B, who explained that cost for storage of data is decreasing, which in turn offers new options. Experts C and L described Cloud Computing as an important technology. They believed that computing should be networked and optimised in the Cloud as it is an open, accessible platform. Therefore, it is also important that the system is safe and reliable. The accessibility was also mentioned by Expert I, who noted that all systems can access the data in the Cloud for further operations and processes. The importance of Cloud Computing was also stated by Expert J, who predicted that in the foreseeable future, over a billion connected devices (sensors and actuators) will upload data onto the Cloud. Also, Expert C mentioned the basic characteristics, which include decentralised and flexible data management, data storage, and computing power. However, in addition to this, he also mentioned the visualisation of information on mobile devices (such as smartphones, tablets or data glass) as a part of future Cloud applications.

Maturity	Since the maturity of Cloud Computing was not discussed in detail by the experts (who merely mentioned it as being affordable), it can be assumed that this technology has matured, and is being utilized in manufacturing.

In several reports including those by Roland Berger (2014b) and Accenture and General Electric (2015), it is emphasised that **IT security** is an important issue and presents a future challenge. The term IT security refers both to a technology and a challenge, and its importance lies in the enablement of technologies. Without a sufficient degree of IT security, technologies cannot be utilised in practice. The findings on IT security systems are provided in Table 12:

Table 12: Findings - IT Security Systems

IT Security Systems	
Secondary Data	
Enabler of other technologies	IT security systems form an important player of I40 resp. IIoT because they enable the practical usage of other technologies (that have been mentioned previously). As Accenture (2014) outline, manufacturing, plants, and equipment are increasingly interconnected (through CPS) and online, and this creates new risks for business. Consequently, when the data in CPS, Big Data and Cloud is not sufficiently protected by IT security, it is too risky to implement these technologies in manufacturing companies.
Changing risks due to digital technologies	Cyber-attacks and data theft of business data (espionage) have increased in tandem with the development of new interconnected technologies. A good overview of the changing cyber and data risks landscape is provided by Ernst & Young (2015). For example, it contains information on espionage in mobile phone-based or Cloud computing. (Further information is available from Ernst & Young (2015), and Piggin (2015).)

Primary Data	
Importance	IT security systems, security of data, and cyber networking were addressed by seven of the experts in the interviews (D, E, G, H, J, I, and L). All of them emphasised the importance of this technology for the success and growth of I40 resp. IIoT. Expert I reasoned that with increased connectivity of everything, the security of systems can become increasingly vulnerable. Expert E gave the example of someone hacking a machine control system and taking over critical machines and devices. A deeper explanation and differentiation was given by Expert D. First of all, the definitions for ‘security’ and ‘reliability’ differ slightly. The term ‘reliability’ infers that a service is available when it is needed, and the faultless transmission of data and information is ensured. Expert D claimed that IT security needs to be differentiated across CPS, Big Data and the Cloud, and that the term ‘security’ concerns the connection (or transmission) between these data banks, and the device that sends or receives data. According to Expert D, security systems are available to make the Cloud safe. The security of the connection (or transmission) of data and information depends on who organises the transmission, or who is the provider. Depending on the choice of the provider, the security level can vary. Expert D identified that in this area there remains room for improvement. The least secure part of the chain are the devices (e.g. machinery, robots, smartphones, and tablets). These devices are often managed by people (e.g. production workers) who are lacking in specialist IT knowledge. Therefore, according to expert D, lies here the highest potential to increase security.
Maturity	As outlined above, the experts expressed many concerns about the data- and cyber-security. Regarding software maturity, Expert H stated that current IT security systems are not mature. Manufacturing business therefore have to solve these new kinds of risks. It is important that data storage is part of a company’s security strategy.

4.4.2 Related Technologies

A further four technologies were mentioned less frequently in the secondary and primary research, as outlined at the beginning of this section. Most of them such as **Autonomous or Smart Robots** (Table 13) describe technologies, which will be mainly used in the manufacturing environment such as in production and logistic processes.

Table 13: Findings - Autonomous Robots

Autonomous Robots	
Secondary Data	
Safety	According to Capgemini Consulting (2014b) and Accenture (2014), the new generation of smart and autonomous robots will be able to work with people together and improve workplace safety for workers.
Process efficiency	In addition, the new robots with improved artificial intelligence can learn without having to be reprogrammed by humans, which increases the efficiency and reduces the complexity (Accenture, 2014; Capgemini Consulting, 2014b).
Productivity	The robots of the IIoT resp. Industry 4.0 era have embedded sensors and human-machine interfaces, which allows the worker to communicate and interlink with them (Roland Berger, 2014a).
Primary Data	
Importance	Expert G mentioned new collaborative robots as being an automation aim, and one of the main technological features of I40 resp. IIoT. Experts H and I outlined also the collaborative aspects of the new robotic generation. According to Expert I, the new industrial robots significantly increase the flexibility in production.
Maturity	Regarding the maturity of the autonomous robots, Expert H emphasised that new mature robots offer new possibilities in human-robot collaboration. Expert C also outlined that such robots were very expensive in the past, which limited their implementation. However, these robots are now affordable and can be implemented in a few hours. This suggests that the technology is mature enough for practical application.

Deloitte (2014), Roland Berger (2014b) and other reports stated that **Additive Manufacturing** is a major technology that digitises manufacturing. The technology is still developing fast, but it can already be utilised in manufacturing, and offers many potential benefits, as described in Table 14:

Table 14: Findings - Additive Manufacturing

Additive Manufacturing	
Secondary Data	
Raw material efficiency	According to the Boston Consulting Group (2015) and Deloitte (2014), the application of additive manufacturing techniques increases raw material efficiency, since it uses additive processes to produce an object by adding material rather than by mechanically removing or milling material from a solid block of various materials. This reduces both waste and the consumption of raw materials.
Process efficiency	Furthermore, additive manufacturing increases the functionality the production, and enables more complex products to be produced without incurring additional costs. Another advance of this technology lies in the supply chain, as it allows inventory reduction, faster delivery times, and customer integration (Deloitte, 2014).
Mass customisation and customer integration	McKinsey & Company (2015a) outlines that objects can be directly produced from three-dimensional digital design files (digital-to-physical conversion). This allows for integration with individual customer specifications. Furthermore, according to Roland Berger (2014b), this technology allows the production of small batch sizes at a low cost, as the costs of a unit are merely related to the weight of the produced object. Consequently, it enables the customisation of almost every product.
Primary Data	
Importance	Additive manufacturing and 3D-printing were mentioned by four experts (A, F, G and I) as I40 resp. IIoT related technologies. However, none of the experts classified it as a major technology or driver of the current industrial revolution; Expert A identified it as an associated technology, but not as a main driver. Experts F and G provided illustrative examples of Adidas and Local Motors utilising additive manufacturing in their production plants. They emphasised the wide range of potential benefits of this technology. Expert G outlined that the technology is not labour-intensive, and so the production could be relocated from low-cost to high-cost countries. Production could be located closer to the customer, which reduces delivery times. Furthermore, the technology allows for a better integration of the customer in the engineering and designing phase, which allows for mass customisation. Production effort will be shifted to the engineering and design phase. According to Expert F, this could lead to a wider separation of production and engineering in the manufacturing industry.
Maturity	According to Expert F, the technology is mature but still developing very fast. At the moment it will be used more as an additional support technology in manufacturing, but in the future, when the technology allows the manufacture of even more complex products and more materials, it could replace conventional manufacturing, especially the production of standard parts.

According to the Boston Consulting Group (2015), **Augmented Reality** is a very young technology that is not yet common in manufacturing. Its potential benefits and application areas in the future are currently not clearly defined; consequently, only a limited evaluation can be presented (Table 15):

Table 15: Findings - Augmented Reality

Augmented Reality	
Secondary Data	
Productivity	This technology has the potential to enhance a variety of services by providing real-time information via an Augmented Reality glass to improve work procedures and the decision-making processes (Boston Consulting Group, 2015).
Complexity reduction	A future application could be work simplification in environments with complex systems or which sell a variety of product models. Augmented Reality provides the necessary information directly in front of the worker so that (s)he can choose the right parts and actions; this reduces the failure rate, and enhances the product quality (BITKOM and Fraunhofer IAO, 2014; Boston Consulting Group, 2015).
Primary Data	
Importance	Augmented Reality was just mentioned by two experts, who did not really discuss the technology in detail. Expert E, for example, described it as a technology associated with I40 resp. IIoT in a wider sense. According to Expert I, Augmented Reality enables devices such as special glasses to support manufacturing and logistic processes.

According to Boston Consulting Group (2015), **simulations** are already used in several manufacturing business for 3D simulations of products, materials, and production processes. In the future, the application of simulations should become more common in plant operations. The findings on simulation are provided in Table 16:

Table 16: Findings - Simulation

Simulation	
Secondary Data	
Efficiency and productivity	According to the Boston Consulting Group (2015), the simulation software (as part of the CPS, Big Data and Analytics) will process real-time data to mirror the physical operations in the virtual world, including machines, products, and humans. As an example, machine settings can be tested and optimized prior to the physical changeover and production. The result is the reduction of machine times and an increase of quality.

Primary Data	
Importance	Experts I and L mentioned simulation as a relevant technology for I40 resp. IIoT. Expert I described it as the ability of computer systems to execute complex simulations in manufacturing such as production processes, which could help to optimise the processes. Expert L outlined that Big Data offers new possibilities to enhance simulation techniques and make simulations more applicable in manufacturing companies.

4.4.3 Discussion

The analysis of the secondary and primary data revealed a wide range of potential benefits and important information of the technologies of I40 resp. IIoT. In comparison to the information gained from the academic literature during the literature review, the secondary and primary data provided more specific information that can be useful for manufacturing business. The primary research findings in particular showed the importance of individual technologies and their relevance for the success of I40. Furthermore, it contained qualitative information about the maturity of the technologies, which provides a better overview of the complete development of the industrial revolution, but also indicates where the main development needs are. This knowledge can support manufacturing business in their digital transformation planning, since they can see which technology is mature enough for their individual purposes and for applications in business. As for the literature review, sources such as Bauernhansl, Ten Hompel and Vogel-Heuser (2014), and Lasi et al (2014) provide only some general and superficial information about the technologies and their potentials. Therefore, a deep synthesis and discussion of the literature review findings with the secondary and primary data cannot be performed.

However, based on the secondary and primary research, it can be concluded that the revolution is driven not by one technology, but rather by a combination of several technologies. This important insight was validated by several experts (A, B, D and E) in the interviews.

As an example, Expert D claimed that the combination of CPS (which he called mobile / networks / computing), Cloud platforms and Big Data capabilities form the main driver of I40 resp. IIoT. Also, Expert A emphasised that the maturity of these three technologies has to be ensured to make the industrial revolution happen.

Another expert (E) listed three technological dimensions which altogether represent the industrial revolution. These include (i) sensors combined with connectivity, (ii) further technologies such as augmented reality, and (iii) data in the wider sense.

Consequently, it can be stated that if the maturity of a main technology is not satisfactory, it undermines the applicability and potential benefits of the other technologies, and so manufacturers could remain hesitant in transforming their businesses.

Beside these main technologies, the secondary and primary research identified and analysed further technologies such as Autonomous Robots, Additive Manufacturing, Augmented Reality and Simulation, which can influence I40 resp. IIoT. These technologies provide various potential benefits in manufacturing and production processes and should not be underestimated. Manufacturing businesses should also consider these technologies in their digitizing processes and future planning.

4.5 Objective 3 – Business Requirements

Since the first and second research objectives address current I40 resp. IIoT development and related technologies (with their potential of becoming the main driver of this industrial revolution), the third research objective considers the business requirements that need to be fulfilled to ensure a successful digital transformation. Since the literature provided only a superficial presentation of the business requirements in regard to I40 resp. IIoT, this research objective is about presenting a holistic and complete explanation of all company requirements identified during the secondary and primary data collection and analysis.

During the literature review, a significant source of information on business requirements was the qualitative secondary data from a global research study conducted by McKinsey & Company, wherein three overall dimensions of company requirements were identified: (1) drive the next horizon of operational effectiveness, (2) adapt business models to capture shifting value pools, and, (3) build the foundations for digital transformation. In view of this third research objective, these three main dimensions were used and developed by analysing the primary and secondary data collected for this research study (Figure 22).

Figure 22: Overview of business requirements (sourced from McKinsey & Company, 2015a)

The research objective is addressed in the following three sub-sections, which are based on the three aforementioned dimensions of company requirements. Within each dimension, the findings on individual business requirements will be presented and analysed in depth.

4.5.1 Drive the next Horizon of Operational Effectiveness

This dimension of company requirements is the need for higher operational effectiveness during all businesses operations. According to the collected and analysed secondary and primary data, this dimension can be divided into four essential business requirements: (1) digital organizational mind-set; (2) digital value and supply chain; (3) digital product and service portfolio; and, (4) capitalization of the value of data.

Following the **secondary data** collection and analysis of consultancy reports, these four business requirements for ensuring highly effective company operations were identified. The majority of these reports expressed the need of a digital, organizational mind-set. PwC Strategy& (2014), Capgemini Consulting (2014b), and McKinsey & Company (2015a) consider this as a fundamental starting point for achieving highly effective company operations, and consequently as a successful transformation towards digital manufacturing. Moreover, Roland Berger (2014b), PwC Strategy& (2014), Capgemini Consulting (2014b), and Cognizant (2014) identify the digitalization of the supply and value chain as a further essential step, whereby information can be shared among various parties, resulting in higher operational transparency and flexibility. This is related to a digitalized product and service portfolio, whereby smart products generate and share important data, which can be used for improving customer services and internal company operations (PwC Strategy&, 2014; Capgemini Consulting, 2014b; Cognizant, 2014). In addition, Accenture (2015b), Accenture and General Electric (2015), McKinsey & Company (2015a), PwC Strategy& (2014), and Capgemini Consulting (2014b) identify the need to accurately use the results of generated data in order to achieve high operational productivity and efficiency during all business operations within the digital manufacturing environment.

As for the **primary data,** the 11 experts who were interviewed mentioned these four business requirements in regard to I40 resp. IIoT. Although the findings of the primary research only partly reflect that of the secondary research, considerable new information concerning this dimension of company requirements emerged. However, these requirements were not equally discussed by the experts in the interviews. The digital, organizational mind-set was mentioned by every interviewee. In terms of frequency, this was followed by digital value and supply chain, digital product and service portfolio, and capitalization of the value of data (see Table 17). However, these results are not a qualitative measure of the importance of each business requirement concerning I40 resp. IIoT.

Table 17: Findings - Overview Requirements (1)

Requirements	Number of interviews during which the requirements has been discussed
Digital Organizational Mind-Set	12
Digital Value and Supply Chain	6
Digital Product and Service Portfolio	6
Capitalization on the Value of Data	5

The secondary and primary data was used in evaluation of this dimension of business requirements, and the four company requirements are discussed below.

The **Digital Organizational Mind-Set** is one company requirement of this dimension. The research findings from the secondary and primary data clearly show that a digital organizational mind-set is fundamental to a successful digital transformation.

Table 18: Findings - Digital Organizational Mind-Set

Digital Organizational Mind-Set	
Secondary Data	
Attention of senior management	Those in senior management need to understand that IT is a central business enabler, and should launch elementary initiatives including appropriate management and leadership practices towards digital transformation (PwC Strategy&, 2014).
Long-term results as main focus	Managers need to develop the mind-set of focusing more on long-term results rather than focussing on quick benefits (Capgemini Consulting, 2014b). Attention must be paid to change management processes that have to be provided with suitable timeframes (in the form of a step-by-step procedure) to ensure successful transformations (ibid). These could be performed through pilot projects, in which those in middle and lower management are strongly involved, since they interface between top management and frontline employees (ibid; Deloitte, 2014).

Organizational changes	As the transformation towards digital manufacturing is a process of fundamental change, a very complex and dynamic future manufacturing environment can be expected (Capgemini Consulting, 2014). This future environment requires considerable organizational changes, with centralized and decentralized operations resulting in new operational procedures (ibid). Due to the need for networked manufacturing (with increased collaborations between different functions, departments, and companies), management and leadership styles, as well as hierarchical structures need to be more flexible, as more external resources need to be involved, and entirely new processes need to be performed. (For example, new employment models need to be considered as project-based teams of different internal and external experts will become increasingly important (ibid).) Companies have to learn individually how to formulate the way they will shape their future operational model, as there will be no one-size-fits-all procedure (McKinsey & Company, 2015a).
Primary Data	
Digital vision	According to experts A, D, E, I, and F, one of the starting points concerning the transformation towards digital manufacturing should be a ‘Digital Vision’ that clearly states how the future organization will appear. Often manufacturing businesses lack such visions among senior managers, and this should be addressed urgently.
Top management task	All 11 experts agreed that the digital transformation needs to be driven by those in senior management, who need to be aware of, and need to understand this development trend. Those in senior management must identify potential opportunities and set clear objectives concerning successful digital operations. Experts B, C, I, and L mentioned that companies hold the mistaken notion that only the IT division drives the digital transformation. The IT division has different objectives (e.g. ensuring reliable IT operations), and is not responsible for performing these more strategic tasks. The role of management is to drive operations by integrating IT into several functional areas (e.g. engineering, marketing, sales, etc.), and forming collaborative groups within the business community that aim to drive a successful digital transformation as a whole.
New executive positon	According to experts A and B, many companies started to introduce the position ‘Chief Digital Officer’, someone who is responsible for a company’s different digital initiatives, and whose duty is to maximise collaborations among different functions, departments, and companies in pursuit of a digital transformation.
Learning organization	As mentioned by 8 experts (A, B, D, E, F, H, and L), employees are exposed to tremendous changes in the digital transformation process towards I40 resp. IIoT. This can be explained through the demands for new skills and capabilities, as dictated by new working procedures. Experts B, C, E, I, and L explained that resistance in businesses against these new digital operations is widespread, since many businesses have performed the same operations for decades and often possess an obstinate mind-set. In this case, the challenge for senior management and leaders is to create a learning organization that is shaped by openness, readiness for change, and new knowledge, in order to embrace the development towards digital manufacturing.

The **digitalization of the supply and value chain** is a further crucial and required step in a successful transformation to digital manufacturing, and which is irrespective of the company size and location (PwC Strategy&, 2014). The findings on this issue are provided in Table 19:

Table 19: Findings - Digital Value Chain and Supply Chain

Digital Value Chain and Supply Chain	
Secondary Data	
Digital supply chain	Due to the use of digital advanced technologies and cyber-physical systems (see sub-section 5.4.1), manual supply chains will become highly integrated and automated so that new ways of collaboration between companies will occur (Capgemini Consulting, 2014b).
Digital value chain	The digitalization of the value chain requires a shift towards the use of horizontal and vertical value chains to an equal extent (see Appendix C: Figure C2) (PwC Strategy&, 2014). In this case, the digitalization of the horizontal value chain is needed in order to integrate and optimise the flow of information and goods from the customer to the manufacturer over the supplier and back (ibid). Part of this process is the integration and control of the firms' internal functions (e.g. purchasing, manufacturing, planning, and logistics), as well as the incorporation of all external value chain collaborators, which are responsible for satisfying customer needs and resultant services (ibid). According to PwC Strategy& (2014), the vertical digitalization of the value chain has to be shaped by a constant flow of information and data, from sales, over product development and planning, to manufacturing and logistics. Due to the optimal connection of manufacturing systems and the usage of better analytics, potential failures will be minimised, and the quality and flexibility concerning individual customer requirements will increase significantly (ibid; Capgemini Consulting, 2014b; Roland Berger, 2014b).
Primary Data	
Flexible and vertical supply network among businesses	According to experts A, B, C, E, G, and F, the horizontal integration of the supply chain needs to change towards a more flexible and vertical supply network among businesses (see Appendix C: Figure C1). This networked manufacturing with a digital supply chain enables manufacturing companies to focus more on core competences, and to perform virtual supply flows that allow for an integration and automation of physical processes, resulting in higher transparency.
Shifts concerning centralized and decentralised operations	Since the digitalization of the supply and value chain will lead to new collaboration processes between different functions, departments and companies (in what is known as networked manufacturing), new considerations and shifts (centralized and decentralised operations) need to be performed (experts A, B, C and G). This requires significant changes in the firm's hierarchical and organizational structure, and those in management must implement new operational procedures for successful digital manufacturing (refer back to 'Digital Organizational Mind-set'). Expert G mentioned that Adidas that has developed small plants, including small manufacturing tools and machines (e.g. additive manufacturing), that can be transported by trucks. This allows for a new shoe production process where plants can easily be located closer to consumer markets, which reduces the time to market by 75 per cent.

