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Industry 4.0: Digital transformation replicability in manufacturing

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Declaration of Authenticity:

I hereby declare that this Master's Thesis, presented under the title "Digital transformation replicability in manufacturing" is my own work, or fully and specifically acknowledged wherever adapted from other sources. This work has not been published or submitted elsewhere.

In Prague, 16th of May 2018

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Industry 4.0: Digital transformation replicability in manufacturing

Abstract:

This thesis outlines a replicable roadmap for manufacturing companies who aim to implement Industry 4.0 technologies into their operations. Based on a thorough literature review, a case study and qualitative expert interviews, this paper identifies key pillars, drivers, and trends of the fourth industrial revolution and their impact on the business, providing specific examples. The author suggests the starting point of a successful digital transformation should be a clear digitalization strategy, followed by an overview of specific goals the manufacturer aims to achieve. This enables the company to identify relevant metrics and detailed KPIs to ensure the company is on track with the digitalization initiatives. Furthermore, different aspects of the company's business model will be impacted by the digital transformation and manufacturers must be prepared to face Industry 4.0-specific challenges.

Key words:

Industry 4.0, digitalization, manufacturing, business model, digitalization KPI

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AI – Artificial Intelligence

AR – Augmented Reality

B2B – Business-to-business

BCG – The Boston Consulting Group

BMIT – Business model innovation typology

CEE – Central and Eastern Europe

CPS – Cyber-Physical Systems

DACH – Region of Germany, Austria, and Switzerland

EDI – Electronic Data Interchange

ERP – Enterprise Resource Planning System

FMCG – Fast-moving Consumer Goods

IoT – Internet of Things

IoS – Internet of Services

IT – Information Technologies

KPI – Key Performance indicators

M&A – Mergers & Acquisitions

MTO – Made to Order

NPS – Net Promoter Score

OEE – Overall Equipment Efficiency

P&G – Procter & Gamble

PLM – Product Lifecycle Management

PwC – PricewaterhouseCoopers

R&D – Research & Development

RFID – Radio-Frequency Identification

ROI – Return on Investment

SME – Small and Medium Enterprises

VR – Virtual Reality

LIST OF FIGURES

INTRODUCTION

“One of our problems right now is you’ve got to fly a plane while you’re changing it.”

(Pharmaceutical CEO cited by Finzi, Lipton, & Firth, 2018)

Under unprecedented pace of technological development and increasing pressure of competitors from across the globe, businesses’ digitalization of some degree is inevitable. Companies are altering their offerings as well as operations to keep up with the changing environment and grow their business further. A term linked to the extent by which digitalization is changing the ways of doing business is Industry 4.0. A notion initially introduced in Germany is nowadays a common buzzword without a unified definition, incorporating a wide range of ideas, widespread in expert literature as well as conference halls as *the* future of manufacturing.

Relevance for international management & problem definition

University courses, forums, teams of consultants and countless books are dedicated to the topic of digitalization and Industry 4.0, the visions, revolutionary potential and great benefits for the business competitiveness and profits. However, when it comes to the real world, it seems that companies frequently struggle to leverage the benefits of the digital technologies. With a huge variety of technologies available, the firms face uneasy decisions of where to start, what to implement and why, oftentimes underestimating the complexity of digitalization. Such initiatives require resources – financial, human as well as material and the firms must be able to eventually measure the success and impact of those digitalization attempts.

Managers across industries are nowadays faced with the challenge whether and how exactly to approach this ever-growing pressure for digitalization. Thus, the relevant question is: Is Industry 4.0 just another buzz word, another bubble that everybody talks about? A futuristic vision, difficult to capture? Or is there a clear goal that each company can identify and follow, gradually undergoing a digital transformation?

Motivation of the author

During her studies, the author has been oftentimes confronted with different approaches to digital innovation, its benefits as well as potential threats. Mostly, those confrontations were rather high-level, case studies from the global perspective, discussing success stories of world’s digital leaders. However, after gaining some knowledge with regards to this area, it became apparent that successful digital transformation of a business is an incredibly complex task. In the context of the Czech Republic with a long history of manufacturing companies, the author wanted to learn more about the digitalization status quo in manufacturing and how can companies in general approach this increasing pressure. The underlying motivation was to gain more insight into the practical side of digitally-driven business innovations and address the ongoing digital disruption not from the perspective of high-level book examples, but rather at the step-by-step real-company level.

Aim of the thesis & research question

This thesis aims to provide a roadmap for manufacturing companies digitally transforming their businesses with focus on what technologies to implement, what parameters to follow and measure by answering the following research question:

What key steps should a manufacturing company implement and what key performance indicators should be tracked when shifting the company's production processes towards Industry 4.0?

Case study selection

The author conducted a brief research on the status quo of manufacturing companies in CEE region. Looking for a company suitable to be the benchmarking case for this paper, the author utilized the network of her university, identified a suitable company, and approached the managing director of the plant directly. The company was chosen since it shows a strong drive towards digitalization with already tangible positive results enabled by digitalization – expressed by introducing the first smart product in its category in 2017, followed by an award in their respective industry for such product innovation and rapidly decreasing the research and development times thanks to digitalization. The company has started its ongoing digital transformation at a business-critical situation and managed to turn the tables towards a rapid business growth and will thus serve as a reference point for others.

Methodology

Given the nature of the topic, this thesis is based on qualitative research. Firstly, the author visited the premises of the chosen plant and went through the production facility with the managing director to see and discuss the plant's digitalization first hand. Moreover, the author met with the company's employees as well as other companies' representatives in the premises and discussed the state of the art in their firms to understand the complexity better. Thus, the key part of this thesis – the case study – is based mainly on primary data collection only with complementary secondary data from additional online research.

The method used for data collection was a set of in-dept one-on-one interviews with the company's managing director, followed by semi-structured interviews with external consultants in order to explore their perspectives and perceptions of given topic (Daymon & Holloway, 2011). Being experts in the digitalization area and familiar with the company's business and its state of digitalization, they helped the author to put the information gathered on the spot into a wider business perspective and to identify and critically assess replicable patterns and best practices of the company as well as areas for improvement. All the interviews were conducted in person, each of them followed by electronic communication elaborating on some of the points brought up during the interviews.

Structure

Starting broadly, the author defines the term Industry 4.0 from various perspectives, listing drivers and enabling technologies of this fourth industrial revolution. Supported by a thorough literature review on trends and potential directions of Industry 4.0, the chapter concludes with a list of pillars that are the cornerstones for potential business implementations.

Secondly, the thesis analyses the impacts of digitalization and Industry 4.0 technologies on business models of existing manufacturing companies. Going from a definition of the business model and its key elements, the author presents an overview of how specifically the elements are impacted by increasing digitalization, and to what extent can the business models be disrupted and innovated. Starting point of any digital transformation is the company's status quo – thus, this chapter defines ways to evaluate the digital maturity of a business and what can the companies expect to get in return when implementing the digital and what are the internal factors that can either support or hinder the digitalization. After looking at the role of data in the business model transformations, the chapter closes with a set of metrics and indicators to efficiently assess the impacts of the digital on the business model and operations.

Those two theoretical chapters together identify the frameworks, drivers and trends of Industry 4.0, where are the new technological possibilities pushing the development of manufacturing with regards to both the business operations as well as the business model. Furthermore, the research and literature review indicated companies that are examples of successful Industry 4.0 transformations mostly from the manufacturing sector. Building on the research, the thesis reflects on the status quo in manufacturing by listing benchmarking cases under each of the pillars. Moreover, this part adds two more aspects that were mentioned across the literature review as significantly affected by digitalization but were not listed under the pillars – human resources and intelligent pricing.

Fourth chapter describes in depth the ongoing digital transformation and implemented digitalized solutions of the chosen company, with a strong drive towards digitalization that will be anonymized due to data confidentiality. This chapter analyses the chosen manufacturer along both the abovementioned pillars as well as business model implications, explaining how the transformation has started there and what are the results the company already sees as positive as well as negative effects of implementing Industry 4.0.

The paper concludes with a set of managerial recommendations, introducing a roadmap to successful digital transformation and a list of performance indicators the companies should follow to assess the extent to which they benefit from digitalization. Synthesising the insights gained both through the literature review as well as the case study and benchmarking examples, the readers are presented with a comprehensive list of changes to the traditional business model and operations that will be brought about by Industry 4.0 solutions and are suggested how to measure the impact of digitalization. After discussing potential challenges of digital transformation and assessing the limitations of the thesis, the author closes with a forward-looking discussion on the potential of Industry 4.0 and its future impact on the whole business ecosystem.

1. INDUSTRY 4.0: FRAMEWORKS AND TERMINOLOGY

This first chapter introduces key terminology and frameworks crucial for further analysis in following parts of the paper. Besides defining the underlying terms such as Industry 4.0, digitalization and cyberphysical systems in manufacturing, the chapter will also discuss key drivers, disruptions, and technological enablers for implementing digital solutions. Finally, the chapter presents nine pillars of Industry 4.0 in the context of increasing pressure for digitalization. The concept is introduced from a single company's perspective rather than from the perspective of manufacturing industry as a whole.

1.1 Industry 4.0 – definition and context

Over the course of past years, there has been a lot of noise around the term Industry 4.0 or, as named by many, the fourth industrial revolution. The term was firstly introduced in January 2011 at Hannover Messe trade fair, where the German federal government initiated it as a "future project" (Sniderman, Mahto, & Cotteleer, 2016). It entails the idea that digitalization and robotization bring such disruption to manufacturing and all other industries, that it can be by its extent compared to other industrial revolutions from the history of mankind.

Namely, the importance of digital disruption as a paradigm shift has been benchmarked against the first industrial revolution induced by the mechanisation and invention steam engine in the late 18th century, the second industrial revolution connected to the discovery and usage of electricity combined with the division of labour and increasing specialisation, leading to mass production at the dawn of 19th/beginning of 20th century, and the third industrial revolution linked to computer technologies and automation typical for the second half of 20th century, that goes hand in hand with globalisation (Rodrigue, 2017). The underlying notion of the fourth industrial revolution is that *Cyber-Physical Systems, the Internet of Things and the Internet of Services will collectively have a disruptive impact on every aspect of manufacturing companies* (Almada-Lobo, 2016).

Industry 4.0 has significant specifics – robotization as such goes beyond mechanisation, providing machines with unprecedented levels of flexibility close to human working skills, enabling robots to solve both simple and repetitive as well as complex tasks (Rodrigue, 2017). Those specificities and historical benchmarks lead to multiple definitions of the term Industry 4.0. The term originated in Germany, due to its global leadership in manufacturing equipment sector, as Industrie 4.0, *a strategic initiative to take up a pioneering role in industrial IT, which is currently revolutionizing the manufacturing engineering sector* (MacDougall, 2014). Building on this initial definition, a study by i-Scoop follows, bringing in the concept of smart factory: *Industry 4.0 is a name for the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the Internet of things, cloud computing and cognitive computing. Industry 4.0 creates what has been called a smart factory* (i-Scoop, 2017). McKinsey & co. defines Industry 4.0 broadly as *digitalisation of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyberphysical system, and analysis of all relevant data* (McKinsey & Company, 2015). Looking at Industry 4.0 from even broader perspective, it can be defined as *integration of the Internet of Things, cloud computing, advanced data processing and other technological advances* *into the heart of production and manufacturing systems. It allows the merging of the virtual and embedded production process physical worlds through cyber-physical systems, enabling intelligent objects to communicate and interact with one another* (Harting, 2017).

A group of experts from Germany, under the name of *Industrie 4.0 Working Group*, published in report *Recommendations for implementing the strategic initiative Industrie 4.0* their vision, that sees Industry 4.0 as a source of greater flexibility and agility with the highest quality standards. This will lead to emergence of dynamic, real-time optimised, self-organizing value chains that can be optimised based on a variety of criteria, such as cost, availability, and resource consumption. Along this logic, they summarized Industry 4.0 as *"networks of manufacturing resources (manufacturing machinery, robots, conveyor and warehousing systems and production facilities) that are autonomous, capable of controlling themselves in response to different situations, self-configuring, knowledge-based, sensor-equipped and spatially dispersed and that also incorporate the relevant planning and management systems*" (Kagermann, Wahlster, & Helbig, 2013).

Another specificity of the fourth industrial revolution is that, unlike its predecessors, it is being predicted, thus enabling the companies to take specific actions to be prepared for the time when Industry 4.0 fully emerges. Even though no one is able to precisely state when will this happen or how exactly would the manufacturing sector be impacted, the research suggests that the late-movers might be forced out of the market. Moreover, when compared to the previous industrial revolutions, the fourth one will have a high impact despite only a partial need for replacement of current equipment thanks to a more intense interconnectedness of already existing machines (McKinsey & Company, 2015). However, this does not mean that implementing Industry 4.0 solutions will come at low costs – putting the relevant technologies into practice is estimated to require the manufacturing companies to invest up to 3,5% of annual revenues by 2020, accounting for more than half of planned capital investments. The largest priority of those Industry 4.0 investments will be supply chain, product development & engineering, planning, and manufacturing (Geissbauer, Schrauf, Koch, & Kuge, 2014).

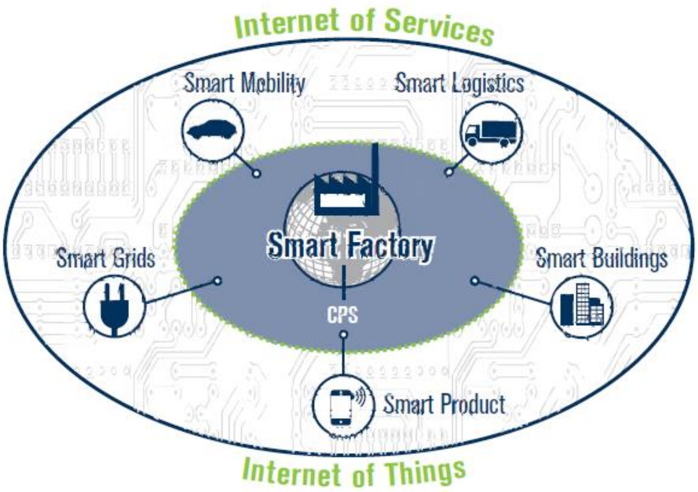

Figure 1: Smart factories as part of the Internet of Things and Services (Kagermann, Wahlster, & Helbig, 2013)

Even though Industry 4.0 as a notion started around innovating manufacturing with the help of digital technologies, automation and data exchange, it grew beyond the factories only, as suggested in Figure 1. In the centre of Industrial internet of things and services are **Cyber-**

Physical Systems (hereinafter as "CPS"). CPS denotes physical objects with embedded software and computing power (Almada-Lobo, 2016) that can interact with one another, using standard internet-based protocol and analyse data to predict failure, configure themselves and adapt to changes. Currently optimized but isolated cells will be thanks to digitalization brought together as a fully integrated, automated, and optimized production flow with greater efficiency (Rüßmann, et al., 2015). The CPS forms the core of a **Smart Factory**, capable of managing complexity, less prone to disruption and able to produce goods more efficiently. Smart factories are characterized by end-to-end engineering, enabling them to achieve seamless convergence of digital and physical worlds (Kagermann, Wahlster, & Helbig, 2013).

The raw material of Industry 4.0 is data and information, revolutionizing industrial production (Bosch Software Innovations, 2015). Thus, Industry 4.0 focuses on creating smart products, procedures, and processes. **Smart products** are uniquely identifiable and steadily locatable (Ramsauer, 2013) physical objects with embedded software and computing power (Almada-Lobo, 2016), knowing the details of how they were manufactured and how they are intended to be used, including information about the parameters within which they can function optimally, thus able to recognise signs of their own wear and tear. This means that under some circumstances, smart products will be able to semi-autonomously control the individual stages of their production (Kagermann et al., 2013). **Smart grids** describe intelligent power networks, providing the factory with energy in an efficient manner regardless the peak- and off-peak times. **Smart mobility** solutions within the current infrastructure networks are energy-efficient, safe, and low in emissions, optimized thanks to information and communication technologies. Smart products together with smart services give way to **smart logistics** that takes away the controlling activities from the people and makes use of fully automated systems. The last part of the matrix are **smart buildings**, linking the production schedules with facility management, with a great potential in energy savings (Ramsauer, 2013)

Industry 4.0 will be enabled by vertical integration within companies and networked manufacturing systems and by horizontal end-to-end digital integration across the entire value chain (Kagermann, Wahlster, & Helbig, 2013), including logistics, workers, recycling, energy aspects and much more (i-Scoop, 2017). Distribution and value chains are no longer local, but rather global – *circular processes to gather resources, transform them in parts and products, distribute finished goods to markets and finally make these resources available again through various recycling and reuse strategies* (Rodrigue, 2017). Suppliers, producers, and consumers can be spread all around the world and companies thus must alter their processes and virtually integrate physically dispersed network of stakeholders to keep up with this level of globalization of the entire supply chains.

Concluding, Industry 4.0 is a popular buzz word, oftentimes considered just a bubble that every company speaks about. Building on the provided definitions, what does it actually mean for a company? Industry 4.0 is about taking the (both new as well as already existing) automated and robotized production machinery, equipping it with the ability to collect data, creating supporting IT infrastructure that can efficiently collect, analyse, and store such data, that is the true revolutionary asset of this fourth industrial revolution. Consistently and systematically working with the data, integrating them into the entire value chain and all activities of the company, using them to drive better decisions, better products and overall better firm's performance is the message behind Industry 4.0.

1.2 Drivers of Industry 4.0

Looking at the fourth industrial revolution from the perspective of company's key drivers, we can identify general ones that are following the patterns of previous industry revolutions. Companies strive to maximize revenues and minimize costs, and every investment devoted into new equipment should facilitate either decrease in costs or increase in revenues, leading to increased efficiency of a firm's resources (Coleman, Damodaran, Chandramouli, & Deuel, 2017). Along those arguments, there are three general challenges in production that are crucial drivers of the shift towards Industry 4.0 (Demme, 2017; Bosch Software Innovations, 2015):

1. Decrease in costs
2. Increase in output
3. Improved quality of output

Those three drivers are linked to a plant's effectiveness and productivity. According to a recent study by PwC, companies expect an increase in productivity of 18% between 2015 and 2020 due to the digitalization of value chains, especially through reduction of redundancies, minimization of quality losses and increased transparency, flexibility, and cohesion of processes (Geissbauer et al., 2014). A term often used in this context is Overall Equipment Effectiveness (OEE), that *identifies the percentage of manufacturing time that is truly productive* (oee.com, 2017). The concept of OEE identifies three underlying factors (three potential effectiveness losses) that influence OEE:

1. **Availability** – there might be situations when the equipment is not available as expected. This factor considers potential availability loss caused by both planned as well as unplanned stops in production, caused by equipment failures, material shortages or changeovers (set up and adjustment of machines) that can limit OEE.
2. **Performance** – potential losses that result in less-than-optimal performance of a machine. Those can be caused by problems such as small stops, machine wear, idling, substandard material or reduced speed of machine's cycles.
3. **Quality** – potential impact on machine's OEE through losses in quality, accounting for manufactured parts that do not reach desired quality standards. Examples are process defects, faulty products and production rejects.

Putting those three factors into a timely perspective, after taking into consideration scheduled loss (all the time when a machine is planned *not* to be in use, such as during lunch breaks or scheduled servicing), one can arrive to a final machine's OEE, expressed in Figure 2.

Figure 2: OEE underlying factors (derived from oee.com, 2017)

Defining OEE enables elaborating on the abovementioned three key drivers of Industry 4.0.

1.2.1 Decrease in cost

Decrease in costs is one of the key motivators of implementing any innovative technology into a company's processes. Major costs in manufacturing facilities are linked to maintenance – both explicit as well as implicit and opportunity costs, since as machine parts are taken for servicing, the plant's production needs to be altered. To reach the production targets, improve machine's OEE and keep the plant's output at its potential maximum, the organizations often make uneasy decisions between weighing lost production time against the mitigated potential risk of a machine breakdown. In manufacturing, one of the key success factors is a well-defined and efficient maintenance strategy that helps the firm to maximize a plant's productive capacity while keeping costs under control. According to a study conducted by Deloitte, *poor maintenance strategies can reduce a plant's overall productive capacity between 5 and 20%* (Coleman et al., 2017). Companies are aiming to maximize the uptime of their machinery (aka the OEE) by either trying to anticipate when the machine might potentially need servicing or by preventive replacements of still-working parts along the logic of avoiding the difficulties caused by an unexpected breakdown.

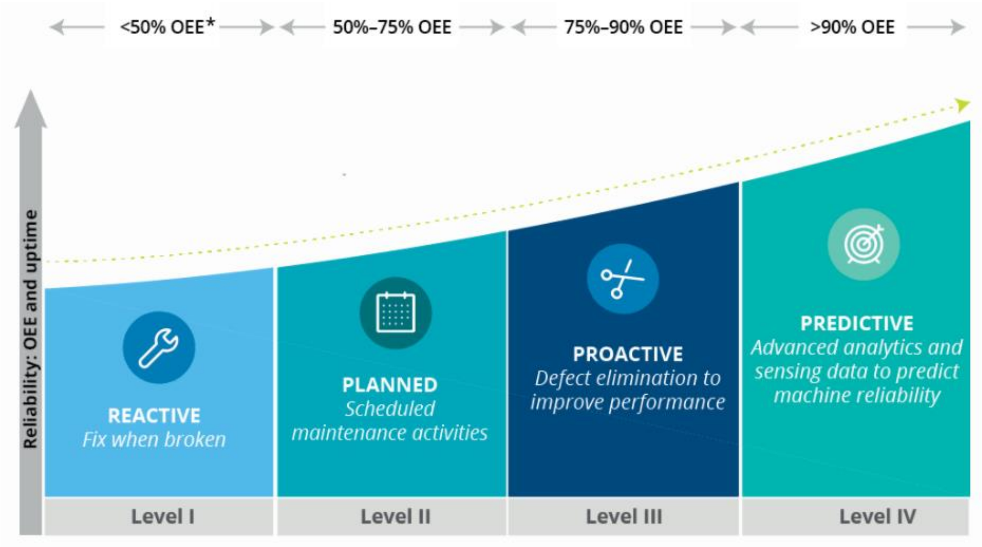

Figure 3 Maintenance strategy continuum (Coleman et al., 2017)

The study by Coleman and collective (2017) identified four categories of maintenance programmes: reactive, planned, proactive and preventive, shown in Figure 3.

- Reactive maintenance allows the parts to run to failure and replacements happen only to fix a breakdown. It is still the most commonly used strategy, offering maximum utilization of a machinery but at potentially high costs and risk of damage, unplanned downtime, or misjudgement of the problem.
- Planned maintenance aims to prevent problems before they occur, by replacing parts in a timely-scheduled and well-planned manner. While this attitude can increase uptime by preventing the breaking of a machinery and thus be more cost-effective than the reactive strategy, at the same time it might be challenging from the perspective of inventory management of the spare parts, increased downtime through scheduled maintenance sessions or from the perspective of managers justifying the replacement of a costly and yet-working part.

- Focusing on the cause of an issue, the proactive maintenance aims to address the problems that may initiate the breakdowns of a machine. Such proactive approach is more data driven, preventing the wear and tear of a machine, for example by addressing improper machinery lubrication or non-optimal temperature conditions. Leading to reduction in failures and longer lifespan of a machinery, proactive strategies effectively decrease costs.
- Under predictive maintenance, the data gathered by interconnected smart machinery should be able to foresee where failures could potentially occur, helping to optimize the uptime and thus increase the OEE of a machine (Coleman et al., 2017).

New technologies under Industry 4.0 enable predictive maintenance, efficiently mitigating downtime in manufacturing facilities and identifying failure modes, leading to cuts in maintenance costs, improved useful life of a machine (OEE), avoiding machine failures and overall ensuring much more efficient operational management (Geissbauer, et al., 2014). Decreased costs and high availability of digital technologies nowadays enable mass deployment of various optimized maintenance systems. Progress in computing power, sensors and various monitoring and controlling systems enable the companies not only to gather data, but also to aggregate and analyse them, identifying root causes of diverse problems that may have been previously unnoticed. Predictive maintenance is said to *reduce the time required by 20-50 %, increase equipment uptime and availability by 10-20 % and reduce overall maintenance costs by 5-10 %* (Coleman, et al., 2017). McKinsey's study is more optimistic and sees potential *10 to 40 % reduction in maintenance costs*, *decrease the total machine downtime by 30-50 % and increase machine life by 20-40 %* (McKinsey & Company, 2015).

The decrease in cost is not restricted only to maintenance. Bauernhansl (as cited in Arnold, Kiel & Voigt, 2016, p. 7) sees 6 types of Industry 4.0-related cost-saving potentials: reduced complexity, maintenance, inventory, manufacturing, logistics, and quality costs. According to a study published by BCG, *Industry 4.0 can drive productivity gains of 5 to 8 percent on total manufacturing costs over ten years,* factoring in material costs (Rüßmann, et al., 2015). Moreover, a PwC study estimates that Industry 4.0 can potentially bring costs savings of 13,8 % between 2015 and 2020, an average of 2,6 % per annum (Geissbauer, et al., 2014). Besides potentially significant savings in maintenance costs, CPS and their flexibility will enable the companies to perfectly adjust the amount of materials needed for a specific produce, save the energy used in production by optimizing the consumption during productive as well as break-time, reducing emissions etc. When looking at the productivity improvements from the perspective of so-called conversion costs (all manufacturing costs excluding material costs), the study assesses that under Industry 4.0 the improvements will range from 15 to 25 %. The study also looks at connected production costs, such as logistics, labour and overhead. With an example case study of component manufacturing, BCG identified that benefits of automation for logistics will generate savings of up to 50 % for the manufacturer, accompanied by cost reductions of 30 % both for labour as well as operating costs. Moreover, overhead costs have the potential to be decreased by 30 % as well (Rüßmann, et al., 2015). Savings in costs in the range of tens of percent indeed are one of the key long-term drivers of implementing Industry 4.0.

1.2.2 Increase in output

Another incentive for a manufacturer to implement innovative digital solutions into their production processes is the desire to increase productivity through enhanced levels of production or through optimizing the resource input.

