New business models with Industrie 4.0 in the German Mittelstand

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Abstract: Medium-sized enterprises called the 'Mittelstand' are an important pillar of the German economy. However, these firms have not been as quick to develop new digital business models that characterise a shift to digital manufacturing, which is called 'Industrie 4.0' or the Industrial Internet of Things (IIoT) in Germany. In this paper, we analyse different types of digital business models, including important external drivers (technology, security, and standards) and internal drivers (business processes, organisation forms, inter-firm cooperation, and human resources strategies). We show that the complexity and the chances of success of new business models with Industrie 4.0 increase with the integration of players from the respective ecosystem and a focus on the system rather than the product. To illustrate such business models in detail, we analyse a German 'Mittelstand' manufacturer that is currently implementing Industrie 4.0.

Keywords: digital business models; digital manufacturing; Industrie 4.0; IIoT; Industrial Internet of Things; German Mittelstand; Germany; technology; hybrid products; case study.

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1 Introduction

Digital technology is fundamentally changing the business world. In the 1990s, the initial major applications of technologies, based on the backbone of the internet, provided the digital infrastructure to allow business models focusing on the consumer (E-commerce, e.g., Amazon). In later years, new platforms developed in the consumer world to allow the growth of social networks (e.g., Facebook), user-generated content (e.g., You Tube), and streaming services (e.g., Spotify) (Fleisch et al., 2014). In recent years, the rapid reduction in costs for sensors and other technologies has enabled digitally connected machines and products (the Internet of Things) and new digital services and business models, such as Pay per Use, Remote Usage Monitoring, and Preventive Maintenance. These new services and business models will have a great impact on the business world, particularly in the area of manufacturing. To date, many large companies (e.g., Siemens, SAP, GE, and Fujitsu) are taking advantage of these new technologies and services and developing new or renewed Industrie 4.0 business models. These range from digital refinements of products and services to intelligent networking of market players in business ecosystems.

The rate of adoption of Industrie 4.0 possibilities has been much slower in small and medium-sized business. In Germany, smaller, typically family owned businesses, often called the 'Mittelstand', are the backbone of the German economy, representing over 95% of firms and over 50% of sales and number of employees (Federal Ministry of Economics and Technology, 2013). It is especially important for them to understand the different mechanisms and drivers of different Industrie 4.0 business models. Possible pathways and relationships in the Industrie 4.0 ecosystems are also highly relevant. As these aspects have not been studied by other authors before, in our paper we aim to close this gap by analysing different Industrie 4.0 business model types, including concrete examples of German Mittelstand companies, to demonstrate their successful Industrie 4.0 implementation.

First, we describe the foundations of the German Mittelstand and digital manufacturing, known as 'Industrie 4.0'. We then discuss the types of business models that these kinds of firms are developing and provide several case examples, linking them always to our developed framework. Finally, we discuss the implications of such a development for the German industry in particular, but for other countries as well.

2 Foundations: German Mittelstand and Industrie 4.0

The foundation for analysing several cases is an understanding of the German Mittelstand and Industrie 4.0.

2.1 German Mittelstand

Mittelstand firms are typically small and medium-sized enterprises in German-speaking countries, especially in Germany, Austria, and Switzerland. There are a variety of definitions about the size of such companies, ranging from 500 to 5000 employees and 50 Million to 1 Billion in sales. However, the designation 'Mittelstand' usually refers to mid-sized firms as opposed to larger publically traded companies. Venohr et al. (2015) state that Mittelstand companies share a common set of values and management practices, such as:

- family ownership or family-like corporate culture
- long-term focus
- independence
- emotional attachment
- investment in their workforce
- flexibility
- lean hierarchies
- innovativeness
- customer focus

- social responsibility
- strong regional ties.

Based on these values, they divide Germany's Mittelstand into three distinct categories.

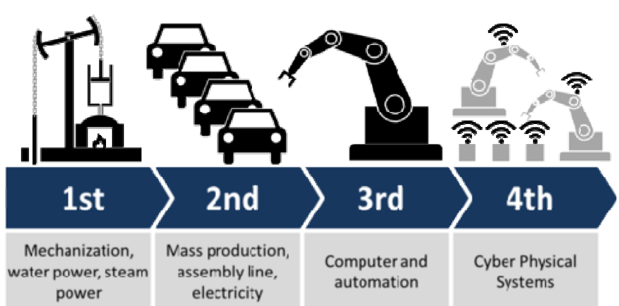
- *'Classic' SME-type Mittelstand firms***,** which account for 99% of German firms (revenue below 50 million EUR)
- *'Upper'-sized Mittelstand firms*, which account for 0.34% of German firms (revenues between 50 million EUR and up to 1 billion EUR)
- *Large corporations*, which account for 0.02% of German firms (revenues over 1 billion EUR) and are more well-known companies, including the DAX 30 companies.