The transformation towards digital manufacturing goes far beyond the digitalization of the supply and value chain. It requires also the **digitalization of the product and service portfolio** (PwC Strategy&, 2014), as discussed in Table 20:

Table 20: Findings - Digital Product and Service Portfolio

Digital Product and Service Portfolio	
Secondary Data	
Change of the product and service portfolio	Products that are purely mechanical will no longer be able to satisfy increasing market requirements, and will have to be equipped with advanced IT technology such as high performance sensors and advanced software to ensure the required connectivity and data generation (PwC Strategy&, 2014).
Smart products	Smart Products are a type of CPS and provide information about the environment (such as current use and status) (see Appendix C: Figure C3) (Capgemini Consulting, 2014). These functions allow autonomous control and changes, and both machine-to-machine and human-to-machine communications via interfaces. All of these functions form the basis of a smart factory, including digital supply and value chains (ibid).
Smart product-service example	Taleris, a joint venture of Accenture and General Electric Aviation, is a good example of the development of smart products in the form of product-service hybrids (Accenture, 2014). Taleris equips airplanes and its customers with high performance sensors (from the tip to the tail) in order to monitor aircraft parts, components, and systems. All sensors constantly provide real-time data, which Taleris analyses via specific software. Taleris thus knows exactly when maintenance is needed across the fleet, and provides notices to its airlines so that they schedule the most suitable times and locations for maintenance. Because of this service, disruptions and the cost of maintenances can be minimised tremendously, as can aircraft downtimes and streamlining spare-parts logistics (ibid).
Primary Data	
Product-service hybrids	As emphasised by experts A, F, G, I, J, and L, companies have to move increasingly to product-service hybrids, which enable companies to make better decisions, ensure a higher transparency and flexibility along the supply and value chain, and improve the firm's productivity and efficiency.
Smart product demand	According to experts I and L, businesses need to ask themselves the following questions: Are their products 'digital ready'? Do they need to be digital at all? Does the connecting of products with the internet really generate added value? And are customers and potential customers willing to pay for such added value? Furthermore, companies need to consider whether service offerings will be needed in the future, or whether they could be replaced by more convenient, faster, and more efficient services (according to experts I and L). Both experts emphasised that these considerations need to be the starting point in a discussion on whether a company should move to develop and offer new smart products in the form of product-service hybrids, or to concentrate more on the envelopment of their existing (and some cases, manual) products.

A fourth business requirement of the first dimension is the need to **capitalize on the value of data**. Accurate and appropriate analysis and utilisation of data will become increasingly important, and become one of the major imperatives in the digital manufacturing environment (PwC Strategy&, 2014). The findings on this issue are summarised in Table 21:

Table 21: Findings - The Need to Capitalize on the Value of Data

The Need to Capitalize on the Value of Data	
Secondary Data	
Data and information as a business asset	The increasing number of sensors, connected devices (Internet of Things), embedded systems, and networking along the digital supply and value chain will generate a huge amount of data. Companies have to filter out the more appropriate collected data in order to benefit fully from the I40 resp. IIoT opportunities (refer back to sections 3.4 and 3.5) (PwC Strategy&, 2014). Companies therefore have to treat and develop data and information as a central and important business asset (McKinsey & Company, 2015a).
Appropriate use of data	According to (McKinsey & Company (2015a), companies are required to actively and appropriately use data during the entire data lifecycle (e.g. collection, storage, analysis, sharing, and archiving), and this needs to be ensured through specific data practices, standards, and policies. Only these procedures will assure that businesses can capitalize on collected data, which in turn needs to be accurate, up-to-date, accessible, usable, and contained. Companies therefore need to define data models, and they have to develop specific regulations concerning data (that will be stored externally) to ensure that all information will be used appropriately across all business operations (ibid).
Primary Data	
Importance of data	Experts A, C, D, and F claimed that the accurate and appropriate use of data will become one of the most crucial operations within the digital manufacturing environment. Companies that understand how to analyse and use data (e.g. manufacturing data, performance data from products, customer data) can use this strength as their Unique Selling Proposition (USP).
Sharing data among collaborators	Experts A, C, D, E, and F noted that collaborations between different companies form another important strategy for ensuring the appropriate use of data during digital manufacturing. Companies need to share data with parties along the supply and value chain, as well as throughout industry, in order to benefit from higher transparency, flexibility, and improved decisions, which in turn can lead to higher productivity and efficiency, and a competitive advantage. However, these shifts require new skills and, more importantly, a different organizational mind-set towards a culture that is willing to streamline data flows within and around businesses (refer back to Table 18). Companies therefore have to generate new financial and governance models in order to mutually benefit from the common use of data.

Data regulations and security	At the same time, businesses have to test such models, enhance interoperability between collaborations, and ensure data security (according to experts C, D, E, and F). Governments need to cooperate with businesses and stakeholders in formulating rules and regulations regarding data ownership, what data can be shared, and how liabilities will be handled, since these are still not adequately regulated under statutory law.

4.5.2 Adapt Business Models to Capture Shifting Value Pools

The second dimension of business requirements represents the need to adapt existing business models to one which more appropriately uses shifting value pools within the digital manufacturing environment. Products, machines, and factories are becoming increasingly smart by sharing and analysing data in real-time. Existing business models therefore need to be reconsidered, and completely new business models need to be developed to capture new arising value propositions. The secondary and primary data findings show that this dimension includes three essential business requirements: (1) smart innovation processes, (2) digital business models, and (3) collaboration in the ecosystem.

The **secondary data** includes publications by leading consultancies, which focus on the need to consider changes to existing business models and company operations in order to better capture value propositions. According to Capgemini Consulting (2014b) and McKinsey & Company (2015a), smart innovation processes essentially and fundamentally identify new potential gains in the digital manufacturing environment, which will require changes to company operations. Furthermore, Roland Berger (2014a), PwC Strategy& (2014), Accenture and General Electric, (2015), McKinsey & Company (2015a), and others express the importance of considering changes to existing business models, and propose the development of new and often disruptive business models. Those new types of business models are often enabled through networking and collaborations along the supply and value chain, as well as between different industry players. Therefore, collaboration in the ecosystem is a further crucial element in regard to this dimension of company requirements, and McKinsey & Company (2015a), PwC Strategy& (2014), and Roland Berger (2014a) emphasise the need for new alliances and strategic partnerships that offer companies more opportunities to focus more on core competencies.

As for the **primary data,** all of the three business requirements were discussed during the interviews. Again, some requirements were mentioned by a greater number of experts than others. The transformation of business models was the most popular topic, followed by the need for collaboration in the ecosystem, and smart innovation processes (see Table 22). As already mentioned, this quantitative result is a measure of frequency, from which qualitative conclusions cannot be drawn on the importance of each business requirement. Following the same procedure in the previous sub-section, the following paragraphs will explain each of these three requirements in detail by discussing the secondary and primary data.

Table 22: Findings - Overview Requirements (2)

Requirements	Number of interviews in which the requirement has been discussed
New Types of Business Models	10
Collaboration in the Ecosystem	8
Smart Innovation Processes	5

Smart innovation processes are one requirement of the second business requirement dimension, and can be defined as the need to perform new types of innovation procedures to ensure sustainable operations in the dynamic and complex future environment of digital manufacturing (Capgemini Consulting, 2014b). The findings on this requirement are detailed in Table 23:

Table 23: Findings - Smart Innovation Processes

Smart Innovation Processes	
Secondary Data	
Types of Smart Innovation	In general, smart innovation processes can be split into two categories: ‘Extended Innovation’ (that embraces the distribution of ideas across organizational borders), and ‘Connected Lifecycle Innovation’ (whereby data is used as the main source of innovation) (Capgemini Consulting, 2014b).
Extended Innovation	Extended Innovation can be explained as a two-way exchange of information by the collaborating of different parties along the value chain (Capgemini Consulting, 2014b). These processes are composed of information flows into and out of the business by using active external partners for innovation support and idea generation. In order for this form of innovation to occur, manufacturing companies have to ensure open innovation processes to and from external collaborators and customers. These are known as ‘outside in’ and ‘inside out’ innovation processes, and they are enabled by advanced and digital technologies (see sub-section 4.4.1). The use of collaboration platforms for instance (that ensure the connectivity, constant exchange of data, and information between all different parties) could be one means of smart innovation (ibid).

Connected Lifecycle Innovation	Connected Lifecycle Innovation uses data gathered along the product lifecycles and the power of digital analytic tools to maximise the value of information, in order to maximise successful innovation (Capgemini Consulting, 2014b). During this process, product-related information is connected with more relevant data (e.g. machine parameters, customer data, etc.), and is analysed, processed, and used to generate innovation, perform data-driven R&D decision-making, and encourage business process innovation across the whole organization (e.g. planning processes). These can lead to optimized production processes, and more efficient and successful sales activates. Companies have to ensure that gathered and analysed information will be accessible across the entire organization, and compatible with different applications. In addition, external partners and customers have to be involved in the process so that they are able to provide feedback through touch points in order to ensure successful connected lifecycle innovation processes (ibid).
Primary Data	
Importance	According to experts A, B, E, G, and L, smart innovation processes are fundamental to a successful and sustainable operation in the digital manufacturing environment. Experts A and F mentioned that for an extended innovation process, companies need to build collaborations with customers and partners, and share data along the ecosystem, in an effort to increase the innovation speed and reduce the time-to-market. An example was provided by Expert G, who mentioned that new forms of production processes (e.g. additive manufacturing - see sub-section 4.4.2) can lead to new forms of innovation, development, and distribution processes, where new products can be developed much faster and be entirely customized, rather than being produced on an industrial scale. Experts G and L explained that companies therefore have to perform innovation processes continuously and consider potential new developments for individual company operations, to ensure on-going development and improvement in business operations.
Gathered data is essentially for smart innovation	Experts A, B, E, and L pointed out that companies often do not use data generated by smart objects which represent high value data for innovation processes. Smart products, for example, generate a great quantity of specific customer data that companies need to use more accurately and appropriately to improve their innovation processes (experts A and B). Expert A mentioned that customer-specific data offers opportunities for maximising the customization of individual customer products, which consequently lead to higher customer satisfaction, additional sales, and opportunities to extend product lifecycles significantly.

In light of (i) increasing digitalization of supply and value chains, (ii) the use of smart products in the form of products-service hybrids, (iii) the use of data analytics, and (iv) the applications of smart innovation processes, there is a rising need for reappraising existing business models and creating **new types of business models** to ensure sustainable company operations (PwC Strategy&, 2014). Regarding this issue, the findings are discussed in Table 24:

Table 24: Findings - New Types of Business Models

New Types of Business Models	
Secondary Data	
Changes in existing business models	Through the use of intelligent physical goods that are able to produce data, companies are capable of offering new digital services (Accenture and General Electric, 2015). These digital services require companies to change their existing business models towards hybrid business models, which in turn combine the benefits of operational effectiveness and the income streams of digital services offered by constantly gathered, used, and shared data (ibid). Business models therefore need to become more database-driven, efficient, and customer-focused (PwC Strategy&, 2014). Companies need to identify how they can capitalize on existing data, how they can collect data to use and generate new value propositions, and what competitors are targeting their customers (other companies, products, services, etc.). Companies need to adapt and modify business models successfully towards the future digital manufacturing environment (McKinsey & Company, 2015a).
Four new types of business models	According to McKinsey & Company (2015a), four new types of business models are emerging in the transformation towards Industry 4.0 and IIoT: (1) Platforms, (2) Service Business Models, (3) Intellectual Property Rights (IPR)-Based Business Models, and (4) Data-Driven Business Models (see Appendix C: Figure C4).
Platforms	Platforms represent the first type of business model, and can be described as a form of exchanging products, services, and information via specific communication channels (McKinsey & Company (2015a)). There are two kinds of platforms: Interacting Platforms, and Technology Platforms (or Ecosystem): An *Interacting Platform* represents a 'marketplace' based on a technological infrastructure that brings together different parties, and allows for appropriate interactions of all platform members. These platforms generate value through the distribution of different goods and services. One example is filed additive manufacturing (see sub-section 4.4.2), where the provider typically focuses on the procedure of selling machinery (ibid). Due to digital manufacturing, however, the trend is increasingly moving towards contract manufacturing, whereby companies use CAD models to create the parts ordered by customers, which are then produced by machinery that is owned and operated by the company. These platforms could act as a marketplace to connect supply (operators, i.e. owners of machinery) with demand (purchasers/customers) (ibid).

	A *Technology Platform* or *Ecosystem* is a business model that supports companies by facilitating product and application developments based on the company's original technologies and products. With this platform, companies can offer different resources and technologies which can be used by all members of the systems, so that the company can benefit from the development of new products, while at the same time promoting its products and brands (McKinsey & Company, 2015a).
Service Business Models	Service Business Models are the second new type of business model. This type of model is based on the condition of pay-by-usage (McKinsey & Company, 2015a). Since technology and automation providers are increasingly moving away from selling machinery to charging companies for the use of machinery only, this business model is based on payments by usage rather than on a high initial fixed total price. As well as enjoying variable costs (and moving away from high fixed costs) for the machinery, suppliers can benefit from the data collection during the operation of the machinery, which generates new data assets and additional value for the company. Moreover, the resulting modularization of production networks is another company benefit. During the time when a machine is located on the production site of one manufacturer, the idle time could be sold to another manufacturer that is producing something in the same area (ibid).
IPR-Business Models	IPR-Based Business Models are another form of digital manufacturing business model. As many manufacturing companies currently lack the expertise and experience in the appropriate use of data, IPR-Based business models could be based on subscriptions of software, maintenance, and support in this area (McKinsey & Company, 2015a). These subscriptions can generate recurring revenue generation, and one-off asset sales can be avoided. Since many manufacturing companies possess extensive expertise and experience regarding their products, this knowledge could be monitored by providing services such as training courses to help companies to improve data management and asset utilization.
Data-Driven Business Models	Data-Driven Business Models represent another form of business model that offers new opportunities for collecting and using data. In general, there are two different options: *direct* and *indirect* monetization of data (McKinsey & Company, 2015a). In the *direct* monetizing of data, data is collected via a primary product. One example is Google's search engine (ibid), which creates a vast data trail through the user's searches, The data is then analysed and used to perform targeted advertising, resulting in a primary revenue stream. Similar models can also be applied in the manufacturing environment. Another way to generate direct data is through crowdsourcing, which enables companies to improve their data-driven operations by using external knowledge. In this case, companies obtain services, ideas, or content via contributions from a large group of external people (e.g. online communities) (ibid). The *indirect* monetization of data uses the insights achieved thorough data gathering and analysing processes, for example, to identify and target specified customer needs, characteristics, and demands. This enables companies to customize their operations, products, and services for each and every customer and partner, and to generate new, important company assets (ibid).

Primary Data	
New value propositions	According to 10 of the experts (A, B, C, D, E, G, H, I, J and L), value propositions will shift significantly in the digital manufacturing environment. Companies need to evaluate their individual company operations, and figure out how they can capture and benefit from these shifting value pools. Companies therefore need to ask the following questions: How can customer needs appropriately be satisfied? What does the customer really want? And will value propositions still be the same in the future with potential new competitors? (Experts A, B, C, D, G, I, J and L). Experts B and I mentioned that during this process, resource capabilities need be considered, and value capture layers need to be integrated in the value chain to ensure appropriate adaptation and development of business models. Expert B mentioned the company Kärcher (a leading manufacturer of cleaning equipment), which sells air to their customers, rather than compressors that produce the air. Kärcher clearly identified the value proposition and the needs of its customers (which is the use of air), and therefore changed its business model towards providing manufactured compressors free of charge, and by selling the produced air for compressors as the main product. A similar example was mentioned by Expert H: tractor manufacturers not only sell their tractors, but also provide precision farming services. Tractors are equipped with smart sensors, and they generate data whenever customers pay for hiring the tractors. The data that is provided by tractor manufacturer can also support farmers, for example, in accurately fertilising their fields. These companies have identified shifted value proposition and have changed their business models towards making the provision of product-service hybrids their main revenue stream.
Organizational flexibility	According to experts A, B, D, and G, business model innovation and adaptation is often a disruptive process that is shaped by openness, partnering, and focus-setting. However, many manufacturing companies still run a traditional 'engineering culture', and appropriate changes in business models have not yet been implemented (experts A, B, D, and G). Expert A, B, D, and G therefore emphasised that it is the duty of senior management to push the organization towards a more entrepreneurial mind-set, in pursuit of successful business model innovations and adaptation processes (refer back to Table 18).

Another requirement in the second dimension is **collaboration in the ecosystem**. Due to the increasing connections between manufacturing companies and third parties along the supply and value chain, alliances and strategic partnerships have become essential. The data findings are described in Table 25:

Table 25: Findings - Collaboration in the Ecosystem

Collaboration in the Ecosystem	
Secondary Data	
Need for collaboration	The main driver for closer co-operation and increased integration with other businesses is the need to satisfy changing customer needs through the adoption of new, digital business models (PwC Strategy&, 2014). Moreover, cooperation is needed due to the dynamic and complex market environment, with shorter product lifecycles, higher innovation speeds, and the demand for more efficient labour (ibid). This requires more integration of data and processes from outside the company in an effort to operate digital value chains and accomplished ground-breaking innovation processes (McKinsey & Company, 2015a). The development and operation of new and digital business models can often only be performed by involving different companies, which in turn offer complementary technologies and competencies in the form of alliances or strategic partnerships (PwC Strategy&, 2014).
Merger and acquisitions	Mergers and acquisitions can help a company to redress gaps and deficiencies in its expertise, knowledge, and operations (Roland Berger, 2014a). Depending on the individual company's status and planned future operations, businesses may need to consider collaborating with other industry players and operate mutually against competition and/or tap into new market areas (ibid). Therefore, collaborations (either in the form of mergers and accusations, or in the form of alliances and strategic partnerships) will be crucial for building up a network, and maintaining a competitive advantage (McKinsey & Company, 2015a).
Primary Data	
Interoperability standards	According to experts A, D, E, F, G, H, J, and L, the increasing need of collaboration requires companies to focus on setting future interoperability standards to ensure competitive advantage, and both organizational and technological readiness. As soon as industry standards are ratified, companies need to apply them to their operations. Experts E, F, and H emphasized that businesses therefore should start partnering with suppliers, customers, technology providers, IT companies, and/or occasionally with competitors, in order to enhance standards across the industry. Companies that do not involve themselves in the procedures of shaping these standards will probably face higher development and production costs (experts E and H). Experts E, H, and F also mentioned that the Plattform Industrie 4.0 association and the Industrial Internet Consortium offer useful information about potential future developments, and provide opportunities to form strategic partnerships.

Concentration on core competencies	Experts D, E, F and H emphasised that due to the need for increasing collaboration, companies should focus more on core competencies, and strategically outsource and/or complement operations by partnering with other industry players to ensure the most efficient operations.

4.5.3 Build the Foundations for Digital Transformation

This is the third dimension of business requirements. Since the transformation towards digital manufacturing will require considerable changes to current business operations, companies have to improve their digital infrastructures and digital capabilities, and they need to manage cybersecurity, proprietary data, and data architectures in an effort to ensure successful digital manufacturing operations. The collected and analysed secondary and primary data show that this dimension can be sub-categorised into three essential requirements: (1) digital infrastructure, (2) future workforce, and (3) data and cybersecurity.