Industry 4.0 technological improvements will lead to an increase in the amount of produce by real-time optimizing the production processes, assets utilization as well as resources usage, leading to higher efficiency of resources. Improved material consumption (thus decreased costs) and increased speed and yield of the processes (bringing more revenues) are strong value drivers. For example, real-time process optimization alone yields an improvement in throughput of up to 5 % (McKinsey & Company, 2015). Additionally, the technologies will not only increase the total volume of produce but will also enable the product spectrum to become broader (Müller, Buliga, & Voigt, 2018).

Moreover, increase in output will be possible thanks to improving efficiency of logistics on the factory floor, such as automated shop-floor processes, autonomous transport vehicles using laser navigation, communicating with one another through wireless networks. Thorough data integration and higher automation will significantly increase manufacturers' flexibility. Such improvements and flexibility will enable the companies to react and respond to change in the production processes much faster, allowing the plant to increase its output (Rüßmann, et al., 2015), leading to a significant shortening of the whole production cycle and time-to-market by 30 to 50 % (McKinsey & Company, 2015).

1.2.3 Improved quality of output

Third crucial driver affecting a company's decision on an investment into Industry 4.0 solutions regards the quality of the products manufactured. Far-reaching quality benefits of Industry 4.0 technologies namely include: better planning and controlling in manufacturing and logistics, higher customer satisfaction, greater flexibility in manufacturing, faster R&D and time to market and product individualization (Geissbauer, et al., 2014). Digitalizing a facility can lead to a decrease in faulty products rate, lowering the number of products to be redone, enabling companies to keep up with the increased levels of demanded customization and decrease administrative red-tape, leading to better fulfilment of customer needs. Resulting from enhanced cooperation between humans and machines, the product quality will improve due the reduction of manual labour as well increased use of technologies analysing real-time data, spotting potential errors much faster (Rüßmann, et al., 2015). Stabilizing the manufacturing processes, improving the inefficiencies, and using Industry 4.0 levers such as advanced process control or statistical process control will affect companies' cost for quality that can be decreased by 10-20 % (McKinsey & Company, 2015).

To summarize, the key drivers of Industry 4.0 thus focus on increasing the overall efficiency and maximizing the plant's fully productive time, measured by OEE, affected by availability, performance and quality of the production, observable through decreased costs, increased output quality and quantity. Companies from different industries will be pushed by different drivers and thus will benefit differently from Industry 4.0 technologies. Industries with a large amount of product variants (such as automotive) can expect productivity gains thanks to greater flexibility, whereas in industries with key focus on high quality, such as pharmaceuticals or chemicals, companies will benefit from the real-time data analysis and adaptation, combined with resource-process effectiveness and decrease in faulty rates (Rüßmann, et al., 2015). Moreover, asset utilization is a key driver in asset-heavy industries, therefore the predictive maintenance, decreasing unscheduled downtime and optimizing a machine's OEE will play crucial role for those firms to capture the value of Industry 4.0 (McKinsey & Company, 2015).

1.3 Disruptive technologies driving digitalization in manufacturing

Every industrial revolution in the past was triggered by a strong disruption in technology available, and the Industry 4.0 is no exception to this rule. Many authors and studies have already dived into analysis of the triggers of this current massive shift towards new technologies – *Industry 4.0 in automated production* by Da Costa, Mendes and Osaki (2017), *Industry 4.0: A Classification Scheme* by Perales, Valero and García (2016) or the backbone of academic Industry 4.0 research by Kagermann et al. (2013) and Hermann et al. (2015) to name a few.

According to a study on digitalization of the manufacturing sector by McKinsey (2015), there are four general clusters of disruptive technologies that enable the shift towards digitalization in the manufacturing sector:

1. **Data, computational power, and connectivity**

Three major drivers can be listed in this cluster – big (open) data, Internet of Things and Cloud technology. Triggered by a significant drop in costs of computation, this cluster makes the ubiquitous use of sensors possible; allowing affordable and powerful processing, data transmission and storage. Sensors and actuators can be embedded in physical objects and interconnected through a network, collecting and transmitting all kinds of data form the production for further analysis, enabling the physical objects to communicate autonomously among each other. New communication protocols for machine-to-machine interactions are designed, making interoperability possible (McKinsey & Company, 2015).

Connectivity allows for smarter supply chains, manufacturing processes and even end-to-end ecosystems (Sniderman et al., 2016). Shop-floor connectivity is not novel in manufacturing – it is the ease and impact of it that is new. The recent technological development and decrease in price make different forms of passive identification tags much more affordable. Some of the more advanced facilities have already implemented technologies such as RFID or transponders into their production processes (Almada-Lobo, 2016). The IoT represented by new hardware devices that are constantly shrinking both in size and in price together with cloud technology enabling data centralization and virtualization make this cluster the cornerstone of Industry 4.0.

2. **Analytics and intelligence**

There has been a huge progress in the area of knowledge and intelligence in recent years. Not only simple and repetitive tasks can now be performed by robots – advanced robots embedded with artificial intelligence (AI) and machine learning enable a whole new field of potentially automated activities (McKinsey & Company, 2015). Regarding the analytics, CPS will generate huge amounts of data that need to be stored, processed and most importantly, turned into useful insights (Harting, 2017), providing a holistic view of manufacturing operations. Improved statistical techniques and algorithms enable much more sophisticated analysis with great potential across industries, potentially identifying inefficiencies based on historical data, allowing corrective or preventive actions. Such analysis can be either done offline with the help of complex statistical models to process both structured as well as unstructured data or, in case of a need for quick response, a real-time analysis can be conducted even before the data is stored (Almada-Lobo, 2016).

3. **Human-machine interaction**

The massive deployment of touch interfaces thanks to increased customer familiarity with new technologies through personal mobile devices serves as a bridge for the industrial implementation. Gesture recognition and augmented reality are already a part of everyday life. Such familiarity eases the implementation of human-machine interactions as a natural feature both in consumer as well as manufacturing environment. Examples that are already in use vary from smart glasses and headsets to exoskeleton devices, making various processes more efficient. New intelligent machinery will adapt to the needs of human beings (Kagermann, et al., 2013), enabling side-by-side cooperation of robots and people at the same section of the production (McKinsey & Company, 2015). Moreover, increasing machine-to-human as well as machine-to-machine interaction will enable even stronger customization and small-batches production (Rüßmann, et al., 2015). Another perspective to this technology cluster is the paradigm shift that is brought about by novel forms of collaborative technologies. It will become increasingly popular that people can conduct their work outside of the factory premises in virtual, mobile workplaces, supported by smart assistance systems with user-friendly interfaces (Kagermann, et al., 2013).

4. **Digital-to-physical conversion**

While the output is a physical object, manufacturing begins with an information, a set of data – for example a design drawing. These data are communicated to the machines that produce them, bringing the digital data to the physical world. Moreover, data from the creation process are often captured for further processing (Sniderman et al., 2016).

Product Impact	Potential applications
PHYSICAL TO DIGITAL	→ Sensors and controls → Wearables → Augmented reality
DIGITAL	→ Signal aggregation → Optimization and prediction → Visualization → Cognitive and high-performance computing
DIGITAL TO PHYSICAL	→ Additive manufacturing → Advanced materials → Autonomous robotics → Digital design and simulation

Figure 4: Potential technological applications along digital-physical-digital loop (derived from Sniderman et al., 2016)

Such interconnectedness of digital and physical worlds creates so called digital-physical-digital feedback loops. This smart and integrated loop is where much of the unexploited opportunities and uncaptured value lies for many manufacturers (Rodriguez, et al., 2018). Examples of specific applications of this conversion that have a great potential in manufacturing are listed in Figure 4. Some of them – such as sensors and wearables – are already a common part of the manufacturing processes.

This what makes Industry 4.0 truly revolutionary – it enables organizations to capture data from the physical world, analyse it digitally and drive informed action back to the physical world. This continuous and cyclical flow of information enables the organizations to react in real-time to the changes in the environment. Additionally, analysing such a mass of data allows the companies to recognize patterns, simulate and model potential scenarios, creating opportunities for new products and services, identifying better ways to serve customers, new types of jobs and even completely new business models (Renjen, 2018). Decreasing costs, progress in precision and quality combined with increasing range of smart materials drive this cluster of disruptive technologies. Additive manufacturing (such as 3D printing) as well as advanced robotics (especially more complex human-robot collaboration) combined with more cost-effective options for storing and harvesting energy (McKinsey & Company, 2015).

These four disrupting technology clusters together – Data, computational power, and connectivity; Analytics and intelligence; Human-machine interaction and Digital-to-physical conversion – lay the foundations for the development of specific pillars Industry 4.0

1.4 Pillars of Industry 4.0

Based on four rather broad underlying clusters of disruptive technologies, a set of specific technologies that are transforming the current industrial production can be identified. Presented as pillars to Industry 4.0 in a BCG study under Rüßmann and collective *Industry 4.0: The Future of Productivity and Growth on Manufacturing Industries* (2015), there are 9 specific technological advancements driving the current disruptive change:

1. **Big Data and analytics** – ubiquitous sensors and smart devices produce huge amounts of data that, without proper analysis and understanding, would be useless. If comprehensively evaluated and understood, data from all those sources can be turned into insights that lead to production quality optimization, energy savings, decreased product failures and improved equipment service (Rüßmann, et al., 2015). Such information helps companies with decision making and real-time process optimization (McKinsey & Company, 2015).
   An interesting perspective on the role and importance of big data and analytics was presented in a study by Deloitte and Singularity University, quoting William Sobel, Chief Strategy Officer at Vimana: "*It is often said that data is the fuel of the industrial IoT, and if data is the fuel, then analytics are the engine.*" (Rodriguez, Libbey, Mondal, Carbeck, & Michalik, 2018)
2. **Autonomous robots –** using robots of some form is a common practice across many industries for decades. Nowadays the robots are moving from their current tasks

towards more complex ones, becoming increasingly autonomous, flexible, and cooperative, developing a greater range of capabilities (Rüßmann, et al., 2015). One of the underlying ideas of Industry 4.0 envisions robots interacting with one another, working safely side by side with humans, from whom they will learn (Kagermann, et al., 2013).

3. **Simulation** in the engineering phase is related to 3D projections of products, materials as well as production processes. Being already in use to some extent, simulations promise to gain more importance in the future, leveraging real-time data to mirror the physical world into the VR, reducing the physical prototyping to an absolute minimum. Simulations enable testing and optimization of the machine's settings before the physical changeover, thus making the machine setup times shorter and of a better quality (Rüßmann, et al., 2015). Some companies use virtual models – so called "digital twin" – that is created in the engineering phase, integrating all relevant data, updated with performance data. Digital twin is "*an evolving digital profile of the historical and current behaviour of a physical object or process that helps optimize business performance*" with a great potential to speed up the development process, reducing time-to-market and limit defects (Parrott & Warshaw, 2017). Moreover, simulation enables companies to produce multiple models in small batch volumes while still being profitable.
4. **Horizontal and vertical system integration** is a crucial success factor for a shift towards Industry 4.0. A study by PwC believes that digitalization of value chains in manufacturing and engineering will increase from 19 % in 2015 to 85 % in 2020 (Geissbauer et al., 2014).
   Horizontal integration, as shown in Figure 5, entails end-to-end integration (McKinsey & Company, 2015): from inventory, planning data, suppliers and other value chain partners to customers, optimizing the flow of information and goods. The key driving force is better satisfaction of customer needs through decreased time to market, higher innovation speed, efficient division of labour and access to expert know-how. Horizontal integration is also vital from the cost-savings point of view – the abovementioned 2,6 % of annual costs savings can be only achieved if all partners along the entire supply chain are able to decrease their costs individually. Estimates are that up to 86 % of horizontal value chains will be highly digitalized by 2020 (Geissbauer et al., 2014).

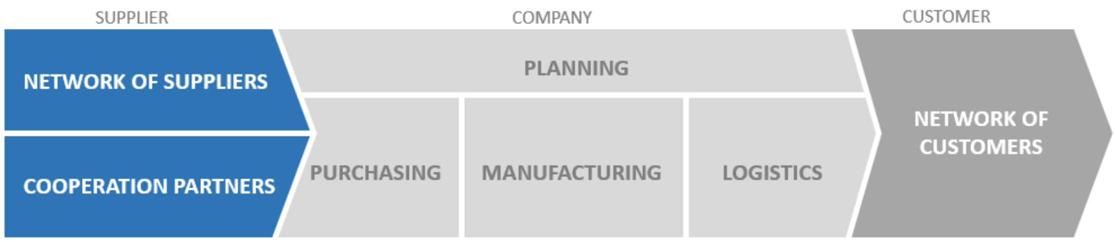

Figure 5: Horizontal Value Chain of a company (derived from Geissbauer et al., 2014)

On the other hand, Figure 6 visualises vertical value chain of a company that should be continuously digitalized and integrated in order to successfully implement Industry 4.0 technologies. Being associated with a consistent flow of data, this chain incorporates a large variety of company's functions (CGI, 2017), from sales and digital order process, customized product development and automated transfer of product data to connected planning and manufacturing systems and further on to integrated customer service. A "digital company" with a continuous digital value chain not only digitally integrates the shop floor, but also the development and sales departments from the office floor. Experts estimate that by 2020 up to 80 % of vertical value chains will be highly integrated (Geissbauer et al., 2014).

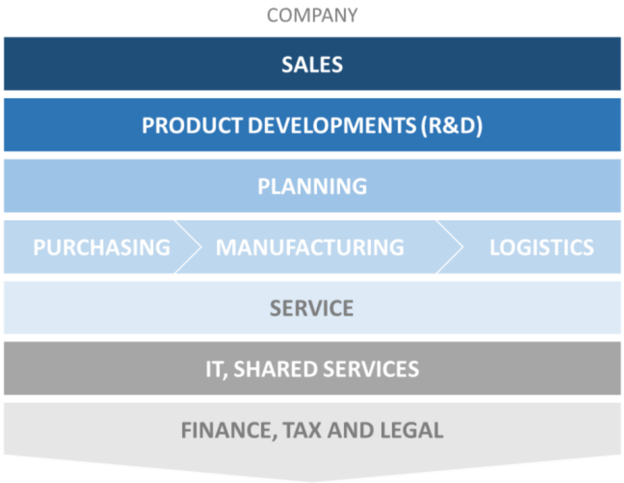

Figure 6: Vertical Value Chain of a company (derived from Geissbauer, 2014)

As mentioned above, the integration can be rather virtual due to the increased physical dispersion of the value chain as well as the companies themselves. The key attribute of such integration is the IT architecture. Majority of the IT systems is not yet fully integrated – not only among companies, suppliers, and customers, but frequently not even within one company. Oftentimes different divisions and functions have different IT systems, collecting their own data without seamlessly sharing them with the other parts of the company, a factor potentially destroying company's competitive advantage. A much more cohesive, cross-company universal data-integrating networks must evolve and enable truly automated value chains (Rüßmann, et al., 2015).

5. **The industrial Internet of Things** tackles the fact that nowadays not all manufacturer's sensors and machines are interconnected and make use of embedded computing. With ongoing digitalization, more and more assets, including unfinished products, will be computing-enriched and interconnected (Rüßmann, et al., 2015). Progressing technologies will enable the devices to autonomously communicate with one another, leading to real-time and decentralized decision making. For example, products at different stages of the manufacturing process can be identified by a unique identifier (such as RFID), transmitting the information which manufacturing steps should be performed
6. **Cybersecurity** is a pillar with increasing importance since the traditional IT security will not be sufficient to protect the digitalized business (CGI, 2017). Currently, companies oftentimes believe that it is safer to keep the management and production systems unconnected – however, Industry 4.0 calls for increased connectivity using standardized communication protocols. To ensure secure and reliable communication, sophisticated access and identity management while protecting individual's as well as company's sensitive data, investment and continuous development is necessary (Rüßmann, et al., 2015).

7. **The cloud** is already in use for some applications, mostly related to various analytics or enterprise activities (Rüßmann, et al., 2015). However, the role of the cloud will be much more production related, enabling data-sharing within the company as well as on the outside. Potentially, all machine data and functionality, monitoring as well as controlling systems could be deployed to the cloud. Moreover, the cloud also enables new approaches to product design – designers and engineers do not have to rely solely on powerful machines anymore but can utilize the data capacity and virtualized computing power provided by the cloud (Ezell & Swanson, 2017).
8. **Additive manufacturing** represented mostly by 3D printing has an incredible potential across multiple industries, ranging from automotive and machinery production to medical and pharmaceutical businesses. With recent advancements, 3D printed models can now consist not only of plastic, but also of wood, metal, carbon or other materials, having benefits for the company as prototypes as well as individual components or even small batches of individualized goods (Rüßmann, et al., 2015). Additive manufacturing also transforms the supply chain by reducing material input and stock on hand (Marchese, Crane, & Haley, 2015) or construction advantages – for its lightweight designs and ability to easily create parts with complex geometries. 3D printed products are already being used for example in aviation, reducing both the companies' costs of raw materials as well as the aircrafts' weigh (NASA, 2018).
9. **Augmented reality** (AR) is another of the commonly used buzz-words together with virtual reality (VR), having potential benefits in many areas of a company's activities. AR can provide workers with real-time information, leading to improved decision making as well as work procedures through displaying relevant information into an employee's field of vision. AR glasses are one of the smart devices used to project information from other stages of the production process, e.g. from logistics. Similarly, data glasses can guide employees to select the correct parts in the assembly or provide workers with repair instructions on how to replace a particular part (Kunkel, Soechtig, Miniman, & Stauch, 2016). Another use might be virtual training – especially for cases that are not very likely to be experienced in the real life, such as emergency trainings and crisis management. Moreover, companies can also use virtual reality for their internal needs, such as workplace optimization (Rüßmann, et al., 2015).

Along those nine pillars or building blocks the digital shift in manufacturing will occur. Many of them are already used in some extent, gradually moving towards increased efficiency in the form of a fully integrated, automated, and optimized production flow. This flow will include not only the production facility but also the whole value chain, suppliers as well as customers, physical produce as well as data and humans as well as robots.

2. DIGITALIZAZION AND BUSINESS MODELS

The second chapter assesses how the digital technologies impact the business models of existing manufacturing companies and defines the necessary terms and frameworks to do so. Sections 2.1 and 2.2 define the business model, its elements, which of them are most likely to be impacted by innovative Industry 4.0 technologies and related aspects of business model innovation. Following part presents a list of incentives that drive the companies to look into the implementation of various disruptive digital technologies, where are they eventually aiming – so-called new mandate of manufacturing. Based on this, following sections will analyse how a company can assess its own digital capabilities and level of digitalization, necessary to be able to integrate the digital into its business objectives and what are the cornerstones of such integration. Chapter 2 concludes with a list of Industry 4.0 relevant KPIs and managerial recommendations relevant for business model digitalization of brownfield manufacturing companies.

2.1 Digitally-driven business model changes in manufacturing

The expert literature is certain about one thing when it comes to Industry 4.0: it will have a lasting effect on existing business models and will lead to emergence of new, disruptive digital business models (Kagermann et al., 2013; Dorst, et al., 2015; Geissbauer, et al., 2014; Rüßmann et al., 2015). This thesis aims to identify key Industry 4.0 factors to be taken into account by *existing* manufacturing companies and thus will not focus on the completely novel business models that are generated through intense digitalization across industries and reduced traditional market entry barriers. Disruptive digital business models such as technology platforms, multi-channel businesses, modular products, as-a-service or recurring revenue business models (Sviokla, 2016; McKinsey & Company, 2015) are thus outside of this paper's scope.

Generally, established business models will become more data-based and customer-focused (Burmeister, et al., 2016; Rüßmann, et al., 2015). The focal point of the digital trend is to increase customer benefits through a growing range of available value-added solutions and to intensify networking throughout the whole horizontal value chain by increased availability and integrated use of relevant data. The whole value chain of traditional manufacturing companies is geared towards increasingly individualized customer requirements, offering more solution-oriented usage models as opposed to a simple sale of physical products (Geissbauer et al., 2014).

2.1.1 Industry 4.0 impact on business models in manufacturing

To identify the changes to business models brought by digitalization, it is necessary to firstly define the business model as such. The research community points out the lack of a generally accepted business model definitions (Massa, Tucci, & Afuah, 2017), since there are countless approaches and visualisations of a business model, its key components, and relationships. A generally quoted notion describes business model as the "*design or architecture of value creation, delivery and value mechanisms of a firm*" (Teece, 2010; Müller et al., 2018). One of the most known visualisations is Osterwalder's business model canvas, consisting of 9 key components (as shown in Figure 7) and the definition where "*a business model describes the rationale of how an organization creates, delivers and captures value*" (Osterwalder & Pigneur, 2010).

Figure 7: Business Model Canvas by Osterwalder (derived from Osterwalder and Pigneur, 2010)

Depending on the company's and industry's specifics, Industry 4.0 will likely have an impact on one or multiple of these 9 elements (Arnold, Kiel, & Voigt, 2016), namely:

1. **Customer segments** are the different groups of people an organization aims to serve, comprising the heart of any business. The level and depth of segmentation depends on a firm's strategy (Osterwalder & Pigneur, 2010). New segments can be addressed thanks to Industry 4.0-driven service orientation and better understanding of customer needs (Arnold et al., 2016).
2. **Value propositions** stand in the centre of a business, seeks to solve customer problems and satisfy customer needs with value propositions – or in other words, to "get a job done" (Osterwalder & Pigneur, 2010) It will be more flexible, resulting in individualized product offerings and decreased batch sizes (Arnold et al., 2016). Stronger and data-driven customer orientation will foster product innovations, allowing optimization of production systems regarding costs, time, quality, and efficiency (Kagermann et al., 2013), as introduced in section 1.2 of this thesis.
3. Value proposition are delivered to customers through communication, distribution, and sales **channels** (Osterwalder & Pigneur, 2010). Under Industry 4.0, they will transform towards all-integrating transparent web-based platforms, allowing integration of web-enabled products and services, customers and partners in an interactive way (Arnold et al., 2016).
4. **Customer relationships** are established and maintained with each customer segment (Osterwalder & Pigneur, 2010). Data analysis will enable deeper customer understanding, integrating customers into product and service engineering and design, resulting in more direct, intensified, and engaging customer relationships. Moreover, better-fitting offer will enhance customers' loyalty, prolonging the relationships (Arnold, et al., 2016; Wischmann, Wangler & Botthof, 2015).
5. **Revenue streams** result from value propositions successfully offered to customers (Osterwalder & Pigneur, 2010). Industry 4.0 technologies enable employing novel revenue models such as pay-by-usage or dynamic pricing (Arnold et al., 2016) as well as innovative payment models with suppliers (Dorst, et al., 2015)
6. **Key resources** are the assets required to offer and deliver the previously described elements, consisting of physical, intellectual, human as well as financial resources (Osterwalder & Pigneur, 2010). Named also as **core competencies** (Arnold et al., 2016),

the necessary skills and technologies for a company to succeed under the fourth industrial revolution are constantly changing. Especially in manufacturing, the hardware-oriented production firms must invest into digital know-how and software development. Among others, this will affect human resources, shifting the role of employees from operators to controllers and problem solvers (Spath, et al., 2013).

7. **Key activities** are performed to deliver the core value proposition to the customer, for example production or problem solving (Osterwalder & Pigneur, 2010). Data and interconnectedness of objects in combination with decentralized production and control processes will enable the companies to gain new insights, requiring them to engage in novel value configuration activities (Arnold et al., 2016).
8. Some activities can be outsourced and some resources acquired outside the enterprise (Osterwalder & Pigneur, 2010)**. Key partnerships** compensate for in-house unavailable resources by providing specific expertise. Those include not only networks of companies but also customers from the perspective of collaborative partners with regards to idea sourcing, design and product development (Arnold et al., 2016).
9. The business model elements result in the **cost structure** (Osterwalder & Pigneur, 2010). Shifts in cost structure due to implementing Industry 4.0 technologies are highly individual. Generally speaking, large investments into IT infrastructure can be expected in exchange for significant cost savings, as described in section 1.2.1 (Arnold, et al., 2016).

It is without discussion that newly available technologies will have a strong impact on companies' business models. Yet, it is often unclear what areas of company's activities and to what extent would be impacted not only from the technological perspective, but also from the managerial point of view. According to an exploratory case study research, based on 69 in-depth expert interviews across Germany's 5 crucial industrial sectors (automotive, medical engineering, ICT, electrical engineering, and machine & plant engineering), the impacts Industry 4.0 technologies on business model components are industry-dependant, as demonstrated in Figure 8 (Arnold et al., 2016).

For the further analysis and relevance for the case study presented in following chapters, the focus of the following section is on *Machine and plant engineering* segment of the study (highlighted in light blue), that represented 39,1 % of the conducted interviews (Arnold et al., 2016). Figure 8 clearly illustrates that the element most strongly influenced in the context of Industrial IoT across all five researched industries is the **value proposition**, confirmed by 95 % of surveyed companies from machine and plant engineering industry. This comes as no surprise, given all that was previously stated about process optimization and the impact of technologies on the features of new smarter products and services. Second most-impacted element are the **core competencies (or key resources**) where 92 % of companies identified a significant change caused by Industry 4.0. Given the shift of central value proposition and digitalization of various technical aspects of production, the study confirms that machine and plant engineering companies are mainly concerned with facing changing workforce qualifications to keep up with the ongoing change. Across the sectors, third most impacted are the **relationships** with 90 % of machine and plant engineering interviewees stating this element significantly changed due to Industry 4.0, especially with regards to intensification.