Based on this classification, over 99% of German firms are members of the Mittelstand. The larger of the two categories 'classic' and 'upper' Mittelstand make up 68% of Germany's exports. In comparison, Germany's large corporations generate 32% of Germany's exports. Therefore, the German Mittelstand represents a large overall share of the German economy (Federal Ministry of Economics and Technology, 2013). However, the digital revolution poses a challenge for these firms, particularly for manufacturing firms adapting to Industrie 4.0.

2.2 Industrie 4.0

Digital technology is affecting all industries and leading to a digitally connected world in many areas, including urban development (e.g., smart cities), mobility systems, health care, and in the industrial world of manufacturing. The application of cyber physical technologies to manufacturing is referred to in Germany as 'Industrie 4.0' to reflect the fourth industrial revolution after mechanisation by steam and water (1st), mass production through electrification (2nd), and computer and electronic automation (3rd) (See Figure 1).

Figure 1 Industrial revolutions (Roser, 2018) (see online version for colours)



The German Federal government adopted this term as part of its high-tech strategy in 2013 (Kagermann et al., 2013; Lasi et al., 2014). Other countries have similar initiatives, such as the Industrial Internet Consortium in the USA, Manufacturing Innovation 3.0 in South Korea, the Robotic Revolution in Japan, and Made in China 2025 (Kang et al., 2016).

The concept of Industrie 4.0 links the Internet of Things (IoT) in the industrial context with the Internet of Services (IoS) (Hartmann and Halecker, 2015; Simonite, 2014; Vermesan and Friess, 2014). This linkage provides significant disruptive potential by changing the value propositions of a product or a company as well as their competitive strategic positioning and business models (Burmeister et al., 2016).

Researchers have described Industrie 4.0 as the "realtime capable, intelligent, horizontal, and vertical connection of people, machines, objects, and information and communication systems to dynamically manage complex systems" (Bauer et al., 2014, p.18, citation translated from German by the authors). Cyber-physical systems (CPS), including data processing units, sensors, and actuators, are the technological core of the IoT (Lee et al., 2015; Rudtsch et al., 2014). The basic technology is embedded systems, i.e., high performance 'microcomputers' that can be incorporated into a variety of materials and objects. Using sensors and actuators, these systems can capture and process a large amount of data from industrial processes. Faster data networks allow such data processing in high volumes and at ever-increasing speeds. Cyber-physical systems arise from the linkage of the embedded systems. These systems typically have IP addresses, allowing access via the internet and processing via software applications (BMBF, 2013).

Industrie 4.0 will have a tremendous positive impact on business and the economy. The most conservative independent estimates place spending to reach $500 billion per year by 2020. More optimistic predictions of the value created by the IoT range as high as $15 trillion of global GDP by 2030. Operational efficiency is one of the key attractions of Industrie 4.0, and early adopters are focusing on these benefits. By introducing more advanced automation and flexible production techniques, manufacturers can boost their productivity by as much as 30%. Predictive maintenance of assets is one such area, saving up to 12% over scheduled repairs, reducing overall maintenance costs by up to 30%, and eliminating breakdowns by up to 70% (Daugherty et al., 2015). However, these savings and increases in operational efficiency are likely to be just the beginning of the enormous potential.

Besides all the positive assessments, it is also clear that companies are faced with completely new challenges when industries 'become digital'. In particular, the entry of new data-driven competitors such as Google, Amazon, and Apple from outside the traditional industry may lead to disruptive forces. Examples include Google's entry into the automotive industry or Airbnb's dominant position in the hotel industry.

The estimated benefits are linked to the challenges of the 21st century, where companies in increasingly volatile and complex markets face an increasing need for flexibility and for customised products and services as well as a shift of the market power towards the customer due to the higher market transparency. It is in addressing such challenges that the benefits of the large investments in Industrie 4.0 become important. For example, increasing automation and communication between machines (and people) leads to higher productivity, to a greater machine availability, and to lower failure rates. Significant cost savings can be a result (Kiel et al., 2017). By increasing process transparency and optimising intra- or inter-logistic processes, procurement and storage times as well as logistics costs can be significantly reduced (Zhong et al., 2015; Zhou et al., 2017). The time saved through automatic and autonomous machine conversions and reconfigurations adds further cost advantages. Open constructed machines, which can perform different functions in a direct time sequence or use different tools at the same time, are also part of the saving potential. They make the entire production much more flexible and are already revolutionising industrial production today. These developments also apply to maintenance and repair of equipment. Industrie 4.0 applications provide transparency about the condition of all machines. The machines can then order spare parts in advance automatically or as soon as signs of wear appear. Such predictive maintenance helps to avoid or eliminate errors (BMBF, 2013). Also in the field of research and development, the increased use of simulations instead of real prototype testing leads to cost savings and a corresponding decrease in time-to-market. At the same time, product and process quality and the robustness of the production processes are growing (Oesterreich and Teuteberg, 2016). To realise this potential, firms will need to make tremendous changes in their organisations and in the mind-sets of managers and employees. These management aspects are essential for the success of Industrie 4.0.