Within the **secondary data** were a variety of consultancy reports, which identified the need for building robust foundations for the transformation towards I40 resp. IIoT, and which discussed different initiatives of building up such elementary foundations. Capgemini Consulting (2014b), Deloitte (2014), Accenture (2014), Accenture and General Electric, (2015), and McKinsey & Company (2015a) express the need to build a digital infrastructure, which is seen as an elementary component of the industrial internet, and which links the required technologies (see section 4.4) with the company's operations. Moreover, Accenture (2015b), Accenture (2014), Accenture and General Electric (2015), Capgemini Consulting (2014), Deloitte (2014), and Roland Berger (2014b) discuss the increasing demand for new employee skills and capabilities, due to the considerable changes in a variety of business operations, processes, and procedures in the transition towards digital manufacturing. In addition, the increasing connectivity and networking of manufacturing parties and equipment (including machine-to-machine communications and the equally strong rise in cybercrime) make IT security one of the most important aspects in the creation of a robust and stable foundation for digital manufacturing; this is widely discussed by Accenture and General Electric (2015), Ernst and Young (2015), McKinsey & Company (2015a), and Roland Berger (2014b).

As for the **primary data,** in almost all the interviews, the experts mentioned the need for new skills and capabilities as a crucial foundation for the transformation process towards digital manufacturing. Accurate management of data and cybersecurity was also widely discussed among the experts, and 4 of them discussed the need to build sustainable digital infrastructures. Table 26 shows the number of interviews in which these requirements were mentioned. Again, this quantitative data is a measure of frequency, not a measure of the importance of each business requirement.

Table 26: Findings - Overview Requirements (3)

Requirements	Number of interviews in which the requirements were discussed
Future workforce	10
Data and cybersecurity	7
Digital infrastructure	4

The **Digital Infrastructure** can be defined as an elementary component of the industrial internet, which incorporates necessary technologies (see section 4.4) into a company's activities (Capgemini Consulting, 2014). The primary and secondary data findings on this infrastructure are described in Table 27:

Table 27: Findings - Digital Infrastructure

Digital Infrastructure	
Secondary Data	
Need for a digital infrastructure	Depending on the company, I40 resp. IIoT require existing IT systems to be adapted and, in some cases, replaced by entirely new systems (Deloitte, 2014). According to Capgemini Consulting (2014), manufacturing companies need to achieve four main requirements to ensure that their IT infrastructure meets the demands of I40 resp. IIoT: make the digital infrastructure powerful, secure, reliable, and scalable (see below):
Powerful	As the amount of data use will increase enormously during the next few years, companies shall have to install powerful IT infrastructures (Capgemini Consulting, 2014). Businesses therefore should try to ensure the use of mainly non-licensed mobile services such as Wi-Fi and Bluetooth as future mobile networks expand and provide new opportunities for high performance networks (ibid). Both intranet and internet systems need to be connected sufficiently by powerful infrastructures so that vast streams of data can be handled appropriately (ibid).
Secure	In addition to being powerful, IT infrastructures need to be secure. Protection against data losses and cyber-attacks needs to be stepped up in highly digitalized company operations. (This is considered in further detail in Table 29.)
Reliable	A reliable IT infrastructure is another crucial requirement for virtualized business operations (Capgemini Consulting, 2014). Companies need to ensure appropriate service level agreements (e.g. with Cloud and big data providers); a high, reliable energy supply; and reliable and invulnerable IT operations in order to ensure a highly stable IT infrastructure.
Scalable	Since more functions and processes will be virtualized, the digital infrastructure must also be scalable, so that system performances are optimized, and associated costs are controlled (Capgemini Consulting, 2014). In this case, it needs to be flexible, and there needs to be spare capacity, new functions, and requirements among different operations (ibid; Roland Berger (2014b).

Primary Data	
Connecting of IT and OT	Experts F, D, and C mentioned that the industrial internet incorporates two systems in one central system: IT (as a resource planning tool and decision support system); and, OT (monitoring and control equipment for manufacturing and production processes). The basic IT infrastructure ensures the proper functioning and connecting of these systems in a high performance network.
Digital infrastructure needs to be adapted, or built from scratch	According to experts F and E, depending on the individual company circumstances, existing IT installations may need to be adapted (which is often the case for large companies that have to harmonise, network, and extend their existing IT-systems). Small companies, however, should focus more on building entirely new IT infrastructures so that they can meet the requirements of future digital manufacturing. Both experts (F and E) also mentioned that the cost implications are a key factor behind the decision on whether to adapt, or to build entirely new IT systems. The considerations will vary with each individual business.
Different divisions need to be considered	Experts F, D, and C emphasised that future IT infrastructure shall consist of large systems characterised by a variety of networks. During the adaptation and creation of IT systems, different functions (such as research and development, production, logistics, marketing, sales, and customer services) need to be integrated into a powerful and efficient IT system.

The **Future Workforce** is a further requirement, and can be defined as the need for new skills and capabilities among employees so that they can successfully operate in the digital manufacturing environment. The primary and secondary data findings on this issue are described in Table 28:

Table 28: Findings - Future Workforce

Future Workforce	
Secondary Data	
New skills and capabilities required for digital manufacturing	Industry 4.0 resp. the Industrial Internet of things demand considerable changes to a variety of business operations, processes, and procedures; future workforces shall also have to adapt. At present, highly automated manufacturing processes require technical expertise, experience, and human judgment. However, in the future digital manufacturing environment with hyper-flexible production structures, these skills will hardly add any value to operations (such as autonomous CPS, Cloud computing, and data analytics) (Roland Berger, 2014b). Due to the computerization and digitalization of tasks and workflows (that currently have restricted automation), new skills and capabilities will be required in data science, software development, hardware engineering, testing, operations, marketing, and sales (Accenture, 2014).

New skills for new types of products	In the move towards offering product-service hybrids, a company's workforce needs to learn how to develop, support, and sell these types of new products (Accenture, 2014). This will require new skills of (i) product managers who shall manage products during the entire lifecycle, (ii) software developers who shall design and test information services, and (iii) hardware designers who shall create these types of new products. Furthermore, new skills must be acquired by data scientists who shall develop analytic tools and interpret data, as well as by user interface and experience designers (ibid). In addition, sales managers and marketers need to develop new skills, in order to sell these new types of products across the sales channels (ibid).
New skill for new types of processes	Moreover, there will be the need for employees to learn how to integrate intelligent equipment and services into a company's operations (Accenture, 2014). These process engineers need technical know-how, data science and quantitative analytical skills, so they can process incoming data for improving worker productivity and customer service (ibid).
New skills for new working procedures	The advances in robot technologies will dictate further changes in how people perform their work (Accenture, 2014). Whereas at present, robots are mainly used to conduct highly repetitive and hazardous tasks, in the future, robots will be designed to be intelligent enough to collaborate with people, and to improve employees' ergonomics and safety (ibid). This new form of working including human-to-machine communication and decentralized controlled machineries will require new skills and abilities (ibid; Capgemini Consulting, 2014).
Primary Data	
Importance of new employee skills	10 of the experts believed that digital organizational capabilities (including an appropriately prepared workforce with new skills and experiences) is fundamental to a successful digital transformation. Expert B mentioned that digital manufacturing requires the collaboration of engineering and IT personnel. Since both divisions often have different objectives, it should be the duty of senior management to specify common aims that can be achieved mutually. As emphasised by experts D and H, the future workforce requires people who are able to think in terms of systems, and who are more flexible with their operations within increasing networking and collaborations. Expert E stated that the right organizational mind-set is the key for the development of new skills among the workforce (refer back to Table 18), and that workers need to learn more IT and digital skills through human resource training and development programmes.
The management have to identify required company skills	According to experts A, B, D and F, company leaders have to focus on the individual company situation, and identify the skillsets needed to realize their vision of future digital manufacturing. Experts A, B, F and H mentioned that senior management needs to flatten the hierarchies, foster new and individually tailored working environments, and create a learning organization with flexible working models and blended learning methods (refer back to Table 18 for notes on the digital organizational mind-set). Experts B and E mentioned that one way of achieving these changes is to establish a digital platform that offers global talent exchanges in order to address skills shortages and to foster a digital mind-set.

Data and cybersecurity is another requirement in the third dimension which has arisen due to the increasing connectivity of machines, processes, and operations, which in turn are the target for an increasing number of cyberattacks. Businesses have to ensure that their operations are secure, in order to operate successfully in the digital manufacturing environment. The data findings on this issue are described in Table 29:

Table 29: Findings - Data and Cybersecurity

Data and Cybersecurity	
Secondary Data	
Need for data and cybersecurity	The increasing connectivity and networking of manufacturing parties and equipment, including machine-to-machine communications, has been accompanied by an equal increase in cybercrime (Ernst and Young, 2015). IT security is therefore one of the most important aspects of company operations that will become more paramount in the future (Accenture and General Electric, 2015). In general, organizations may not be able to prevent all security incidents, but they can control the way that they respond to these incidents (Ernst and Young, 2015).
Need for clear security guidelines, organizational principles, and management tools	According to Roland Berger (2014b), new digital businesses operations require clear security guidelines, organizational principles, and management tools. Since most companies currently lack these operations, they should start identifying potential threats and weaknesses in the value chain. Companies need to perform these by considering potential risks from two different perspectives: (i) in terms of the end-to-end process; and (ii) in terms of the company's key assets (e.g. intellectual property, physical and digital products, process knowledge) (ibid). As soon as firms have identified potential risk areas among their operations and assets, they need to prioritize how urgent security actions in different areas will be. Following this, companies then must design comprehensive and suitable systems, and specify all the necessary responsibilities for establishing or adjusting data management systems in an effort to ensure cyber-security across the entire organization (ibid).
Assessments of security implications need to be performed constantly	Since technology and companies have been evolving constantly at a high pace, organizations within I40 resp. IIoT need to constantly assess security implications (Ernst and Young, 2015). Comprehensive and multi-perspective security risk assessments need to be performed constantly to ensure appropriate security systems. These can be driven by applying suitable procedures and regular testing, enabling businesses to become smarter, and helping employees to become more aware of potential risks (ibid).

Primary Data	
The management have to build up an organizational risk and security awareness	According to experts D, E, F, G, and H, senior management needs to push the entire organisation towards greater risk awareness and improved risk mitigation (refer back to notes on the digital organisational mind-set in Table 18). Experts D and H mentioned that an organization must know the environment inside and out, learn and evolve continually, develop competent incident and crisis response methods and mechanisms, and include cybersecurity within business objectives. Organizations need to act in unison to develop successful cybersecurity actions in an effort to ensure secure and sustainable business operations in the digital manufacturing environment (experts D, E, F, H, I, and J).
Data rights, regulations and security	As described in Table 21 ('capitalize on the value of data'), experts C, D, E, and F mentioned that businesses have to acquire new financial and governance models to include data security. Governments have to cooperate with businesses and stakeholders when formulating laws and regulations regarding data ownership and security. Expert D emphasised that the exact regulations and rules will vary from company to company. Expert D noted that Siemens equips its products (e.g. control units) with smart sensors that are used to control automated machines (e.g. automated drilling machines) and generate data from these machine operations, which are then transferred to Siemens's Cloud system for storage. Customers often think that such data concerns their business operations, but this is not the case, since the data only contains information about the health of the machines, and is used to perform predictive maintenance operations (rather than detail what is being produced by the machines). In the case of Coca-Cola, if machines provide data about their machine operations for the purposes of predictive maintenance, then they could also provide information about production processes, including chemical processes (Expert D). Expert D emphasised that each company individually needs to consider its current and potential future operations, and consider the benefits and potential threats (see above). At the same time, companies should participate in and contribute to associations such as Platform Industrie 4.0 and Industrial Internet Consortium to push through data and security rules, regulations and standards (experts C, D, E, F, G, and H).

4.5.4 Discussion

As shown in the previous few tables, the secondary and primary data provided a deep and detailed explanation of company requirements under I40 resp. IIoT. Whereas significant knowledge gaps were identified during the literature review, the information provided in the interviews covers a sweep of new issues on the requirements of manufacturing businesses for undergoing a successful digital transformation.

The third research objective has been addressed through the identification of 10 different generalized and essential business requirements, which should enrich the existing academic literature.

The first dimension ('Drive the next Horizon of Operational Effectiveness')

The existing academic literature provides only superficial business requirements without clearly emphasising their importance and necessity. Within both the secondary and primary data, the majority of consultancy reports and all 11 interviewees clearly pointed out that the right organizational mind-set (in the form of a digital organizational mind-set) is elementary, and is one of the starting points for a successful digital transformation. Whereas the academic literature only specified that companies have to develop and adapt a new way of thinking (Soley, 2014; Davis et al, 2012; Lee and Lee, 2015), only in the context of developing business models and collaborations, and not in the context of the organizational mind-set as a whole.

Furthermore, the digitalization of the supply and value chain, as well as of the product and service portfolios, is considered to be essential for improving the effectiveness and efficiency of operations (as emphasised by 9 experts (A, B, C, E, F, G, I, J, L), and mentioned by Roland Berger (2014b), PwC Strategy& (2014), and Capgemini Consulting (2014b)). The academic literature only provided some requirements about smart products (such as the need for generating and sharing data, as well as the need for customization) (Lasi et al, 2014; Brettel et al, 2014); and, the digitalization of the supply and value chain was not mentioned.

The need for capitalizing the value of data was expressed by experts A, C, D, E, F, and is mentioned in consultancy reports by Accenture (2015b), and McKinsey & Company (2015a). They identified this as being crucial in light of the generation and sharing of data in the digital manufacturing environment. However, the academic literature only mentioned the need for centralizing and sharing information between different company departments (Brettel et al, 2014; Lee and Lee, 2015; Soley, 2014), essential aspects such as data value, importance, regulations, and security were not mentioned.

The second dimension ('Adapt Business Models to Capture Shifting Value Pools')

The academic literature also provided only superficial explanations about these business requirements. Regarding the requirement of smart innovation, experts A, B, E, G, and L, and the consultancy reports by Capgemini Consulting (2014b) and McKinsey & Company (2015a) identified the need for new types of innovation processes, and described new forms of smart innovation and their importance; by contrast, no research concerning this area was found in academic literature. The need for new types of business models was mentioned by 10 experts (A, B, C, D, E, G, H, I, J and L) and 8 consultancy reports, whom/which explained new forms of business models and emphasised their impotence in digital manufacturing. In the academic literature, only the need for senior management to consider shifting value propositions is mentioned (Brettel et al, 2014; Soley, 2014; Davis et al, 2012), and there was no information on specific requirements for developing and implementing new business models, or on their future importance.

As for the collaboration, experts A, D, E, F, G, H, J, and L, and reports by McKinsey & Company (2015a), PwC Strategy& (2014) and Roland Berger (2014a) have demonstrated the need for greater collaboration in the dynamic digital manufacturing environment, whereby companies need to focus more on core competencies to perform effective and efficient operations. In the academic literature, a similar view is expressed by Brettel et al (2014), and Soley (2014), but they do not consider necessary standards and interoperability problems (both of which had been widely expressed by the interviewed experts and consultancy reports).

The third dimension ('Build the Foundations for Digital Transformation')

Experts C, D, E and F, and reports by Capgemini Consulting (2014b) and Deloitte (2014) emphasise the need for a digital infrastructure, and presented detailed requirements that need to be fulfilled by companies, including adaptions to existing IT systems, or even a complete IT system replacement. The academic literature only reports the need for collaborations within and outside business (Brettel et al, 2014; Wahlster, 2014), and specific requirements for transforming existing IT systems and creating entirely new systems were not found.

10 of the interviewed 11 experts, and the majority of consultancy reports strongly pointed out the need for new skills and capabilities among employees. They explained that changing business operations will require a different workforce with new skills and experiences. The need for new skills and capacities is also been mentioned in academic literature (Dworschak and Zaiser, 2014; Brettel et al, 2014), but it contains no information on different working fields, or on the fundamental requirements that need to be fulfilled in the development of new skills (e.g. the right organizational mind-set in the form of a learning organisation).

Data and cybersecurity was widely discussed among the interviewed experts and in the consultancy reports. Experts D, E, F, H, I, and J, and the consultancy reports by Accenture and General Electric (2015), Ernst and Young (2015), and McKinsey & Company (2015a) mention the need for appropriate and continuous company operations concerning data and cybersecurity. They also carefully explained how such procedures could be applied appropriately. The need for security systems due to the increasing connectivity of devices, machines and processes is also mentioned in the academic literature (Soley, 2014; Harvard Business Review, 2015), but no detailed explanations for how businesses should address these procedures was found.

The secondary and primary research therefore provides a significant contribution to the canon of knowledge, wherein 10 main business requirements have been identified and described. The majority of these requirements is interconnected, since the achievement of one requires the accomplishment of another. Therefore, manufacturing companies need to specifically identify the importance of each individual requirement, and prioritise all the requirements; these will vary between individual businesses, and managers need to identify the most appropriate operations in the transition to digital manufacturing.

4.6 Objective 4 – The Way Forward

In answer to the previous three research questions, the findings of this study have provided a comprehensive overview of the latest developments in, and potential benefits offered by, new technologies. Furthermore, it contains detailed descriptions and analyses of the requirements which manufacturing companies need to satisfy in order to successfully take advantage of I40 resp. IIoT. The fourth and final research question considered when and how businesses can best start the transformation process towards becoming I40 resp. IIoT industries, and what potential future developments can be expected.

The **secondary data** provides some basic information on the issues concerning the fourth research objective. In terms of the best starting point or strategy for a transformation, useful information was identified in a range of reports by Accenture (2014), PwC Strategy& (2014), Capgemini Consulting (2014a, 2014b), Capgemini Consulting, WZA RWTH Aachen and Fraunhofer IPT (2014), Cognizant (2014), Roland Berger (2014a), and Boston Consulting Group (2015). However, the strategic advice in these reports is mostly generic, and merely specified some main approaches. Future development trends and time frames are mentioned in a few reports, such as by the World Economic Forum (2015), China Materialia - Finland Team (2014), and Chand and Davis (2010), which report survey results on potential I40 resp. IIoT future envelopments.

As for the **primary research**, all the interviewed experts addressed aspects relating to the fourth research objective. Most responses could be counted as strategic advice, but some interviewees also addressed the issues of the right starting times and time frames of future development trends. However, the expressed statements by the experts are not unanimous. They examined the topics from different point of views and angles, and they identified a wide range of strategic aspects that can be considered by manufacturing business in developing a successful transformation strategy.

4.6.1 The Starting Time

Before developing a strategy for transformation, the best starting time for a manufacturing business needs to be ascertained. The secondary and primary data has been analysed to determine the optimal starting time, and the approaches that can be used to define the optimal starting time (Table 30):

Table 30: Findings - The Optimal Starting Time

The Optimal Starting Time	
Secondary Data	
Starting time	The best starting time for manufacturing businesses to begin taking advantage of I40 resp. IIoT was rarely mentioned in the investigated business and consultancy reports. One of the few reports has been written by Capgemini Consulting (2014b), which indicates that now is the best time to start transforming, since manufacturing businesses currently enjoy a unique strategic position. Accenture and General Electric (2015) recommend that industrial companies should rapidly implement digital initiatives in order for the potential benefits to be guaranteed. Since all the cited business-oriented reports outlined the high potentials, this signifies that businesses should start thinking now about the opportunities, and start transforming.
Strategic identification of starting time	A strategic approach of determining the best starting times is provided in PwC Strategy& (2014). The three different strategic approaches are 'Leading', 'Adapting quickly' and 'Waiting'. By taking a 'Leading' approach, companies must act quickly in implementing digital concepts, which in turn may include the creation of standards. On the other hand, they have to take higher risks when undertaking the first developments and implementing untested solutions. The 'Adapting quickly' approach is where companies learn from and copy the pioneering companies, and utilize their experiences to quickly adjust to and implement digital concepts. However, the risk with this approach is a lack of competitive advantage (if a competitor has already undergone a transformation). Companies that take the 'Waiting' approach are those that wait for information on widely tested solutions with defined standards and established profitability analyses. Due to the fast changing world, these companies may also fall behind in the global competition. Identification of the best approach is dependent on several factors, and the best one will not be the same for every company. The maturity of a company's systems and the extent of required changes both play an important role in the choosing of an optimal strategy. Furthermore, the nature of existing customers and competitors, along with the willingness to invest, need to be taken into account.
Primary Data	
Starting time	Most of the experts did not outline a specific starting time, although many experts (such as experts A and B) emphasised that many potential benefits that can be utilised by the manufacturing businesses, and they inferred that businesses should start the transformation now. Experts C and E validated this opinion by outlining that businesses should start the process of transformation now, and assess the potential impacts on their businesses.