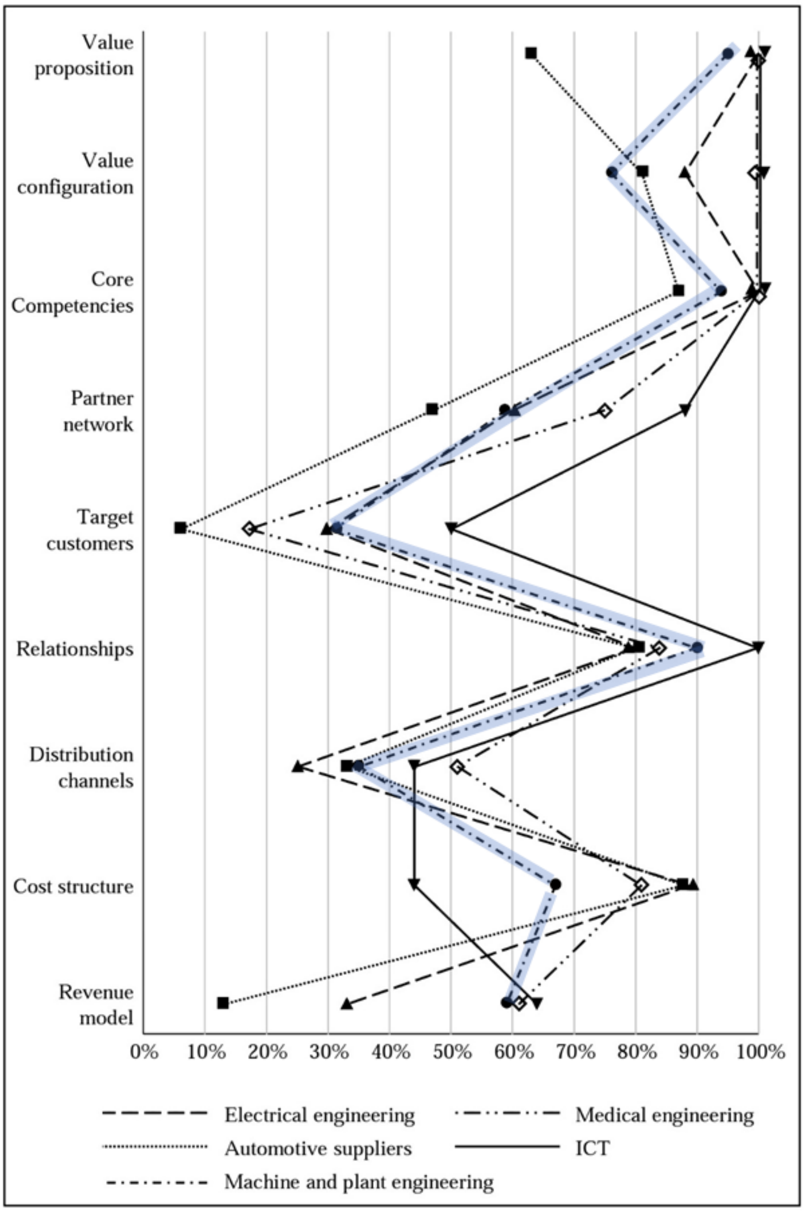

Figure 8: Relative frequency of business model element changes by industry *(Arnold, Kiel, & Voigt, 2016)*

Value configuration (representing key activities from Osterwalder's Business model canvas) was impacted at 75 % of the surveyed machine and plant engineering companies, especially in the logistics segment, followed by **Cost structure** in 65 % of cases. Interestingly, *human resource costs* are noticeably more often affected than in any other examined industry. Specifically, 28 % of surveyed machine and plant engineering companies experienced such a cost structure change due to rising costs for highly skilled employees. This can be explained by the fact that especially in this sector, manufacturers used to be focused on hardware development and production and digitalization forces them to engage in software-related activities. As a result, the manufacturers have to hire adequately skilled employees and retrain and adapt the skills of their current workforce, which is in both cases costly. This calls for new initiatives by the human resource departments, such as introducing educational frameworks that would be more interdisciplinary, for example in cooperation with relevant universities. 60 % of both **partner networks** and **revenue model** elements had to be altered due to Industry 4.0. Least impacted are **target customers** (30 %) and **distribution channels** (35 %), playing only a subordinate role for all sectors (Arnold et al., 2016).

Confirmed by a case study on 68 German SMEs by Müller et al. (2018), Industry 4.0 is expected to have a wide range of impacts on individual business model elements. The study does not approach the business model elements from the perspective of Osterwalder's Business Model Canvas, but rather from the perspective of three key business model mechanisms: value creation, value offer and value capture. Figure 9 summarizes what changes do companies expect with regards to Industry 4.0 implementation in the production, where the number in the brackets reflect the number of respondents that noted this element of a business model being influenced by the Industry 4.0 technologies. Aligned with the findings of Arnold et al. study, workforce is one of the business model areas with the highest level of concerns:

The effect of Industry 4.0 on the business model elements of manufacturing SMEs.

Value creation	Value offer	Value capture
Production equipment (26) - Productivity increases - Energy savings - Load balancing - Higher fault resistance of production equipment - Fast access to manufacturing data - Machine-health monitoring - Self-controlled production - Increased in-house production - Lower stocks - Easier production maintenance - Retrofitting of older machinery and new equipment required	Products (20) - Larger product spectrum - Less maintenance required - Versatile, flexible products (particularly machines) - Higher quality and output of the produced machines - Incorporation of manufacturing data in products and in production management systems - Products tailored to customer demands - Human-machine-interfaces	Customer groups (11) - New customer groups addressed within the B2B customer base - Both the risks and the opportunities for customer retention are intensified
Workforce (22) - Attenuation of job shortages in manufacturing, yet likely shortages in Industry 4.0-qualified personnel - Better integration of lower qualified and elderly personnel - New job profiles - New workplaces - Higher technical expertise and employee trainings required - Technology-based trainings - Support in failure recognition - Decreasing number of manufacturing jobs	Services (15) - Machine retrofitting services - Condition monitoring - Remote maintenance - Digitization services for customers - Data analytics services - Manufacturing and product simulations - Virtual product development - Engineering and product configuration services	Customer interaction (23) - Customer contact via digital platforms - Eased interaction through digital communication - Co-design and co-engineering - Higher cost transparency - Joint decision-making - Value chain integration of customers - Suppliers become more transparent to customers - Decreases in customer loyalty due to higher anonymity
Partners and suppliers (16) - Higher inter-company connectivity - Co-design of the value offers - Joint data analysis - Higher information transparency - Higher delivery reliability - Innovative partnerships - Increased virtual contact - Higher standardization required		Payment methods (12) - Digital accounting and automated invoices - Increased payment reliability - Streamlined payment documentation - Increase in subscription models, pay-per-use and pay-per-feature

Figure 9: Effect of Industry 4.0 on Business model elements (Müller et al., 2018)

2.1.2 The extent of business model innovation under Industry 4.0

Given the lacking unified definition of a business model, defining a business model innovation is an equally complex task. After comprising a simple framework on the bases of literature review of 150 publications on business model innovations, Foss and Saebi (2017) define it as *designed, novel, nontrivial changes to the key elements of a firm's business model and/or the architecture linking these elements*. This definition implies that innovation introduces new tasks that go beyond simple adaptations to the company's environment and that management takes a leading role in designing such innovation (Müller, Buliga, & Voigt, 2018).

A research on business model innovation by Koen, Bertels and Elsum (2011) formulated a unified Business model innovation typology (hereinafter as BMIT, visualized in Figure 10), classifying the business model innovation along three dimensions – technology, value network and financial hurdle rate, further described below the figure.

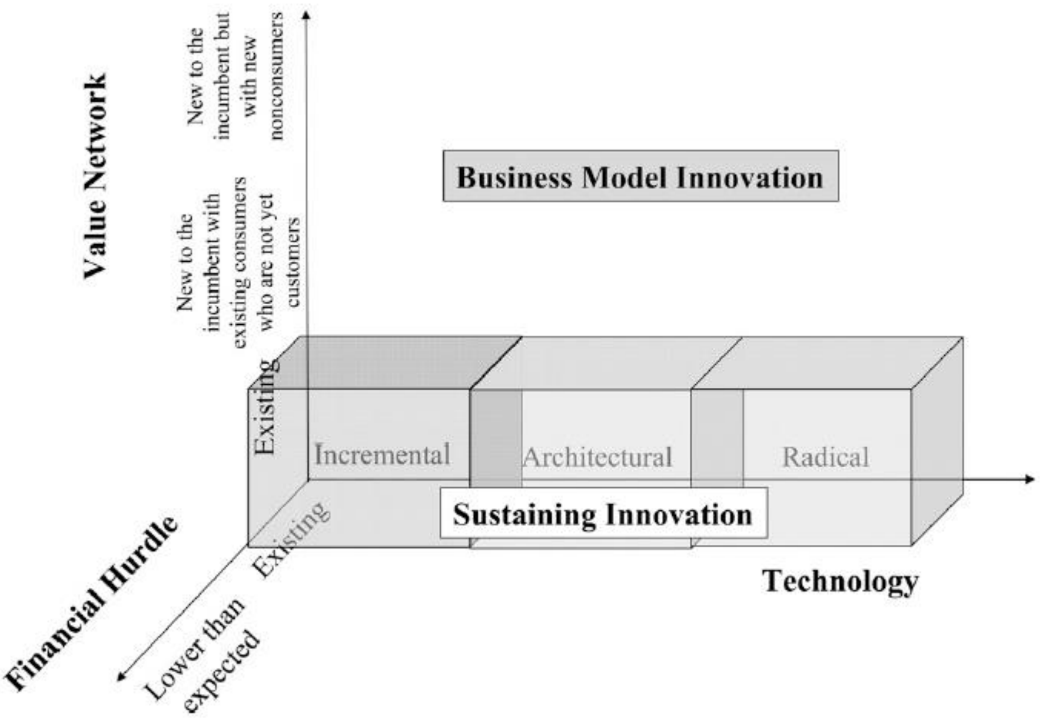

Figure 10: BMIT model (Koen et al., 2011)

1. **Technology dimension** – the BMIT further distinguishes three kinds of innovation along this dimension:
    a. **Incremental technical innovation** involves the refinement, improvement, and exploitation of existing technology, such as continuous incremental improvements of Gillette razors, allowing them to stay ahead of competitors (Muckersie, 2016).
    b. **Architectural technical innovation** involves creating new ways to integrate novel components (such as design) into existing technology. iPod is an example of such innovation – it did not incorporate any new technology, only provided a completely new design.
    c. **Radical technical innovation** introduces an entirely new technology, such as when Sony managed to completely redefine the market of portable music devices when they introduced the Walkman.

2. **Value network dimension** encompasses how a firm identifies, works with, and reacts to customers, suppliers, and competitors, embracing the unique relationships of a company across its value chain. Business model innovation often incentivises the development of a new value network. A good example of such innovation is Nestlé – their Nescafé instant coffee was distributed through the existing mass market grocery stores, a network already familiar to Nestlé thanks to their product portfolio. On the

other hand, when introducing Nespresso, the company had to develop a completely new network of high-end coffee stores to reach the desired segment. There are two sub-types of value network innovation:

   a. **Within the company's existing network**
   b. **Requiring new networks** with new components

3. **Financial hurdle rate dimension** describes the relationship of a given project's financial projections and the minimal expected return. The limitation for established companies is that the hurdle rate of a potential project might not meet the expected hurdle rates and rates of return, giving way to novel low-cost business models (Koen, Bertels, & Elsum, 2011).

Furthermore, the authors divided the innovation space into two "zones" – *sustaining innovation*, where established firms generally succeed, and *business model innovation*, where otherwise successful firms oftentimes fail. Sustaining innovation represents technological innovation (incremental, architectural as well as radical) within company's existing financial hurdle rates and existing value networks, represented by three gray cubes in Figure 10. Sustaining innovation represents the majority of product development activities.

This classification is in line with the one presented by Arnold et al. in *How industry 4.0 changes business models in different manufacturing companies* (2016). The paper takes on a less complex approach, identifying two potential types of changes of a business model, parallel to the "zones" of BMIT. On one hand, there is **radical innovation** (denoted as "Business Model Innovation" in the BMIT model), often triggered by the company's external environment, resulting in a fundamentally novel business model, oftentimes referred to simply as a "*business model innovation*". On the other hand, there is the **incremental innovation** ("Sustaining Innovation" in the BMIT model), internal-oriented slight changes in parts of the business model that do not affect the fundamental value creation architecture. Incremental business model change is also referred to as a "*business model development*" (Arnold et al., 2016).

Building on these theoretical definitions and frameworks, with regards to machine and plant engineering industry that is the most relevant for the following case study, companies in this sector comparably often only adjust current activities and are able to further run the adapted business model. In other words, under Industry 4.0 it is much more common that a machine manufacturer undergoes an incremental innovation of specific business model elements rather than a radical shift of its whole model. The hurdle is that innovation is oftentimes looked upon as an inconvenient change, since the company's management would be forced to alter their currently used models and logic, resulting in companies opting rather for smaller adjustments and incremental changes than radical business model innovations (Arnold et al., 2016).

Concluding on the key aspects of successful business models and changes of their elements in the context of Industry 4.0, Geissbauer et al. (2014) provide the following list:

- Stronger digital network with customers and partners
- Focus on providing "solution systems" rather than standalone products
- Expansion of digital services with additional customer benefits
- Efficient and safe cloud technologies

- Development and expansion of value-adding services (such as apps or data visualizing platforms)
- More direct business with end customers
- Strengthening the own position with regards to new digital players.

2.2 Manufacturing's new mandate

After defining specific elements of a business that will be most strongly impacted and innovated by Industry 4.0 technologies, the thesis will look at what specifically the manufacturing companies must master through technology-led innovation in order to remain competitive and grow further. In other words, what are the current trends and drivers initiating a change of individual business model elements. A brief overview will be based on a Framework to speed Manufacturing's Digital Business Transformation (Figure 11) as presented by Krishnan, Pujari and Sarkar (2015), combined with other exploratory studies.

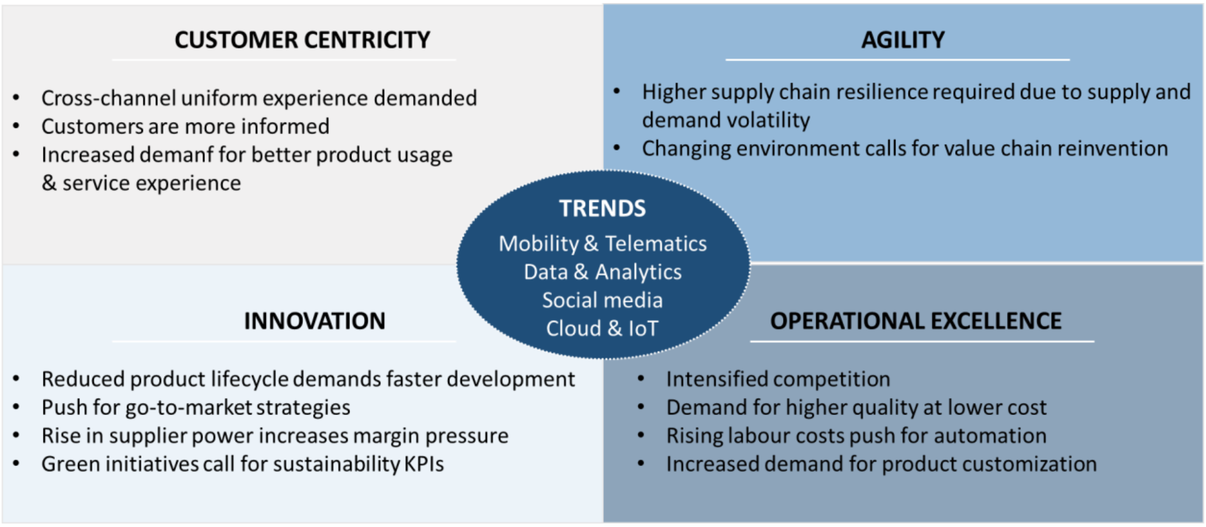

Figure 11: Four key mandates of technology-led manufacturers (derived from Krishnan et al., 2015)

Trends standing in the centre of the matrix are the drivers as well as enablers of the four key new mandates of manufacturing and are in other words the pillars of Industry 4.0, presented in 1.4.

1. **Operational excellence** = productivity and efficiency across processes and functions. Increased competition calls for higher quality at lower costs and companies must optimize its processes to be able to keep up with such a pressure. For brownfield sites, the value lies in end-to-end optimization, making use of information that is not used/captured/available today (McKinsey & Company, 2015). This push for excellence goes beyond incremental improvements in quality, productivity, and waste reduction. Embedded devices are making modern shop floors highly automated, enabling the companies to leverage the industrial IoT, enhancing flexibility as well as efficiency, allowing the firms to fulfil customers' demands for increasingly customized products with the least possible price impact (Krishnan et al., 2015; Rüßmann et al., 2015). From the business model perspective, this will have direct impact on value proposition, key resources, activities, and partnerships.

Optimizing the operations also has an employee perspective. Companies should identify key areas for improvement (such as flexibility, quality, or speed) and consider how the presented pillars of Industry 4.0 can drive desired improvements (Rüßmann et al., 2015). As aforementioned, changing workforce is one of the key concerns for machine and plant engineering companies, calling for adaption of existing roles, training as well as recruiting (Arnold et al., 2016). According to a study on manufacturing employment in Germany, it is expected that Industry 4.0 will stimulate growth in employment of up to 6 % between 2015 and 2020, with mechanical engineering growing the fastest of all industries at almost 10 % (Rüßmann et al., 2015). New skills will be required from this additional workforce.

2. **Agility** = response to internal and external changes, potentially impacting the whole model.
   With increasing complexity of supply chains, manufacturers should integrate partners through a common platform to facilitate efficient communication. Thus, adopting enabling technologies, such as mobility and cloud, is necessary (Krishnan et al., 2015). As a starting point, the businesses should assess their current assets and develop new business cases based on these. Afterwards, the firm should secure control points in the shift and understand the changing environment dynamics, engraining agility not the business's DNA (McKinsey & Company, 2015).
3. **Innovation** = initiatives leading to cost reductions and new revenue opportunities.
   As mentioned, existing manufacturers in the plant and machine industry are not very likely to develop completely new and innovative business models. Nevertheless, the challenge of innovation is relevant – manufacturers have to figure out what elements of their business to innovate and how, how to address customers' pain points, taking the trends into account. In the context of Industry 4.0, this can be viewed as digital transformation of the business – building digital capabilities, collaborating in the ecosystem (eg. through formulation of standards), managing data as a valuable asset, while efficiently managing cybersecurity (McKinsey & Company, 2015). This innovation does not tackle only the value proposition and the remaining 8 elements of a business model – recently, there is a huge pressure for a holistic approach to business, including environmental sustainability (Krishnan et al., 2015).
4. **Customer centricity** to meet the increasing customer expectations
   Müller et al. (2018) summarized the urgency for customer centricity: *"Companies will either fully retain their customers or completely lose them to technologically leading competitors."* Customers can access information and conduct transactions anywhere at any time, using mobile technology and constantly increasing their expectations. According to a recent study, online reviews impact purchasing decisions for over 93% of consumers (Fullerton, 2017). Consequently, "Customer is king" (Krishnan et al., 2015) is the motto of many companies today, especially in the context of extreme power of social media and word of mouth, where one bad review of an unsatisfied customer can spread like a wildfire if not detected and dealt with immediately. This is also aligned with the previous analysis that customer relationships are one of the three most Industry 4.0-impacted elements of a business model.

2.3 Business digitalization – how to assess it and integrate the digital?

This section will firstly focus on defining the key aspects and factors when assessing a business's level of digitalization, continuing with an overview how can a company incorporate the digital into business's everyday practice and what is the specific role of the key stakeholders.

Just as there was no universally accepted definition of a business model, such definition is lacking also in the context of digital transformation of a business. George Westerman, principal research scientist with the MIT Sloan initiative, biefly defines it as follows: "*Digital transformation is when companies use technology to radically change the performance or reach of an enterprise"* (Boulton, What is digital transformation? A necessary disruption, 2017). Solis & Littleton (2017) provide a more complex definition: *The investment in and development of new technologies, mindsets, and business and operational models to improve work and competitiveness and deliver new and relevant value for customers and employees in an ever-evolving digital economy.*

2.3.1 Digital maturity of a business

This subchapter has two key referencing points: a three-year lasting broad study conducted by MIT Sloan Management Review in cooperation with Deloitte that surveyed more than 3500 business executives from all around the world, researching on how businesses achieve digital maturity in 52 all-encompassing questions (Kane, Palmer, Phillips, Kiron, & Buckley, 2017). Second is a study "The 2017 State of Digital Transformation" by Solis & Littleton (2017) conducted on 528 executives, assessing the stages and challenges of implementing the digital transformation. These two studies take different perspectives on how to assess and effectively approach digital transformation of a company based on the real-life examples from executives, not only on theory.

Kane et al. (2017) opted for a self-assessment method of the survey participants, asking them:

"Imagine an ideal organization utilizing digital technologies and capabilities to improve processes, engage talent across organization, and drive new and value-creating business models. On a scale of 1 to 10, how close is your organization to that ideal?"

Figure 12 visualises the responses of all 3500+ participants, a sample large enough to reflect the overall situation on the market with regards to digital maturity of businesses. Digital maturity is about adapting the organization to compete effectively in an increasingly digital environment and can be seen as a *continuous and ongoing process of adaptation to a changing digital landscape.* Going beyond a simple implementation of a new technology, **digitally maturing** companies aim to align the strategy, workforce, culture, technology as well as company's structure, in order to meet the expectations of customers, partners as well as their own employees. In general, the digital initiatives are at the centre of a company's business strategy. **Digitally developing** companies do already engage in various digital initiatives, however, such actions rather support only certain business objectives, are disjoin and not the core to the business strategy. Companies assessed as **early** might be engaged in some level of digital initiatives, nevertheless, this engagement is limited, and the companies talk about digital business more than actually doing it (Kane et al., 2017).

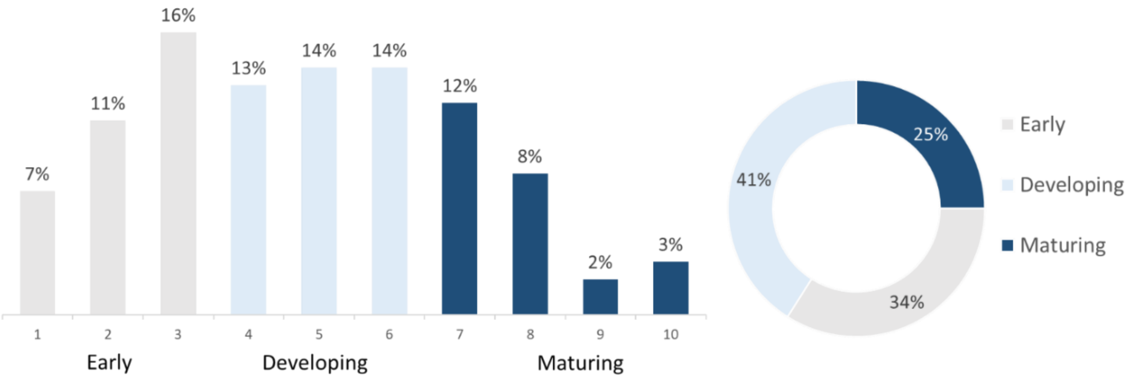

Figure 12: Digital maturity groupings (derived from Kane et al., 2017)

Interestingly, 34% of companies still evaluate themselves as being early on the process, which suggests a large place for improvement across the market. 6 questions of that survey are particularly relevant for this thesis and its key focus on the replicability of digital-related change of business and will be shortly commented.

Solis & Littleton (2017) see the way towards an ideal of digital maturity as a way of six distinct stages that together serve as a guide to purposeful transformation towards digital maturity, shown in Figure 13. The first phase "doing business as usual" corresponds with the "early" stage as presented by Kane et al. (2017), continuing in the familiar approach to customers, processes as well as technologies. "Present and active" together with "Formalized") can be seen as parallel with the "Developing" companies, slowly experimenting with various new ideas, improving crucial touchpoints and driving digital literacy, gradually becoming bolder in experimenting. The last three ("Strategic", "Converged" and "Innovative and Adaptive") together comprise the "Digitally maturing" companies, with the digital in the core of their activities, probably with a dedicated digital team, comprehensive digital strategy, transforming their processes, roles, and infrastructures.

Figure 13: Six stages of digital maturity (Solis & Littleton, 2017).

Other approach to assessing digitalization can be seen in studies published by consultancies who assess the digital maturity of the business by creating various types of matrixes, taking into account multiple variables. For example, PwC defines four categories of companies: digital novice, vertical integrator, horizontal collaborator, digital champion (Geissbauer, et al., 2014).

Kane et al. (2017) identified strategy as the key when implementing the digital into a business, denoted by 20 % of respondents as the most significant success factor, as shown in Figure 14. Additionally, 40 % of respondents stated their organization needs to improve digital strategy and innovation (Kane et al., 2017). Such strategy should not be focused primarily on technology but should be truly customer-centric in order to keep up with the changing buying behaviours and environment (Solis & Littleton, 2017). Leadership, supportive company culture, and commitment followed in the ranking. Surprisingly, existing digital knowledge as well as technology were stated by less than 15% of respondents cumulatively, showing that the success of a digital implementation is much more in the hands of management and their skills than dependant on the current technological capabilities of a company. Correspondingly, "cultivating a strong digital business culture" together with "mandating from management" and "motivating employees to embrace digital business opportunities" are the key drivers of a business's digitalization.