For the customers, these technological developments allow more flexibility and increased customisation, which can represent a new source of income for the manufacturing companies. The decreasing product variety resulting from standardisation will increase again with IoT applications. In the past, the fulfilment of customer-specific requirements was only possible at the price of higher production costs. With Industrie 4.0, however, individualised production at a lower cost is possible using smaller scale standardisation of many individual process steps. The German Ministry of Economics has stated that "the once dominant quest for economies of scale to lower costs is nowadays less important. This is the qualitative leap of the fourth industrial revolution" (BMBF, 2013, p.14, citation translated from German by the author).

New business models based on exploiting Industrie 4.0 technologies offer promising potential for competitive advantages and new sources of income (Arnold et al., 2016). As mentioned above, the adjustment of current or the development of new business models is necessary to achieve additional value through higher prices or greater market shares. Such business models must offer clear advantages beyond existing ones in the form of lower costs or price premiums from customers.

In Table 1, we give an overview of the possible advantages of Industrie 4.0 (Kiel et al., 2017). These advantages also have corresponding challenges. For example, companies must first make large investments in new technologies when the potential profits remain uncertain (Kagermann et al., 2013). Laudien and Daxböck (2016) argue that Industrie 4.0 applications and business models can initially lead to increased time-to-market and decreased control. Uncertainty also exists as to whether potential customers are willing to pay the price for such new or enhanced products and services. Other influencing factors include the technical integration of Industrie 4.0 systems as well as organisational and personnel challenges.

Overall, developments in the context of digital manufacturing are occurring very differently in Germany, Europe, and the USA. Germany has been slowly developing Industrie 4.0 with the creation of a Platform Industrie 4.0 linking government ministries, industry, and academics. This platform is initiating lengthy processes for the discussion about norms and standards. In the USA, the Industrial Internet Consortium (IIC) follows a more pragmatic approach with 'trial and error' to develop use cases that are setting de facto new standards and developing new business models very quickly (Burmeister et al., 2016).

Table 1 Benefits of Industrie 4.0 (Kiel et al., 2017)

Benefits	*Explanation*
Competitiveness	• Expansion and protection of market shares • Strategic differentiation and competitive advantages based on innovative offerings
Costs	• Enhanced value creation and growing sales volumes • Cost reduction potentials
Overall equipment effectiveness	• Optimisation of product and process quality • Higher productivity, machine availability, production process, and output robustness • Lower scarp and failure rates • Self-optimisation of machinery
Individualisation	• Batch-size of one production • Flexible production enables customisation of product, services, and hybrid solution offerings
Novel business models	• Value offerings in terms of hybrid product/service solution • Integration of software solutions • Pay-by-usage or platform-based business models
Resource efficiency	• Optimisation of resource utilisation • Digital simulations, continuous data, and autonomous control loops enable leaner processes • Reduction of manual activities due to higher automation levels
Data & information	• Vertical and horizontal connection enables targeted reduction of media disruptions within information chains • Transparency of process, machinery, stock, or logistics data facilitates traceability of commodity flows • Smart Big Data analyses allow short information flows and effective data exploitation
Time	• Shorter set-up and lead times as well as faster machine speed facilitate faster and more flexible response to customer demands • Decrease of time-to-market due to simulations, e.g., in engineering and R&D • Reduction of non-value-adding activities and time
Human resources	• Higher quality of work due to simplification of processes and tasks based on technical assistance systems • Optimised human–machine interaction and higher safety features facilitate employee involvement • Security of employment due to novel jobs in emerging IIoT-specific departments within established companies

In 2015, 57% of German companies surveyed by a McKinsey study saw themselves as well prepared in the area of Industrie 4.0, compared to over 83% of the US companies surveyed. Over 90% of US companies expected new competitors in their industry because of new technologies, compared to only 46% among German companies (McKinsey Digital, 2015). In a representative survey of large companies with a minimum annual turnover of 250 million Euros or US dollars in the USA and Germany, 50% of US companies expected concrete results in their organisation through digitalisation in less than a year (Etventure, 2017). In Germany, only 6% believed in such impacts. Ninety percent of these US companies saw their workforce as qualified to meet the challenges of digitalisation. In Germany, only 42% believed this about their workforce. At the same time, 37% of German companies said that the processes of digital transformation among employees mainly cause uncertainty. Only 6% in the USA had the same opinion (Etventure, 2017).