4.6.2 Strategic Approaches and Aspects

As previously mentioned, information on various strategic approaches and aspects was obtained through the secondary and primary research, and is described and analysed in Table 31:

Table 31: Findings - Strategic approaches and aspects

Strategic Approaches and Aspects	
Secondary Data	
PwC Strategy&'s maturity model, and the three pragmatic steps	According to PwC Strategy& (2014), for most companies the transformation process will take several years. As mentioned (in answer to the previous research objective), PwC Strategy& outline that the starting point needs to be determined by senior management, which should appreciate the importance of the issue. The next step, according to PwC Strategy& (2014), is the recording of existing competencies and capabilities across different dimensions, as based on the developed maturity model by PwC Strategy&. As well as providing guidance on assessing maturity, the model provides digitization measures, which can be applied in on-going and planned activities. This altogether forms an integrated I40 strategy. The four maturity stages are 'Digital novice', 'Vertical integrator', 'Horizontal collaborator', and 'Digital champion'. In order to classify a company in terms of these stages, five dimensions of the business' capability need to be assessed: 'Business models, product and service portfolio'; 'Market and customer access'; 'Compliance, legal, risk, security and tax'; 'Value chains, processes and systems'; and, 'Organisation and culture'. (Further information about the models is provided in Appendix C: Figure C5.) In addition to this maturity model, PwC Strategy& provides three first steps for businesses to follow. These three pragmatic steps can be considered regardless of which I40 resp. IIoT strategy will be followed. (1) First of all, the companies should start to give all things a name. As an example, each product and production material should be ascribed identification names or codes, such as bar codes or unique names. If this is not performed, the value chain and the products cannot be digitized or connected. This first step allows data collection to commence, and results in the complete internal description of the parts; this in turn will yield increased efficiency in inventory and supply chain management. (2) Businesses should start to measure all processes and sensor data along the value chain. If such devices are not already in operation, they should be installed at multiple measuring points so as to track the current state of products and equipment in the production process. (3) Companies should connect up their products, production materials, and manufacturing process data. In addition, the other data sources should be connected, and that may require the establishing of new communications and IT infrastructures. Hence, the companies should build their Big Data systems to analyse and use the data.

Capgemini's 6-step strategic approach	Capgemini Consulting (2014a and 2014b) also provide a way forward towards I40 resp. IIoT with a six-step journey. Before describing this strategic approach, Capgemini emphasises that the transformation process is not a quick-fix solution, but a long-term commitment. (1) This step-by-step process starts also with an assessment of digital maturity. A comprehensive analysis of maturity will reveal the business' strengths and weaknesses, which is a good starting point for strategy development. (2) The businesses then have to identify the opportunities and threats in relation to I40 resp. IIoT. Changing customer demands, digital best practices, and competitive dynamics are the major value drivers in the industry. (3) When these factors have been understood by the companies and recorded, the companies can define their own digital vision and strategy. A clear vision provides a clear view on how the business will succeed in the future and achieve its aims. A deep integration of the vision in the corporate culture can be achieved by the commitment of executive managers, and clear top-down communication. (4) Following this, companies should prioritize the transformation domains. Since some digital initiatives have to be integrated with existing core business processes and systems, the transformation of some domains is more complex than others. The prioritising will help to identify quick wins and long-term initiatives. (5) Next, an I40 resp. IIoT roadmap must be prepared, which contains the details of the transformational phases. The roadmap is formulated by management executives and IT staff, and it provides everyone with a clear picture showing that the actions are commonly aligned. (6) The final and most difficult step is the implementation of the strategy based on the roadmap. The companies have to change the traditional thinking of their employees, i.e. that IT is seen as a service provider. The new role and responsibility of IT as that of a business partner along the value chain, and this new perception needs to be clearly promoted through digital leadership capabilities. Due to the rapid pace of I40 resp. IIoT technological innovation, manufacturing businesses need to continuously change and adapt along the transformational journey.
People and collaboration-based approach of Accenture	Another comprehensive seven-step-model for moving forward has been proposed by Accenture (2014). This model differs from the previously mentioned models in several ways. Beside the basic steps of assessing maturity, and identifying strengths, weaknesses and potentials, this approach contains steps for considering/creating a partnering ecosystem, business model opportunities, financial aspects, and legal issues. As an example, it outlines that the companies should think about cooperation and collaboration with partners in the value chain and also in the supply chain. When the companies introduce new hybrid products with inclusive services and business models, they should promote these new products to their sales and dealer network to ensure their support in selling the products. In addition, different financial models and aspects in investment should be examined by the manufacturing business to ensure return on investment.
Further approaches	Further approaches for the way forward are provided by Boston Consulting Group (2015), Cognizant (2014) and Capgemini Consulting, WZA RWTH Aachen and Fraunhofer IPT (2014). However, these approaches are not as sophisticated as the previously described strategic approaches. The main strategic elements have been already explained in the previous models as well.
Roland Berger – New plants versus progressive upgrade	A slightly different approach is prescribed by Roland Berger (2014a), in which he outlines that there are only two ways to move into the I40 resp. IIoT age. The first is to transform existing plants completely or make greenfield investments. The other option is to progressively adapt existing plants. Both options have their advantages and disadvantages, and should be considered by manufacturing businesses.

Primary Data	
Difficulty of providing a generalised approach	A strategic approach for manufacturing companies would be difficult to generalise, since it depends on each business case and on several factors. This was emphasised by several experts such as experts A and C. These factors range from manufacturing segments to the company size to the digital foundations.
Ultimate objectives: operational efficiency versus top line growth	According to experts A, D and J, the main objective must be decided first (e.g. if the company wants to increase operational efficiency (save costs), or top line growth (increase turnover or generate new revenue)). According to Expert D, this is important because different decision makers are responsible, and each business case has to be calculated differently.
Start small	Expert A continued that the companies should start in small steps: they should identify the potential opportunities for improving or enhancing specific processes with digital initiatives, and then start with pilot projects. After the companies have gained some experience, they should develop a digital vision and strategy for the transformation. This includes identification of the required skills and HR development, as well as organisational change, and the introduction of new positions such as Chief Digital Officer. The synergies between information technology and operation technology have to be recognised and developed. As Expert A outlined, the corporate culture cannot be forced from the top down, and so the best solution is a combination of top-down motivation and bottom-up implementation through several small initiatives. Also, smaller manufacturing companies should consider all possibilities, since not every suitable technology costs millions of dollars (or equivalent). Expert C's recommendation regarding the strategic approach is quite similar to that of Expert A. Companies should create small rooms within the company in which ideas and developments of I40 resp. IIoT can grow. The companies need to learn how to handle the technologies, and it is important that the workforce is integrated because they have to use the technologies. Furthermore, when the companies understand the technologies and learn more about the new shortened innovations cycles, then they can start to implement the technologies in small pilot projects.

Is an upgrade of the production worthwhile?	Expert E explained that company managers should start by evaluating the I40 resp. IIoT transformation potential in the company and the industry. They need to identify the main drivers in the industry, and where the company can achieve the biggest value and return on investment. However, in addition to this, Expert E mentioned that not every factory will become smart. The new factories will be equipped with new smart machinery, but for many existing factories the return of investment may be too low to justify upgrading them with sensors and other smart elements. Moreover, companies have to understand that some opportunities will pay off quickly, but other opportunities require long-term investment until they pay off. This approach has been also explained by Expert G, who added that the products the company manufactures also need to be considered, since plants that manufacture products with a long life cycle (e.g. airplanes or ships) cannot easily change and upgrade their production systems. For products with a fast life cycle (like consumer electronics or automotive parts), the transformation and upgrading of the manufacturing by levering of new technologies can be faster. In addition to this, Expert G discussed approaches for the location of new plants. In countries like China, product demand is higher, economic growth is faster and the development of inventions is faster; therefore, new plants will probably be constructed more rapidly in China, than in Europe or the USA. Despite this, there is concern on whether such ‘low’ cost countries possess the necessary infrastructure and expertise to operate highly automated and smart plants. Expert I believed it is very unrealistic that a complete factory or production will be transformed or upgraded.
Start within main business, or in parallel	Experts B and I outlined different issues that have to be considered by manufacturing businesses. They mentioned that one heated question is whether businesses should start to implement a transformation in the main business, or in parallel to the business. If it is started inside the business, strategic changes in business and operations will be required, and this in turn can lead to problems, including: (i) cannibalisation of the old business model; (ii) conflicts in the ultimate business objectives between the existing and new business models; (iii) resource allocation problems; and, (iv) internal resistance by a workforce with a traditional mind-set. On the other side, if the I40 resp. IIoT initiatives are started outside the main business in parallel, there is the danger that these will not connect properly with the operations in the main business, and synergies will be difficult to identify and utilize. However, this other approach allows people more flexibility to think, act and do freely, since a parallel transformation programme has its own budget, which in turn is not limited. The latter approach is often chosen when the aim is to develop a new product. The merging of the two businesses will almost certainly not be possible and, therefore, the only options are to close the old business, or sell one of the businesses. The transfer of human resources is also limited due to the differences in required skill profiles between the businesses. Expert B claimed that management skills are needed in order to determine the best approach.
General qualities for a successful strategic approach	Experts H and L outlined that companies have to be aware about the new and latest technologies. According to Expert H, with this knowledge they can develop a vision that answers the following questions: Which business model should be used? Which organisational model is compatible with the chosen business model? How can the company best adapt to the age of I40 resp. IIoT? Expert L added that companies should internalize a start-up mentality, which is more flexible, and which can react faster; L also added that the companies should be more willing to take risks.

A structured status quo/target analysis approach	A very structured and strategic approach was presented by Expert I. Companies must start by defining their actual state (which includes assessing maturity in relation with digital and new technologies). The company should then define their target state, and consider their objectives and decisions if they want to adopt one technology, or a group of technologies. After these definitions and decisions are specified, the company should identify capabilities within their business, and which initiatives can be best implemented in view of these capabilities (ranking of initiatives).

4.6.3 Future Development Trends and Time Frames

Since I40 resp. IIoT development is in its initial stages, further developments and trends are inevitable. Some indicative time frames exist in the primary and secondary data, which provide an overview of how long the transformation in the manufacturing industry might take. The results of the secondary and primary research are described and analysed in Table 32:

Table 32: Findings - Future Trends and Time Frames

Future Trends and Time Frames	
Secondary Data	
Time frames and future development trends	The majority of time frames identified in the secondary research ranged from 5 to 10 years (in which I40 resp. IIoT will have to be attuned to by all manufacturing companies to some extent). Boston Consulting Group (2015) states that it might take 20 years to reach complete transformation, but that key advances will be achieved in 5 to 10 years, by which time the first winners and losers of I40 resp. IIoT transformation will be known. McKinsey & Company (2015a) quote a business expert in their report, who stated that within 5 to 10 years, every business should have a digital foundation. Reports by the World Economic Forum (2015) (in collaboration with Accenture), China Materialia - Finland Team (2014), and Chand and Davis (2010) provide phase models detailing future developments and trends. The World Economic Forum (2015) lists four phases (both near-term and long-term). During Phase 1 (‘operational efficiency’) and Phase 2 (‘new products and services’), immediate opportunities for the manufacturing business will be gained within the next two years. These short-term phases are followed by Phase 3 (‘outcome economy’) and Phase 4 (‘autonomous, pull economy’) in the long term, the latter of which starts approximately three years prior to mainstream adaptation. Phases 3 and 4 include opportunities and features such as pay-per-use models, new connected ecosystems, platform-enabled marketplaces, continuous demand-sensing, end-to-end automation, resource optimization, and waste reduction.

3-Phase Model	China Materialia - Finland Team (2014) provide a three-phase model. (1) The first phase represents physical and pseudo-physical aspects, whereby hardware will be embedded with smart elements (e.g. sensors, actuators, small computer chips) and networks, and infrastructure will be further developed. In this phase, companies with software and system expertise will be the winners because they can use the data in its initial stages. (2) In the second phase, the utilisation of intelligent decision-making is possible, und this gives manufacturers the chance to optimize their operations. Additionally, Big Data Analytics and machine learning will be features of this phase. (3) The third phase will bring more I40 resp. IIoT-specific and mature machinery and equipment on the market. Algorithms will be exponentially improved. Improvements in infrastructure and standards will also enhance their applicability and success. According to China Materialia - Finland Team (2014), this is not the end, but rather the beginning, and many more potential opportunities and benefits will be exploited.
Primary Data	
Overall time frames	According to Expert E, general time frames cannot be accurately forecasted as they depend on the types of industry segment, company, factory and machine. Expert B estimated a time frame of 5 to 10 years, one that was often mentioned by other experts. In addition, Expert A described the revolution as an evolution that will last 10 years until the migration of operations is completed. According to Expert G, the companies may have to spend a minimum of 10 to 15 years making changes before I40 resp. IIoT transformation is completed. Expert H suggested a time frame of 10 years, by taking the analogy of the other Industrial Revolution, which happened in around 10 years. Expert D argued that the transformation will happen in 5 years, but did not justify this view. According to Expert C, neither large companies nor small/medium sized enterprises (SME) have an advantage during transformation. The implementation of I40 strategies in SMEs may be faster and less complicated. However, they cannot afford to make any mistakes. Large companies on the other hand have more resources (in the form of investment and know-how); however, they also have more complex organisational structures, processes, and procedures, all of which could decelerate the transformation. Expert I argued that large companies can make bigger changes in the next 4 to 5 years, and that I40 resp. IIoT opportunities will have been fully explored in the next 10 years. However, it could take SMEs a few decades to make a transformation, and some SMEs might never succeed in developing the necessary I40 resp. IIoT systems.

Technology related time frames	According to Expert A, the data quality for production control, process transparency, tracking and predictive maintenance will have matured in 5 years. Self-learning machines and decentralised production control will become a reality within 10 years. Expert C suggested that the time frame depends on the technologies. He underlined that due to insufficient data quality and topicality, as well as proprietary ERP systems, machine learning might not be possible for another 5 to 10 years. Small data utilisation may be available earlier, but the utilisation of Big Data may not become a reality for another 10 years. In addition, Expert F outlined that 3D printing / additive manufacturing can be utilized in 10 years' time for almost anything.

4.6.4 Discussion

The information gained in the secondary and primary research is sophisticated and of a high quality. In comparison to the academic literature reviewed at the beginning of this dissertation project, the business and consultancy reports of the leading consultancies in the area of I40 resp. IIoT (such as Accenture, Boston Consulting Group, Capgemini, PwC and Roland Berger) contain some useful advice for manufacturing businesses on how to handle the transformation and develop a successful strategy. As outlined in the literature synthesis (refer back to Chapter 2), the academic literature does not provide any information on strategic plans, time frames, or optimal starting times. Therefore, this discussion does not compare and discuss the literature review and research findings, but presents the main result and important implications.

All the interviewed experts contributed detailed explanations and statements in answer to the four research objectives. The main facts and strategic aspects described in the secondary research have been validated by the experts. They have even provided more information, and have presented different point of views and angles. The most valuable information gains are in the area of strategic advisory and approaches. The information about the optimal starting time was addressed in secondary and primary data less frequently. Nevertheless, it can be concluded from the gathered information on strategic approaches and the issues of development that every manufacturing company should start a transformation process now, even by just gathering the necessary information about the latest developments to identify potential opportunities enabled by I40 resp. IIoT. The time frames of future development trends formed a very critical topic, since all experts argued that it is almost impossible to estimate exact time frames. However, a general time frame in relation to technology developments might be provided, which could provide a rough overview of the essential developments for the manufacturing industry.

Consequently, the results of the research (which are presented in the tables above) provide manufacturing businesses with a good overview of the aspects that have to be considered when deciding when to start a transformation, and how to develop a successful strategy for the transformation. The predicted future development trends and time frames give the manufacturing industry an idea on what developments could impact them in the future, and how they could respond to these developments.

All this strategic information shall be used in combination with the research into technologies and requirements (described in the previous chapters) to formulate a generalized framework model, which can be used by manufacturing business to perform a successful digital transformation process. This will be presented in the following chapter.

5. Derived Digital Transformation Model

Following the presentation and discussion of the secondary and primary data in view of the four research objectives, this chapter (which constitutes the fifth step of this research study - see Figure 1) combines all results and insights gained from the research into a generalized digital strategy development framework (or digital transformation) model. This framework model will help, manufacturing companies to develop an individual digital transformation strategy by providing a generalized and systematic strategy composed of 5 steps. This generalised framework is based on the collected and analysed secondary and primary data. Exact guidance may need to be amended for each individual business case in the manufacturing industry. The aim of this model is to help companies identify their individual and current conditions, define clear objectives, and identify appropriate digital initiatives that need to be analysed and prioritised before the implementing process in the company's operations can commence. In the following sections, each step of the model will be presented in detail by referring to the generalized (E&F) Digital Transformation Model (see Figure 23).

5.1 Condition Analysis

In the first step of this digital transformation approach, companies need to analyse their individual and actual conditions. This needs to be performed by analysing both a company's **internal** and **external** environment conditions.

For an analysis of the **internal conditions**, a general digital maturity assessments need to be performed by evaluating a company's maturity concerning a successful digital transformation process. This can be accomplished by applying different models provided by Capgemini, Accenture, PwC Strategy&, and Ernst & Young, which were developed to help companies assess their digital maturity in detail. At the same time, businesses need to clearly identify their own strengths and weaknesses in order to produce a transparent diagnosis of the actual company conditions.

For an analysis of the **external conditions**, companies need to assess the influences caused by the external environment. Businesses need to assess the external environment (in terms of potential opportunities and threats) by clearly identifying the value driver in the operating industry(ies), and their own position in the value chain. Furthermore, companies need to assess the industry players that are driving I40 resp. IIoT development; this is crucial for the early identification of necessary developments, and potential changes in business operations. In addition, the competitive dynamics needs to be considered continuously to ensure sustainable operations and to maintain a comparative competitive advantage.