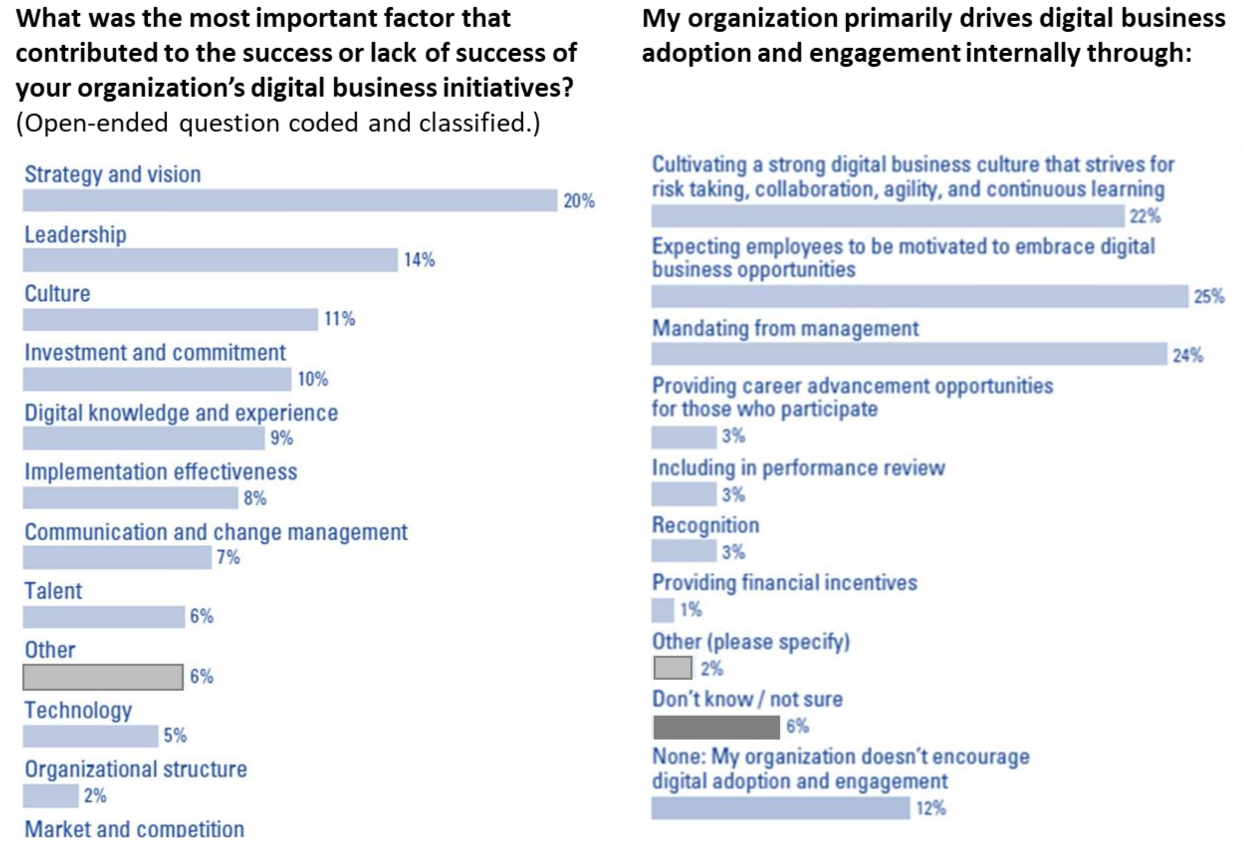

Figure 14: Success factors and digital business drivers (Kane et al., 2017, questions 10 & 16)

Figure 15 summarizes two questions aiming at potential management mistakes and areas for approach alternations when it comes to digitalizing a company. The fact that 22 % of respondents stated "lack of understanding of digital technologies" as the most crucial reason clearly shows that even though the business itself does not have to be excellent from the technological point of view (see Figure 14), the managers initiating the change should have a very extensive knowledge not only about the technologies they are trying to implement, but also about their impacts.

Figure 15: Managerial mistakes and potential improvements for digitalization (Kane et al., 2017, questions 14 & 41)

Additionally, Figure 15 shows what should be improved for the companies to move forward towards higher digital maturity. Corresponding with the previous figures, improving strategy and innovation was mentioned by 37% of respondents. Worth noticing is the second most-mentioned factor, developing better talent model, mentioned by 23% of the surveyed. Along the same logic of execution challenges from the company-wide perspective, according to Solis & Littleton (2017), three most common challenges for digital transformation are: lacking digital talent and expertise (31,4 %), followed by the fact that digital transformation is seen as a cost rather than an investment, denoted by 30,9 % of companies and company culture mentioned by 30,5 % of respondents. This finding is in line with the previous analysis that showed the talent and human resources will be the crucial success factor especially in machine engineering industry. Yet, it is interesting to realize that indeed almost a quarter of the surveyed companies questioned sees this as the top turning point for their companies in the future (Kane et al., 2017).

The following graphic taps deeper into the question of talent sourcing, that seems to play a crucial role when digitalizing a business. As shown in Figure 16, developing internal talent is the most common practice for digitally transforming companies (Kane et al., 2017. In line with the previous analysis, this finding proves that companies will have to devote significant resources (both time and money) to improve the skills of their employees. Solis & Littleton (2017) found out that 62 % of companies are introducing new training programmes to make their employees more digitally literate. With regards to attracting talent from the outside, recruiting new employees shows almost the same scores as hiring external talent and consultants. This proves the way companies work with employees will indeed shift into more task-related and flexible projects, especially thanks to cloud and mobile technologies (Boulton, What is digital transformation? A necessary disruption, 2017). Concluding with the most sought-for attributes of the key talents, leaders, and managers, it seems that willingness to experiment, take on risks as well as challenges while being confident at leading such activities will be the key attributes of the future leaders. This should be also reflected in the company's talent sourcing activities.

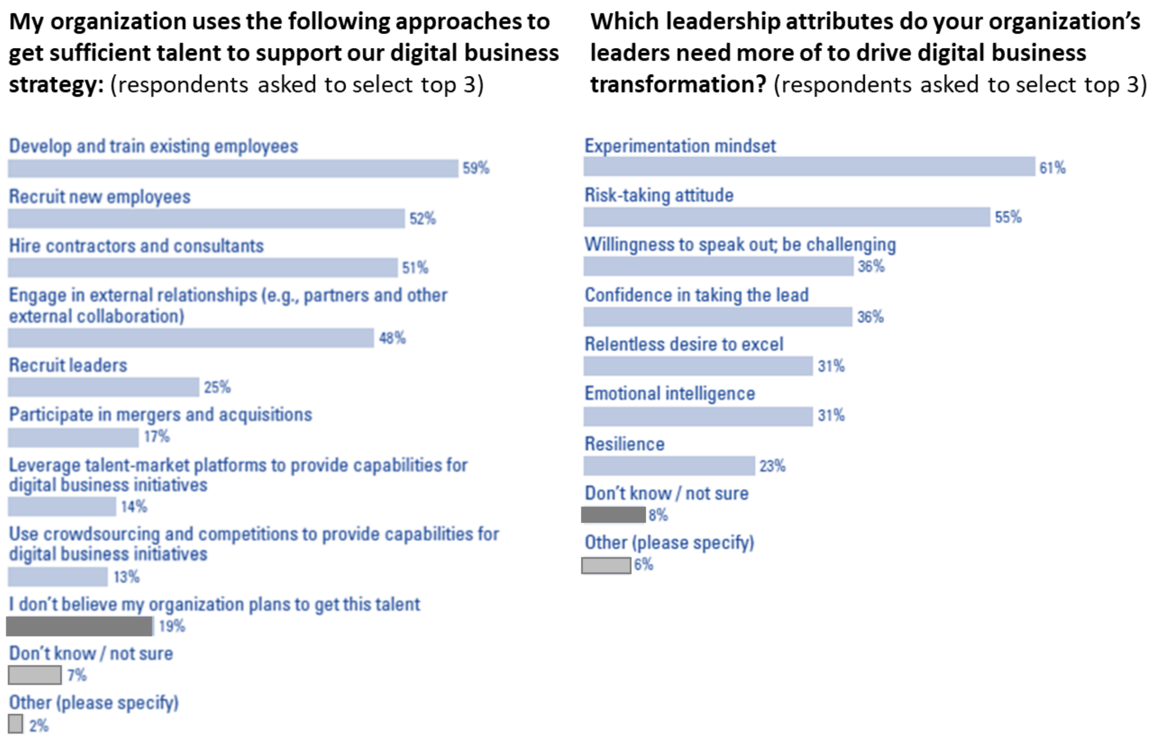

Figure 16: Talent sourcing and leadership attributes for digitalized businesses (Kane et al., 2017, questions 25 & 39)

To summarize, digitally equipped businesses and their leaders with clear strategy and strong drive towards creating an experiential digital business culture are the key for a successful cultivation of a digital strategy (Boulton, Why companies struggle to cultivate digital strategies, 2017). Such strategy should be enterprise-wide (Solis & Littleton, 2017), not focused too closely primarily on technology (a "technology-first approach") but rather customer-focused (Shein, 2017) as well as employee-focused (Kane et al., 2017). With regards to understanding customers, companies should map their customers' journey in detail to define and prioritize the most relevant digital transformation strategies and to avoid investments into technologies that would not bring any value to the business nor to the customers (Solis & Littleton, 2017).

Through their leaders, the companies must evolve a certain level of digital literacy and a corresponding company culture (Solis & Littleton, 2017). Experimenting mindset is an important part of the leaders and their businesses, potentially scaling small digital experiments into enterprise-wide initiatives (Kane et al., 2017). Further confirmed by Solis and Littleton (2017), *many company cultures are risk-averse, and their leaders do not feel a sense of urgency to compete differently, despite global consumers' embracing smart telephones and the Internet for more than a decade.* Additionally, the biggest hurdle on the way towards digital maturity and effective customer centricity are politics, egos and fear. From the perspective of Industry 4.0 functionalities, a survey by Bosch Software Innovations (2015) identified that managers are looking for such digital solutions, which enhance transparency in the production process. Specifically, the most relevant functionalities are monitoring of deviations (such as sending automated notifications), visualizing of production data (gathered through different systems and databases) and providing context-based and relevant information (such as suggesting solutions in case of a machine downtime). These functions provide managers with better insights into the plant's manufacturing processes, allowing them to respond promptly to losses or even prevent them from happening, enabling the production to cut time and costs (Bosch Software Innovations, 2015).

Moreover, the leaders' vision should go beyond their corporate career, if they want to push the company towards greater digital maturity. One of the key findings of Solis and Littleton's study on The State of Digital Transformation (2017) states that: *Often when companies do invest in digital-transformation initiatives, they are viewed as short-term cost centres with very limited budgets and other resources, not the long-term investments they must be for long-term success.* Agreed upon by Boulton (2017) as well as Kane et al. (2017), companies aiming to become digitally mature should "play the long game", looking out five years or more while fostering cross-departmental and -functional collaboration and teams.

2.3.2 Integrating the digital to achieve business objectives

Under Industry 4.0, information in manufacturing serves as a value creator, a trigger that can uncover new ways of doing business and new ways of approaching customers. However, the physical perspective of production is still a crucial part of the value chain. Companies must find ways to integrate the digital and the physical to operate and further grow their business. Manufacturing value chain – t*he series and sequence of activities through which an organization transforms inputs into outputs and ultimately sells, delivers and continuously supports those outputs for customers* (Sniderman et al., 2016) – is focused on the production of physical objects, from design and development to manufacture, sale and related service. Industry 4.0 technologies can accelerate different parts of the value chain and it is up to the company, where the focus would be directed.

A report by Deloitte on manufacturing ecosystems denotes that there are two business imperatives for manufacturers: to operate and to grow their business. As illustrated in Figure 17, within these two imperatives the authors identified 4 core business objectives, some addressable through traditional technologies, some through Industry 4.0 (Sniderman et al., 2016):

From the perspective of <u>business operations</u>:

1. **Productivity improvements** – regarding decreasing costs from different parts of the manufacturing value chain as well as regarding asset utilization and maximizing OEE;
2. **Risk reduction –** with regards to material and inventory sufficiency, efficient warranty management or geographic risks;

From the perspective of business growth:

3. **Incremental revenue** – identifying growth opportunities within the core business and strengthening the customer integration;
4. **New revenue** – expanding the business (geographically, through new products and offerings or through M&A.

Figure 17: Industry 4.0 and business objectives (Sinderman et al., 2016)

When considering implementation of the digital into business operations, looking at the potential of digital with regards to productivity improvements and risk reduction, there are three key areas where the digital will have an immediate impact (Sniderman et al., 2016):

- **Planning** – predicting changes and responding in real time
- **Factory** – creating a digital link between operations and IT
- **Support** – automating and scaling aftermarket operations

From the business-growth point of view, including incremental as well as new revenues, the digital will have a strong impact throughout the whole manufacturing value chain, affecting the following (Sniderman et al., 2016):

- **Engineers** – various Industry 4.0 technologies are accelerating innovation and design cycles from the very beginning of the manufacturing value chain, where the digital can improve the design cycle already in the R&D phase. Rapid prototyping combined with newly available technologies is speeding up the design process, significantly reducing time to market.

Moreover, manufacturability can be optimized using advanced technologies, evaluating product design options based on the assembly process. Using data from simulated usage can anticipate design flaws and correct them, leading to a better link between the design and product intelligence. Virtual simulations and augmented reality in the form of virtual product development and testing can drive improved engineering effectiveness.

One trend under this group of applications is the open source innovation or crowdsourcing, allowing freelancers and enthusiasts to improve products through open sharing of intellectual property.

- **Products** – the impact of digital with regards to creating or augmenting smart products and services, bringing additional revenues to the company. Additive manufacturing, advanced computer numerical control, robotics and other technologies will cause major transformations, allowing the development of completely new offerings. Cost-effective mass customization and extensive product innovations will create new service formats.

  Digitalization of the product and service portfolio is the key to a sustainable corporate success – products that are primarily mechanical today will be enriched by digital solutions and connectivity. Companies with highly digitalized portfolio are said to have achieved above-average growth in the past years and are likely to be the fastest-growing for the upcoming years. In Germany, 27 % of manufacturing companies showed high level of product digitalization in 2015, assuming that high portfolio digitalization will reach 75% in 2020, enabling greater customization at competitive cost level, even at batch sizes of one (Geissbauer et al., 2014).

  Companies can make already existing products smarter by adding sensors and connectivity, thus improving product performance and its OEE, alternatively its safety; improving the user experience by connecting products to mobile applications or by adding advanced materials to improve performance. Products can also send out automated notifications (such as via e-mail or via a user interface of an application) in case of deviations from their optimal setting, informing the user as well as the engineers about a necessity of an action (Bosch Software Innovations, 2015).

  Moreover, data generated through existing business operations from smart technologies can be offered as a product or service, potentially creating a completely new offering.

- **Customers** – information gathered from intelligent products enable manufacturers to better understand their customers, connecting and integrating them in new ways.

  Firstly, Industry 4.0 has the potential to market and sell products more intelligently – using gathered data to drive customer intelligence, develop smart pricing strategies based on both customer as well as inventory data; predicting the need for spare parts.

  Secondly, the company can improve the aftermarket experience and asset utilization by using data to track failures and product conditions, predicting customers' needs and maximizing uptime of an asset. Additionally, the user experience can be enhanced through sensor-enabled apps and dashboards.

  Third application with regards to customers would be the optimization of performance and distribution, using the gathered data to place the right products at the right time with the right dealers, allowing better inventory management, potentially tracking the usage, performance as well as location of the products. (Sniderman et al., 2016):

On top of that, according to a PwC study with 235 German industrial companies, half of the surveyed companies anticipates double-digit revenue growth between 2015 and 2020 due to the intensified digitalization of their product and service portfolio, an average of 2,5% growth per annum. Specifically, manufacturing and engineering companies expect to cumulatively grow by 13,2% between 2015 and 2020 (Geissbauer et al., 2014).

2.4 Data relevance for business models under Industry 4.0

Data is the new most important raw material transforming industrial productions worldwide with ever-increasing importance (McKinsey & Company, 2015; CGI, 2017; Kagermann, et al., 2013). However, due to the unprecedented amounts of data available through ubiquitous sensors and actuators, it is oftentimes rather challenging for the managers to identify the most relevant data (Lee & Lee, 2015) with the biggest potential to be turned into useful insights (Coleman, et al., 2017).

Integrated analysis and use of data are the key capabilities for companies on the way to implement Industry 4.0 technologies. Data is standing at the centre of Industry 4.0 business models with increasing importance (Burmeister, Piller, & Lüttgens, 2016). It is estimated the importance of data will rise significantly, from 40% of companies with a great importance of data in 2015 to 87% in 2020 (Geissbauer et al., 2014). Integrated analysis of data enables the companies to examine processes in an integrated manner, resulting in process optimization. Obtaining useful insights from the large amounts of production data leads to increasing the quality and reliability of delivered products, since manufacturers can examine hundreds of parameters that influence the quality of the product (Küpper, Kuhlmann, Köcher, Dauner, & Burggräf, 2016) and can thus detect and disqualify faulty parts early in the manufacturing process.. Moreover, data analysis and use are decisive factors for business model innovations, customer interaction and most importantly, for increase of a company's profitability (Geissbauer et al., 2014).

Machine data (cycle times, malfunctions and failure rate, OEE, operating status and utilization rate) and process data (measured process results) were identified as the most relevant data to be gathered through Industry 4.0 technologies, aligned with the aforementioned KPIs – maximizing the output, minimizing the downtime. Other categories of Industry 4.0 relevant data are related to orders and employees (Bosch Software Innovations, 2015).

Specifically, the most important data competencies are (Geissbauer et al., 2014):

- Efficient exchange of data along the own value chain
- Clear labels (bar codes, RFID)
- Use of real-time data to manage products
- Use and exchange of data with cooperation partners
- Analysis of large data amounts in real time
- Generating additional data (for example with enhanced sensor technology).

2.5 Metrics to measure digital transformation & relevant KPIs

Clearly, almost every company nowadays acknowledges the importance of the digital for their future business operations and growth. Yet, based on the literature review conducted, it seems that companies are oftentimes struggling how to measure the digital transformation.

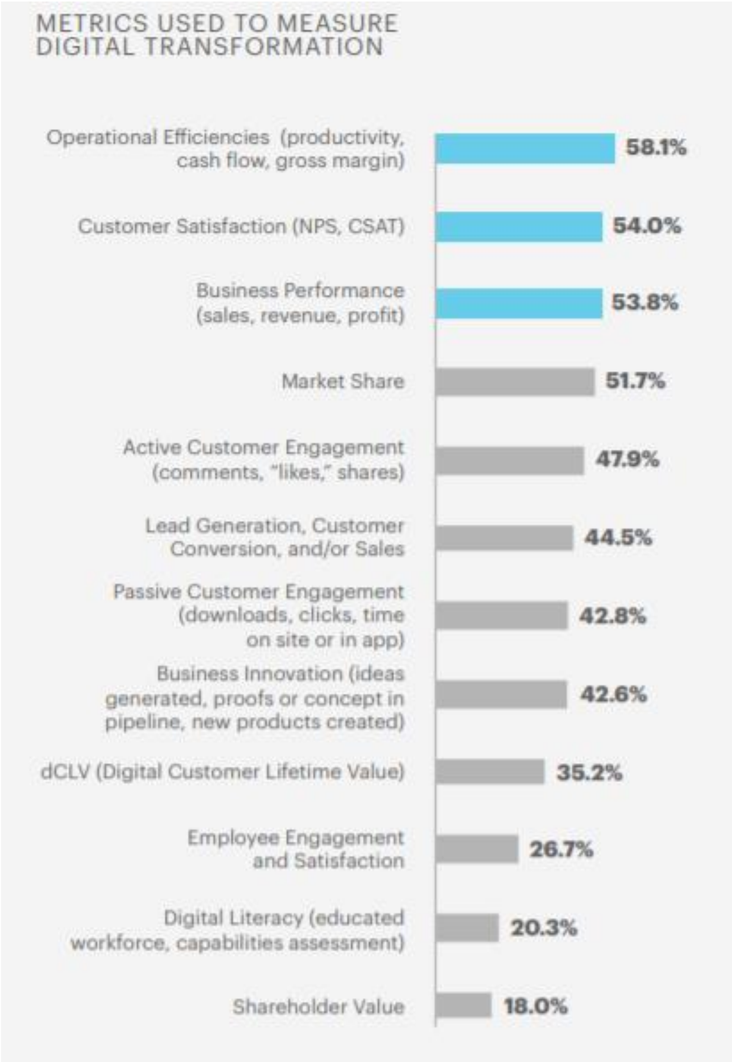

Figure 18: Metrics to measure digital transformation (Solis & Littleton, 2017)

Solis & Littleton (2017) addressed this issue in their fourth consecutive report on the stage of digital transformation. Figure 18 shows 12 most relevant metrics used to measure digital transformation. Corresponding with the Industry 4.0 drivers introduced in the first chapter, on top of the list stay "Operational Efficiencies" relevant for over 58 % of respondents – productivity, cash flow and gross margins. "Customer satisfaction" follows with 54 %, expressed by Net Promoter Score (NPS) among others. NPS is an *index ranging from -100 to 100 that measures the willingness of customers to recommend a company's products or services to others* (Medallia.com, 2018). Looking at the overall satisfaction with a product or a service, it measures customer experience, loyalty and predicts business growth (netpromoter.com, 2017). Third most important measure identified was "business performance" – in terms of sales, revenues and profit are seen as one of the key metrics by 53,8 % of respondents. The figure also clearly shows that customer-related metrics are truly crucial when assessing digital transformation of a business – 6 of the metrics listed are directly referring to the company-customer relationship. Ultimately, digital transformation initiatives must have a clear link to ROI – 8 of the top 12 metrics shown in Figure 18 are directly linked to ROI.

Further elaboration is necessary with regards to the first point in the previous figure, operational efficiencies. According to a study conducted by Bosch Software Innovations in 2015 on a sample of 181 participants from manufacturing companies across DACH region, there are three most relevant sets operations-related KPIs that a company wants to address when implementing Industry 4.0 technologies, aligned with the aforementioned drivers of Industry 4.0 (Bosch Software Innovations, 2015):

1. **Costs of maintenance and repair** was identified as the most important KPI to be followed when implementing Industry 4.0, with 66 % of respondents assigning crucial importance to this factor;
2. **Failure costs** identified by 60 % of the surveyed as another crucial identificatory;
3. Improved **Production output** was mentioned by 50 %. Figure 19 shows specifically for what OEE losses the respondents saw the greatest leverage of Industry 4.0 technologies. Technical downtime was named as the most leverageable one, followed by performance losses (such as cycle-time losses) and organizational downtime (such as shortages of materials).

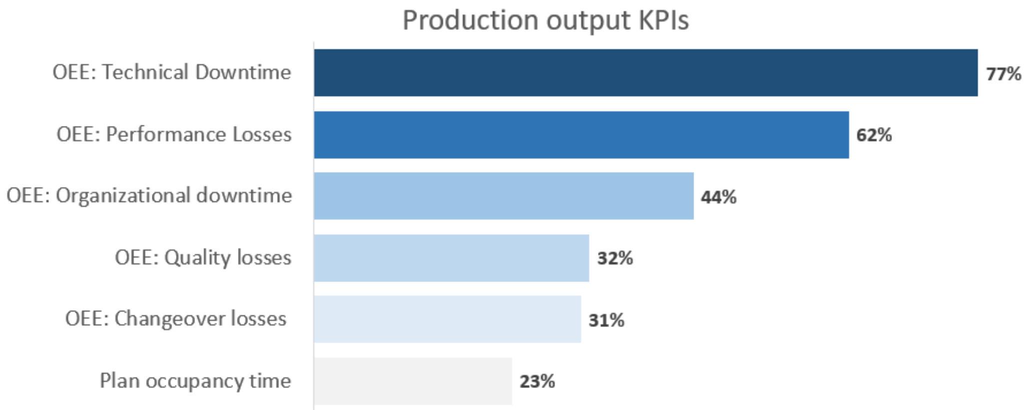

Figure 19: KPIs for production output improvements under Industry 4.0 (derived from Bosch Software Innovations, 2015)

Other KPIs mentioned in the survey were Logistic costs (by 31% of respondents), inventory (30%), direct labour costs (12%), indirect labour costs (9%) and fixed costs from investments (9%).

To summarize the findings of this chapter from the managerial perspective, adapting manufacturing business models to the novel Industry 4.0 technologies will bring 4 key challenges (Arnold, 2016). Those have one thing in common – they all start and end with the customers and their increasing demands:

1. **Workforce**. Their tasks will shift from operators and product-makers to controllers and problem-solvers. Enhanced focus is on ongoing education and interconnecting the companies with educational institutions will become a necessity, in order to keep up with the constantly-changing customer behaviours and increasing requirements.

2. **Partner networks**. Finding the right partners to compensate for the missing skills and resources, adding agility and flexibility to the business is crucial. Especially with regards to IT suppliers and customers, serving as collaborative key partners.
3. **Data security**. Protecting production systems from unauthorized access, data manipulation and destruction, combined with the power of data as a new key resource, will increasingly gain importance. This is highly relevant not only from the inter-company perspective, but also with regards to the partners and most importantly, customers.
4. **Financials**. Industry 4.0 brings great opportunities in terms of cost savings, efficiency increases and even potentially novel income source. Those new sources can be thus used to finance all the necessary investments into IT facilities and skills that are crucial for the future success of any manufacturer. Managers should not feel discouraged by the fact that the upfront investments are rather large – quite on the contrary, the potential future benefits should not be underestimated. Among the most relevant investment-assessing criteria is the customer perspective, customer experience and journey and the added value that such innovation will bring to them.

3. INDUSTRY 4.0 – STATUS QUO

To put the trends and current development into the context of real business practice, this chapter presents specific examples and benchmarks of successful implementations of Industry 4.0 technologies. Focus lies mostly on manufacturing companies (mechanical, chemical, automotive, or healthcare) who shifted towards digital technologies, rather than on "born-digitals" or pure service providers. Put into the framework of the 9 abovementioned Industry 4.0 pillars, some of the benchmarking business cases focus exclusively on one part of the business's operations, while other success stories, such as Mercedes or General Electric, are examples that incorporate digital transformations in more pillars, affecting more building blocks of their business model at once.

Interestingly, the literature review did not provide the author with examples of a fully digitally transformed business model of an existing manufacturing company. Such examples were not found after discussions with consultants from Deloitte, PwC and BCG either, suggesting that such business model transformations are still at their beginning and that companies are only now starting to implement Industry 4.0 technologies in a complex all-business-encompassing way.

3.1 Implementing Industry 4.0 pillars

Given the speed of change and rapid pace of technological progress, there are many success stories that could fit into the presented framework. Each of the 9 pillars will be put into context by a few showcase examples of successful implementation to briefly describe the status quo in manufacturing. Those cases were chosen in a manner that they are either directly relatable to the case study presented in the following chapter or have potential implications for the analysed company in the future.