With our review of the development of Industrie 4.0, we show both the advantages and challenges of these technologies and the different paths and implementation efforts followed in different countries. In the literature, however, analyses of different levels of Industrie 4.0 business models, which are also especially applicable for the medium-sized German manufacturing companies, are largely missing. Our paper aims to close this gap by developing a structured framework including various company examples and one company case study to give even more insights.

3 Characteristics of Industrie 4.0 business models

As indicated above, the characteristics of Industrie 4.0 are extensive (Arnold et al., 2016; Loebbecke and Picot, 2015; Porter and Heppelmann, 2014). They include:

- digital refinements of products and services
- intelligent networking of operation and production
- new business models through connected and intelligent products and services
- new business models through intelligent networking of market players in an ecosystem.

Changes go beyond the pure functionality of individual, independent products to offerings of complete product and service systems.

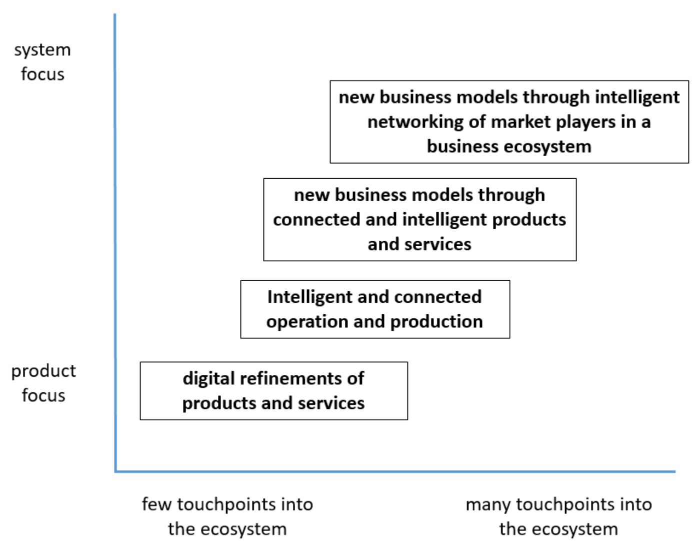
> "Manufacturers have traditionally focused on producing a physical good and capturing value by transferring ownership of the good to the customer through a sales transaction. The owner is then responsible for the costs of servicing the product and other costs of use, while bearing the risks of downtime and other product failures and defects not covered by warranties. Smart, connected products allow the radical alteration of this long-standing business model. The manufacturer, through access to product data and the ability to anticipate, reduce, and repair failures, has an unprecedented ability to affect product performance and optimise service. This opens up a spectrum of new business models for capturing value, from a version of the traditional ownership model where the customer benefits from the new service efficiencies to the product-as-a-service model in which the manufacturer retains ownership and takes full responsibility for the costs of product operation and service in return for an ongoing charge." (Porter and Heppelmann, 2014, p.84)

Going one-step further, Porter and Heppelmann (2014) suggest that firms should apply smart, connected products and services in four areas: monitoring, control, optimisation, and autonomy. These applications build on each other. To have control capability, for example, a product must have monitoring capability.

The transformation from such technologies in some industries will move companies from pure production and sales to platform business models (Gawer and Cusumano, 2002). For such platforms, the role of ecosystems in complex innovation processes comes into play. Ecosystems are cooperative networks or business alliances to drive innovative products and services. Rather than being part of a single industry, companies understand themselves to be part of a community of organisations that are mutually interconnected. These systems include, for example, suppliers, customers, stakeholders, trade associations, government organisations, and competitors (Gawer and Cusumano, 2014; Iansiti and Levien, 2004; Moore, 1993, 1996).

The characteristics of Industrie 4.0 described above show a variety of possibilities for different digital business models. Researchers have shown, on the one hand, an increase in the complexity of the business models due to the focus away from pure product and service towards system thinking (Y axis in Figure 2) as well as through an increasing focus on the corresponding ecosystem around the company with more and more relationships that need to be integrated (X axis in Figure 2). On the other hand, these developments are consistent with the expansion, refinement, and development of these business models and further revenue generation and competitive advantages of the company. Figure 2 illustrates these developments and can be seen as options for companies on their way to developing new business models using Industrie 4.0 technologies.

Figure 2 Applications of Industrie 4.0 (own illustration) (see online version for colours)



3.1 Digital refinements of products and services

Examples of digital refinements of products and services as a first stage of the applications of Industrie 4.0 include the integration of barcodes or RFID tags into products and product components in order to make purchasing, material flow, production, storage, delivery, and subsequent service more efficient and cost-effective. This application represents the most generic type of connection between components, products, and their production systems and has been used by a variety of manufacturing companies (for example, in the context of Kanban and just-in-time supply) for some time. For example, the company Würth Industrie Service, one of the largest family-owned companies in Germany, has been producing screws and bolts for industrial purposes for many years. Recently it developed an 'Ibin Optical Ordering System' as a world-wide service for manufacturing companies. As part of a comprehensive management ordering system, information about the supply of materials such as bolts can be obtained digitally and in real-time via a built-in camera and RFID sensor (Würth, 2018).