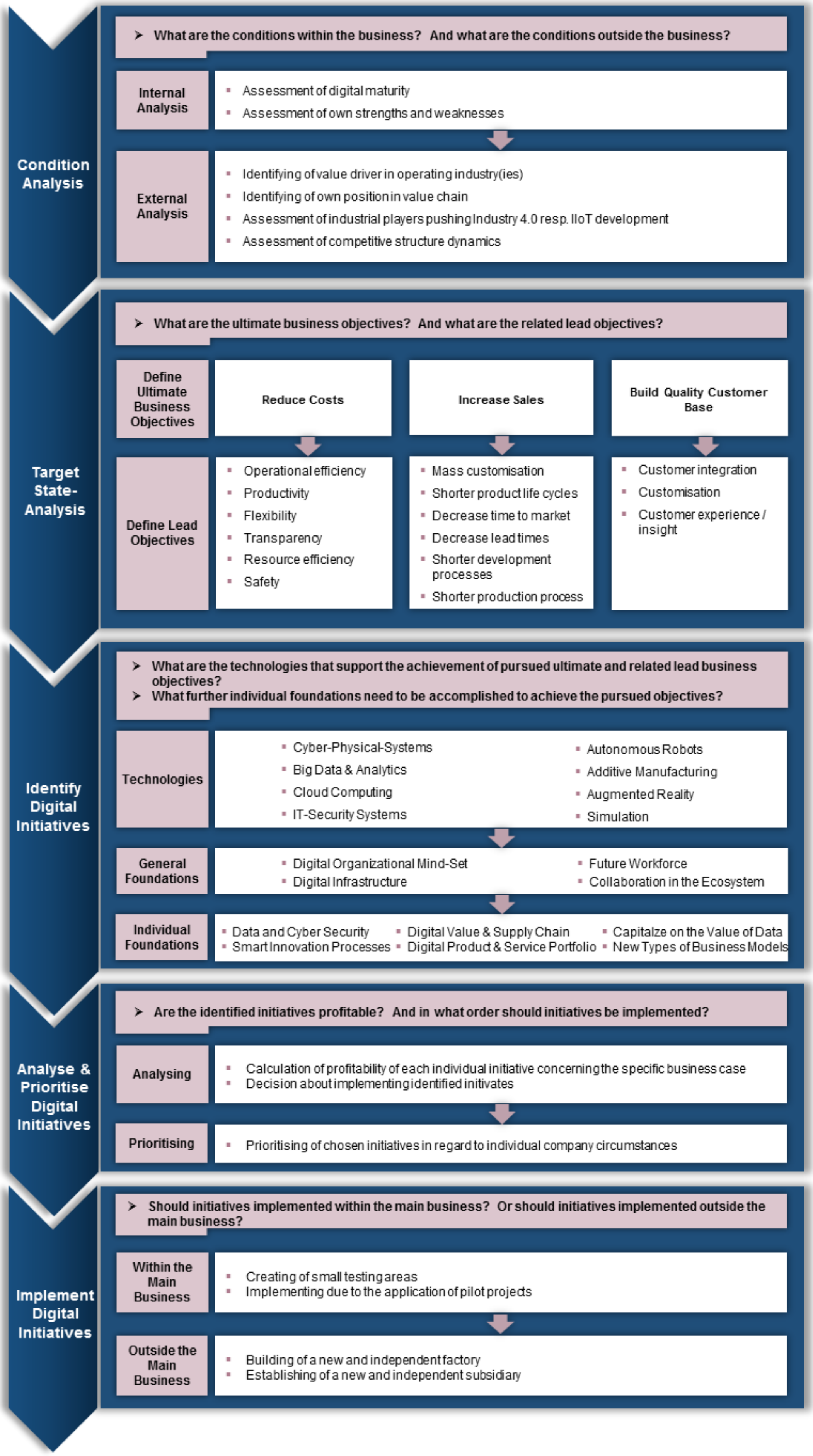


Figure 23: Derived Digital Transformation Model

5.2 Target State Analysis

Following the assessment and analysis of the internal and external conditions, the companies need to define which ultimate business objectives will be targeted. According to Hamill (2015), there are three ultimate business objectives: **reduce costs**, **increase sales,** and **build a quality customer base.** These are the only main objectives that can be delivered by digital technologies.

However, these ultimate business objectives can be broken down is **lead objectives**. Those are sub-objectives, which will be triggered directly by the digital and technological initiatives taken to achieve the ultimate business objective. Consequently, different lead objectives can help achieve the same ultimate business objectives. As an example, the lead objectives of operational efficiency (shorter development process, increased security, etc.) or resource efficiency can be specifically applied with digital and technological initiatives (measures) to reduce costs (ultimate business objective). Equally, a better understanding of customer experience and satisfaction meets the objective of building a quality customer base. The lead objectives have to be chosen individually by the manufacturing businesses in consideration of the targeted business objectives, and in view of the potential digital and technological initiatives that could be utilised. Moreover, the lead objectives are not as limited in number as the three ultimate business objectives. The lead objectives in Figure 23 have been identified and are derived from the research in this study; potentially, more objectives can be identified, depending on the individual company circumstances. Therefore, companies have to consider potential further objectives based on their individual cases.

When developing a strategy for a successful digital transformation, manufacturing companies should also recognise and consider current and future developments in the field of I40 resp. IIoT. This is important since the potential benefits of fulfilling each objective are affected by the progress of I40 resp. IIoT technologies and further developments. As outlined in Figure 24, not all potential developments can be enabled directly from the beginning. A successful digital transformation strategy of a manufacturing business should therefore include short-term and long-term objectives, as well as measures that reflect on-going development trends and opportunities emerging under I40 resp. IIoT. Since there could be new possibilities and changing development trends, the digital transformation strategy should contain flexible elements to react to those.

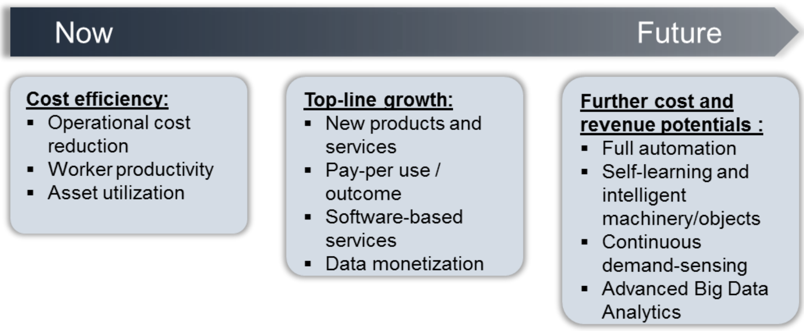


Figure 24: Future development trends of I40 resp. IIoT

5.3 Identify Digital Initiatives

In order to achieve both the lead objectives and the ultimate business objectives set in the previous step, the manufacturing business has to utilise a wide range of **digital and technological initiatives** (see technologies in Figure 23). Each technology and digital measure offers different potential opportunities. Some of them can be implemented separately, and some offer their full potential only in a group with other technologies. The findings (refer back to section 4.4) provide manufacturing business with an overview of the different potential benefits and important factors that should be considered for each technology. Depending on which objectives shall be achieved, the company can select technologies that target these objectives.

In order to utilise the technologies and digital initiatives, a company needs to consider some foundations (i.e. requirements - refer back to section 4.5), irrespective of which lag and lead objectives are being pursued. These foundations should be accomplished as part of the digital transformation process in order to successfully transform the manufacturing business. The extent to which these foundations have to be considered depends on the digital maturity, which will have been assessed in the first step.

The **general foundations** can be described as general requirements that need to be accomplished for every successful digital transformation strategy. These include requirements such as a digital organisational mind-set, and new skills in the future workforce.

The **individual foundations**, however, contain further requirements, which have to be considered by the manufacturing companies on an individual basis. These specific foundations are partly related to the lag and lead objectives, but are especially interrelated to the technologies and digital initiatives that shall be implemented in the business. The specific interrelation between the technologies and lead objectives with specific foundations is not provided in this model. A company needs to investigate whether certain individual foundations are relevant for its business, and what further foundations need to be met for the successful implementation of the technologies, and achievement of the targeted objectives.

5.4 Analyse and Prioritise Digital Initiatives

As soon as different initiatives have been chosen, companies need to **analyse** and **prioritise** the individual identified initiatives.

The **analysing** process needs to be performed by considering the profitability in regard to each initiative. In general, businesses need to consider their current operations and clearly identify the actual expenses and benefits. Based on this, the profitability (i.e. return on investment) has to be calculated by considering factors such as investment costs and long term expenses, as well as potential benefits and savings in regard to each identified initiative. This comprises often a variety of different considerations and calculations, which have to be performed by considering a company's individual business case.

Having analysed and identified profitable initiatives, the next step is the **prioritising** of these initiatives. During this step, companies need to prioritize initiatives by taking into account the digital maturity of their operations (identified during the condition analysis). Depending on the company's digital maturity, some initiatives will be easier to implement than others and also will be more beneficial than others. Every company individually needs to consider and decide on the most appropriate strategy for systematically implementing the identified initiatives.

5.5 Implement Digital Initiatives

This is the last and also the most challenging step, and the implementation of digital initiatives needs to be planned systematically. Generally, decisions need to be made on whether the identified digital initiatives have to be implemented **within the main business** or **outside the main business.**

The implementation of initiatives **within the main business** (refer back to sub-section 4.6.2) is a very common and widely used method, whereby companies often create small rooms beside their main operations so that new initiatives can be tested. Through this process, companies can learn how to handle new processes and procedures. The workforce can be integrated into, and thus learn about, the new initiatives, which in turn are vital for a successful implementation process. Once companies understand and reach an agreement on these new conditions, the implementation of initiatives in form of small pilot projects can be started. This will enable companies to change their existing operations directly within the main business. However, problems arise if strategic changes in business operations result in a cannibalisation of the old business model, conflicts between the existing and new business models (in terms of the ultimate business objectives), resource allocation problems, and internal resistance from a workforce with a traditional mind-set.

The other approach is the implementation of initiatives **outside the main business** (refer back to sub-section 4.6.2), whereby companies build new production facilities or even entirely new factories that are independent from the main business, and through which all new planned initiatives are directed from the beginning. The main business is independent from this process, which allows personnel more flexibility to think, act and do freely, as the process will not be limited and restricted by the business' main operations. However, there is the risk that such a process cannot connect properly with the operations in the main business, and synergies will be difficult to identify and utilize.

Businesses therefore have to individually consider current and planned future operations, and strategically identify the most appropriate approach of implementing the identified initiatives within a company's operations.

6. Conclusion

This chapter, which is the sixth and final step of the study (see Figure 1), draws conclusions on the research results obtained in this dissertation project. This chapter starts with a summary of the research results and their contribution to the canon of knowledge, followed by a brief discussion of their implications for businesses and the wider environment. Recommendations for governments and associations, technology providers, and industrial users are provided followed by a consideration of this research study's limitations. This chapter is concluded with a self-reflection, in which the authors recount the experiences and knowledge gained in this study.

6.1 Summary and Contribution to Knowledge

The aim of this dissertation study was to investigate the current state of I40 resp. IIoT development by considering related technologies, and the requirements and strategic approaches towards a successful digital transformation.

The **first research objective** was to analyse the current state of I40 resp. IIoT development. In particular, the secondary and primary findings provided deep insights in answer to the first research objective. Thus, it could be ascertained that I40 resp. IIoT offer tremendous opportunities worldwide, which not only affect manufacturing businesses, but also affect the manufacturing industry and whole economies worldwide. Whether this development will occur as a revolution or an evolution is not agreed consensually, but the majority opinion tends towards it being a revolution with some evolutionary characteristics. Alongside manufacturing businesses, other identified stakeholder groups include technology providers, governments, and associations. The study revealed that especially in this initial stage of the development, but also in the future, collaboration and cooperation among groups and associations of manufacturers is a key driver that will foster the transformation of manufacturing businesses and of the entire manufacturing industry.

The focus of the **second research objective** was on I40 resp. IIoT technologies, and the main technological drivers of the new industrial revolution. These technologies can be divided into two groups based on the qualitative research:

The main driver comprises CPS, Big Data & Analytics, Cloud Computing, and IT-Security Systems, which will enable tremendous opportunities for manufacturers in their combined applications. Many of these technologies in the manufacturing industry are fairly mature; however, there is the potential for further development, namely in Big Data Analytics.

The second group of technologies include Autonomous Robots, Additive Manufacturing, Augmented Reality, and Simulation. These technologies will help drive manufacturing businesses towards digital manufacturing, and so are related to I40 resp. IIoT in a wider sense. Although the potential and maturity of these technologies have been addressed in less detail by the secondary and primary data sources, the potential of each individual technology is significant for manufacturing businesses. These technologies are expected to mature over the next years, and will foster I40 resp. IIoT development.

To implement such technologies and to reap the benefits from I40 resp. IIoT opportunities, companies have to lay the necessary foundations, and accomplish several requirements (both of which have been in discussed in answer to the **third research objective**). This study prescribes 10 generalized business requirements, which should be considered by manufacturing businesses. Some of them, such as a 'Digital Organisational Mind-Set', 'Digital Infrastructure', 'Future Workforce', and 'Collaboration in the Ecosystem' are fundamental, regardless of business size and business objectives, and the digital and technological initiatives that shall be implemented.

Further requirements included 'Data and Cyber Security', 'Smart Innovation Processes', 'Digital Value and Supply Chain', 'Digital Product and Service Portfolio', Capitalizing on the Value of Data', and 'New Types of Business Models'. These are more specific requirements that have to be considered by the manufacturers on an individual basis, depending on the targeted business objectives, the chosen digital and technological initiatives, and their own digital maturity. However, in order to benefit from the potential opportunities of I40 resp. IIoT and to digital transform successfully, manufacturing companies have to address all these requirements. In addition, it has been determined that the majority of these requirements are interconnected, in that the achievement of one requires the accomplishment of another.

The **fourth research objective** was to investigate when and how the manufacturing business should start to develop a digital transformation strategy. There is a strong indication that manufacturing businesses should initiate a strategy now, since there already exist many potential benefits that can be exploited. Furthermore, as soon as manufacturing businesses start experimenting with new technologies, and engage with or cooperate with partners and associations, they need to keep up to date on the latest developments, and respond quickly to change. In terms of how manufacturing businesses should start an initiative, the findings of this study reveal various strategic approaches, including helpful advice by industry experts in both the secondary and primary research. It is important that businesses follow a systematic approach, and consider several factors including the requirements and potential benefits identified in this study. Businesses also need to decide whether they want to utilize digital and technological initiatives (of I40 resp. IIoT) to reduce costs (e.g. operations), or if they want to increase top line growth with, for example, new products and services. Most of the interviewed experts recommended that a business should start small by running pilot projects to learn more about development, and thereafter transform on a wider scale. In the future, new potential opportunities will be realised by further and new developments. Therefore, businesses need to be able to react fast and flexibly, and identify the long term potential goals of development.

The high quality of information gathered for each research objective in this study significantly contributes to the canon of knowledge. Indeed, this study may provide the first comprehensive overview of the complete I40 resp. IIoT developments required of manufacturing businesses worldwide.

The results of this study were used to create a generalized theoretical framework in form of a **'Digital Transformation Model'**, which consolidates the research findings in the form of a model that can be practically applied in the manufacturing industry. This model not only provides a step-by-step plan, but also contains valuable advisory and strategic aspects, which in turn are derived from interviews with leading experts in the research field. Since there is no academic literature that provides any comparable strategic model for manufacturing businesses (the academic literature merely describes technologies and requirements), the contribution to knowledge is significant from the academic perspective.

6.2 Implications

6.2.1 Business Implications

The findings of this study contributed sophisticated information in answer to each research question. As the study was conducted with the main focus on manufacturing businesses worldwide, it is necessary to consider the business implications. It has already been clarified that businesses should start developing their successful digital transformation strategies now and, therefore, will have to consider various requirements.

This dissertation takes an outside perspective on manufacturing businesses, and its findings have far-reaching implications form businesses adapting to the I40 resp. IIoT revolution. The new technologies that will be connected in networks and to the internet enable decentralised decision making by intelligent machines, as well as workers on the shop floor level. In addition, these new technologies are expected to combine with human labour, which will result in new working environments wherein different expertise and skills will be in greater demand than they are at present in most of companies. Consequently, new organizational mind-sets will be needed to shape organizations that are characterised by openness, readiness for change, and new knowledge. In the future, every object in the manufacturing could be smart, and new products and services will be developed which require new business models, processes, and procedures. In addition to this, their product life cycles will be accelerated by the new digital technologies, therefore, smart innovation processes shall be essential. All these developments will lead to new competitive dynamics, and if companies do not address the changing manufacturing industry and the new market conditions, companies will lose their competitive advantages and unique selling propositions.

In this fast-changing market and against intense competition, businesses shall have to concentrate more on their core competencies, and embrace more cooperation and collaboration in industrial ecosystems to retain their competitive positions and improve innovation. This also includes the deeper integration of the customer, and the execution of mass customisation through innovative and digital technologies.

The main keyword that will challenge the manufacturing business in the future is *Connectivity*. This includes connectivity with partners, of machines and data, and the risk landscape will therefore change in the future. Hence, manufacturing businesses have to develop new competencies and strategies, for example in cybersecurity.

Consequently, by using the developed strategic approach that has been prescribed in this dissertation (which considers the potential benefits enabled by technological initiatives and the 10 business requirements), manufacturing businesses can address these implications to some extent. At the very least, the findings of this study are thought provoking, and manufacturers should consider their implications.

6.2.2 Wider Implications

The next industrial revolution will not only have repercussions on businesses, but will affect the whole manufacturing industry and even whole economies. As previously mentioned, new competitive structures in the markets and in digital connectivity will intermingle with the manufacturing industry and its market structure, and this in turn will cause disruption and will change the power structure in the markets.

In order to reap the full potential economic benefits (on a national level), several requirements need to be met, including a sufficient digital infrastructure, and adaptation of education systems to produce a workforce with the necessary skill profiles. If these changes can be accomplished, it is likely that manufacturing will migrate from low-cost countries back to high-cost countries, since ‘cheap’ labour will no longer be the only prerequisite in manufacturing.

6.3 Recommendations

The findings of this study lead to several recommendations. One is that an I40 resp. IIoT transformation for a manufacturing business should be a joint project and not a one-player game. There is the need for collaboration and cooperation with other organizations in various contexts, such as in the value and supply chain, and when expediting digital transformation. The collaboration in associations and groups will accelerate the development and the transformation of businesses towards digital manufacturing, and so towards fulfilling the vision of being a successful business that can withstand the I40 resp. IIoT revolution. Another recommendation is that industry standards and references need to be issued, so that manufacturing equipment, objects and data management systems can interoperate with each other, and will be utilisable and more attractive for manufacturing businesses.

All manufacturers, be they small, medium or large companies, should be looking to the future in the manufacturing as the changes under I40 resp. IIoT intensify. Large companies may be able to transform more quickly, or start implementing changes at an earlier stage. However, smaller companies should also devise strategies, or else 'miss the boat' in a forward-looking digital and technological manufacturing industry. Even by engaging within associations and groups, smaller firms can gain up-to-date information about the latest developments, and should be able to modify their practices and capture the potential benefits that I40 resp. IIoT offer. It is highly recommended that all manufacturers should start their initiatives now.

Some specific recommendations for each stakeholder group are presented in Figure 25:

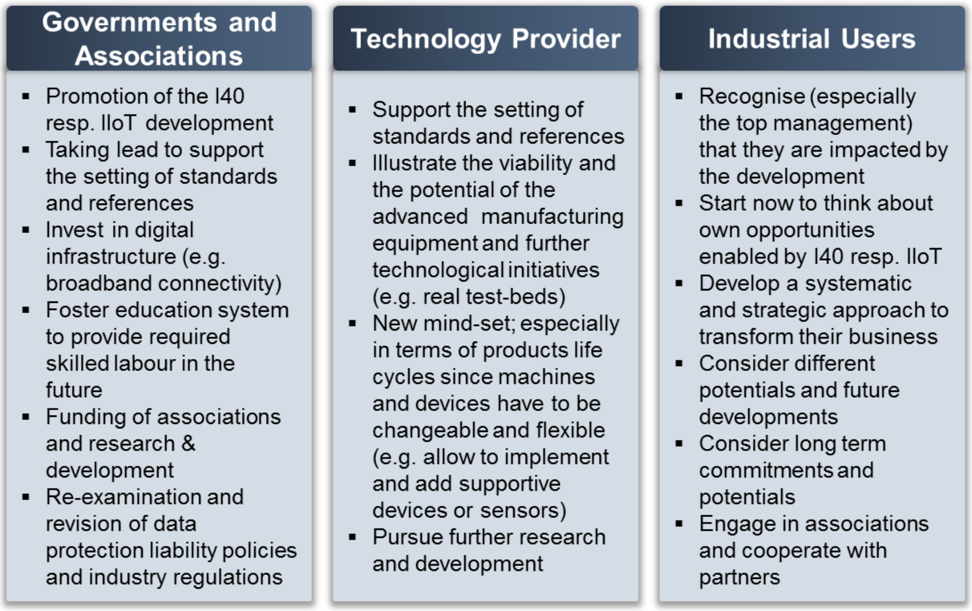


Figure 25: Recommendations

6.4 Limitations

Since the literature provides only superficial information I40 resp. IIoT, this study could be slightly limited in its theoretical suitability. The main body of cited literature comprised reports published by industry associations, consultancies, and other business-oriented organisations, which resulted in a more practice-oriented research study. However, since the study is mainly aimed at manufacturing businesses, this should not affect its applicability.