3.1.1 Big Data and analytics

Data, if used well, are the fuel of digitalization and can be used to increase the company's efficiency, improve customer relations, decrease costs as well as drive new business opportunities. Pivotal for such data-driven success is consolidation, centralization, and standardization of the data.

First example is Accuride – a leading global manufacturer of wheels, who started its journey towards digitalization by replacing inefficient paper-based performance tracking processes from their production facilities. By standardizing systems and processes and using a single cloud platform, the company was able to clean and utilize the data, ensure remote access and increase the process transparency (Ezell & Swanson, 2017). Data consolidation had a strong positive impact on operations, sales as well as supply chain. The system automatically collects real-time operational data and projects them to an OEE dashboard, generating automated notifications informing about machine's downtime. This caused the company to switch from the old reactive more into data-driven proactive approach, speeding up innovation. In combination with sales as well as supplier data and lean manufacturing, the company was able to reduce lead times by 30 - 40 % while improving customer satisfaction (Bishop, 2016).

Automotive has been widely impacted by digitalization. Currently, vehicles are as much as 40 % software and 60 % hardware (Ezell & Swanson, 2017). Mercedes-AMG started leveraging huge volumes of data collected from their embedded products, leading to waste reduction and increase in efficiency (Krishan et al., 2015). Moreover, they have piloted a quality assurance platform based on historical test data and predictive analysis, leading to real-time optimization of their testing capacity (Overby, 2014). Additionally, Mercedes Benz can connect all its factories worldwide and get visibility down to the sensor level. This means that a lead plant for compact cars, for example, can access data from other compact car plants and assist with any necessary troubleshooting or even reprogram robots (Gill, 2017). Interconnectivity is an important aspect of the industrial IoT and will be mentioned further. Another example from the automotive industry is Daimler – through machine data evaluation the car manufacturer can detect deviations and irregularities early in the production process. This allowed them to react fast, alter relevant processes, leading to reduced error rate, improved quality of the produce and decreased costs (Infineon, 2018).

From the consumer electronics industry, Lenovo uses analytics to enhance customer satisfaction and loyalty. Installing telemetry software on customer machines, with the customers' consent, allowed Lenovo to gather granular information about the user's behaviour and usage (Ransbotham & Kiron, 2018). Through data gathering from various streams, including social media, Lenovo can engage in one-to-one customer relationships, providing them with a high potential level of personalisation and highly relevant data for an effective marketing campaign (Krishan et al., 2015). Johnson & Johnson, active in medical devices industry as well as pharmaceuticals and FMCG, collects data across its 65 countries of operations. Their cloud-enabled platform facilitates real-time data analysis at scale, allowing the company to identify patterns and relationships and gaining relevant insights (Ezell & Swanson, 2017). Eventually, Johnson & Johnson was able to significantly increase their operational efficiency by decreasing provisioning times from three months to less than an hour (Intel.com, 2016).

Big data can also help in terms of the abovementioned predictive maintenance. An example from the chemical industry is BASF Corporation – the company developed an early-warning system, signalling the need for maintenance of individual parts of the production plant. Thanks to the analysis of both real-time as well as historical data, BASF can identify upfront where and when there will be a need for maintenance (Infineon, 2018), allowing them to avoid unexpected downtime. Moreover, digitalization enabled BASF to create an integrated supply chain with their customers, allowing them to respond to their client's needs faster (BASF Global, 2018). Another successful example is General Electric. By clustering information from the operating environment, the company was able to realize that the efficiency of a jet engine was dependant on the geographical location, more specifically, on the weather conditions. Data analysis showed that planes operating in extreme environments, such as the Middle East, were facing clogged engines and thus oftentimes needed unexpected maintenance. This insight enabled alternations to the operation routines, such as higher frequency of engine washing, leading in turn into significant cost savings in jet fuel due to improved efficiency of the engines (Winig, 2016).

An interesting example in terms of real-time management of huge amounts of data comes from Boeing. The aircraft manufacturer offers a tool to commercial airlines called Airplane Health Management (AHM) that gathers all in-flight airplane information and transmits it in real time (Ezell & Swanson, 2017). To illustrate complexity of such a tool – sensors on one aircraft cover more than 300 000 parameters, including engine data. An average commercial flight creates 20 terabytes of data *per engine per hour* of flight (Pohl, 2015). Such amount of data needs to be turned into meaningful insights – AHM offers three basic types of decision support – real-time fault management & diagnosis, customer-specific alerting and analysis and performance monitoring, ensuring fuel efficiency and flight optimization (Boeing Edge, 2012). For example, predictive analysis can turn data into actionable information for the technician crew on land (Pohl, 2015).

Data also give way to mass customization, where each product at the end of the supply chain can have unique characteristics, defined by the customer (Almada-Lobo, 2016). Companies can tailor their products to specific customer's needs – a renowned example is Mini, the UK-turned-German car manufacturer. The car configurator on their website allows the buyers to design their car not only in terms of colour of the body of the vehicle and basic interior changes, but also in terms of lights, mirror shapes and caps, rooftop (whether with a print, plain or even a panoramic sunroof), adding stripes and other decors to the body and other personalization areas (Mini USA, 2018).

3.1.2 Autonomous robots

As noted by Gill (2017): *"there are many assembly processes that can benefit by marrying the cognitive superiority of humans with the robot's greater endurance and reliability"*. Mercedes is again an example here – specifically, their double-clutch transmission assembly. The traditional manual assembly process is rather complicated and tedious, requiring handling of heavy workpieces. With the newest generation of robots, that can sense and assess their environment, a side-by-side collaboration is possible. The robot manipulates with the load and ensures positional integrity, the human's task is to control a perfect alignment of the gears of the clutch (Gill, 2017).

One of the key players in the area of industrial robots is ABB, a true pioneer in the industry, who sees the industrial systems to move from automated towards autonomous. Automated robots and systems are in place for normal operations – to steadily control the state of the production, sense it, analyse it and act on it. Autonomous robots, on the other hand, are able to manage and engage in complete plant lifecycles – such systems have the ability to understand the perceived state and solve the problems (Husain, 2017). ABB partners with various start-ups to leverage their complementary knowledge to develop automated solutions. For example, in cooperation with Vicarious, the company introduced YuMi – a "*collaborative, dual arm, small parts assembly robot solution that includes flexible hands, parts feeding systems, camera-based part location and state-of-the-art robot control*" (ABB.com, 2018). The abbreviation stands for "you and me" – YuMi is human-sized, with extensive safety features and ability to cease operations in milliseconds if necessary, so that it can work side-by-side with human workers without the traditional need for cages or fencing. ABB is also trying to show the width of potential usage of autonomous robots to the public in engaging and unusual ways. In September 2017, the company took YuMi to Teatro Verdi in Pisa, Italy, to conduct an orchestra, starring the world-famous tenor, Andrea Bocelli. Director of the orchestra helped YuMi to prepare for the performance – YuMi's sophisticated technology allowed the robot to fully reproduce the gestural nuances of a human conductor (ABB.com, 2017). YuMi has been also implemented into real industrial operations – Clarion, Japan-based manufacturer of in-vehicle devices, integrated YuMi into its assembly line in Malaysia (Clarion Malaysia, 2016).

The increasing pressure on flexibility and mobility of a smart factory is in the core of operations of KUKA, mobile robot manufacturer. With focus on internal logistics, the company offers a wide portfolio of solutions, from fully automated to manually movable. Their automated devices do not need any navigation markings (such as lines on the floor, magnets), are able to seamlessly cooperate with humans, increasing the CPS efficiency. Other models, such as flexFELLOW, can be easily moved manually to other locations and excel in flexibility (KUKA.com, 2016). Successful integration of KUKA robots into the assembly line comes from BMW's plant in Munich where, among others, the robot-based systems enabled reduction of interruptions in the casting process from 180 minutes to only 30 minutes (KUKA.com, 2017).

Automated robots capable of robot-human interaction are still looked upon with concerns about safety, reliability as well as financial demands. Thus, it is crucial that various research and educational institutions facilitate the interaction of local companies as well as public with the new technologies and serve at the same time as a networking and knowledge-sharing platform. CIIRC at Czech Technical University in Prague represents a great example of such initiatives – their experimental concept called Testbed for Industry 4.0 enables testing of innovative solutions and processes for smart factories. Moreover, the visitors can see autonomous robots in action, such as the abovementioned KUKA flexFELLOW and try tools of virtual and augmented reality to gain better understanding of potential implementations (CIIRC, 2018).

3.1.3 Simulations

Especially in the engineering phase, the ability to make use of 3D simulations of products as well as production processes allows the companies to increase its flexibility and speed of product development while significantly decreasing costs.

General Electric is implementing digital twinning for various parts it supplies to power plants, wind farms as well as electrical grids. Their operating system Predix creates individualized software representations of turbines, jet engines, power plants and other parts of industrial equipment. These digital twins utilize data coming from similar devices as the one they are currently representing, leading to better performance of those devices (Ezell & Swanson, 2017). This technique enables development of real-time digital simulation models, using sensors, high performance computing and signal aggregation. Such models enable the plant operators to understand the condition of specific parts, optimize power, determine the right time for machinery maintenance as well as simulate various conditions to test the potential impact on the plant (Sniderman et al., 2016). This initiative aims to sell engines and turbines as a software service, orchestrating a digital transformation of the business activities (Boulton, What is digital transformation? A necessary disruption, 2017).

Siemens has realized that there are too many variations to be efficiently physically tested and developed a platform that connects various testing tools. This enables the German manufacturer to generate digital originals so precise that they can be easily replicated in the real world, once they pass the virtual testing. This way the company can test individual parts to be mounted into various bigger systems as well as the large systems themselves. Moreover, the system collects status and performance data from physical counterparts, enabling the company to predict how the machine will operate in the future, indicating potential failures. Eventually, Siemens aims to develop a platform for the customers to run the tests and simulations in their own applications (Rüth, 2017).

Increasing impact of those technologies is observable in automotive industry. Ford, for example, estimates that its use of rapid prototyping during vehicle design could save weeks of time and result in the new models being brought to the markets months earlier, since it usually takes 4 to 6 weeks to create a prototype using traditional methods (Sniderman et al., 2016). Mercedes uses digital simulations to run digital crash tests, simulating the crash process and its impact on a computer, lowering costs and shortening time to market (Gill, 2017). Similarly, General Motors transformed its global IT infrastructure into an enterprise data centre. The crash-test simulations that are run there save the company each time $350.000 it otherwise takes to conduct a physical crash test (Glowik, Mentuccia, & Tamietti, 2014).

3.1.4 Horizontal and vertical system integration

Broader integration of industrial supply chains is facilitated through cloud computing platforms. Those enable the companies to create an environment for cooperation throughout the whole value chain, integrate multiple IT platforms, increase scale and decrease the costs. A success story of a fully-integrated cloud-enabled supply chain comes from Pfizer, a global player in the drug production. As one of the cloud-integration pioneers, Pfizer asked all its 500 suppliers and external providers to implement a "cloud-based common-information-exchange framework" (Bhasin, Mooraj, O'Riordan, Schmidt, & Wickramasing, 2013) their IT systems. Such virtualization of supply chain insulates Pfizer from potential physical shifts and enables faster response to daily situations as well as unexpected disruptions. Moreover, such integration enhanced the traceability of their products, bringing vital business insights. Pfizer insisted that all the partners adopt identical common framework to ensure smooth flow of information and device-independency, enabling them to "plug in or unplug anyone" (Taylor, 2012) and thus facilitating further expansion.

Another example of such integration is partnership of P&G and Walmart – both companies struggled with fluctuations in demand from the price-driven end consumers, causing P&G serious problems with fluctuations in their material orders from their suppliers (Harsono, 2017). They opted for loose vertical integration of information and product supply chains, where P&G gained exclusivity for supplying specific categories of products. Integrating their backend information systems allowed them to align and optimize the inventory across stores. This lead to increase in sales by 8 times (Smartsheet.com, 2017)

Customers stand on the other side of the supply chain integration – for example with Mercedes-Benz. The car manufacturer, who is one of the digital leaders in the industry, introduced initiatives such as Smart Sales and Smart Service. Thanks to a customer portal

"Mercedes Me", customers can connect with the brand, potentially avoid workshop visits and get online updates for specific vehicle equipment via the platform (Gill, 2017). As an interesting add-on, Mercedes has recently announced that selected models can now be connected to Amazon Echo or Google Home. This enables the car owners to connect their vehicle, navigation services, wearables, and their smart household into an intelligent ecosystem of modern convenience (Daimler, 2017).

An example of excellent vertical integration is Dell, whose success story comes already from late 1990's when the company pioneered in the vertical "virtual integration". Its founder, Michael Dell, decided to eliminate and outsource activities they were not great at – such as software (supplied by Microsoft) and, surprisingly, retail reselling (Smartsheet.com, 2017). Instead, he created a "tightly coordinated supply chain" demanding the highest quality from its partners (The Economist, 2009). Since its inception, the company has been focusing on their key competencies (R&D, assembly and delivery of final products) and direct relationships with the customers. This enabled Dell to eliminate the resellers' margins, keep only a small inventory, build products-to-order, and deliver fast (Dell, Magretta, & Rollins, 1998). Later, the business strategy together with customer expectations evolved, and Dell had to shift from a single supply chain to a customer segmentation supply chain. This led to cost reductions of $1,5 billion between 2008 and 2010 (Davis, 2010)

Such integration can also go beyond the benefits of a single company and its partners. An example is AirDesign – European aerospace and defence collaboration platform created by Dassault Systèmes and BoostAeroSpace (Rüßmann, et al., 2015). Designed to integrate key industry players and provide a neutral workplace, this as-a-service platform aims to dramatically reduce operational costs thanks to open standards (Dassault Systèmes, 2014), easy information access and exchange of technical data (BoostAeroSpace, 2015).

3.1.5 The Industrial Internet of Things

Physical flows in manufacturing are continuously mapped on digital platforms, creating a network of cyber physical systems that form the centre of Industrial IoT. Cyber-physical production systems – software-enhanced production machinery with integrated computing power – are changing todays manufacturing. Enabled by a wide range of embedded sensors and increasing connectivity, such systems identify their capacity, alter their own configurations, and make decisions regarding their tasks autonomously (Almada-Lobo, 2016).

Sensors are one of the crucial parts of the industrial IoT. In production, different types of parts' identification can be used – such as bar codes or RFID. An example of a successful RFID implementation can be spotted in Volkswagen – the car manufacturer uses RFID chips integrated into the components to collect test data from the vehicles. During testing, controllers and engineers can efficiently identify and display information needed for further progress, that is afterwards more precise, faster, and thus cheaper (Infineon, 2018).

Bosch Rexroth represents another outstanding example of a smart factory that uses RFID in its production processes, enabling the workstations to be automatically informed which step needs to be done (Rüßmann, et al., 2015). The company produces drive & control systems and various kinds of industrial hydraulics and other technologies and is both a lead operator as well as supplier of Industry 4.0 solutions (Rexroth Bosch Group, 2016). Their plant in Homburg, Germany, showcases a real-life example of implementation of all three abovementioned key drivers of Industry 4.0 – decrease in costs (specifically, 30 % reduction in stock), increase in quantity and quality of output (one line can assemble more than 200 different valves, representing a 20 % performance increase and 10 % increase in the amount produced) (Rexroth Bosch Group, 2016).

Another example is General Electrics. During every part of the production process, each part of a product is tracked with serial numbers and bar codes that carry the entire genealogy of the product. This enables the company to link the product and its performance with its specific production processes to draw conclusions in terms of potential improvements in quality, performance, and other aspects. Moreover, sensors can also be used to monitor the manufacturing space as such – General Electric uses sensors to monitor physical conditions, such as temperature, humidity or even machine operating time and energy consumption per unit produced. Together with iPads that are used in the factory to control the processes, this allows for real-time adjustments, increasing the efficiency of production and decreasing costs (Ezell & Swanson, 2017; Fitzgerald, 2013).

Similarly, the production facility of Harley Davidson is interconnected. The ionic motorcycle manufacturer uses cloud end-to-end digital engineering. Data collected from the shop floor assets are analysed in real time and algorithmically altered according to for example environmental fluctuations (Ezell & Swanson, 2017). Moreover, the data collected are used to predict potential maintenance issues, preventing the machines from breaking, minimizing unexpected downtime and workflow interruptions. Harley Davidson is one of the leading companies when it comes to smart factories – digitalization enabled them to decrease its operating costs by $200 million at single plant alone and, astonishingly, improve the speed of order from fixed 21-day production schedule to only six hours (Kumar S. , 2016).

3.1.6 Cybersecurity

In direct proportion with expanding technology possibilities, the skills of hackers and potential threats are also increasing. Poor cybersecurity practices can have disastrous impacts, potentially enabling the informational and operational technologies to manipulate the physical world. The risks connected to cybersecurity directly relate to the company's reputation, manufacturing efficiency, revenues and even personal safety of the customers and product users. The relevance for manufacturing is significant – after healthcare, manufacturing is the second most-attacked industry (Perelman, 2016). The biggest challenge in manufacturing is that some cybersecurity tools, even as simple as an antivirus software, can have a harmful impact on the performance of the systems (Zimmerman, 2017). Moreover, updating software for robots causes delays and forces the factories to stop their productions, representing too much of a cost and thus being oftentimes skipped (Greenberg, 2017).

The most troublesome situations arise when hackers attack an IT system of a company and their actions are almost undetectable. Recently, specialists at Trend Micro and Politecnico di Milano discovered serious flaws in ABB's IRB140 industrial robot's protection (Polyakov, 2017). The experiments hacked the robotic arm, changed the $75.000 operating system using a USB drive plugged into the computer or even load their own detrimental commands to the robot from the internet. This was especially alarming, since the code uploaded allowed the hackers to change the instructions completely, introducing defects, altering configurations, cause damage to itself or human operators or even stopping the production completely (Greenberg, 2017). Another "supervised hack" was conducted by researchers on a 3-D printer and its system to demonstrate the ease of potential manipulation with the design files of drones (Polyakov, 2017).

An example in the spotlight is Tesla. Tesla's CEO Elon Musk acknowledges that cybersecurity is one of Tesla's top security priorities. With no other vehicle fleet being as interconnected as Teslas, making sure the system of the cars is not hacked has personal-safety implications. During his speech at National Governors Association event in July 2017, Musk said: "O*ne of the biggest concern for autonomous vehicles is somebody achieving a fleet-wide hack"* (Musk, 2017). Tesla's developers are thus constantly improving the data security – for example, in case of a successful hack, the cars are equipped with a button that would enable the person in the car to take control over the vehicle, once it starts acting oddly. The potential breach of cybersecurity is prevented through cryptographic validation of firmware updates. (Lambert, Elon Musk says preventing a 'fleet-wide hack' is Tesla's top security priority, 2017).

3.1.7 The cloud

Cloud-based solutions enable the firms to support company-wide data analytics to improve the operations regardless the physical limitations. Gradually, manufacturing companies are leveraging cloud computing to effectively manage every facet of their operations, especially when geographically dispersed. An example of successful virtual operations management is Mystery Ranch from Montana, a specialist in high-end backpacks. The cloud helps them to manage and run every perspective of their operations at five manufacturing locations. From design and engineering through production and quality control, employee- and inventory management, financials, to the final consumer through e-commerce, sales and marketing. The cloud brings transparency to various parts of the business, such as controlling the consumption of raw materials, the state of inventory, timestamps of products shipped to the customers etc (Emerson, 2016).

General Electric identified an opportunity in the cloud sphere as well – both for their internal use as well as for the business relationships. Already in 2012, the company spotted a need for a cloud-based software platform and thus they created Predix. Initially intended to facilitate access to real-time information to the machine operators and engineers, informing their own production activities, the potential of such platform turned to have a much wider business impact. Additionally, Predix helped improve customer relationships – in connection with the abovementioned predictive maintenance, the cloud technology allowed the company to proactively identify any potential issues of a specific customer's machine, ultimately leading to lower service costs (Winig, 2016).

The cloud also plays a crucial role in terms of customer relationship management. An example of leveraged cloud technology is Dow Chemical. The company was able to gain flexibility, visibility and transparency across the whole value chain. With globally dispersed operations and more than 6 000 products, the company had to find an effective way of managing customer requests. The second largest chemical producer introduced a platform, where customers could submit sample requests. facilitating customer follow-up, bringing large amounts of useful insights (Krishnan, Pujari, & Sarkar, 2015). Furthermore, the platform enables the company to boost the relevance and impact of its marketing campaign – achieving response rate to the sample-based programs to grow by 60 %. In addition, this single cloud-based platform powered by Oracle reduced the complexities and brought transparency to customer communication around the world (Oracle, 2018).

There is a trend labelled as "product servification" (Ezell & Swanson, 2017) – when the cloud technologies allow the companies to stay in touch with their products, enabling remote updates, maintenance or even being sold as a service. One of the well-known examples of a digitalized manufacturer is Tesla, a pioneer in many areas of Industry 4.0, bringing disruption and innovations to the automotive industry and beyond at unprecedented pace. Uniquely, Tesla uses over-the-air updates for their vehicles, ensuring their fleet is the safest possible and showing that not only the digitalization of production processes, but also of the product portfolio is exceptional. Over-the-air updates can remotely improve the original mechanical design features, introduce new add-ons to already-bought Teslas, such as autopilot feature (World Economic Forum, 2016). Other car manufacturers are starting to exploit these opportunities as well, such as Ford or Hyundai (Ezell & Swanson, 2017).Tesla fundamentally disrupted the traditional business model in the automotive industry – especially from the perspective of franchise dealerships typical for car manufacturers. Tesla's business is not depending on a middleman servicing the vehicles. Rather, there is a great motivation to try to service and fix Tesla vehicles remotely (Lambert, 2017).

3.1.8 Additive manufacturing

With advancements in materials that can be processed, additive manufacturing is becoming a real part of everyday business for many companies. Airbus leverages 3D printing in combination with the cloud-enabled "generative design", that is able to mimic the nature's natural processes. In this technique, "engineers enter design goals into software, along with parameters such as materials, manufacturing methods, and cost constraints, and the software algorithmically explores all possible permutations of a solution" (Ezell & Swanson, 2017). The products designed in this way are optimized, more efficient, lighter in weight and more durable. Airbus used this technique to design Bulwark, its new aircraft – specifically, a part called "bionic partition" that separates the seating area and the galley of a plane. It is the world's largest 3D printed airplane component and weights 50 % less than it's the regular partitions (Autodesk Research, 2018; Ezell & Swanson, 2017). Recently, Airbus also added first 3D-printed part (specifically, a spacer panel that fills an end-gap in a row of overhead compartments) visible to passengers to its A320 model flying under Finnair that are 15 % lighter than if made conventionally (Airbus.com, 2018).

3D printing is also leveraged in the automotive industry. Local Motors redefined the traditional automotive industry and design. The company introduced the world's first 3D printed car, the Strati, that takes only 44 hours to produce (Geier, 2015). and the company is able to quickly bring the 3-D printed cars designed in low-volumes to the market. Moreover, Local Motors are leveraging other opportunities presented by Industry 4.0, such as disrupted intellectual property and open source innovation. The company created an innovative platform to reach out to its customers and enthusiasts in the community (Local Motors, 2015), holding design competitions and allowing client to have a strong hand in the design of their cars (Sniderman, et al., 2016).

Another example of successful implementation of additive manufacturing is GE. Many areas of operations have already benefited: aerospace (3D printing parts of engines that are lighter and enable for better fuel efficiency), consumer electronics (such as components for dishwashers or cooling channels), food and beverage (spare parts for beverage filling plants), manufacturing (cooperating with Bosch to redesign an internal engine component to improve operational effectiveness), medical (using 3D metal printing to redesign medical instruments) or oil & gas (developing a stronger, single-piece component of combustors). (GE Additive, 2017)

3.1.9 Augmented reality

An example of augmented reality (AR) implementation in production comes from Mercedes. Previously, the car manufacturer used a robotic arm on the assembly line to please head-up displays precisely into the right viewable position for the driver. This process required the car to be parked at an exact position on the assembly line, which was quite time consuming. Nowadays, an operator enters the vehicle with the help of AR technology and gets visual guidance on a tablet device how to tilt the display into correct position. Such use of AR and overturn of the usual human-robot interaction leads to not only faster, but also cheaper calibration process (Gill, 2017). Another example is Rolls Royce, who uses augmented and virtual reality to train their engineers to help them navigate in complicated airline maintenance tasks (Pickup, 2017). Together with digital twinning, AR is also helping in the areas of product development and virtual testing to assess the safety and performance of their machines and systems. (Rolls Royce, 2017)

Another example of successful AR and AI implementation into regular business operations is Sephora. The global beauty retailer showcased a customer-centred transformation, following their (female) customers in their increasingly digital shopping behaviours, providing the relevant tools and experiences. After identifying a gap on the market based on a consumer study, Sephora joined forces with ModiFace to develop the most fitting beauty visualisation tools with great facial features recognition. Firstly, Sephora Virtual Artist enables the customers to try on makeup via AR, enabling them to test out thousands of make-up looks (Sephora Virtual Artist, 2017). Secondly, feature called Color Match uses AI to help the shoppers navigate in the wide product portfolio by matching their skin tone (from an uploaded photo) to the best-matching shade of foundation. The customer is given a Color IQ Number that can be later utilized to navigate through the available products, filtering out only the ones that match the tone of their skin. These two functions solve a specific pain points – being overwhelmed by the number of products available in the store or online. Furthermore, a truly unique device Fragrance IQ enables sampling and fragrance testing using a touch-interface and scented air. Sephora digitalized its entire business strategy around customers' needs (Rayome, 2018)

3.2 Further areas of digital transformation

Cases of successful implementations of digital technologies in many areas of manufacturing have already gone beyond those nine Industry 4.0 pillars and the list of exciting examples is rather extensive. In the context of the latter case study, the author decided to point out two areas of significant changes that digitalization has already brought to practice – human resources and intelligent pricing.