3.2 Intelligent and connected operation and production

The most common application of Industrie 4.0 solutions is the transformation of a former 'analogue' production into an intelligent and digitally connected production (see Stage 2 in Figure 2). This stage includes the connection of products and components described above, both during and after the manufacturing process, but goes one-step further towards the connection of all machines, products, and human control. This stage is also referred to as the *Smart Factory* (Kagermann et al., 2013), which is a great challenge for the machinery makers in a plant and goes beyond the isolated approach described in Section 3.1 above. For example, the machine park, the manufacturing, quality control, and delivery processes as well as the specifications of the production management are linked together via one central digital production system so that anticipated disturbances can be simulated before the digital twins become available. In recent years, the German Fraunhofer IPA research institute has estimated enormous cost-saving potential in this area through rating various projects of this type. In addition to the reduction in inventory costs, the focus of the smart factory is to reduce complexity costs. For example, firms can collect safety information continuously over the entire value chain via real-time information. Experts estimate a potential cost saving of up to 40%. In terms of reduced complexity, managers can make faster and better decisions by improving communication and information sharing so that waste can be reduced, thereby realising potential savings of up to 70% (Bauernhansl et al., 2015).

An example for this is the German Mittelstand company Maschinenfabrik Reinhausen (MR). With more than 2700 employees worldwide, MR manufactures high-voltage tap changers for electric grid transformers that provide for more than 50% of the world's electricity. By introducing Industrie 4.0 applications, MR reduced costs by up to 32%. With a machine park of 17 machines, this saving resulted in an annual cost reduction of over 500,000 Euros. MR also reduced its set-up time of the machines by about 40% (Reinhausen, 2018).

3.3 New business models through connected and intelligent products and services

Industrie 4.0 projects often remain in these first two stages – the refinements of products and services, and production optimisation; however, some companies are using the opportunities of Industrie 4.0 to develop new business models (Stage 3 in Figure 2). These models must create increased and new value for customers and open new market and sales opportunities for companies. Such models often require a radical reorientation of the company to confront new competition and to be able to deal with the new market participants (Etventure, 2017).

Firms are developing new business models within the entire internal value chain and outside of the company and are also usually developing ecosystems with suppliers and customers – as they are often not able to develop and market these intelligent solutions – using smart, connected products and services that go beyond mere digital refinements. Using Industrie 4.0 technologies, firms can develop applications and products that are able to record their status via data streaming. They use this data, for example, to constantly monitor processes and to carry out corrections and repairs independently in case of deviations. Some systems use artificial intelligence to become self-learning, to communicate with their environments, thereby becoming capable of initiating autonomous improvements, and even to improve safety in dangerous environments and in remote locations (Porter and Heppelmann, 2014).

For example, the German company Trumpf, one of the world's leading suppliers of machine tools, implemented such an Industrie 4.0 project with its 'TruConnect' Smart Factory application. Trumpf has a highly complex value chain with 42 interfaces with partners, distributors, and customers; 2450 interfaces between machines, quality, logistics etc.; and 870 interfaces between machines and sensors. The TruConnect system achieves savings of up to 75% in planning and management costs and up to 50% less logistics costs when used in the areas of quote generation, production planning, intralogistics, and shipping and contracts (Trumpf, 2018). This system represents a significantly new business model beyond the past of linear production and sales.

3.4 New business models through intelligent networking of market players in a business ecosystem

The last application we have identified (Stage 4 in Figure 2) is the creation of business models through intelligent networking in the context of platform strategies of several partners. In consumer industries, firms have developed many different kinds of platforms to link suppliers to customers. For example, the success of Apple and the Iphone starting from 2007 became possible after Apple developed the I-Tunes platform to provide third-party apps for its phones. Google has followed a similar strategy with its Play Store (Chan, 2015; Iansiti and Lakhani, 2014; Van Alstyne et al., 2016).

> "Though they [the platforms] come in many varieties, platforms all have an ecosystem with the same basic structure, comprising four types of players. The owners of platforms control their intellectual property and governance. Providers serve as the platforms' interface with users. Producers create their offerings, and consumers use those offerings." (Van Alstyne et al., 2016, p.54)

In standard production systems, firms convert raw material to products and then distribute them to consumers. In platform business models, firms link producers outside of their company to customers in a two-sided market. Other successful examples in the consumer world are Airbnb, (which owns no hotels), and UBER, (which owns no cars) (Parker et al., 2016).