Another limitation that occurs in qualitative research is the limited generalisability of the research findings and results. Since this qualitative research was exploratory and was tailored to a specific population, its findings and conclusions cannot be applied to other populations.

Finally, the limited time frame for the conduction and the limited scope of this dissertation restricted the range of qualitative primary research gathered in the form of interviews with industry experts.

Nevertheless, this study has revealed valuable insights, and it is recommended that its results should be validated through further primary research. Additionally, on a wider perspective, the whole field of Industry 4.0 resp. IIoT should investigated in greater detail by academic researchers and scientists.

REFERENCES

Accenture (2014) *Driving Unconventional Growth Through the Industrial Internet of Things.* Available at: https://www.accenture.com/mz-en/_acnmedia/Accenture/next-gen/reassembling-industry/pdf/Accenture-Driving-Unconventional-Growth-through-IIoT.pdf (Accessed: 25 June 2015).

Accenture (2015a) *From Productivity to Outcomes: Using the Internet of Things to Drive Future Business Strategies.* Available at: http://m.accenture.com/SiteCollectionDocuments/PDF/Accenture-CEO-Briefing-2015-Productivity-Outcomes-Internet-Things.pdf (Accessed at: 25 June 2015).

Accenture (2015b) *Winning with the Industrial Internet of Things.* Available at: https://www.accenture.com/t20150523T023647__w__/pl-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Dualpub_11/Accenture-Industrial-Internet-of-Things-Positioning-Paper-Report-2015.pdf (Accessed: 25 June 2015).

Accenture and General Electric (2015) *Industrial Internet Insights Report.* Available at: https://www.gesoftware.com/sites/default/files/industrial-internet-insights-report.pdf (Accessed: 25 June 2015).

Advanced Manufacturing National Program Office (2015) *FAQ: The Digital Manufacturing & Design Innovation Institute (DMDII) & the Clean Energy Manufacturing Innovation Institute on Smart Manufacturing ("Smart Manufacturing").* Available at: http://manufacturing.gov/docs/Digital-vs-Smart-Mfg-Inst-Comparison.pdf (Accessed: 4 July 2015).

Alvesson, M. and Sköldberg, K. (2009) *Reflexive Methodology: New Vistas for Qualitative Research.* 2rd ed. London: SAGE Publication Limited.

ARC Strategies (2014a) *Planning for the Industrial Internet of Things.* Available at: http://www.arcweb.com/brochures/planning-for-the-industrial-internet-of-things.pdf (Accessed: 2 July 2015).

ARC Strategies (2014b) *The Future of Manufacturing: Scenarios for Investment in Manufacturing through 2050.* Available at: http://www.siemens.com/future-of-manufacturing/assets-downloads/arc-strategies-scenarios-for-investment-in-manufacturing-en.pdf (Accessed: 1 July 2015).

Aspers, P. (2009) 'Empirical Phenomenology: A Qualitative Research Approach'. *Indo-Pacific Journal of Phenomenology*, 9, pp.1-12.

Attunity (2014) *Releasing the Value Within the Industrial Internet of Things.* Available at: http://www.odbms.org/wp-content/uploads/2014/04/Releasing-the-Value-Within-the-Industrial-Internet-of-Things-_WP.pdf (Accessed: 1 July 2015).

Baker, M. J. and Foy A. (2012) *Business and Management Research: How to Complete Your Research Project Successfully*. 3rd edn. Helensburgh: Western Publishers Limited.

Bartevyan, L. (2015) *Industry 4.0 – Summary report.* Available at: http://www.dlg.org/fileadmin/downloads/food/Expertenwissen/Lebensmitteltechnologie/e_2015_5_Expertenwissen_Industry_4_0.pdf (Accessed: 27 June 2015).

Bauernhansl, T., ten Hompel, M., and Vogel-Heuser, B. (2014) *Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung· Technologien · Migration*. Berlin: Springer-Verlag.

Bertschek, I., Clement, R., Buhr, D., Hirsch-Kreinsen, H., Falck, O., Heimisch, A., Jacob-Puchalska, A. and Mazat, A. (2015) 'Industrie 4.0: Digitale Wirtschaft – Herausforderung und Chance für Unternehmen und Arbeitswelt', *ifo Schnelldienst*, 68 (10), pp.3-18.

Biggam, J. (2008) *Succeeding with Your Master's Dissertation: A Step-by-Step Handbook.* Berkshire: McGraw-Hill Companies Incorporated.

Binner, H. F. (2014) 'Industrie 4.0 bestimmt die Arbeitswelt der Zukunft'. *e & i Elektrotechnik und Informationstechnik*, 131 (7), pp.230-236.

BITKOM (2015) *Industrie 4.0 – Deutschland als Vorreiter der digitalisierten Vernetzung von Produkten und Produktionsprozessen.* Available at: https://www.bitkom.org/Publikationen/2015/Positionspapiere/Industrie-4.0-%E2%80%93-Deutschland-als-Vorreiter-der-digitalisierten-Vernetzung-von-Produkten-und-Produktionsprozessen/150310_Policy_Paper_Industrie_4.0_web.pdf (Accessed: 29 June 2015).

BITKOM and Fraunhofer IOA. (2014) *Industrie 4.0 – Volkswirtschaftliches Potenzial für Deutschland.* Available at: https://www.bitkom.org/Publikationen/2014/Studien/Studie-Industrie-4.0-%E2%80%93-Volkswirtschaftliches-Potenzial-f%C3%BCr-Deutschland/Studie_Industrie_4.0.pdf (Accessed: 27 June 2015).

Bosch (2014) *Creating Connected Manufacturing Operations in The Internet of Things.* Available at: http://www.mcrockcapital.com/uploads/1/0/9/6/10961847/20140901_bosch_software_innovations_connectedmanufacturing_white_paper_final.pdf (Accessed: 26 June 2015).

Boston Consulting Group (2015) *Industry 4.0: The future in productivity and growth in manufacturing industries*. Available at: https://www.bcgperspectives.com/content/articles/engineered_products_project_business_industry_40_future_productivity_growth_manufacturing_industries/ (Accessed: 26 June 2015).

Botthof, A. and Hartmann, E. A. (2014) *Zukunft der Arbeit in Industrie 4.0*. Berlin, Heidelberg, New York: Springer-Verlag.

Brettel, M., Friederichsen, N., Keller, M. and Rosenberg, M. (2014) 'How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective'. *International Scholarly and Scientific Research & Innovation*, 8 (1), pp.37-44.

Bryman, A. and Bell, E. (2015) *Business Research Methods*. 4th ed. Oxford: Oxford University Press.

Bryner, M. (2012) 'Smart Manufacturing: the Next Revolution'. *Chemical Engineering Progress*, 108 (10), pp.4-12.

Brynjolfsson, E. and McAfee, A. (2014) *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies.* New York: W. W. Norton & Company.

Burmeister, C., Lüttgens, D. and Piller, F. T. (2015) *Business Model Innovation for Industrie 4.0 - Why the 'Industrial Internet Mandates a New Perspective on Innovation.* RWTH-TIM Working Paper. Available at http://ssrn.com/abstract=2571033 or http://dx.doi.org/10.2139/ssrn.2571033 (Accessed: 3 July 2015).

Capgemini Consulting (2011) *The Challenges of the Digital Revolution.* Available at: https://www.capgemini-consulting.com/resource-file-access/resource/pdf/Digital_Transformation_Review__No_1__July_2011.pdf (Accessed: 29 June 2015).

Capgemini Consulting (2014a) *Digitizing Manufacturing Ready, Set, Go!* Available at: https://www.de.capgemini-consulting.com/resource-file-access/resource/pdf/digitizing-manufacturing_0.pdf (Accessed: 29 June 2015).

Capgemini Consulting (2014b) *Industry 4.0 - The Capgemini Consulting View: Sharpening the Picture beyond the Hype.* Available at: https://www.de.capgemini-consulting.com/resource-file-access/resource/pdf/digitizing-manufacturing_0.pdf (Accessed at: 29 June 2015).

Capgemini Consulting (2014c) *Monetizing the Internet of Things: Extracting Value from the Connectivity Opportunity.* Available at: https://www.capgemini-consulting.com/resource-file-access/resource/pdf/iot_monetization_0.pdf (Accessed: 29 June 2015).

Capgemini Consulting (2015) *Digital Transformation.* Available at: https://www.capgemini-consulting.com/digital-transformation (Accessed: 29 June 2015).

Capgemini Consulting, WZA RWTH Aachen and Fraunhofer IPT. (2014) *Digital Value Networks in the Tool Manufacturing Industry: Understanding the Impact of Digital.* Available at: http://www.wzl.rwth-aachen.de/de/581fac723d976ccac125791700214432/2013_studie_wzl_digital_value_networks_in_the_tool_manufacturing_industry.pdf (Accessed: 29 Jue 2015).

Caudron, J. and Van Peteghem, D. (2014) *Digital Transformation: A Model to Master Digital Disruption.* DearMedia

Chand, S. and Davis, J. (2010) *What is Smart Manufacturing?* Available at: http://www.rockwellautomation.com/resources/downloads/rockwellautomation/pdf/about-us/company-overview/TIMEMagazineSPMcoverstory.pdf (Accessed: 5 July 2015).

China Materialia - Finland Team (2014) *The Industrial Internet: Robotics, Automation, and the Future of Manufacturing*. Available at: http://www.tekes.fi/globalassets/julkaisut/cm_the_industrial_internet_automation_robotics_and_the_future_of_manufacturing_v13.pdf (Accessed: 30 June 2015).

Cognizant (2014) *Informed Manufacturing: The Next Industrial Revolution* Available at: http://www.cognizant.com/InsightsWhitepapers/Informed-Manufacturing-The-Next-Industrial-Revolution.pdf (Accessed: 30 June 2015).

Cooper, D. R. and Schindler, P. S. (2014) *Business Research Methods.* 12th ed. New York: MCGraw-Hill/Irwin.

Creswell, J. W. (2012) *Qualitative Inquiry and Research Design: Choosing Among Five Approaches.* Thousand Oaks, CA: SAGE Publications.

Davis, J., Edgar, T., Porter, J., Bernaden, J. and Sarli, S. (2012) 'Smart Manufacturing, Manufacturing Intelligence and Demand-Dynamic Performance'. *Computers & Chemical Engineering*, 47, pp.145–156. doi:10.1016/j.compchemeng.2012.06.037

De Clerck, J.-P. (2015) *Digital Transformation: Change, Intent and Transformation.* Available at: http://www.i-scoop.eu/digital-transformation/ (Accessed: 3 July 2015).

Deloitte (2014) *Industry 4.0: Challenges and Solutions for the Digital Transformation and Use of Exponential Technologies.* Available at: http://www2.deloitte.com/content/dam/Deloitte/ch/Documents/manufacturing/ch-en-manufacturing-industry-4-0-24102014.pdf (Accessed: 27 June 2015).

Deutsche Bank Research (2014) *Industry 4.0: Upgrading of Germany's Industrial Capabilities on the Horizon.* Available at: https://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000333571/%20Industry+4_0:+Upgrading+of+Germany%E2%80%99s+industrial+capabilities+on+the+horizon.PDF (Accessed: 2 July 2015).

DKE & VDE (2014) *The German Standardization Roadmap Industrie 4.0.* Available at: https://www.dke.de/de/std/documents/rz_roadmap%20industrie%204-0_engl_web.pdf (Accessed: 1 July 2015).

Dorst, W. (2012) *Fabrik- und Produktionsprozesse der Industrie 4.0 im Jahr 2020.* Available at: http://scheer-management.com/wp-content/uploads/2014/10/IM_3_I.4.0_Seiten_34-37_I4.0-im-Jahr-2020.pdf (Accessed: 4 July 2015).

Doz, Y. (2011) 'Qualitative Research for International Business'. *Journal of International Business Studies,* 42, pp. 582–590. doi:10.1057/jibs.2011.18

Dworschak, B. and Zaiser, H. (2014) 'Competences for Cyber-physical Systems in Manufacturing – First Findings and Scenarios'. *Procedia CIRP*, 25, pp. 345 – 350.

Easterby-Smith, M., Thorpe, R. and Jackson, P. (2012) *Management Research.* 4rd edn. London: SAGE Publications Limited.

Echelon (2013) *Requirements for the Industrial 'Internet of Things*. Available at: http://media.digikey.com/Resources/Echelon/IIoT-WP.PDF (Accessed: 3 July 2015).

Echelon Corporation (2014) *Control Networking for the Industrial Internet of Things (IIoT) - Gaining the Advantages of IP Enablement without Starting Over*. Available at: http://www.echelon.com/izot-platform Accessed: 3 July 2015).

Ernst & Young (2015) *Cybersecurity and the Internet of Things.* Available at: http://www.ey.com/Publication/vwLUAssets/EY-cybersecurity-and-the-internet-of-things/$FILE/EY-cybersecurity-and-the-internet-of-things.pdf (Accessed: 12 June 2015)

European Commission Consulting Group (2009) *ICT and Energy Efficiency: The Case for Manufacturing.* Available at: ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/micro-nanosystems/smart-manufacturing_en.pdf (Accessed: 3 July 2015).

Faller, C., and Feldmüller, D. (2015) 'Industry 4.0 Learning Factory for regional SMEs'. *Procedia CIRP*, 32, pp.88-91.

Farquhar, J. D. (2012) *Case Study Research for Business.* London: SAGE Publication Limited.

Feld, T., Hoffmann, M., & Schmidt, R. (2012) 'Industrie 4.0: Vom intelligenten Produkt zur intelligenten Produktion'. *Information Management & Consulting*, (3), pp.38, 42.

Filho, W. L., Ubelis, A. and Berzina, D. (2015) *Sustainable Development, Knowledge Society and Smart Future Manufacturing Technologies.* Berlin, Heidelberg: Springer.

Fisher, C. (2004) *Researching and Writing a Dissertation for Business Students.* Edinburgh: Pearson Education Limited.

Forstner, L., and Dümmler, M. (2014) 'Integrierte Wertschöpfungsnetzwerke – Chancen und Potenziale durch Industrie 4.0'. *e & i Elektrotechnik und Informationstechnik*, 131 (7), pp.199-201.

Fraunhofer IAO (2013) *Produktionsarbeit der Zukunft – Industrie 4.0.* Available at: http://www.produktionsarbeit.de/content/dam/produktionsarbeit/de/documents/Fraunhofer-IAO-Studie_Produktionsarbeit_der_Zukunft-Industrie_4_0.pdf (Accessed: 29 June 2015).

General Electric (2015a) *Industrial Internet.* Available at: http://www.ge.com/stories/industrial-internet (Accessed at: 29 June 2015).

General Electric (2015b) *Why Interconnectedness Matters for Industrial Companies.* Available at: https://hbr.org/sponsored/2015/06/why-interconnectedness-matters-for-industrial-companies?utm_content=bufferc4d69&utm_medium=social&utm_source=linkedin.com&utm_campaign=buffer (Accessed: 29 June 2015).

Germany Trade & Invest (2014) *Industrie 4.0: SMART MANUFACTURING FOR THE FUTURE* Available at: http://www.gtai.de/GTAI/Content/EN/Invest/_SharedDocs/Downloads/GTAI/Brochures/Industries/industrie4.0-smart-manufacturing-for-the-future-en.pdf (Accessed: 29 June 2015).

Gneuss, M. (2014) 'Als die Werkstücke Laufen Lernten.' In Reflex Verlag (2014) *Industrie 4.0 Die Vierte Industrielle Revolution* Available at: http://www.gfos.com/fileadmin/news/PDF/Ref_Industrie40_HB.pdf (Accessed: 30 June 2015).

Goetzpartners (2015) *Industrial Internet of Things.* Available at: http://www.goetzpartners.com/uploads/tx_gp/2015_goetzpartners_Industrial_Internet_of_Things.pdf (Accessed: 28 June 2015).

Goldman Sachs (2014) The Internet of Things: Making Sense of the Next Mega-Trend. Available at: http://www.goldmansachs.com/our-thinking/outlook/internet-of-things/iot-report.pdf (Accessed: 30 June 2015).

Graetz, G. and Michaels, G. (2015) 'Robots at Work'. *CEPR Discussion Paper No. DP10477*. Available at: SSRN: http://ssrn.com/abstract=2575781

Haiping, Z., Yu, L., Qin, L. and Yunqing, R. (2014) 'Cloud Service Platform For Big Data Of Manufacturing'. *Applied Mechanics and Materials*, 456, pp.178-183. doi:10.4028/www.scientific.net/AMM.456.178.

Hamill, J. (2015) *Unit 4: Digital Business Strategy Development* [Lecture to MK811], Digital Leadership: Strategy & Management. The University of Strathclyde. (Accessed: 7 August 2015).

Hannover Messe (2015) *How Far are We? Industry 4.0*. Available at: http://www.european-rubber-journal.com/wp-content/uploads/2015/01/Hannover-Messe-IoT-whitepaper.pdf (Accessed: 30 June 2015).

Hardy, Q. (2014) *Consortium Wants Standards for 'Internet of Things'.* Available at: http://bits.blogs.nytimes.com/2014/03/27/consortium-wants-standards-for-internet-of-things/?_php=true&_type=blogs&_php=true&_type=blogs&_r=4 (Accessed: 09 July 2015).

Hartmann, E. and Bovenschulte, M. (2013) *Skills Needs Analysis for "Industry 4.0": Based on Roadmaps for Smart Systems.* Available at: http://www.iit-berlin.de/de/publikationen/skills-needs-analysis-for-industry-4-0201d-based-on-roadmaps-for-smart-systems (Accessed: 27 June 2015)

Harvard Business Review (2015) 'The Digital Transformation of Business'. *Harvard Business Review Analytic Services*, pp.1-12.

Heise.de (2015) *Gabriel will Industrie 4.0 und Digitalwirtschaft voranbringen.* Available at: http://www.heise.de/newsticker/meldung/Gabriel-will-Industrie-4-0-und-Digitalwirtschaft-voranbringe (Accessed: 2 July 2015).

Henning, C. (2015) *For Industrial Internet of Things Success – Standardize*. Available at: http://us.profinet.com/industrial-internet-things-success-standardize/ (Accessed: 2 July 2015).

Hinks, J. (2015) *5 things you should know about Industry 4.0.* Available at: http://www.techradar.com/news/world-of-tech/future-tech/5-things-you-should-know-about-industry-4-0-1289534 (Accessed: 2 July 2015).

Hirsch-Kreinsen, H. (2014) 'Welche Auswirkungen hat „Industrie 4.0“ auf die Arbeitswelt'. *WISO direkt, Friedrich-Ebert-Stiftung, Bonn*.

Hirsch-Kreinsen, H., & Weyer, J. (2014) 'Wandel von Produktionsarbeit–„Industrie 4.0'. *Soziologisches Arbeitspapier*, 38.

Horn, R. (2009) *Researching and Writing Dissertations: A Complete Guide for Business and Management Students.* London: Chartered Institute of Personnel and Development.

Hyde, K. F. (2000) 'Recognising Deductive Processes in Qualitative Research'. Qualitative Market Research: An International Journal, 3, pp. 82 – 90.

IBM Institute for Business Value (2011) *Digital transformation: Creating New Business Models Where Digital Meets Physical.* Available at: https://www-935.ibm.com/services/us/gbs/thoughtleadership/pdf/us_ibv_digita_transformation_808.PDF (Accessed: 2 July 2015).

Industrial Internet Consortium (2014) *Executive Summary.* Available at: http://www.industrialinternetconsortium.org/docs/Industrial_Internet_Consortium-Introductory_White_Paper.pdf (Accessed: 5 July 2015)

Industrial Internet Consortium (2015) *Resource Hub.* Available at: http://www.iiconsortium.org/resource-hub.htm (Accessed: 2 July 2015).

Jazdi, N. (2014) 'Cyber Physical Systems in the Context of Industry 4.0'. *Automation, Quality and Testing, Robotics*, 2014 IEEE International Conference, pp.1-4.