3.2.1 Human resources

Parallel to the shift in customer expectations, digital trends and continuous automation of manual tasks mean that there is also a shift in the requirements and skills of employees (Hecklau, Galeitzke, Flachs, & Kohl, 2016). The shift is not only in the requirements for flexible (both geography- as well as task-wise) digital-savvy workforce and workplace, but also for digital HR (Volini, Occean, Stephan, & Walsh, 2017). Well-designed HR processes adjusted to the digitalization trends could provide instant value, especially in the form of time- and cost-efficiency. Digital maturity of a firm's HR incorporates operational HR efficiency (aka fully integrated internal HR processes supported by relevant digital systems), HR omnichannel (implementing the digital into new ways of interaction and engagement between the employer and the employees), and HR digital ecosystem management platform to leverage the benefits of digital technologies (Blixen-Finecke, 2016).

As mentioned above, cultivating a culture of innovation is crucial for a successful implementation of the novel ideas into business's daily operations. 3M is aware of the unprecedented potential of digital technologies and fosters innovation mindset of its employees. New processes and platforms allowed for this, encouraging employees to spend up to 15 % of their time on projects outside their defined scope of work, creating measurements to tolerate mistakes and encourage successes, rewarding successful innovations (Govindarajan & Srinivas, 2013). The company also makes use of cross-geographical collaboration within the 3M network, where employees working on a specific project are encouraged to make use of the vast 3M talent base regardless the location (Kalra, 2017).

Employee engagement is also increasingly digital – not only in terms of hundreds of emails. IBM reinvented the feedback and performance management process by replacing its global learning management system with a new digital learning platform (Volini, et al., 2017). The app-based performance review system called Checkpoint enables the employees to set short-term goals (rather than yearly), receive quarterly feedback from their managers, who assess them in along five criteria in a more complex way (Zillman, 2016). Moreover, enterprise social network platform is an increasing trend – creating a place where colleagues can interact, share their experiences cross-divisionally, source ideas to solve specific challenges or just share successes. IBM's social media platform Connections was used to source the Checkpoint platform from its own employees (Zillman, 2016). Many companies do not develop their own platforms but integrate ones from specialized providers, such as Microsoft's social media platform Yammer that is used by companies such as Hilti, Xerox, ABB (Microsoft, 2015).

Digital trends are also impacting the recruitment process. From the FMCG industry, Unilever has digitalized its graduate recruitment process that now also includes 20 minutes of gaming

(Volini, Occean, Stephan, & Walsh, 2017). Candidates are screened through a short online form tied to the candidate's LinkedIn rather than by their CVs. Next step is an engaging 20 minutes gaming session that assesses candidate's skills the company is looking for, followed by a self-recorded interview video at a time that most suits the candidate. This enabled Unilever to grand feedback quickly and significantly reduce the time between application and offer to less than two weeks (Unilever, 2016).

3.2.2 Intelligent pricing

Data and information gathered from customers can be efficiently used for intelligent pricing strategies. Successful examples can be seen with transportation companies – Deutsche Bahn (Sniderman et al., 2016) as well as Czech Regiojet railway companies make use of monitoring sensors. Combined with customer ordering ang billing database and real-time data analysis around traffic, such algorithms enable those companies to generate intelligent pricing models customized to client's needs, driving the revenues. Another example are ridesharing platforms such as Uber, Lyft or Taxify. Complex algorithms drive dynamic pricing models that enable the platforms to adjust and surge their regular charges by manifold in times of peaking demand. Domino's Pizza also cites its current trajectory and success by becoming a technology company that also makes and delivers pizza around the world. Domino's Pizza Chief Executive Officer (CEO) Patrick Doyle shared lessons about making radical change to traditional business models at a 2016 CEO summit titled How to Transform a Legacy Company Into a Technology-Enabled, Nimble, Category-Disrupting Machine. Domino's prioritizes investments in technology and expertise to emphasize innovation in pizza delivery. As a result, it hired 400 software and analytics professionals to explore application improvements and new delivery capabilities, such as drones, autonomous cars, and mobile ovens. (Solis & Littleton, 2017)

To conclude, such changes in production processes lay foundations for the companies to adopt new business models and other innovations, crucial for the organizations and their abilities to mass-customize their production, enabling them to enrich their offering and keep up with the increasing customers' demands (Rüßmann et al., 2015). Specifically, manufacturing companies can exploit new business opportunities connected to after-sales and data monetization – as shown for example by Mercedes-Me.

4. CASE STUDY

This chapter aims to reflect the theoretical frameworks and current trends presented in chapters 1 and 2 onto a case study of a manufacturing company that has already started its digital transformation that has clear and measurable impacts on its business operations. Benchmarked against showcases presented in chapter 3, this part of the thesis will provide an overview of how the disruptive Industry 4.0 technologies impact course of the business of a single company, that will be kept anonymous due to the sensitivity of information provided.

As described in introduction, the company was chosen after a thorough research conducted online as well as with consultants from Deloitte, PwC, and BCG on which manufacturing companies are exemplary and considerably advanced with regards to digitalization. After winning an award connected to the digitalization in 2017, the company's digital transformation was showcased at conferences as an example for other manufacturers to gain confidence with regards to Industry 4.0 technologies. Name and industry details of the company are well-known to the author, supervisor as well as the opponent. Sources of information include personal visits to the manufacturing site with industry experts, observations on the spot as well as structured interviews with the management.

4.1 Company background

With more than 70 years of experience in machine engineering and manufacturing industry in Europe, the analysed company competes at top global level within its specialization. Their business is B2B as their produce is not a standalone, but rather a part of a complex mechanical system. With 1100-1400 employees, the company plays a strong role in attracting local talent.

4.2 Industry 4.0 implementation & successes

In the context of three Industry 4.0 drivers introduced in chapter 1.2, the primary driver to implement digitalized solutions was the quality of product (individualized with much shortened time-to-market) and increased competitiveness through cost-optimization. Specifically, when asked about the company's drivers, the plant's GM's replied that firstly, the need for a change was identified based on changing needs of customers. In the past, the company was able to succeed in the market with a series production – but given the changing environment, this premise was no longer relevant. The company realized that the customers do not place orders in batches anymore, but in rather small lots – at an average of 1,86 piece per order. The type of production is "made-to-order" with small additional engineering alternations, enabling individualization of the final product. These highly individual needs and the push towards fast-reacting customization were the main reasons driving digitalization. Secondly, there was the question of competitiveness – the times when the company started with its digitalization initiatives was just before the financial and economic crisis of 2008/2009. With the production plant running continuously 24/7, the company was not even able to do effective maintenance on the production machines, leading to delayed delivery dates and missed deadlines. Moreover, due to the global economic slowdown, the production volume decreased by almost 30 %. These problems were almost existential and triggered the company to act, to ensure they remain active and competitive in the future.

To illustrate the situation today: the company produces around 300 pieces daily, leading to around 60.000 – 70.000 products annually. Regarding the increasing need for individualization mentioned in the theoretical part of this thesis – the company produced 78.000 different *variants* of the product over the course of last 5 years. Annually speaking, there are around 12.000 new product variants every year. According to the plant's GM, it is unthinkable that such variance could have been achieved with the old ways of running the business.

In line with the frameworks of Industry 4.0 introduced in previous chapters, the company's GM sees the impacts of Industry 4.0 technologies on their activities in three key dimensions:

- **Smart factory** – where their digitalization started and progressed the most;
- **Smart product** – which they introduced in 2017 and are planning to expand;
- **Innovative business models** – where they aim for the future.

Naturally, the company did not implement digitalization overnight, there were many different digital technologies put in place over the course of the years. The biggest challenge was that every technology was implemented into the production processes individually, depending on the specific application in the different departments or stages of the production process. The amount of applications and technology customizations was so extensive that the company's management started to struggle with following their mutual interconnectedness. Such fragmentation of digital technologies was the main obstacle to be overcome at the beginning and the need for unification was one of the driving forces of the digital transformation. Following parts will elaborate specific implications of the digital along the abovementioned pillars of Industry 4.0.

4.2.1 Big Data and analytics

Sensors are widely used in automated production, where the machine takes information from the product's barcode and knows exactly how large it should be, what exactly are the steps that need to be done at this stage and assembles it accordingly. However, the production process is not completely without humans – there are control checkpoints to make sure the high standards are kept, where the human controller checks quality of the produce at given stage and if everything is correct, he or she passes the product further in the process, sometimes equipping it with a new barcode identifier for further stages of the production process. Not all working stations are automated though – some task are too complex to be conducted by robots, meaning that mostly physically-demanding tasks were automated at this stage.

Interconnectedness is crucial for the success of Industry 4.0 – therefore, the company connected 130 most important production machines to the internet. Digitalization does not concern only new production machinery – the company connected even decades-old machines to the system and the internet to collect data and ensure the whole production process is as smooth as possible. In the context of machines' OEE, dashboards connected to the production machines enable the company to track which machines were producing, turned on but not producing or not communicating with the system in real-time. This enables the company to analyse the utilization of the machines, compare the theoretical technological processes from ERP with real production times, optimize the OEE and save significant amounts of money, which was one of the first aims with regards to digitalization.

Besides the real-time OEE tracking, the company can track which orders are being processed at which working stations and by whom, interconnecting the data from the machines with the data from the ERP system (in this case SAP) and the touchscreens at the workplaces, where the employees log in with their ID card. Such data helped the company with a human-productivity related issue – given the three-shifts-a-day production schedule, the night shift has always been the lowest performing one across all industries and companies. Analysing data from the production machines resulted in balancing such disbalance, leading to an increase in the productivity of the night shift up to the point where all three shifts are equally productive.

Having the machines connected to the internet is just the beginning, however. The company is currently piloting projects for predictive maintenance in the production itself to monitor the overall condition of the production machines and not only a few separate indicators, such as temperature, machine vibrations or uptime. They are looking into connecting the machines to the company's cloud, where they could do real-time data analytics and visualisations, gaining insights by transforming the production data. This task is still a long-run due to administrative alignments with the connected companies. Moreover, not all machines have been connected to the internet, yet – such process is demanding from both timely as well as financial perspective. Thus, with regards to maintenance, majority is done in planned or reactive manner, partially by the operating staff, partially by the maintenance staff. Big data is thus not fully leveraged and still holds a great potential for the company. Predictive maintenance is one of the priorities in the company's digitalization strategy for this year.

Digitalization and big data are not helping the production itself exclusively – rather the whole ecosystem around the plant. The plant uses digital technologies to manage its energy consumption – smart lighting in the production halls reacts to the break-times as well as the amount of day light and adjusts its own luminous intensity, leading to significant energy savings. Heating systems work on the same principle, leading to optimized energy consumption – the heating system is managed according to the shifts schedule and current weather conditions. Moreover, the company does not rely solely on the external electrical energy network – by using their own photovoltaic panels and cogeneration units, the factory is better balancing its processes towards energetical sustainability. This small solar power station saves 22 tonnes of $C0_2$ annually. Currently, the crucial machines and technological units are consistently monitored for their energy consumption and any potential fluctuations and deviations. Gradually, the company plans to connect all its machines into this system. An interesting case is the usage of drones – the company uses drones with sensors, ultraviolet light cameras etc. to analyse its buildings for energy-efficiency, water, or heat leakages.

4.2.2 Autonomous robots

The company uses new technologies in a way that eventually reduces the need for manual human labour. The production plant does not have many robots in the traditional sense – self-standing units with arms, used to transfer goods and materials between places and help with assembly. Majority of the robots is embedded and hidden in the machines in a way that enables minimization of human interaction with the produce only to a necessary level. Barcodes and ubiquitous systems enable the machines to scan and read the information about specific product. At some workstations, the system then automatically sends a request to the inventory what materials need to be dispatched for the task. The system automatically dispatches the correct palette with the right materials that are directly automatically transported to the right machine. Once at the machine, the production device automatically takes the material exactly at the required quantity and proceeds further with the production.

4.2.3 Simulations

Testing represents a crucial part for product development of every manufacturing company. Being able to fully digitalize not only the information retrieved from the testing, but also the testing itself represents an incredible competitive advantage.

In 2017 the company incorporated digital twinning into its product development that enables much faster and more precise prototyping. The company creates virtual 3D models, runs simulations and tests, and only afterwards makes a physical prototype. This is in direct contrast with the previous approaches, where the company started with a physical prototype, ran physical test, identified problems and flaws and then re-designed and re-created the product. All data from testing at any part of the production process can be automatically transferred and linked to the production orders as well as already made products, analysed, statistically evaluated, and then returned to the R&D phase to be implemented for further quality improvements of the products – forming the physical-digital-physical loop.

Digital twin is not only about the 3D model, but also about the information and data linked to different parts of the product, such as trial records, control certificates, product operation progress and development reports etc. The company can use the data for its private purposes and product improvements or share it with the customers as a part of the abovementioned "servification" of the physical product. Moreover, digital twins can also improve processes – by adjusting and optimizing the production flow, identifying potential flaws and inefficiencies.

4.2.4 Horizontal and vertical system integration

Vertical system integration starts on the shop floor. The company overcame the hurdle of days-long delays in providing information from the production. Data from the shop floor are transmitted online in real time, enabling efficient production management including the costs. During daily morning meetings, the management is able to see where the additional costs are exceeding expectations which is particularly helpful – and strikingly contrasting with the non-optimized system, where the cost data were available only once a month.

Regarding supply chain integration, automating administrative tasks helped the company greatly on its way towards further digitalization. They developed Product Lifecycle Management system (PLM) not only to work with the products, but also to develop new tools and substances. With regards to electronic data integration and sharing, the company is gradually integrating its suppliers as well as customers into their system, currently having integrated only the biggest ones. Through their own application, the company shares for example technical documentation with their suppliers, meaning that the most accurate drawings and materials are constantly available online. Industry 4.0 also revealed a need for new partners and suppliers, especially in the IT area.

Some materials have a unique replenishment system – if a worker is missing a specific material at certain stages of the production, he or she simply goes to specialized material pickup points. Using a chipcard, the worker simply "withdraws" the material he or she needs from the pickup point that is connected to the system and automatically reports that some material has been taken out and should be reordered. By implementing this system, the supplier and inventory management is extremely efficient. As in man industrial manufacturers, the company has a fully automated inventory in order to minimize the stock being hold– the system tracks the state of the stock, automatically reordering materials when needed.

With regards to further horizontal integration, the company communicates with the customers solely electronically. Before the digital transformation, they also accepted orders and requests in writing, but that is no longer possible. The company is using SAP as their ERP system, however, it is not fulfilling the company's requirements for flexibility anymore, since the plant's operations require hourly planning and SAP only allows planning in day-slots. Thus, the company has developed a system for advanced planning, able to respond flexibly and keep the information about production machinery. In case of an unplanned machine downtime, the plant is able to flexibly adjust the capacity to even-out the unexpected drop in hourly-cycles. Every part of the produce has a variety of procedures in which it can be made – in case of an unplanned complication in the production, the system has some flexibility to adjust and knows there is a plan B and even a plan C to produce the given order within the timeframe, regardless the downtime of one machine.

Customer integration is still at the beginning. Only the biggest customers are currently partially integrated to the Electronic Data Interchange (EDI), where they can electronically confirm orders, receive invoices and delivery notes. In case of the smart products, the company can track their status at the customer's property and thus is able to plan and offer maintenance and potentially plan the production accordingly. Communication with smaller customers is still using standard electronical interfaces and has not progressed in terms of the integration yet.

Concluding with the horizontal integration, the company is actively shaping the whole ecosystem by organizing seminars and workshops where the attendants share their best practices, concerns, and successes in order to stimulate the progress.

4.2.5 The industrial internet of Things

Shop-floor digitalization and automation

One of the first steps in the production digitalization was incorporating paperless production. After successfully piloting with one production line, all 300+ working locations within the plant were equipped with a touch screen and a bar-code scanner, enabling the workers to have full information about the order and product. Stickers with barcodes or QR codes are uniquely identifying every part of the product at each stage of the production process. Employees receive the orders listed in the order in which they should proceed with them and the application also includes all the product documentation available. From technical drawings and technological requirements to control processes, even including "how-to-do" videos showing step by step the process of successful product assembly, all the relevant information comes within the barcode. The touch-screens are also used for quality control – if an employee detects a faulty product that does not fulfil the requirements, by using a button it indicates such state and the system automatically generates report regarding the quality issue, contacting the relevant responsible person to solve it.

RFID technology is also used with technological and logistic assets, such as palettes, measuring instruments or hanging systems. For example, in processes that require repeated rounds on the same line, RFID allows to control how many times has the product already been at this position and what exactly needs to be done with it. RFID can be found also on pallets with specified kits of components that are needed for a product, are grouped together on a palette, used for transporting the products between stages in the production process.

Automation also regards logistic on the shop floor that is divided according to explicit rules, where is what type and what part of the produce assembled. Each worker has two locations where he or she is working and needs the full kit to be able to work on the given produce. Once his or her task is done, and all parts of the kit has been used, the worker presses a button and moves to the second workplace. This notifies the system and inventory that a new kit for this specific workplace should be dispatched. The inventory prepares such kit and notifies the fully automated trolley that was co-developed and implemented together with a leading automotive producer. This trolley is automatically transporting materials from the inventory to the different locations within the production hall, being navigated by lines on the floor and sensors on the walls.

Inventory digitalization

Voice-command technology is used in the inventory. Employees are equipped with a headset connected to the system that provides them with instructions, allowing their hands to be free to manipulate with items. Moreover, the employees do not have to waste time by looking into the computer to check the information what material from what shelf to dispatch, confirm etc. – information is automatically transmitted from SAP to the headset and a simple "OK" said at the end of the material collection confirms to the system that all the material necessary for the specific order has been dispatched, which signals to the system that it should prepare an invoice for the material transmission from the inventory to the production.

Smart Product

In 2017, the company introduced the first smart product with an embedded data-collecting device and accompanied by a digital twin. The products are no longer equipped with paper user manuals – all documentation about the produce is provided under a QR code and accessible through a special application. This fully-digital "birth certificate" of the product makes it more convenient for both the company andmcustomers. Currently as 2D (and aiming for 3D) documentation, it includes mechanical data, how-to manuals as well as spare-parts information enabling automated re-ordering that will send the request directly to the production.

The real break-through with the smart product is that it adds the data dimension to the physical produce and has the potential to create new business models for the company. Cloud-based storing of the product activity and operations data enables the customers to check in real-time what the configuration of the product is and whether there are any problems in physical indicators. Moreover, the product itself knows the ranges within which it should be operating and is able to identify on its own when there is any breach of such limits. In such case, the product automatically communicates with the customer that there is an issue with for example overheating, efficiency or if it needs maintenance. This eliminates preventive or reactive maintenance – all maintenance of the smart products is predictive, highly targeted only when needed. The system works on Wi-Fi or VLAN, transmitting the operational data every minute to the cloud where with the help of various algorithms the data are analysed and evaluated, and then displayed to the customer's dashboard within the app. Second option is data transfer via Bluetooth, where the controller walking around the facility can load the production data to his or her mobile device and check the operating conditions of the product.

4.2.6 Cybersecurity

The question of cybersecurity is of a great importance to any manufacturer. Acknowledging that this is an ongoing challenge that is constantly being addressed, the company has separated the production network (machine controlling, production management as such) and the IT network that have different rules for access. Moreover, a system of firewalls and other security instalments guards the safety of the network and its data.

4.2.7 The cloud

Connected with the abovementioned Smart Product able to transmit operational data to the cloud, the company leverages the cloud not only for the internal analytics, but also to provide the end-customers with a comprehensive overview displayed on a dashboard within the customer's app. Within the app it is up to the customer what they want the dashboard to show – enabling the customer to manage the whole fleet of products, clearly seeing which products might need maintenance or assistance, how are they performing etc.

4.2.8 Additive manufacturing

Additive manufacturing has been implemented as 3D printed samples, playing an important role in the processes. Not yet for the final products as such, but only as a help during the product development and communication with the suppliers and partners. The company is aware of its huge potential in the future with regards to flexibility, customization as well as cost savings.

4.2.9 Augmented reality

Virtual reality (VR) is also part of the company's operations – specifically, when the company was building a new workplace, they used VR to optimize the physical layout of the workplace. Modelling the future workplace from cardboard boxes, the company invited all the workers who would be working on this workplace to consult them and optimize the layout. Afterwards, the company created a virtual 3D model of the workplace and ran tests with VR glasses where the workers were asked to conduct the regular tasks they would do in reality. The management consulted the workers on everything – including the location of walls, working desks etc – to make sure the conditions are optimal for smooth flow of production.

4.2.10 Human resources

As illustrated above, human resources, workforce and talent acquisition are key drivers of business operations. Digitalization is oftentimes perceived as a threat to employment, "stealing the people's jobs" and replace humans with robots. The company strongly contradicts this. At the current tough labour market situation, even with such a pioneering position, the company is understaffed and still looking for talents. Naturally, the structure of the workforce has shifted – there are more technicians rather than operators in the production. Over the past year, the number of employees rose by almost 10 % and they are planning to hire additional 100 employees, constantly looking for talents, both senior as well as junior. Thus, the company is actively engaging with the local talent pool. By engaging in activities with relevant study programmes at local universities and broadening the network, the company proactively approaches and attracts students of IT and other technical specializations. Moreover, the management is also active in the relevant academic field.

In case of many solutions implemented, it would be very demanding to source them from external partners due to a high level of individualization and data sensitivity. Thus, the company hired teams of IT experts to internally develop and programme the needed systems. The company is linked closely to other firms in the industry, both partners and suppliers, being an accelerator and even IT solutions provider of the Industry 4.0 ecosystem in the region.

Generally speaking, people do not like and sometimes even fear changes. The company had to cope with such resistance when they started implementing the digital – especially machine operators were doubting at the beginning that the planned changes would be anyhow beneficial for them. The plant's GM confirms that this resistance was not due to the fear of losing their job, but rather due to the fear from the unknown – implementing technicalities such as touch-screens, barcode scanners, automated machines etc. The firm tackled this by building a training centre to teach the staff how to use the new technologies, including the operators already from the workspace planning and designing phase to ensure the largest possible acceptance.

4.2.11 Intelligent pricing

The complexity of the industry does not allow for a clear statement whether digitalization enabled the company to increase or decrease prices. The price of the final product is strongly dependant on the prices of inputs, especially physical materials. Prices of the final products have been decreasing over the past few years, but due to the fluctuations in prices of raw materials it is difficult to assess the clear impact of Industry 4.0 on the final product's price. Nevertheless, the newly developed Smart products and potential monetization of the data collected enables the company to evolve an intelligent pricing system. While still at the very beginning, the management calculates that after-sales services such as providing the customers with different data sets at different pricing levels poses a great opportunity for the business.

4.3 Impacts on the course of business

In this chapter, the implemented digital technologies are put into the perspective of the company's digitalization strategy, business model, and how specifically did these technologies improve the business's operations.

4.3.1 Digitalization strategy

As noted by the plant's management and as mentioned in chapter 2.3.1, one of the crucial success factors for a company when implementing the digital is a clear strategy – specifically, a systematic digitalization management. Digitalization became one of the core pillars of the company, along with efficiency, competence, and business growth. When formulating a comprehensive digitalization strategy, the company discusses and sets the following:

1. Strategy as such – defining the aims and targets, what are the business expectations in the short as well as in the longer run, what should be the concrete improvements and progresses, analyses costs and benefits of such change;
2. IT architecture that is required as a tool for the implementation;
3. Information Technologies that are necessary to reach the desired state, acquired either externally or internally;
4. Employees' qualifications and additional talent sourcing that is necessary for execution.

Specifically, the company looks at three crucial areas when defining the strategy. Each of those three areas of activities has specific criteria that are tracked to assess the current state of art and move forward, as briefly shown in Figure 20:

- Digital objects and processes
- Horizontal and vertical integration
- Digital engineering

AREAS OF DIGITAL ACTIVITIES	DIGITAL OBJECTS AND PROCESSES	HORIZONTAL & VERTICAL INTEGRATION	DIGITAL ENGINEERING

CRITERIA	▪ IDENTIFICATION AND TRACKABILITY
	▪ HUMAN-MACHINE COMMUNICATION
	▪ ASSISTANCE SYSTEMS
	▪ AUTOMATION OF DATA PROCESSES
	▪ PROCESS MONITORING & OPTIMIZATION
	▪ AVAILABILITY OF IT INFRASTRUCTURE
		▪ CUSTOMER INTEGRATION
		▪ SUPPLIER INTEGRATION
		▪ VERTICAL CONSISTENCY OF PRODUCTION DATA
			▪ DIGITAL TWINNING
			  ▪ PROCESSES
			  ▪ PRODUCTS

Figure 20: Pillars of digitalization strategy (derived from the company's materials)

Note: Due to highly sensitive data, more specific steps and processes regarding the strategy could not be disclosed.

As demonstrated in Figure 14, along with clear strategy, companies identify leadership and business culture as key success factors when undergoing digital transformation. The plant's management decided to cultivate a strong digital culture that would be widely accepted across the company by engaging their employees in the digital transformation of their workplaces as well as providing them with trainings. Moreover, the plant's GM shows strong personal leadership, and is a personality who is a respected advocate of the digital shift in the company.

Multiple resources from the theoretical part also stressed the importance of not only a well-defined, but also long-term-oriented strategy for digitalization. Traditionally, the company plans projects and financing for the upcoming 3 years. However, with regards to Industry 4.0, the strategy is planned in a longer run, until 2025. Investments planned are not dependant on the company's turnover or revenues – rather, they are benchmarked towards company's annual depreciations. Specifically, the company annually invests amounts corresponding with the 5-years-average of depreciation. Any investment the company makes is either improving the situation in one of the four key areas (speed, flexibility, process efficiency or quality) or is otherwise beneficial to the company's operations and must incorporate elements of digitalization. With regards to financing such digital transformation, the company's GM says the resources should come from both investments as well as financial savings.

Furthermore, the company has assigned resources in the value of millions of € solely for the development of the production digitalization and automation, acknowledging the importance of the digital for the future.