We are now beginning to see firms using Industrie 4.0 technology to develop business models through intelligent networking linking all suppliers with customers in business-to-business markets by partnering with suppliers and customers (Bauernhansl et al., 2015). This may even include direct competitors offering a certain product.

We found such a case in the German Mittelstand. Claas is a family-owned agricultural machinery manufacturer producing harvesters, balers, mowers, rakes, tractors, and other farming machines. In 2013, Claas developed a spin-off digital platform called 365FarmNet to link itself and other producers digitally to farmers. This platform works with an open architecture based on services provided over internet cloud-based technology. 365FarmNet allows over 30 other producers and service providers to offer their services to farmers. For example, Bayer AG provides weather information and recommendations about what pesticides are appropriate. The seed company KWS provides information about when farmers should plant which seeds to achieve higher yields. 365Farmnet provides basic weather and information on crop protection free of charge. Farmers can purchase other applications according to their needs. These range from fertiliser planning, machine communication, and field route optimisation to individual herd management (see www.365farmnet.com). Currently, more than 2.000 farmers are paying for this additional information. By using this new business model, Claas has taken advantage of the possibilities of Industrie 4.0, opened up new market and sales opportunities, and created additional value for its customers.

Another strategic alliance for Mittelstand machine tool and engineering companies is ADAMOS (**ADA**ptive **M**anufacturing **O**pen **S**olutions). This venture uses a platform strategy. The aim of the alliance is to bundle knowledge in mechanical engineering, manufacturing, and information technology and to establish ADAMOS as a global industry standard. The platform is manufacturer neutral and combines IT technology with mechanical and plant engineering industry knowledge to provide joint solutions to customers. The platform focuses on two areas: it provides basic functionalities of a 'Platform as a Service' (PaaS) and is the technological basis for digital marketplaces (ecosystems) of ADAMOS partners. The partners use the central basic platform and develop customer-specific interfaces. The second core area is the ADAMOS App Factory Alliance, which is creating a development environment in order to quickly and efficiently implement technology standards (see www.adamos.com). The example of ADAMOS also shows how new business models from the Industrie 4.0 applications are being created by developing a strategic alliance of various partners in mechanical and plant engineering in combination with IT technology.

From these examples, it is clear that companies face a multitude of challenges in a macroeconomic and company-specific sense. Therefore, in the following, we will focus on drivers to implement Industrie 4.0 business models successfully.

4 Drivers to implement Industrie 4.0 business models successfully

In this section, we discuss success factors for the implementation of Industrie 4.0 business models. We will use these factors to analyse a more detailed case study.

4.1 External macro drivers

4.1.1 Standards

In order to develop Industrie 4.0 business models, companies must obviously have access to the necessary hardware and software technologies. Such technologies are widely available in the developed world but less so in developing countries. In addition, global companies that have production sites and markets in developed, emerging, and non-developed countries also need global standards for connection, and real-time communication and knowledge generation. Firms and governments are still developing such standards for Industrie 4.0 applications (Bauernhansl et al., 2015). Kiel et al. (2017, p.16) state: "Inter-firm connection in all supply and value chains necessitates an industry spanning standardisation of IIoT technologies and interfaces in order to ensure cross-company interactions".

Standards form the framework for the structuring, development, integration, and operation of the technical systems for Industrie 4.0 applications. Standards must bring together the different approaches into a common and uniform view by agreeing on fundamental structuring principles as well as interfaces (Kagermann et al., 2013). For companies, this sometimes requires large investments in intra- and inter-firm connections based on modern IT infrastructure, in order to ensure a harmonisation of mechanical, electrical, digital, and connected components, thus creating an essential prerequisite for the development of Industrie 4.0 business models (Kiel et al., 2017). A continuous digitalisation of internal processes with no media-breaks is a prerequisite of an efficient external delivery of digitalised products. In addition to private investments and efforts by companies, governments also play an important role by providing the necessary fixed and mobile broadband. The focus of governments should be on factors such as availability, quality, reliability, and security of networks in order to enable appropriate technology availability and real-time communication.

4.1.2 IT security and legal issues

The second important driver is the security of Industrie 4.0 technologies used internally in different departments and locations as well as vertically with other players in the ecosystem and along the entire value chain. Security problems include outside attacks on the electronics (processors and memories) and the software via various network connections (e.g., ethernet or WiFi) (Kumar and Patel, 2014).

> "Hackers can compromise software malicious code, such as trojans, viruses, and runtime attacks. Communication protocols are subject to protocol attacks, including man-in-the-middle and denial-of-service attacks. Even humans operating CPPS are subject to social attacks, such as phishing and social engineering." (Sadeghi et al., 2015, p.3)

The relevant security technologies must prevent attacks in advance, detect them, and, if necessary, be able to recover data (Kagermann et al., 2013). In addition, internal IT security, i.e., the safe operation of smart objects without human intervention or the possibility of recording and interpreting personal data from the value added process, is also part of this process (Bauernhansl et al., 2015).