Jennings, A. (2015) *Visibility In Manufacturing: The Path To Industry 4.0.* Available at: http://www.manufacturing.net/news/2015/05/visibility-in-manufacturing-the-path-to-industry-40 (Accessed: 2 July 2015).

Kane, G. C., Palmer, D., Phillips, A. N. and Kiron, D. (2015) *Is Your Business Ready for a Digital Future?* Available at: http://sloanreview.mit.edu/article/is-your-business-ready-for-a-digital-future/?utm_content=buffer63396&utm_medium=social&utm_source=linkedin.com&utm_campaign=buffer (Accessed: 2 July 2015).

König, C. (2014) ‘Forschung für die Fabrik der Zukunft‘, In Reflex Verlag (2014) *Industrie 4.0 Die Vierte Industrielle Revolution*. Available at: http://www.gfos.com/fileadmin/news/PDF/Ref_Industrie40_HB.pdf (Accessed: 30 June 2015).

Kracht, S. (2015) ‘Production in a New Dimension: How 3D Printing is Changing the Industrial Landcape’. *Business Journal of the German Chamber of Commerce in China*, 1, pp.19-20.

Kühnle, H. and Bitsch, G. (2015) *Foundations & Principles of Distributed Manufacturing: Elements of Manufacturing Networks, Cyber-Physical Production Systems and Smart Automation.* Heidelberg: Springer International Publishing Switzerland.

Lasi, H., Kemper, H. G., Fettke, P., Feld, T. and Hoffmann, M. (2014) ‘Industrie 4.0.‘ *Springer Fachmedien*, pp. 239-242. doi: 10.1007/s12599-014-0334-4.

Lass, S. and Kotarski, D. (2014) *IT-Sicherheit als besondere Herausforderung von Industrie 4.0.* Available at: http://www.gito.de/homepage/gito/gitoshop.nsf/download.html/1F3E402EB972E145C1257DAF00518C07/$File/lass_IT-Sicherheit-als-besondere-Herausforderung-von-Industrie-4-0_HAB-Tagungsband-2014.pdf (Accessed: 6 July 2015).

Lee, I. and Lee, K. (2015) ‘The Internet of Things (IoT): Applications, Investments, and Challenges for Enterprises’. *Business Horizons*, 58 (4), pp 431 – 440.

Lee, J., Bagheri, B. and Kao, H. (2014) ‘A Cyber-Physical Systems Architecture for Industry 4.0-based Manufacturing Systems’. *Manufacturing Letters*, 3, pp.18-23.

Lee, J., Kao, H. and Yang, S. (2014) ‘Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment’. *Procedia CIRP*, 16, pp.3-8. doi:10.1016/j.procir.2014.02.001.

Lee, N. and Lings, I. (2008) *Doing Business Research: A Guide to Theory and Practice*. London: SAGE Publications Limited.

Lopez Research LLC (2014) *Building Smarter Manufacturing With The Internet of Things (IoT).* Available at: http://www.cisco.com/web/solutions/trends/iot/iot_in_manufacturing_january.pdf (Accessed: 8 July 2015).

Luo, Z. (2014) *Smart Manufacturing Innovation and Transformation: Interconnection and Intelligence: Interconnection and Intelligence*. Hershey: IGI Global.

Matt, D. T., Rauch, E., and Dallasega, P. (2015) Trends towards Distributed Manufacturing Systems and Modern Forms for Their Design. *Procedia CIRP*, 33, pp.185-190.

McKinsey & Company (2013a) *Finding your Digital Sweet Spot.* Available at: http://www.mckinsey.com/insights/business_technology/finding_your_digital_sweet_spot (Accessed: 28 June 2015).

McKinsey & Company (2013b) *The Internet of Things and the Future of Manufacturing.* Available at: http://www.mckinsey.com/insights/business_technology/the_internet_of_things_and_the_future_of_manufacturing (Accessed: 28 June 2015).

McKinsey & Company (2014) *How Big Data can Improve Manufacturing.* Available at: http://www.mckinsey.com/insights/operations/how_big_data_can_improve_manufacturing (Accessed: 28 June 2015).

McKinsey & Company (2015a) *Industry 4.0: How to Navigate Digitization of the Manufacturing Sector.* (Confidential)

McKinsey & Company (2015b) *Manufacturing's Next Act*. Available at: http://www.mckinsey.com/~/media/McKinsey/dotcom/Insights/Manufacturing/Manufacturings%20next%20act/Manufacturings%20next%20act.ashx (Accessed: 28 June 2015).

McKinsey & Company (2015c) *McKinsey-Studie zu Industrie 4.0: Deutsche Unternehmen trotz wachsender Konkurrenz zuversichtlich.* Available at: http://www.mckinsey.de/mckinsey-studie-zu-industrie-40-deutsche-unternehmen-trotz-wachsender-konkurrenz-zuversichtlich (Accessed: 28 June 2015).

McKinsey & Company (2015d) *The Internet of Things: Full 2.* (Confidential)

McKinsey & Company (2015e) *The Internet of Things: Full 3*. (Confidential)

McKinsey & Company (2015f) *What it Takes to Build Your Digital Quotient.* Available at: http://www.mckinsey.com/insights/organization/what_it_takes_to_build_your_digital_quotient (Accessed: 28 June 2015).

McRock Capital (2013) *Apps for the Industrial Internet: The Future of Industrial Software.* Available at: http://www.mcrockcapital.com/uploads/1/0/9/6/10961847/mcrock_industrial_software_report_2013.pdf (Accessed: 1 July 2015).

McRock Capital (2014) *The Industrial Internet Of Things.* Available at: http://www.mcrockcapital.com/uploads/1/0/9/6/10961847/mcrock_industrial_internet_of_things_report_2014.pdf (Accessed: 1 July 2015).

Meltzer, D. (2015) *Securing the Industrial Internet of Things.* Available at: https://c.ymcdn.com/sites/www.issa.org/resource/resmgr/journalpdfs/feature0615.pdf (Accessed: 27 June 2015).

Metz, R. (2014) *Augmented Reality Gets to Work.* Available at: http://www.technologyreview.com/news/524626/augmented-reality-gets-to-work/ (Accessed: 12 July 2015)

Meyer, M. (2014) *Inequality and Work in the Second Machine Age.* Available at: http://socialeurope.eu/wp-content/uploads/2014/12/RE4-Meyer.pdf (Accessed: 27 June 2015).

MHP (2014) *Studie Industrie 4.0 – Eine Standortbestimmung der Automobil- und Fertigungsindustrie.* Available at: http://www.mhp.com/fileadmin/mhp.de/assets/studien/MHP-Studie_Industrie4.0_V1.0.pdf (Accessed: 29 June 2015).

Nanry, J., Narayanan, S. and Rassey, L. (2015) *Digitizing the Value Chain.* Available at: http://www.mckinsey.com/insights/manufacturing/digitizing_the_value_chain (Accessed: 29 June 2015).

National Instruments (2015) *The Industrial Internet of Things.* Available at: http://www.ni.com/internet-of-things/ (Accessed: 28 June 2015).

Neosperience Team (2015) *How Industrial Internet of Things Will Transform Business & Customers.* Available at: http://blog.neosperience.com/how-industrial-internet-of-things-will-transform-business-customers (Accessed: 27 June 2015).

Novak-Marcincin, J., Barna, J., Janak, M. and Novakova-Marcincinova,L. (2013) 'Augmented Reality Aided Manufacturing'. *Procedia Computer Science*, 25, pp.23–31.

O'Brien, M. (2015) *Q&A: Martin Ford, On The Robots Coming For Your Job*. Available at: http://www.mercurynews.com/business/ci_28301217/q-martin-ford-robots-coming-your-job (Accessed: 29 June 2015).

OPITZ CONSULTING (2015) *Digitalisierung zwischen Erwartung und Implementierung.* Available at: http://www.opitz-consulting.com/fileadmin/redaktion/veroeffentlichungen/pdf/im-io-2015-01_digitalisierung_coupette_sicher.pdf (Accessed: 29 June 2015).

Perera, C., Liu, C. H. and Jayawardena, S. (2015) 'The Emerging Internet of Things Marketplace From an Industrial Perspective: A Survey'. *IEEE Transactions on Emerging Topics in Computing*, (1), pp.1-1.

Piggin, R. (2015) 'Are Industrial Control Systems Ready for the Cloud?'. *International Journal of Critical Infrastructure Protection*, 9, pp.38-40. doi:10.1016/j.ijcip.2014.12.005.

Plattform Industrie 4.0 (2013) *Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0*. Available at: http://www.plattform-i40.de/sites/default/files/Report_Industrie%204.0_engl_1.pdf (Accessed: 27 June 2015).

Plattform Industrie 4.0 (2015) *Umsetzungsstrategie Industrie 4.0: Ergebnisbericht der Plattform Industrie 4.0.* Available at: http://www.bmwi.de/BMWi/Redaktion/PDF/I/industrie-40-verbaendeplattform-bericht,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf (Accessed: 30 June 2015).

Plattform-i40.de (2015) Plattform. Available at: http://www.plattform-i40.de/plattform (Accessed: 09 July 2015)

Ploss, R. (2014) 'Industrie 4.0 - Chance für Europas Wirtschaft'. *e & i Elektrotechnik und Informationstechnik*, 131 (7), pp.198-198.

PwC (2013) *Rethinking Innovation in Industrial Manufacturing: Are You Up For The Challenge?* Available at: http://www.pwc.com/en_GX/gx/industrial-manufacturing/publications/pdf/pwc-rethinking-innovation-in-industrial-manufacturing-are-you-up-for-the-challenge.pdf (Accessed: 27 June 2015).

PwC (2015) *Industrie 4.0 ist ein CEO Thema.* Available at: http://www.pwc.de/de/digitale-transformation/industrie-4-0-ist-ein-ceo-thema.jhtml (Accessed: 30 June 2015).

PwC Strategy& (2014) *Industry 4.0: Opportunities and Challenges of the Industrial Internet* Available at: http://www.strategyand.pwc.com/media/file/Industry-4-0.pdf (Accessed: 26 June 2015).

Qiming, T. (2015) *Are You Ready for Industry 4.0*? Available at: http://e.huawei.com/mediafiles/MediaFiles/B/5/8/%7BB58C514C-4AD2-4333-9CC7-A13BA795CE3C%7DAre%20You%20Ready%20for%20Industry%204.0%EF%BC%9F.doc.pdf (Accessed: 29 June 2015).

Qualres.org (2015) *RWJF - Qualitative Research Guidelines Project*. Available at: http://www.qualres.org/HomeRefl-3703.html (Accessed: 06 August 2015)

REFA-Institut e. V. (2015) *Industrie 4.0 setzt stabile Produktionssysteme mit einer humanorientierten Arbeitsorganisation voraus.* Available at: http://www.presseportal.de/pm/82380/3021178 (Accessed: 26 June 2015).

Roland Berger (2013) *Additive manufacturing: A game changer for the manufacturing industry?* Available at: http://www.rolandberger.com/media/pdf/Roland_Berger_Additive_Manufacturing_20131129.pdf (Accessed: 28 June 2015)

Roland Berger (2014a) *INDUSTRY 4.0: The new industrial revolution - How Europe will succeed.* Available at: https://www.rolandberger.com/media/pdf/Roland_Berger_TAB_Industry_4_0_20140403.pdf (Accessed: 28 June 2015)

Roland Berger (2014b) *THINK ACT: COO INSIGHTS - INDUSTRY 4.0.* Available at: http://www.rolandberger.com/media/pdf/Roland_Berger_TAM_COO_Insights_E_20150113.pdf (Accessed: 28 June 2015).

RTI (2014) *DDS: the Right Middleware for the Industrial Internet of Things?* Available at: https://www.rti.com/whitepapers/Right_Middleware_for_IIoT.pdf (Accessed: 26 June 2015).

Sabo, F. (2015) *Industry 4.0 – A Comparison of the Status in Europe and the USA.* Master thesis. FH Kufstein – University of Applied Sciences

Sailer, J. (2014) 'M2M–Internet of Things–Web of Things–Industry 4.0'. *e & i Elektrotechnik und Informationstechnik*, *131* (1), pp.3-4.

SAP (2014) *The CEO Perspective: The Internet of Things for Industrial Machinery and Components*. Available at: https://www.sap.com/bin/sapcom/tr_tr/downloadasset.2014-10-oct-10-16.the-ceo-perspective-the-internet-of-things-for-industrial-machinery-and-components-pdf.html (Accessed: 30 June 2015).

Saunders, M. N. K., Lewis, P. and Thornhill, A. (2009) *Research Methods for Business Students.* 5th ed. Edinburgh: Pearson Education Limited.

Scales, B. (2014) There is a Future: Smart Manufacturing. Available at: http://www.bhert.com/publications/newsletter/BHERTNews32.pdf (Accessed: 30 June 2015).

Schuh, G., Gartzen, T., Rodenhauser, T., and Marks, A. (2015) 'Promoting Work-based Learning through INDUSTRY 4.0'. *Procedia CIRP, 32,* pp.82-87.

Sekaran, U. and Bougie, R. (2010) *Research Methods for Business: A Skill Building Approach.* 5th ed. Chichester: John Willey & Sons Limited.

Shakib, T. (2015) *Connected Machines: Taking Manufacturing To The Next Level Of IoT*. Available at: http://radar.oreilly.com/2015/06/connected-machines.html?utm_content=buffer62d7b&utm_medium=social&utm_source=linkedin.com&utm_campaign=buffer (Accessed: 30 June 2015).

Shenton, A. K. (2004). 'Strategies for Ensuring Trustworthiness in Qualitative Research Projects.' *Education for Information*, 22(2), pp.63-75.

Sinfield, J., Calder, N. and Geheb, B. (2015) *How Industrial Systems Are Turning into Digital Services*. Available at: https://hbr.org/2015/06/how-industrial-systems-are-turning-into-digital-services?utm_content=buffer511fd&utm_medium=social&utm_source=linkedin.com&utm_campaign=buffer (Accessed: 30 June 2015).

Smartmanufacturingcoalition.org (2015) *About SMLC | Smart Manufacturing Leadership Coalition*. Available at: https://smartmanufacturingcoalition.org/about (Accessed: 09 July 2015)

Smith, J. (2015) *After Robots Take Our Jobs, This Is What the Economy Will Look Like*. Available at: http://mic.com/articles/119896/after-robots-take-our-jobs-basic-income-is-the-best-solution?utm_content=bufferdfc5a&utm_medium=social&utm_source=linkedin.com&utm_campaign=buffer (Accessed: 30 June 2015).

Sohn, G. (2015) *Normierung 4.0*. Available at: http://www.theeuropean.de/gunnar-sohn/9702-die-denkfallen-der-industrie-40-initiative (Accessed: 30 June 2015).

Soley, R. (2014) 'The Industrial Internet: The Opportunities ... and the Roadblocks'. *The Journal of Information Technology Management*, 27 (11), pp.6-10.

Terpitz, K. (2015) *Die Angst des Mittelstands vor der Digitalisierung*. Available at: http://www.golem.de/news/industrie-4-0-die-angst-des-mittelstands-vor-der-digitalisierung-1505-114018.html (Accessed: 30 June 2015).

The Economist Intelligence Unit (2014) *Networked manufacturing - The Digital Future.* Available at: http://www.economistinsights.com/sites/default/files/EIU%20-%20Siemens%20-%20Networked%20manufacturing%20The%20digital%20future%20WEB.pdf (Accessed: 30 June 2015).

The Economist, (2012) *The Third Industrial Revolution*. Available at: http://www.economist.com/node/21553017 (Accessed: 5 July 2015).

The MIT Center for Digital Business (2015) *Digital Business*. Available at: http://digital.mit.edu/ (Accessed: 30 June 2015).

The World Bank (2015) *Manufacturing, Value Added (% of GDP).* Available at: http://data.worldbank.org/indicator/NV.IND.MANF.ZS/countries/1W-US-DE?display=graph (Accessed at: 5 July 2015)

Tschohl, C. (2014) 'Industrie 4.0 aus rechtlicher Perspektive'. *e & i Elektrotechnik und Informationstechnik*, 131(7), pp.219-222.

Tschöpe, S., Aronska, K. and Nyhuis, P. (2015) 'Was ist eigentlich Industrie 4.0?'. *ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb*, 03, pp.145-149.

T-Systems (2014) *What Did That Machine Say Again?* Available at: http://www.t-systems.de/umn/what-did-that-machine-say-again-t-systems/1263892_1/blobBinary/Best-Practice_02-2014_Top-Story_EN.pdf?ts_layoutId=1264136 (Accessed: 30 June 2015).

UK Goverment Office for Science (2014) *The Internet of Things: Making The Most Of The Second Digital Revolution*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/409774/14-1230-internet-of-things-review.pdf (Accessed: 25 June 2015).

Vde.com (2015) *Future Project Industry 4.0*. Available at: https://www.vde.com/en/dke/std/Pages/Industry40.aspx (Accessed: 9 July 2015)

VDE/VDI & ZVEI (2015) *Referenzarchitekturmodell Industrie 4.0 (RAMI4.0).* Available at: https://www.vdi.de/fileadmin/user_upload/VDI-GMA_Statusreport_Referenzarchitektur-modell-Industrie40.pdf (Accessed: 25 June 2015).

VDMA (2015) *Willkommen beim VDMA-Forum Industrie 4.0.* Available at: http://industrie40.vdma.org/ (Accessed: 28 June 2015).

Vermesan, O., and Friess, P. (Eds.). (2014) *Internet of Things - From Research and Innovation to Market Deployment*. River Publishers.

VINT (2014) *The Fourth Industrial Revolution: Things to Tighten the Link Between IT and OT.* Available at: http://vint.sogeti.com/wp-content/uploads/2014/06/VINT-Sogeti-Internet-of-Things-Report-3.pdf (Accessed at: 29 June 2015).

Wahlster, W., Grallert, H. J., Wess, S., Friedrich, H. and Widenka, T. (2014) *Towards the Internet of Services: The THESEUS Research Program*. Heidelberg: Springer.

Walker, B. (2015) "*Rise of the Robots" Author: Job-Replacing Technology Is Unstoppable.* Available at: http://www.vdare.com/posts/rise-of-the-robots-author-job-replacing-technology-is-unstoppable (Accessed: 27 June 2015).

Wegener, D. (2015) *Industrie 4.0 – die Zukunft der digitalen Fabrik.* Available at: http://www.qucosa.de/fileadmin/data/qucosa/documents/16418/00_Plenum2%20Wegener.pdf (Accessed: 27 June 2015).

Westerman, G., Bonnet, D. and McAfee, A. (2014) *Leading Digital: Turning Technology into Business Transformation.* Boston: Harvard Business Review Press.

Woodside Capital Partners (2015) *THE INTERNET OF THINGS: "Smart" Products Demand a Smart Strategy*. Available at: http://www.woodsidecap.com/wp-content/uploads/2015/03/WCP-IOT-M_and_A-REPORT-2015-3.pdf (Accessed: 30 June 2015).

XMOS (2015) *Industry 4.0 and Smart Manufacturing.* Available at: http://www.xmos.com/news/articles/17707 (Accessed: 30 June 2015).

Yen, C. T., Liu, Y. C., Lin, C. C., Kao, C. C., Wang, W. B., and Hsu, Y. R. (2014) 'Advanced Manufacturing Solution to Industry 4.0 Trend Through Sensing Network and Cloud Computing Technologies'. In *Automation Science and Engineering (CASE), 2014 IEEE International Conference*, pp. 1150-1152.