4.3.2 Business model implications

The case study confirmed suggestions of chapter 2.1.2, that most changes of the business model induced by digitalization are extensive and rather incremental for brownfield manufacturing companies than truly radical. Operating within its existing financial hurdle, not realizing investments that would be seen as too risky, and within its existing value network. The company looks into expanding and deepening the relationships through significantly improving and innovating its current product offering. Such concept of sustaining innovation means that the company is not coming up with disruptively novel products or business models, but rather combining available technologies in novel ways to facilitate the shift in the business model, such as introducing the first smart product or cooperating with a globally leading automotive company to customize fully automated shop-floor solutions.

The company itself is solely focused on the production, B2B sale of the products and after-sale services – however, the company's partners, regional sale units and the mother company decided to enrich and extend their offer by providing the end customers with a possibility to rent or lease the products, adding even more flexibility.

From the perspective of Osterwalder's business canvas, the company has seen significant changes in five elements of the canvas. First three, higlighted by dark gray in Figure 21, are the three blocks identified by Arnold, Kiel and Voigt (2016, see chapter 2.1.1) as the most impacted ones by machine & plant engineering companies. The extent of digitally-enabled changes in those three areas incited a company-wide business model development. Moreover, the case study showed two additional areas facing digital disruptions:

- **Value proposition** – faster lead times, much higher customization, after-sale services and potential for both the company as well as the customers to benefit from predictive maintenance, deeper horizontal & vertical integration and advanced data analytics. With the new products is is not anymore about the physical produce, but also about the data the machine is able to collect any analyse thanks to the embedded sensors and software;

- **Key resources** were enriched with new commodities, such as data, digital-savvy workforce including expert IT teams and, of course, automated robots and smart machinery forming cyberphysical systems around the smart factory;
- **Customer relationships** were intensified and smoothened, with the key customers even integrated through EDI. Thanks to digitaization, communication is now much more direct with effective feedback loops and growing extent of after-sales services with the smart product. Moreover, thanks to digitalization, the company can produce even small lot sizes, targetting potentially new segments of smaller customers.
- **Key partners** on both ides of the value chain. New business partnerships especially from the IT sector, relationship building with educational institutions that are becoming a key source of digital talents are existential for further growth of the business.
- **Key activities** – even though the core activities of the business stay the same, delivering made-to-order products at the best potential quality and shortest time, digitalization has caused the company to be more proactive and expand the portfolio of activities with regards to business (offering new data-related services and applications thanks to the smart products), operations (being more conscious and proactive in terms of energy savings and implementing new solutions; fully digitalizing testing processes and simulations; teams of programmers creating internally applications and systems), workforce education (internal trainings to improve their skills, participating in varous company-wide CSR activities).

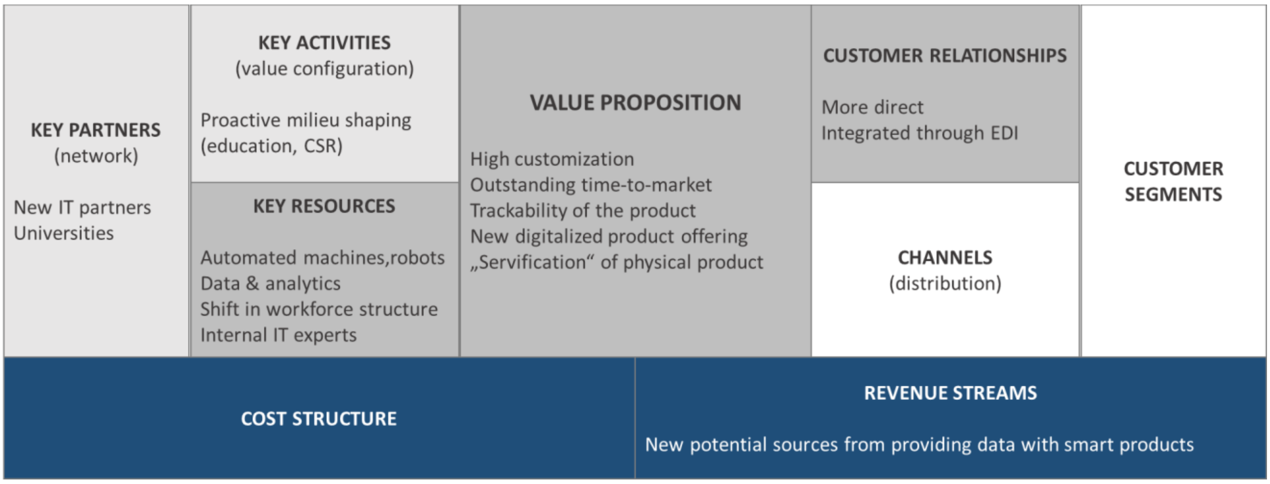

Figure 21: Impacts of digitalization on the business model of analysed company
(source: author's judgement, building on the business canvas framework by Osterwalder, 2010)

The novel smart product is a great showcase example of what complexity Industry 4.0 brings to the manufacturer's business model. Looking into the future, smart products introduced in 2017 allow the company to innovate and enrich its business model more radically, alter the key offering and bring additional revenue streams (as suggested in Figure 21). Altered value proposition and the product's characteristics might attract different segments (let's say, much smaller companies or born-digitals who leverage data as their core business). This might result in changes to distribution channels, altered communication (aka customer relationships via the application or dashboards), and new partnerships. Combined with the need for new resources (data, IT infrastructure, digital workforce needing IT specialists and quality controllers rather than manual workers), novel activities and shifts in cost structure (e.g. labour costs of manual workers substituted by capital costs of machines, shifts in inventory and maintenance costs etc.), this shows that Industry 4.0-enabled solutions should not be assessed only through the lense of one or few business model aspects, but rather from the complex perspective.

When compared to the outcomes presented by Arnold, Kiel and Voigt (2016), the study suggested that cost structure is also strongly impacted by digitalization. The case study analysis is lacking an overview regarding the shifts in the company'ss cost structure due to high data confidentiality that could not be provided under any level of anonymization.

4.3.3 Digital maturity

Opting for the same self-assessment as presented in chapter 2.3.1, the GM was asked to assess the digital maturity of their own business: *"Imagine an ideal organization utilizing digital technologies and capabilities to improve processes, engage talent across organization, and drive new and value-creating business models. On a scale of 1 to 10, how close is your organization to that ideal?"*

Placing the company to the "developing" part of the scale by scoring 3-5, the GM elaborated:

"I would say we are somewhere in the first half of this scale, probably between 3-5. I am not sure whether it is at all possible to ever reach the ideal state, aka to score 10. In my opinion, such state does not exist, since new technologies are constantly evolving and changing, pushing the technologies and the overall business digitalization further and further. Given the industry, I would say we have done a lot of work in our factory over the past few years. However, the ideal state would be that the machines and robots are completely self-directing their actions, communicating and transporting the products among themselves – and that is still very far away and for me currently unimaginable. We are limited by a large extent of manual work that for now and for many years to come only humans will be able to perform, since the robotization of those would be extremely financially demanding. Each and every time when we decide to implement any automated or digitalized solution, we are calculating whether such implementation brings benefits in the areas of imrpoving the speed, flexibility, quality or process efficiency of our production, and, naturally, whether we can expect the return on such investment in a reasonable time horizon."

(managing director, machine engineering and manufacturing factory)

After thoroughly examining the company's operations and the state of digital transformation, the author argues that such statement of the company's GM is overly critical. According to the digital maturity frameworks presented in chapter 2.3 (Kane, et al., 2017), the status quo seems to be more of a digitally maturing company. As stated above, in this phase the company aims to align the align the strategy, workforce, culture, technology as well as company's structure; is strongly customer-oriented and puts digital initiatives to the centre of the strategy, which is in line with the analysed case study. From the perspective of six stages of digital maturity presented by Solis & Littleton (2017), according to the author's opinion, the company stands at the "strategic" phase. With a strong personal leadership of the plant's managing director, the company has a clearly defined digital strategy with specific aims to reach, guiding company's operations and digitalization strategy with a great focus on customers' needs.

4.4 Tracking the progress & setting KPIs

Reflecting on the new manufacturing mandate, where digitalization leads the companies, presented in chapter 2.2 and Figure 11, the discussed company showcases progress in all four mentioned areas, that will be further elaborated with specific KPIs:

1. **Operational excellence** – digitalization helped them to significantly improve the quality and variety of products offered, optimizing production processes, energy consumption, machines' OEE and inventory management;
2. **Agility** – through value chain integration, the company is able to react quickly and flexibly to both changes in the external environment as well as internal challenges, such as unplanned downtime of a machine;
3. **Innovation** – significantly reducing the time-to-market of their newly developed products, order lead-times and push for energetic sustainability;
4. **Customer Centricity** calling for cross-channel experience and more information available through the company's app and electronic data sharing and integration.

Along this logic, the company aims to grow in following four key areas, assessing the impacts of digitalization on the business, tracking specific KPIs:

Speed – the company aims to shorten the innovation cycles (new products development), shorten the order-to-offer time (from receiving the customer request to sending an offer), shorten lead times (reducing overall production time from confirmation and assigning the order to the shipment), and ultimately, shortening the overall lead time (product delivery time from the order placement to the final delivery). Specifically, digitalization helped them to:

- Significantly shorten its R&D time. From innovation cycles of almost 20 years before the 1990's and almost five years in early 2000's, the company managed to shorten its R&D process to 18 months in 2017. Moreover, in 2017 the company was able to digitally equip their produce and introduced a smart product, able to collect data, transmit them to the system, thus help in gaining better insights.
- Reduce time to process the orders administratively from 6 to 2 days.
- Industry 4.0 significantly shortened the overall lead times from the order placement to the final product delivery from approximately 100 working days before the implementation to approximately 15 days in 2018. Ultimately, the company aims to reduce the average order-to-delivery time to 5 working days.
- Delivery accuracy (in terms of due date compliance) increased from 94 % to over 99 %.

Flexibility – the company wants to offer individualized MTO products to its customers rather than standardized "catalogue" products. Additionally, enriching the physical product by offering relevant digital data to those individualized products – from usage manuals to spare-parts online management system; integrating engineering since the order placement through an online configurator that would lead to decreased number of necessarily processed offers. They saw:

- Great increase in flexibility and customizability of the product, expressed by the company's ability to produce 12.000 new variants of products annually without compromising on lead times, quality of the product, due dates, or lot sizes.

- Available data for individual products and flexible analysis thanks to smart products.

Efficiency of processes – from the cost perspective, the company aims to reduce production and connected maintenance costs, increase machines' productivity and the overall OEE by reducing planned downtimes, machine configuration times etc; monitor energy consumption; substituting manual human labour by automated machine labour; paperless production deployment; gradually implement condition monitoring of machines predictive maintenance; data integration and optimized transition between the operations and production machines. Specifically, digitalization allowed them to:

- Increase in the machinery usage (OEE) by up to 20 %;
- Automate the order management by more than 50 %;
- Reduce the average pure production time by 33 %, currently it takes 11 days and the company aims to reduce it to 5 days;
- Automate up 75 % of the tasks even at those assembly lines, where the tasks are the most demanding for manual work, since they simply need human thinking to be done.

Quality – aim is to significantly decrease non-conformance costs both in their own production as well as with their customers; improve the traceability of the components and their quality; using simulations to optimize production as well as technological processes. So far, the company saw:

- Increase in quality to 99,92 %;
- Decrease in claims for replacement to 0,08 %.
- Decrease in internal faulty product rates by 66 %.
- Better visibility, transparency, and traceability of the individual parts

Overall, digitalization impacted the company's business especially by providing them with a competitive advantage of uniquely short read times. In combination with favourable economic situation of 2017, the impacts of digitalization were following:

- Annual revenue growth rate almost 45 %;
- Annual growth in pieces manufactured around 30 %,
- The company is able to assemble more complex products at the lead times they were assembling simpler ones in the past,
- Their workforce grew by more than 30 % since they started the digitalization in 2008/2009
- Annual productivity growth is at 5 % - overall productivity growth measured as year-to-year cost savings (both material and staff related) while keeping the turnover constant
- Savings in operational cost are thanks to digitalization around 800.000€ annually

To conclude, cases of digitally-enabled improvements from Chapter 3 prove that there is still much to be done for the company to fully leverage the potential of Industry 4.0. The case study demonstrated a best practice in terms of defining a strategy and a final goal (decreasing the production time from 100 working days to 5), having a leader and setting steps that are necessary to reach that state. Additionally, the plant has already seen clear evidence and positive impacts of their gradual digitalization. However, the plant is still piloting the technologies that are the true differentiators of Industry 4.0 and simple robotization – integrating all production data, transforming them into business-relevant insights, deploying predictive maintenance, smart products at large, dashboards for both customers and the management. Digitalization of the product is increasing – digitally accepted order, by 50% automated order management, newest smart models are digitally connected and trackable, have a digital twin, are connected to the company's cloud with a potential to soon deploy predictive maintenance projects. Nevertheless, what still seems lacking, is integration of the plant as a whole – only 130 machines are connected to the internet and their data is collected, but not yet efficiently analysed, visualized, and leveraged to drive further improvements in the production.

5. REPLICABILITY,RECOMMENDATIONS & DISCUSSION

Think big, start small, scale fast.

(Jim Carroll, 2010)

Defining a universal roadmap for companies to successfully implement and benefit from Industry 4.0 technologies is demanding, since as the theory and benchmarking studies showed, every company is currently at somehow different phase and has thus a different starting point. Moreover, Industry 4.0 technologies bring complex challenges and the companies cannot implement the solutions individually, as isolated cells, but should be prepared for company-wide changes along the entire value chain.

The aim of this final chapter is to outline a comprehensive and generally applicable set of steps that manufacturing companies could follow when shifting their operations and business models towards Industry 4.0 technologies, building on synthesised insights from the theoretical part together with the case study.

5.1 Managerial recommendations

The fourth industrial revolution brings disruptions not only to the business' operations, but to the whole value chain and the ecosystem around the company. Customer centricity is a must for those who want to stay competitive – well informed customers with ever-increasing push towards mass customization pose a major challenge for manufacturers. Companies are forced to be more agile and flexible, to react fast to the shifts in demand and trends, innovate and communicate with the stakeholders in more intense ways. How can the companies advance within this new mandate, what specific steps should lead them to a successful digital transformation and what changes to their business models they can expect?

5.1.1 Roadmap to successful digital transformation

A successful digital transformation is led top-down and starts with a strategy definition and with setting a clear goal where it should take the company. The firm should start with mapping where the strengths and weaknesses are and what the state of digitalization is. In other words, critically assess the company's current state of digital maturity – is it still early in the process, when the business is conducted as usual and digitalization is more of a cafeteria topic, or can they already see some formalized development towards a strategically digitalized company? This assessment can be done either internally or with the help of external experts.

The relevant decision makers – members of the board, management, owners, or shareholders – should afterwards together decide regarding the focus and priorities of the digital transformation. As with every investment decision, setting up a digitalization strategy must be backed up by a business case. Just as importantly, it should be backed by customer-centric reasoning, justifying why such investment is necessary and what exactly it will bring to the business.

- Does the company want to start with digitalizing and integrating its production machinery, focus on the digital objects, the processes (such as product development and testing), focus on human-machine interaction optimization, optimize the inventory management, after-sales activities or is there a vision to develop completely new business models, expand to new markets or address new customer segments?
- Generally speaking, what would be the key driver? To decrease costs, increase output or improve quality of the produce?
- What is the expected business-added value of digitalization in this particular area?
- What exactly would be desired and recognizable impact, the change at first sight, when walking into the plant after successful implementation?
- What is the required return on such investment?

After having an overview of what the status quo is, the decision and commitment to make an investment must be made. Defining, aligning, and understanding the expectations and motivations of various stakeholders is especially important because undergoing a complex transformation requires prioritization. The companies will be impacted at large and such alignment will ensure the final digitalization strategy will be widely accepted. Figure 22 summarizes the proposed roadmap to digitalization:

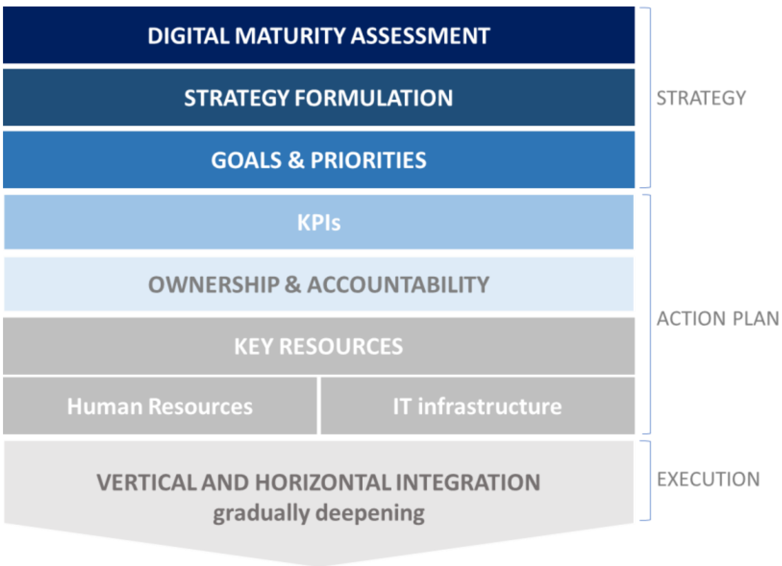

Figure 22: Digitalization roadmap (source: author)

After defining the aims and areas of priorities, the company must decide how will they keep track of progressing in those areas – by focusing on OEE, i.e. improving quality, performance, or availability, on flexibility and speed of response to shifts in demand, on innovation, decreasing machines' downtime or savings in costs? To efficiently assess this, they must define a set of relevant KPIs, including internal indicators, indicators towards customers, towards suppliers and partners etc. Eventually, the ultimate goal of any business innovation investment is to increase the value of the business to the owner, who will most probably be looking into general business KPIs such as profit or, when assessing an investment, into ROI. Figure 23 suggests what KPIs could be tracked under different business priorities:

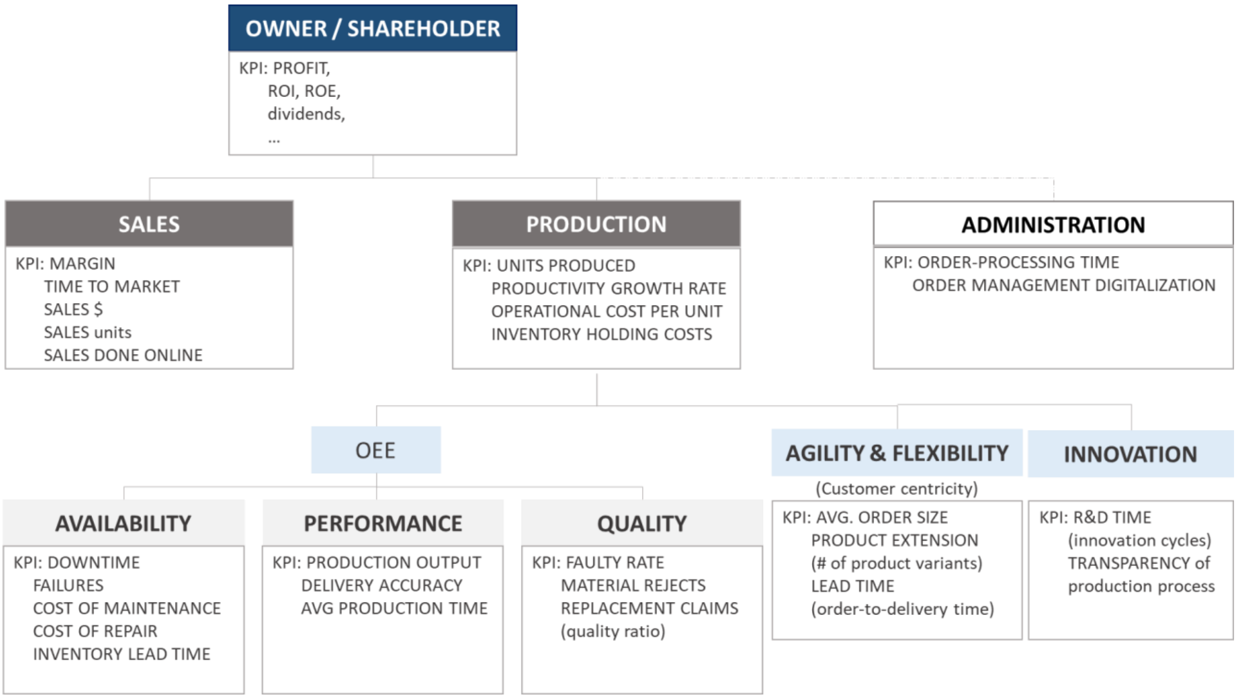

Figure 23: Digitalization KPIs in manufacturing (source: author)

Another important aspect to be decided right at the beginning is the ownership – who will be the person(ality) or team driving the innovation? Accountability is critical for the success and it cannot be relied only on the CIO to monitor activities across departments. In case the transformation project is large at its scope, it should be officially declared and incorporated into company's internal directives or guidelines, with regular progress reporting to the board level, who would be proactive and as helpful as possible. In case the transformation is progressing well, the management knows the team lead or supervisor whom to praise – in the opposite case, it is clear who will be held accountable.

After outlining what should be done, it is necessary to make an action plan how will it be done and what key resources the company needs. The key resources of Industry 4.0 are not as much about what is visible, the new digital machinery and robots, but rather what is behind and around. In general, Industry 4.0 technologies call for two key enabling resources that are both financially and timely demanding – people and IT infrastructure:

- **Human resources** needed for successful transformation must be found and trained. Such talent sourcing can be conducted either internally through relocation and requalification or externally through new recruits. The companies must ensure that they have access to pool of candidates with relevant skills and knowledge, e.g. by partnering up with local universities, actively participating at job fairs.
  Given the changing digital requirements on employees, the companies should create a talent model that would serve as a consistent framework for recruiting, developing, and managing the teams, fostering digital-friendly corporate culture. Focusing on crucial digital capabilities such as IT skills, analytical competences, process understanding, or digitally-enabled decision making (Hecklau, Orth, Kidschun, & Kohl, 2017), the recruiters should pay attention to the team dynamics to ensure they have the right people to sustain the company's growth, pushing digitalization forward.

- **IT infrastructure** is probably the biggest differentiating factor whether a company stays only with its digital visions or whether the digital transformation happens. As suggested by the theory and confirmed by the case study, simply connecting machinery to a network is not sufficient. Even an older machinery is able to produce data, collecting and storing them is only a question of connecting it to the internet and paying a data storage fee. The differentiator is what the company does with the data. Rather than collecting random data sets, being overwhelmed, and struggling to make use of them, the companies should base its data collection decisions on the defined business targets and support it by an adequate IT infrastructure and collect only such data, that will bring added value. Such pragmatic approach from the beginning will prevent time-consuming and financially demanding problem analysis, driving the digitally-enabled improvements in quality, quantity, or other efficiencies.

  Thus, what truly drives business value is a well-worked-through IT architecture that connects all that is needed in a meaningful way, is able to collect, consolidate, store and transform data into meaningful and implementable insights along the entire value chain. This does not mean only implementing a new software, but rather a complex solution (Küpper, et al., 2016) of platforms, cloud technologies (bot private and public), SaaS solutions, applications, dashboards, and analytical tools, gradually transforming the existing manufacturing business models.

Final step is a systematic and thorough integration – both vertical and horizontal. Prioritizing and starting from points where it makes the most business sense and adds value to the company, gradually encompassing the whole value chain, progressively incorporating the abovementioned Industry 4.0 pillars.

Vertical integration (as shown in Figure 6) should progress towards following**:**

- **Sales** – ideal state would be where sales staff is able to use some form of mobile technology with an app connected to company's IT infrastructure. By making a deal with a customer, the order placed would automatically go through the systems all the way to the production itself, where the system would evaluate how much material is available, automatically reordering what necessary. Additionally, the company could benefit from leveraging intelligent pricing – depending on the product and based on data analytics, the company can identify patterns, cycles and seasonality of their sales and use such data to run efficient promos and alter their pricing strategies. Moreover, in this ideal scenario, the machines could automatically alter their configurations according to the order's specifications and no human intervention would be needed in the overall order management.
- **Product development** – incorporating digital twin of a product adds on great flexibility, saves costs (especially in automotive or aviation, where the savings from digitalizing crash test are major) and thanks to bidirectional data streaming, the system would be able to create feedback loops to improve the product attributes for the future, optimize material consumption and optimize even basic processes. Additive manufacturing also has a great potential. Thanks to plummeting prices of 3D printing, firms can potentially integrate additional processes or simple-parts production inhouse, meaning the production would be smoother, cheaper and faster on the market.

- **Planning** is connected to advanced data analytics. Predictive maintenance allows for forecasting and production planning at much shorter time slots, optimized for material and energy consumption, order of the products (let's say in the chemical manufacturing industry, orders for detergents of one colour are sorted one after another, saving machine's downtime and improving its OEE).
- **Purchasing** and optimized inventory management is again based on leveraging data and transforming them into guidelines, able to predict when and how much of what material will be needed, minimizing the monetary value kept in the physical stock.
- **Manufacturing –** as already mentioned, plant-wide connectivity and relevant infrastructure can significantly increase quality of the products, OEE of the machines, flexibility, and efficiency of the plant.
- **Logistics** could benefit from collecting data regarding the orders across the value chain. The company can optimize the time and resources needed to load the trucks by managing the products already when leaving the production line. Instead of collecting the products at specific spots, automated robots could identify exactly when and where should be the order prepared for loading. By transporting it directly there, and thanks to the system integrating all necessary data, this would be indeed time saving.
- **Service** – by creating engagement platforms and apps for the customers to stay in touch with the company, ask for guidance with technical products, have access to documentation, manuals, how-to videos, spare parts management and reordering, the company can increase the customer loyalty and NPS thanks to outstanding service and offered convenience.
- **IT, shared services** have great potential in the context of Industry 4.0. With sensors embedded into the products, the company can offer additional after-sale services such as performance tracking, predictive maintenance etc. to the final customer. Moreover, the data can also be utilized internally – by tracking how their products behave in real conditions, out of their testing environments, the company can optimize the development and configurations of the future generations of products.
- **Finance, tax & legal** – digitalization impacts company's invoicing and salary management as well as additional legal & tax activities.