Issues of IT security inevitably also lead to issues of legal security. First, as in the case of all technologies, these are liability and data protection issues, e.g., regarding EU-GDPR. In this context, Kagermann et al. (2013, p.58) stated that

> "the de facto power of new technologies and business models can be so great that it becomes almost impossible to enforce existing legislation. Consequently, short technological innovation cycles and the disruptive nature of new technologies can result in the danger of a chronic 'enforcement deficit' whereby current regulation fails to keep pace with technological change.

> While Industrie 4.0 does not, on the whole, tread completely uncharted regulatory territory, it does significantly increase the complexity of the relevant regulatory issues."

There is also uncertainty concerning the ownership of information and data from Industrie 4.0 applications. Smart machines generate data on their own. In the next step, for example, they transfer it autonomously across company boundaries to other companies for optimised production and logistics control. In addition, they may enrich this with additional data so that initially confidential company-internal information allows unexpected insights into corporate management or strategies for third parties. In many cases, it is unclear who owns the new data and who may use it and how. The monetarisation of such data by third parties or cooperative groups is also difficult to manage (Bauernhansl et al., 2015; Bischoff et al., 2015; Kagermann et al., 2013; WEF, 2015).

4.1.3 Competitive environments

In addition to the above-mentioned drivers, digitisation in general and the new opportunities offered by Industrie 4.0 in particular are causing changes in the competitive environment. Industry boundaries that were considered fixed in earlier decades, such as in the automotive industry, have become open to new entrants with a focus on IT and tech companies such as UBER and Tesla. Large established companies are suddenly faced with smaller, more agile start-ups as serious competitors (Kiel et al., 2017). Suppliers and customers may become competitors. For example, Siemens offers an Industrie 4.0 platform called 'Mindsphere' to link suppliers and customers, but some Mittelstand suppliers are concerned that Siemens could use information to enter their markets. On the other hand, Industrie 4.0 applications allow the emergence of new business models and their monetarisation capabilities (see above), which increases the 'level playing field' for all, thus making the competitive situation more positive. The challenge will be to integrate current and new players into the business models.

4.2 Internal micro drivers

In particular, the move away from pure physical products to data and to system perspectives forces companies to consider the drivers of cooperation and openness internally.

4.2.1 Cooperation

Collaboration between individual departments as well as working in an interdisciplinary team is crucial for implementing Industrie 4.0 applications. Companies must reorganise formerly functional and department-specific tasks and processes in an interdisciplinary manner within an agile project organisation. 'Business Model Innovation Teams' composed of employees from the Sales, Marketing, IT, Operations, Production, Legal, and Project Management departments have proven highly successful. Ideally, these teams are not only composed of individuals from a single entity but rather from across different business units. It is important that they can act independently as well as with the support and resources from top management. Only in this way can customer solutions be brought to the market quickly and effectively, without being delayed by bureaucratic structures

(Burmeister et al., 2016). A joint incentive system to measure team performance must focus on the project and not on the individual or unit functional task.

These cooperation drivers must go beyond the own organisation and include alliances with other market participants in the ecosystem – from a loose exchange to specific strategic alliances (Ben Letaifa, 2014; Gierej, 2017; Papert and Pflaum, 2017). Firms must develop a deep understanding of how to cooperate with other firms and build a culture for cooperation. Burmeister et al. (2016, p.140) stated: "We believe that the professional partnering and openness of BMs [business models] is one of the core success factors in the course of I40 [Industry 4.0], given its requirement to combine and link interdisciplinary skills, data relationships, and value creation processes".

4.2.2 Culture

Companies must link the driver of openness reviewed above to cultural drivers such as developing an entrepreneurial mind-set and a culture for organisational transformation. In the Industrie 4.0 environment, a corporate culture characterised by flexibility, greater freedom of choice for individuals, and acceptance of failure or errors in the new business areas is crucial to ensure speed, agility, and innovation. Bureaucratic structures, silo thinking, and isolation of individual departments counteract this kind of culture and prevent the necessary organisational transformation (Teece, 2012). The biggest barriers to digital transformation are often established rigid processes, the defence of existing structures, and a lack of willingness to change among employees (Etventure, 2017). With shared incentives and resources from top management, the interdisciplinary teams mentioned above can be the first impetus for this transformation in order to achieve an overall innovative and proactive attitude in the company (Zahra et al., 2006).

In addition, firms should use established techniques for encouraging an entrepreneurial culture, such as scrum development, design thinking, crowdsourcing, or other open innovation mechanisms. These instruments can help companies to quickly identify opportunities and turn them into saleable products or services.