APPENDIXES

Appendix A – Literature Review

Figure A1: Rankings of countries' Industrial Internet of Things enabling factors (Accenture, 2015)

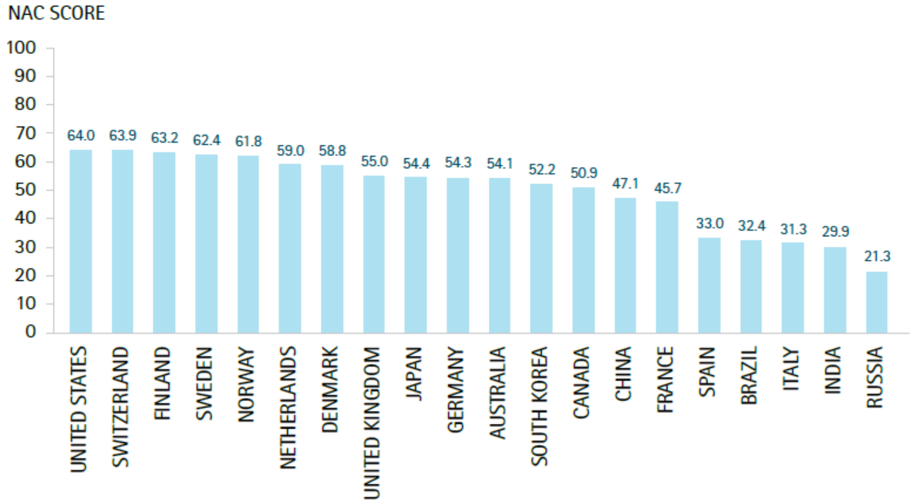


Figure A2: Manufacturing, value added (% of GDP for USA and Germany (The World Bank, 2015)

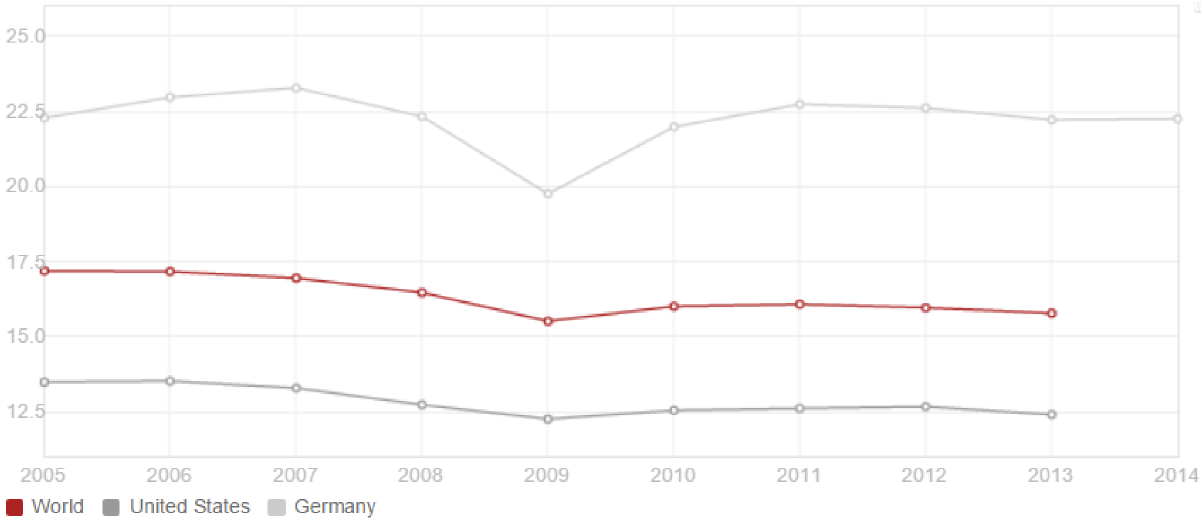
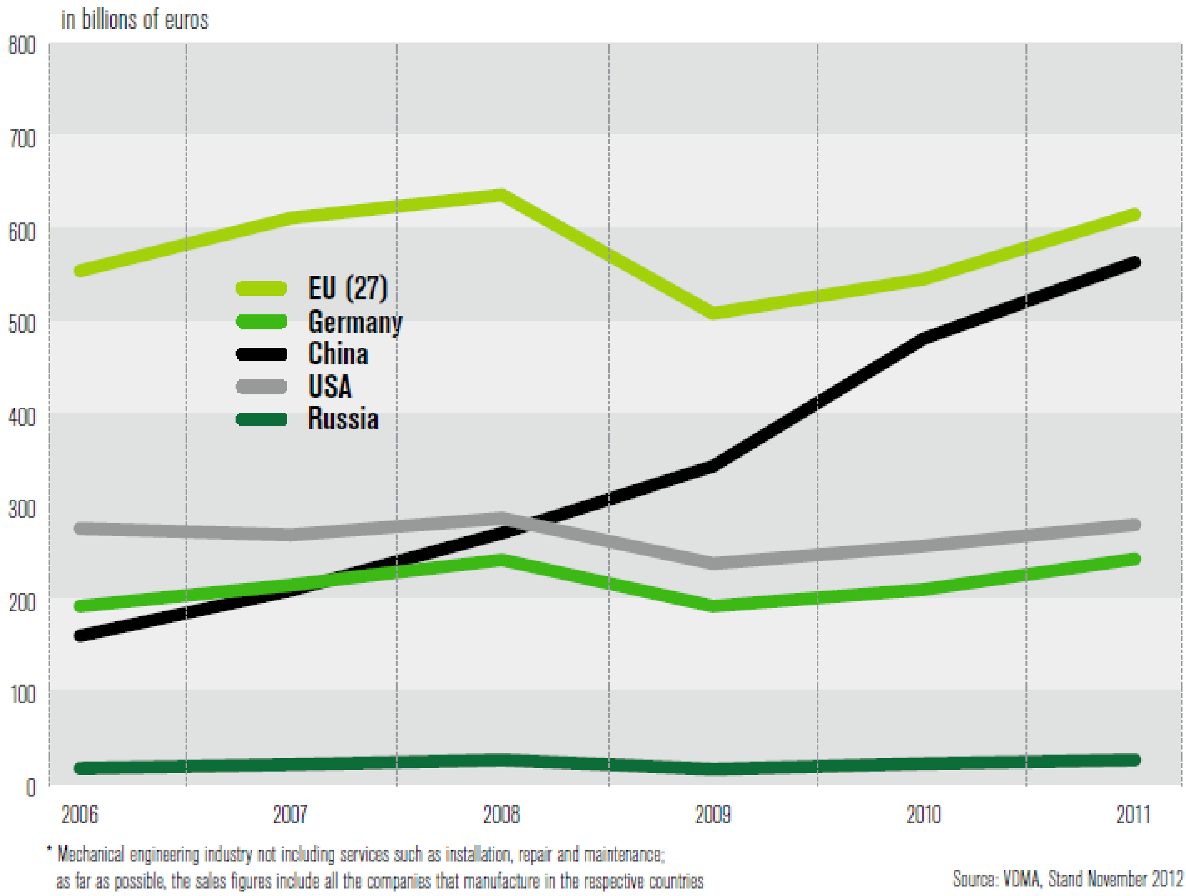


Figure A3: Mechanical engineering industry sales in selected countries (Plattform Industrie 4.0, 2013)



Appendix B – Methodology

Figure B1: Semi-structured interview (example)

Primary Research for Master Dissertation: Industry 4.0 / IIoT
University of Strathclyde Business School

Interview Details:

Interviewee: Name (Organisation)

Interviewer: Florian Ernst and Patrick Frische

Date: 14/07/2015 (9:00 – 9:30am MET)

Key Interview Questions:

Questions	Length
Industry 4.0 / IIoT – Current Development	
1. How would you describe the current development of Industry 4.0 / Industrial Internet of Things?	3 minutes
Industry 4.0 / IIoT – Related Technologies	
2. What technologies do you see as the main drivers for the current industrial revolution?	3 Minutes
3. From a general perspective, how will these existing technologies change/envelop?	3 Minutes
4. What new technologies need to be developed to make use of Industry 4.0 / Industrial Internet of Things?	5 Minutes
Industry 4.0 / IIoT – Challenges and Requirements	
5. What will be the main requirements businesses need to fulfil to ensure successful operations regarding the current industrial revolution?	8 Minutes
6. How will the current industrial revolution impact businesses during future operations and what timeframe (5 years? 8 years? 10 Years? 15 years?) will be appropriate for this consideration?	5 Minutes
7. How will businesses best perform the process of implementing these needed changes within their daily operations?	3 Minutes

Florian Ernst & Patrick Frische July 2015

Figure B2: Permission form (example)

Primary Research for Master Dissertation: Industry 4.0 / IIoT
University of Strathclyde Business School

Interview details:

Interviewee: Name (Organisation)

Interviewer: Florian Ernst and Patrick Frische

Date: 14/07/2015 (9:00 – 9:30am MET)

Permission for use of interviewee and/or company name:

I, the interviewee, authorise the master project students, Florian Ernst and Patrick Frische, to mention in their master dissertation my:

- Name with position/profession, ☐
- Company/Organisation name, ☐
- Neither of both. ☐

Please tick in the provided boxes.

Signature:____________________ Date:____________________

Florian Ernst & Patrick Frische July 2015

Appendix C – Findings

Figure C1: Basic structure of a connected supply chain (Capgemini Consulting, 2014b)

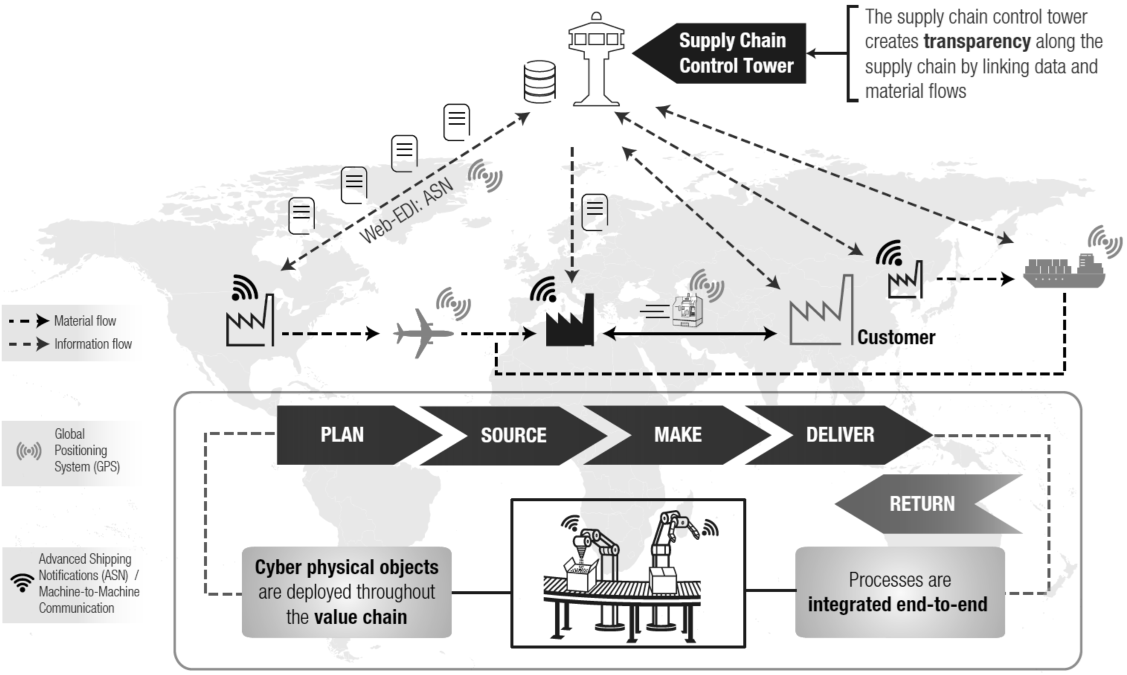


Figure C2: Digitization of the horizontal and vertical (PwC Strategy&, 2014)

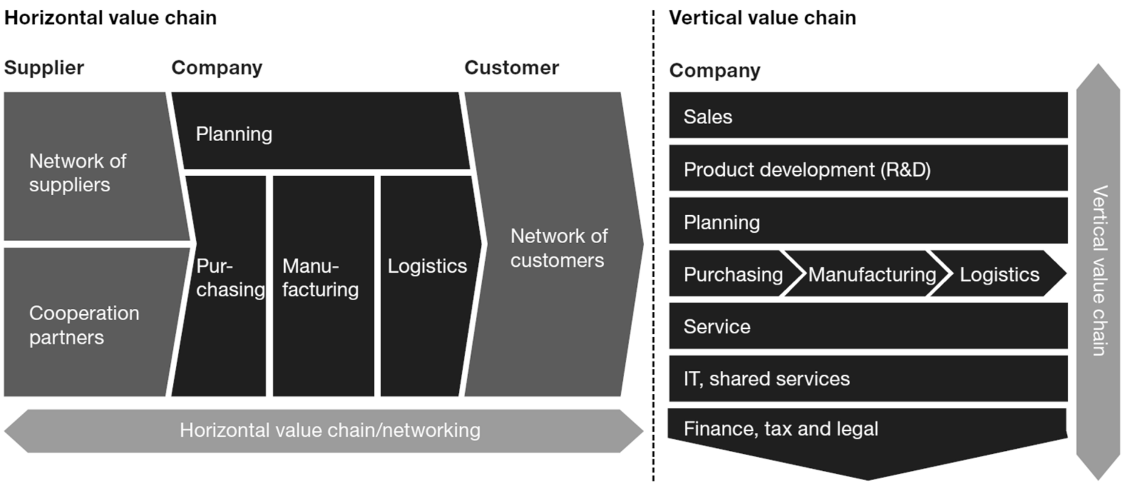


Figure C3: Defining characteristics of Smart Products (Capgemini Consulting, 2014b)

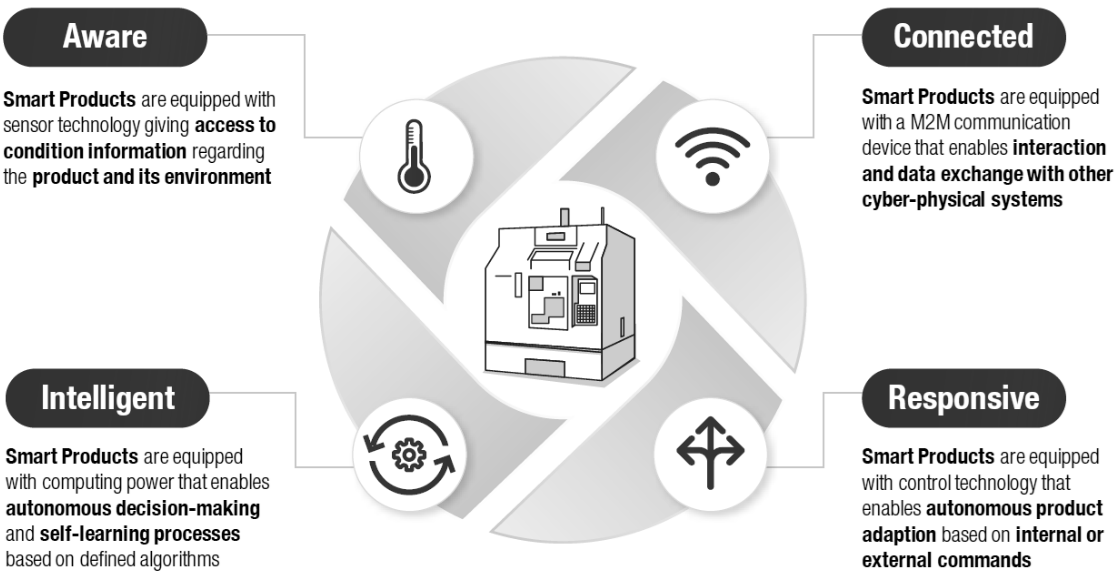


Figure C4: Trends in new business model (McKinsey & Company, 2015a)

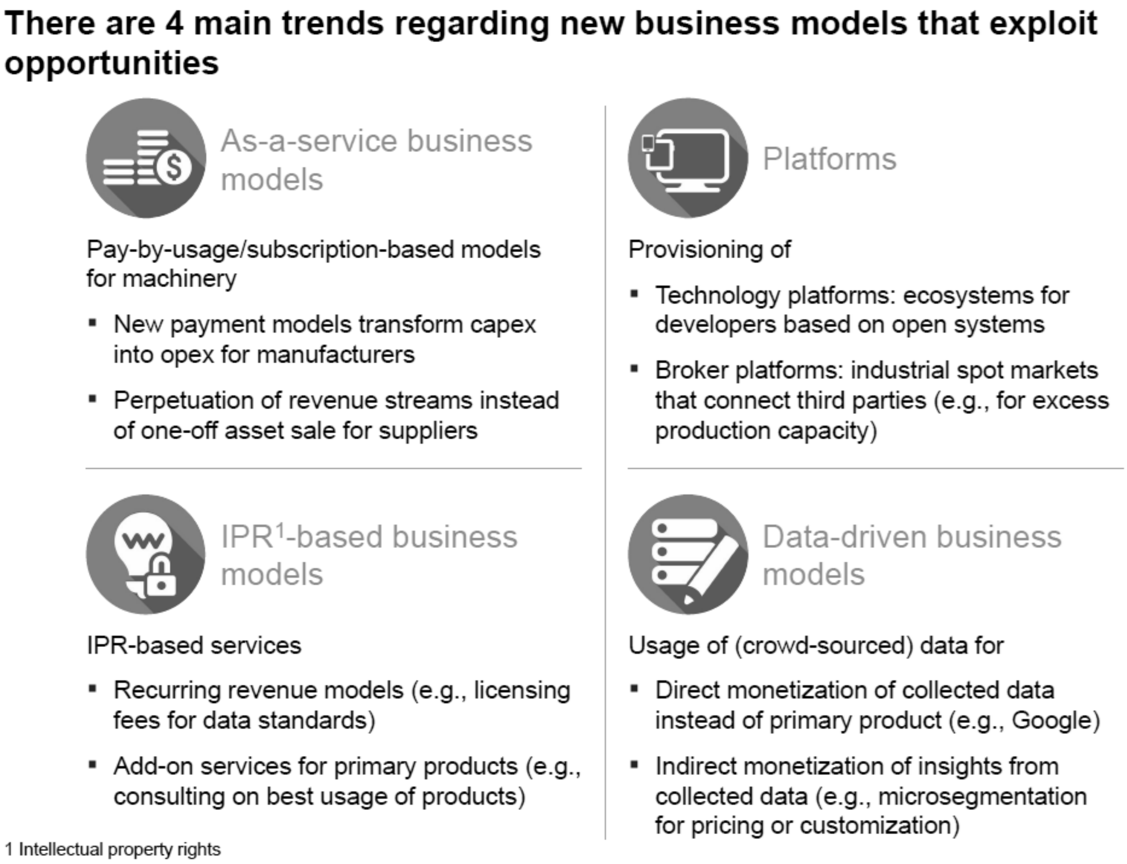


Figure C5: PwC Strategy&'s Digital Maturity Model (PwC Strategy&, 2014)

	1 Digital novice	2 Vertical integrator	3 Horizontal collaborator	4 Digital champion
Business models, product and service portfolio	First digital solutions and isolated applications	Digital product and service portfolio with software, network (machine-to-machine) and data as key differentiator	Integrated customer solutions across supply chain boundaries, collaboration with external partners	Development of new disruptive business models with innovative product and service portfolio, lot size of one, product and component identification
Market and customer access	Online presence is separated from offline channels, product focus instead of customer focus	Multi channel distribution with integrated use of online and offline channels; Data analytics deployed, eg, for personalisation	Individualised customer approach and interaction together with value chain partners	Integrated Customer Journey Management across all digital marketing and sales channels with customer empathy and customer relationship management
Value chains, processes and systems	Digitized and automated sub processes	Vertical digitization and integration of process and data flows within the company	Horizontal integration of processes and data flows with customers and external partners, intensive data use	Fully digitized, integrated partner ecosystem with selfoptimised, virtualised processes, focus on core competency, decentralised decision making & autonomy
Compliance, legal, risk, security and tax	Traditional structures, digitization not in focus	Digital challenges recognised but not comprehensively addressed	Legal risk consistently addressed with collaboration partners	Optimising the value chain network for legal, compliance, security and tax
Organisation and culture	Functional focus in "silos"	Cross functional collaboration but not structured and consistently performed	Collaboration across company boundaries, culture and encouragement of sharing	Collaboration as a key value driver