Horizontal integration (as shown in Figure 5) will impact:

- **Network of suppliers** – integrating suppliers through EDI into a unified system to enable smooth cooperation, inventory management, invoicing etc.
- **Partners** not only in terms of business partners integration through EDI or other systems, but also accessing and integrating potential talent pools such as universities (proactive approach, offering internships, workshops and other activities to attract digitally-savvy students-recruits), networking with companies with similar concerns to benefit from knowledge sharing and help one another navigate in the complexity.
- **Network of customers** especially in terms of the after-sale services. With increasing customization requirements, strengthening the digital relationship with the customers is crucial. In industries with not that extensive network of customers, knowing how they use the product, what might their unique needs be and providing them with predictive advice is what could help the company to outperform its competition.

After defining the strategy and ensuring the key resources and tools are available, the deployment in production should start with a small project – either with a single asset or with a simpler production line. Something that is not terribly difficult to implement yet brings visible added value to the company (for example paperless production, equipping working stations with barcode scanners and products with bar codes). This will enable the company to try the new technology out, acquaint the workers with it, learn from hurdles and problems, fix them, and then deploy fast at larger scale. The motto at the beginning of this chapter should be a golden rule for those who want to be successful.

5.1.2 Business model recommendations

Given the outlined complexity of Industry 4.0, companies should anticipate a digitally-driven shift across all the building blocks of their business models. The case study did not contradict the abovementioned theory with regards to the most impacted aspects of the business model. Besides the necessary digital alternations to the **value proposition**, the companies should be primarily ready to actively work on and alter their **core resources** (as mentioned towards data, IT infrastructure, digital-savvy human resources) as well as their **relationships** that will become much more direct through an interface of apps or dashboards. **Core activities** and **partnerships** will also be digitally changed, as mentioned in previous subchapter – towards talent pooling, networking, and IT-leveraging partnerships.

All the building blocks are likely to be impacted incrementally in case of brownfield companies, progressively changing their business operations towards increased productivity rather than making ground-breaking, radical changes that would pose a significant disruption to the company's business model. This links back to chapter 2.3.2 on implementing the digital into business operations, where the theory states that from the perspective of operations, digitalization will impact especially planning (key resources and activities), factory (key resources, partnerships, value proposition) and support (relationships).

In case of a successful extension of the product portfolio or of the offer as such thanks to providing additional services, the companies will grow their business, welcoming new revenue streams to their business models, as suggested in chapter 2.3.2, the case study, Mercedes-Me benchmark etc. Such extension might be the inception point to an architectural or radical business model development or even business model innovation and will incorporate a wide range of stakeholders, from engineers and product developers to final customers. In this case, the company must carefully assess the risk level that is still bearable in order to move forward and alter the business model. Once the decision is made, the company should, again, start with a small pilot project, quickly validate it, discover its flaws, fix it and roll out fast at bigger scale.

The companies will also face shifts in their cost structures. Besides the obvious savings in manufacturing costs due to optimized material and energy consumption, the firms may expect a significant drop in maintenance costs thanks to the potential of predictive maintenance, accompanied by savings in inventory costs, logistics, quality (significantly reduced faulty products rate) and complexity (due to value chain integration). However, the companies must expect the labour costs to rise due to increased skill requirements, accompanied by the necessary investment into the IT infrastructure and production facility as such.

What plays just as important role as the abovementioned strategy, leadership, and changes of the business model's building blocks is the change that stays above the business model itself – in the company's culture. People at different positions will have different fears connected to digitalization – the workers might fear that robots will replace them, foremen might fear how to operate the new solutions and use them in the processes they were used to, shift leaders might struggle with keeping track of the efficiency of their shift with the new technologies and dashboards, and managers might find it difficult to lead people and operations in a completely new ecosystem. Without carefully developing the culture, the company will, sooner or later, face serious issues such as resistance, passivity, decreasing engagement, and even increased employee turnover, which is especially hard in the times of talent scarcity like we have nowadays. Thus, taking the time to include this aspect into the strategy planning, incorporating the people into the process from the very beginning rather than issuing new directives and miscommunicated Industry 4.0 targets is crucial.

5.2 Challenges to successful Industry 4.0 implementation

Industry 4.0 has the potential to be game-changing for those who successfully implement it. No matter how demanding it might be to suggest a universally applicable roadmap to implement Industry 4.0 technologies, the challenges brought by digital transformation are universal, concerning companies across industries. After looking at the benefits and gains it can bring, this section points out the challenges that digitalization can bring, from both managerial as well as operational perspective.

1. **Interconnecting systems to ensure seamless integration**
   Proved both by the case study as well as theory, integrating and interconnecting the systems is necessary for automation along the whole value chain, to be able to automatically process an order, adjust the production plan and material orders (Pavlík, 2017). As proved by the case study, since every company has already implemented some digital solutions, interconnecting the isolated machines at different levels of automation and digitalization is crucial for creating added business value. Additional threats to the business operations arise when an interconnected machine malfunctions, potentially disrupting a larger part of the interconnected process (Müller, et al., 2018).
   Connecting multiple software systems that must communicate stands at the very beginning of Industry 4.0 technologies implementation. To overcome this challenge, a clear strategy and targets should be set, and a thorough cost-benefit analysis or ROI calculation should be prepared to justify the investments into Industry 4.0 compatible software and IT infrastructure (Bosch Software Innovations, 2015).

2. **IT architecture & infrastructure**
   Digitalizing company's operations will require more than a simple upgrade of current IT systems – rather a complex view of the whole automation and digitalization process (Pavlík, 2017).Creating a completely new IT infrastructure is demanding in terms of time, human as well as financial resources and oftentimes the readily-available solutions on the market are not sufficient. The case study provided a great example of overcoming this challenge – since there was no perfect solution available on the market

at a reasonable price, they internally created one specifically for their purposes, hiring necessary talents to ensure the most relevant insights and flexible reactions.

3. **Data availability and reliability**
Gathering data is not an issue – however, efficiently managing them, transforming into reliable and helpful insights that will be consistent across units of the company, that is a different story. The ability of machines to communicate with one another at the field level, in real time and with an intelligent functionality that gathers all the data together is crucial for success (Harting, 2017). Issues such as unclear definition of standards, lacking compatibility with existing systems and availability of relevant tools are the most basic ones and must be tackled in order to leverage the value adding operating systems.

4. **Cybersecurity**
Data security is a great concern not only from the perspective of personal consumer data, but also from the perspective machine and production related data, for reasons as manipulation, espionage, cyberattacks, and potential losses of differentiating know-how and intellectual property (Bosch Software Innovations, 2015). The companies must strive to systematically identify security risks – both cybernetical as well as physical (Pavlík, 2017) – before someone else does and misuses this knowledge.

5. **Organizational challenges**
The success of Industry 4.0 projects depends on IT experts and engineers speaking a common language. The IT experts need to gain a thorough knowledge of the production process to provide the best possible help (Bosch Software Innovations, 2015), working together side by side to reach the company's vision. This requires a clear strategy, strong leadership and digitally-accepting corporate culture.
When introducing the changes connected to digitalization to the company, most probably there will be some level of resistance to change. Especially with the buzz around the technologies and their implications, the management is often rather sceptical. After interviewing experts, company management and external consultants looking into digitalization, it became apparent that not only the operational staff, but also the decision makers oftentimes struggle to imagine implementing solutions that are radically different from their current ones. They might fear that the company is not well suited for incorporating digital technologies into production, which is confirmed by experts (Holý, 2018) and expressed by one of the participants to the factory visit as: *"We are currently at the level of Industry 2.0 and I cannot imagine how would we ever skip to the 4.0."* Current state of the art oftentimes presents a set of barriers (both real as well as mental) – leading to resistance, denial, and scepticism from the management.

6. **Human resources**
The challenge will regard talent sourcing & retention, education, and adapting to new roles. Industry 4.0 might enable employees of ever-higher age to stay working longer even in the manufacturing industry and bring jobs back, counteracting the outflow of manufacturing jobs from the recent years to low-income countries. However, new job profiles will evolve (Bosch SI, 2015) and human resources will be a challenge both from

the perspective of lacking expert know-how, qualifications and capabilities as well as manpower shortage for putting the Industry 4.0 technologies into practice (Bosch Software Innovations, 2015). Especially for rural and remote areas, sourcing digital-savvy talent is a demanding task due to shortage of qualified people. Company's departments will have to join forces with the HR teams to find solutions that will enable them to leverage the newly available technologies.

7. Decentralization, cross-functionality, and knowledge sharing

Linear management will no longer be sufficient, companies will have to decentralize and be prepared for increasing virtualization of the teams as well as the operations themselves. A shift towards more inter-department inter-role project-oriented management (Pavlík, 2017) will occur, accompanied by autonomous robots able to take decisions and communicate with one another. The companies will face the need to implement mechanisms to direct these intelligent autonomous actions (Wang, Wan, Li, & Zhang, 2016). Moreover, with the challenge of talent shortage, companies must make sure that once they acquire (either internally or externally) a key skill set, the knowledge stays in the company even if the person leaves (Pavlík, 2017).

8. Unclear financial benefits, ROI, and scalability

Implementation of any innovation comes with a price tag – and for Industry 4.0 it can be a large sum, depending on the initial state of the company. Industry 4.0 technologies will require investments into machine parks, IT infrastructure and personnel (Müller, et al., 2018) with not-yet enough business cases that could serve as successful benchmarks. Solutions are novel, require significant changes for companies with complex and uncertain quantification of outcomes (Geissbauer et el., 2014) and their high costs cannot justify an increase in price of the final product to the customers to compensate for it

9. **Ecosystem challenges**

According to a study that polled 1600 C-level executives across industries, 2 out of 3 executives believe that businesses will have much more influence than governments and other entities on shaping the Industry 4.0 future, social and economic equality and stability (Deloitte Insights, 2018). This means that further complication might be lack of agreed-upon standards, potentially requiring cross-sector cooperation. Policy makers should step in to help the companies by promoting entrepreneurship, improving education frameworks, helping with international standardization and competitive data protection laws (Geissbauer et al., 2014). Connected to this and the abovementioned knowledge sharing is the increasingly popular open-source software and crowdsourcing.

10. Demand volatility and ever-increasing push for customization

Decreasing batch sizes may have a negative impact on the business through reducing the output per production line, leading to operational issues and delays due to low standardization (Müller, et al., 2018). In connection with social media and fast-moving information, dissatisfied customer posting a negative review online might discourage others from making the purchase, redirecting them to the competitors.

5.3 Discussion, future research & limitations

The final subchapter summarizes the key findings by answering the research question and discusses alternative views and approaches to the topic. By looking at the potential of Industry 4.0 in the future, the author outlines potential areas of future research, concluding with limitations of this paper.

5.3.1 Summary of key findings

The abovementioned managerial recommendations will be summarized by answering the research question: *What key steps should a manufacturing company implement and what key performance indicators should be tracked when shifting the company's production processes towards Industry 4.0?*

With regards to what key factors a company should implement when undergoing a digital transformation, the author (visualized in Figure 22) suggests following:

1. Assess the company's **digital maturity**. Either internally or with the help of external consultants, critically evaluate the company's digital status quo, strengths as well as weaknesses and areas for potential growth.
2. Define a **digitalization strategy**. At this point, the key decision makers should set a clear and long-term digitalization strategy, bearing in mind what the aim for the company is, what the key drivers are, what the company wants to ultimately achieve. The firm must keep the customers and their needs in the centre of those decisions. Financial aspect of digitalization is important – the company should talk about the desired ROI and make sure that all relevant stakeholders have aligned expectations.
3. Set **goals and priorities**. Specific and operational to identify where does it make the most sense to start, what areas have the strongest potential and are backed by a strong business case.
4. Define relevant **KPIs** to keep track of the digitalization progress.
5. Make someone **accountable.** Project ownership and clear leadership are extremely important for a successful transformation for both the management as well as the workers. Everybody knows who the person or team-lead responsible is, coordinating the project and who will provide regular reports to the management.
6. Ensure the **key resources** are available. Under Industry 4.0, the key differentiators for a successful digital transformation are digital-savvy human resources who will together with a well-designed IT infrastructure be the crucial enablers of the success. Without a well-working IT infrastructure capable of leveraging all the new technologies and data available, supported by a skilled staff, the whole digital transformation will end as a vision rather than a success story.
7. **Integrate** – both horizontally and vertically, both physically by connecting the assets as well as virtually. To leverage the new opportunities introduced by Industry 4.0 and data integration, geographically dispersed parts of the value chain from the company's suppliers and business partners to the final customers will require a novel and complex approach to the ways of running the business.

With regards to the digitalization KPIs, the company should base its decision on the defined strategy and aims and track the following (as shown in Figure 23):

- **Sales KPIs** – besides the traditional sales KPIs such margin or sales in units or in monetary value, digitalization can be also tracked by time to market;
- **Production KPIs** – overall, the company can track the progress by monitoring the productivity growth rates, numbers of units produced per a timeslot. Digitalization can also help the company with regards to cost management – tracking operational costs per unit or inventory holding costs.

  With regards to measuring plant's OEE, the company can track three key **OEE's attributes**: <u>Availability</u> of the machines by monitoring machines' downtime, failures and incidents or inventory lead times. Moreover, monitoring costs in this category will also provide the company with valuable insights regarding the success of digitalization – by tracking costs of maintenance and costs of repair where the digitalization has a great savings potential.

  <u>Performance</u> of the plant can be monitored by measuring production output (per production line, per machine, per a time slot), average production time or delivery accuracy.

  <u>Quality</u> of the final product and its improvements thanks to digitalization can be measured by the percentage of replacement claims from the customers. In the production process, the quality can be assessed by tracking faulty products rate and the amount of material rejects.

  Production's **agility and flexibility** with the focus on digitalization can be monitored by number of variants available (product extension), lead times (order-to-delivery) or by average order size (digitalization enables the companies to decrease the size of the orders while remaining profitable).

  Innovation is an important part of the digital transformation and can be assessed by the R&D times (overall time needed to bring a completely new product to the market).
- **Administration** can be improved especially with regards to order-management, where digitalization decreases the order processing times and speeds up the overall administration.

5.3.2 Discussion

Industry 4.0 systems, digital thread and other technologies have the potential compress supply chains from current days or weeks to only hours or minutes, impacting the entire manufacturing ecosystem in major ways. Supply chain will be transformed through integration and technologies into digital supply network, with data flowing both ways – creating feedback loops, automatically reordering materials, helping to develop the next generations of product by learning from and optimizing the processes today. Processes that are normally managed internally by both people and machines and move them into the Cloud where they can be managed from anywhere in the world. Everything changes and virtualizes – from the very beginning of a product lifecycle, from the design part. With technologies that enable creating digital twins of physical parts, creating "smart parts" that can be changed, tested, modified, even completely redone – all in the digital world (Cotteleer, et al., 2018). The big question for the companies nowadays is how to make use of these non-linear processes and connectivity with technologies that are evolving exponentially.

Currently lacking standards and available guidelines should not stop the companies from leading the change. They should not wait for the governments to define those standards but should rather proactively participate and experiment by implementing concrete applications to help define what standards the industry actually needs. Knowledge-sharing and open standards will drive the change further. Companies, especially SMEs, should proactively participate in regional platforms, such as Testbed introduced in the Czech Republic (Holý, 2018) to overcome the fear of the unknown and perceived technological barriers and above-listed challenges, educate themselves and broaden their network, to learn that Industry 4.0 is not only a buzzword and sci-fi, but a solution that can be utilized to achieve specific business goals.

Another burning question is: how will the companies deal with the instant-gratification market, pushing for ever-increasing customization and new value creating through novel efficient combinations of previously separate resources, but with lacking customer loyalty? Current situation is a double-edged sword (Steiner, 2017) – if you do not change, the competition will run over you. But if you change too much or too fast, you risk losing the customers instantly. In case of a failed innovation or unsuccessful digitalization attempt, one bad review can spread like a wildfire, potentially destroying the company's reputation and years of hard work.

As suggested at the beginning of the thesis, the specificities of the fourth industrial revolution differentiate it significantly from the previous ones. Some authors see Industry 4.0 and the new technologies it brings as true revolution and a paradigm shift (Geissbauer, et al., 2014, Krishnan, et al., 2015; Mařík, et al., 2016, McKinesy & Company, 2015; Bosch Software Innovations, 2015), some argue that since it is being predicted, it is more of an evolution, continuous development (Kagermann, et al., 2013; Da Costa, et al., 2017; Rüßmann, et al., 2015; Hermann, et al., 2015). Such tension among the experts brings up discussion and different attitudes towards implementing Industry 4.0. Assuming that companies defined their digitalization strategy – how should they proceed? Should companies approach it revolutionarily, trying to implement radically new digital solutions into their businesses to see the results fast, changing some crucial parts of their value chains and fixing the remaining parts only afterwards? Embedding the existing machinery with digital connectivity and data collection tools to have a relatively easy yet (from the plant's perspective) revolutionary starting point? Or should they approach Industry 4.0 more conceptually, acknowledging the complexity of the change it brings to the operations as well as the entire business models? There is no unified answer to these tensions and with industries still at the beginning of the digital transformations, only time and additional case studies will prove whether is it more beneficial to revolutionize the company's activities radically or rather to evolve them gradually.

5.3.3 Looking into the future: potential impacts of Industry 4.0

Disruption of such extent will doubtlessly have an impact beyond the smart factories and optimizations of processes and manufacturing techniques (Geissbauer et al., 2014), including the business models, employees, customers as well as the society at large. According to a study by Deloitte conducted with more than 1600 C-level executives worldwide, 2 out of 3 questioned executives believe that businesses (both private and public organizations) will have larger influence than governments on the environment.

Some of the impacts might be contradictive from the business perspective. For example, for many tasks it is still cheaper to hire a worker than buy a machine – however, with the increasing strength of voice of the employees and unions and increasing living standards, some tasks simply would not be accepted by humans anymore, especially not in the developed economies. Thus, the companies are faced with a dilemma – they would hire a worker rather than a machine from the financial perspective, but there is simply no workforce available for the task. Hence, there is no other solution than buying the expensive machine, if the company wishes to stay in the business.

Companies will thus be faced with unprecedented complexities from all sides brought by Industry 4.0 and must take them into account, assessing how to face them and prioritize. Following list is based on the abovementioned Deloitte study (Kagermann, et al., 2013):

- **Meeting individual customer requirements** through including individually-specific criteria in all stages of a product manufacturing process, from design and configuration through ordering, planning, manufacture and operations, enabling last-minute changes to be incorporated. This represents one of the key aspects that companies should not overlook, given the increasing pressure from the consumers for ever-increasing individualization. Such ability represents a break-through for companies in terms of potentially manufacturing one-shot designs in the batches of 1 whilst still making a profit.
- **Flexibility** thanks to ad-hoc networking, enabling dynamic configuration of different aspects of business processes, such as quality, time, risk, robustness, price and eco-friendliness. This enables the company to adjust materials consumption and supply chains to best fit the current demands. Moreover, it also means that the processes can be more agile, overcoming and compensating for potential temporary shortages through increases in output in a short period of time.
- **Optimised decision-taking** even at a very short notice, since Industry 4.0 provides end-to-end transparency in real time, allowing more flexible resources.
- **Resource productivity and efficiency** – just as under traditional industrial manufacturing processes, Industry 4.0 stull aims to deliver the highest possible output at a given input volume (resource productivity) and using the lowest possible volume of resources to reach a particular output (resource efficiency). Thanks to CPS, the processes can be adjusted on a case-by-case basis and continuously optimised during the production in terms of choosing only such configurations, where the energy and material consumption as well as emission levels are as low as possible (Birgit, Gülden, & Ursula, 2012).
- **Creating new value opportunities** for both companies as well as individuals, since new business opportunities arise with insights gained through big data analysis
- **Responding to demographic change in the workplace,** such as aging population and shifts in the diversity and skillsets of workforce. Industry 4.0 will provide individuals with more flexible career paths, enabling people to remain productive longer.
- **Work-life balance** is becoming increasingly important for the workforce and companies must address this in order to stay attractive to both the current as well as potential employees. Most likely, this will be done through continuous professional development programmes and smart assistance systems, providing new flexible ways of organizing work, enabling meeting both the companies' targets as well as individuals' needs. Moreover, Industry 4.0 will inevitably change the type of tasks employees will

perform, from repetitive routine tasks towards more creative, value-adding activities. To seamlessly undergo this shift, it is necessary for the companies to engage employees in learning and professional development programmes, workshops and other initiatives.

5.3.4 Limitations

Saying that every company has already implemented some digital solution is hardly an overstatement. However, every company is at different stage of the digitalization process, has different needs, targets and available tools and resources. As with any general guideline, providing a roadmap to successful Industry 4.0 implementation might be viewed as an oversimplification. The author's aim was to present a "manual" as generally applicable as possible, summarizing the trends in manufacturing from different business-relevant perspectives in a way that every company can reflect its status quo on the provided framework, evaluate its strengths and weaknesses and move forward towards digitally-driven and measurable business growth.

Even when compared to examples of other manufacturing companies and their implementations of Industry 4.0 technologies, the main limitation of this thesis is its focus on one relatively strong firm with regards to digitalization as a starting point for general recommendations. The author strived to be well informed about the topic prior to the visit and connected interviews to be able to objectively assess the wide picture of digitalization impacts on a business. However, as a novice researcher, some implications, signs, and hidden meanings might have not been observable to the author given the imperfect expertise. This potential weakness of the paper was mitigated by conducting interviews with external Industry 4.0 experts from leading global consultancies to help the author objectify the insights and gain critical approach to the topic.

Connected to the fact that the thesis draws conclusion on a single-company analysis is the limitation of data sensitivity. Regardless the anonymization, some data regarding cost structure and its development due to digitalization or margins evolution were considered too sensitive to be shared. The limitation here is obvious – the theory references costs as one of the main reference points and traceable indicators when it comes to evaluating the impacts of digitalization and the case study unfortunately does not address this in much detail. Nevertheless, the suggested framework compensates for this lacking case study data by synthesising this from the theory and presented benchmarks.

CONCLUSION

The aim of the thesis was to provide a roadmap for manufacturing companies digitally transforming their businesses with focus on what technologies to implement, what parameters to follow and measure when shifting the business's operations towards Industry 4.0.

To reach this goal, the study firstly defined the underlying term Industry 4.0 and put it into context of relevant frameworks, drivers, pillars, and trends. Furthermore, the reader was presented with an overview on business model and business model innovation under Industry 4.0 by defining the terms, elaborating on what aspects of a business model are the most impacted by the digital shift. A wide set of metrics to assess the impact of digitalization outlined areas of potential digitalization evaluation. Additionally, the paper introduced benchmarking cases of successful business implementations of the Industry 4.0 pillars across the world before thoroughly analysing the case company. Observing the firm's digital transformation from the perspective of the digitalization pillars, changes of its business model and specific examples of how the digitalization drove their business further, the final recommendations are made based on synthesising the case studies with the information obtained from the literature review.

The study has shown that there is a great interest in the topic of Industry 4.0 and the challenges and promises it brings. The literature review has proved that due to the complexity of the fourth industrial revolution, there is no unified definition. The term's meaning is depending on what the expectations of the experts and companies are regarding the potential of Industry 4.0, its drivers and where the added value is seen. Even though the topic is thoroughly discussed across the academic as well as business literature, it seems that there are not yet many examples or case studies of successful digitally-driven company-wide Industry 4.0 transformations. The research suggests that the term is a bit demonized, oftentimes too complex for the companies to efficiently navigate themselves in the current industrial revolution, indeed like a buzz word that companies struggle to grasp. Nevertheless, there are clear benefits for those who approach Industry 4.0 systematically and strategically.

The author strived to outline generally applicable guidelines for manufacturing companies to direct the firm's actions at the dawn of the fourth industrial revolution by answering the research question: *What key steps should a manufacturing company implement and what key performance indicators should be tracked when shifting the company's production processes towards Industry 4.0?*

The author suggests that a successful digital transformation should start with assessing the company's digital maturity, its strengths as well as weaknesses, enabling the decision makers to define a clear digitalization strategy with specific goals and priorities. Once the goals and strategy are defined, the company should focus on an action plan how to reach this aim and what KPIs to follow, in order to efficiently evaluate the impacts of digitalization on the business's operations. At this point it seems of a large importance to identify a leader, a project owner, who would be held accountable for the progress of the digital transformation. Industry 4.0 represents a challenge also in terms of the specific resources a company needs in order to transform its operations. With increasing importance of data along the entire value chain, a well-designed, reliable, and secure IT infrastructure plays a vital role. In combination with new roles of digitally-skilled employees, these two resources are the key drivers of a successful digital transformation. Ensuring these are in place, the company can move to the final part of the process – integrating. Horizontally as well as vertically, physically or virtually – the fourth industrial revolution calls for interconnectedness across the entire value network, regardless the physical distances.

With regards to the second part of the research question on what digitalization KPIs should the company monitor, the answer depends on the defined strategy and specificities of the firm. When transforming the production, digitalization can be effectively measured in terms of the OEE – of the plant as well as of a single machine. Specifically, the companies can track the availability (through downtime, failures, cost of maintenance, cost of repair), performance (production output, delivery accuracy, average production time) or quality (faulty products rate, material rejects or replacement claims). Besides the OEE, the company can also assess its agility and flexibility, which translates as how digitalization helped the company with regards to customer centricity. Explicitly, the companies can track the amount of product variants available, lead times or average order size. Finally, the firm can also keep track of the innovation progress, since digitalization has the potential to impact R&D times.

Given the dynamic nature of Industry 4.0, it is impossible to state a single approach that would be regarded as the only correct one. There are different approaches to the whole idea of Industry 4.0, some looking at it revolutionarily, others evolutionarily. Moreover, many companies are still at early stages of digital maturity, there are multiple implementation challenges and lacking examples of successful end-to-end digital transformations to lead the change. Readers should approach the recommendations of this thesis rather as a general roadmap directing the steps and actions of a company than a detailed to-do list that would guarantee a success. To conclude, it is fair to say that the complex potential of Industry 4.0 is yet to be fully uncovered and gradually implemented and leveraged by manufacturing companies.

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