4.2.3 Employees and managers and training

However, a company can only succeed with Industrie 4.0 if the right employees and executives are in the company. Industrie 4.0 applications lead to significantly higher complexity, abstraction, and problem-solving requirements for all employees (Kagermann et al., 2013). For many employees, digitisation and new technologies are causing fears of job loss (Etventure, 2017). Managers must establish a common, positive understanding of the Industrie 4.0 applications company-wide. In addition, the mixture of the workforce is even more critical: "Such employees will include product managers, software developers to create and test new information services, hardware designers to develop the products, data scientists to create and interpret analytics, and user interface and experience designers" (Daugherty et al., 2015, p.14). Especially in the manufacturing sector, this mix typically does not exist and means new investments in recruiting employees with specialised skills (Porter and Heppelmann, 2014).

Companies must also focus on the importance of training and continuing education in companies:

> "There is a growing need for people to have a grasp of the overall context and to understand the interactions between all the actors involved in the manufacturing process. Consequently, in addition to increased demand for metacognitive skills, social skills are also gaining in importance owing to the growing significance of real-life and computer-based interactions resulting from greater integration of formerly demarcated departments and disciplines. In technical terms, much greater emphasis will be placed on interdisciplinary skills, an area where much work still remains to be done. (Kagermann et al., 2013 p.55)

5 BHS Corrugated: the case of a German machinery manufacturing company

5.1 Case study research method and data

One of the co-authors of this paper provided the data for the following case of a digital transformation in a Mittelstand company. The co-author is a member of the advisory board of this company. The case data comes directly from meetings within the management team and from their decision processes.

5.2 BHS and digitalisation of the industry

BHS Corrugated (BHS) is the world market leader in the development, production, and installation of production facilities for manufacturing cardboard, including the machines that produce cardboard from paper rolls (corrugators), and BHS will soon also produce digital printers. The company also offers a variety of innovative service solutions in the areas of corrugating rolls, individual machines, and complete corrugators. The cardboard produced is then processed and customised to the needs of the BHS customers for their business customers. Companies today use cardboard in a wide number of industries, and therefore there is great variety in terms of robustness, size, and colour.

Digitalisation offers new challenges and opportunities for machine producers and their customers. BHS believes that they could use digital technologies to provide even more sophisticated solutions to their customers throughout the value chain. This opportunity includes more in-depth interconnectivity within the corrugator, between the machinery in the plant, and between suppliers and customers as well as cooperation with established and new partners.

BHS initially believed that digitally specialised IT companies providing cloud computing and other services like big data analytics from outside the cardboard industry could enter the industry. BHS also assumed that E-commerce companies would enter the industry by providing spare parts etc. Other new technologies like digital printing and 3d-metal printing require accurate data from cardboard manufacturing processes. Therefore, BHS assumed there would be different competitive threats from outside their traditional industry and that customers will have a demand for a kind of these offerings in the future at least when their own customers will ask for them.

Due to the worldwide trend towards digitalisation, data collection, and transmission, BHS will have much more access to data from the machines used in the corrugating process. BHS can then use such data to improve the production and the processing of cardboard after production.

5.3 Product and portfolio changes

In order to develop Industrie 4.0 applications, BHS first developed an internal data platform with the highest industry security standards to monitor all applications around the corrugators. In addition, BHS equipped all new machinery with more sensors to monitor the cardboard manufacturing process within the corrugator (see Phases 1 and 2 in Figure 2). BHS developed its own internal platform in order to maintain its independence from big data platform providers and to keep costs for BHS and its customers low. The platform is called BHS ICorr and forms the basis for an operations support application and a business automation application with a direct connection to a fully-integrated e-commerce platform and an integration in the BHS internal production planning. It also provides an ICorr Smart Maintenance application, e.g., with interactive smart classes. Using ICorr, BHS is able to optimise the cardboard manufacturing process by collecting data from within the corrugator. BHS can also use this data to provide predictive maintenance and even to better sell its machines by providing more sophisticated performance offerings (Stage 3 in Figure 2).

Furthermore, analysis of the data provided in real-time from the corrugator allows BHS to apply big data techniques to generate new knowledge about process interdependencies. The big data application is embedded in the machinery, e.g., in combination with intelligent corrugating rolls that can store data for long periods. This data can be transmitted to other machines or be used for predictive maintenance, for example, to predict which parts may need to be replaced before they wear out (Stages 1 and 2 in Figure 2).

BHS uses the data collected throughout the plant to optimise in-house logistics for paper rolls and produced cardboard, leading to own new product offerings. BHS can also share this data with industry partners to provide complementary products and services for the entire cardboard industry and use this data to develop new advanced machinery with and without partners to further improve and expand its product portfolio. This data and the new opportunities to provide equipment apart from the corrugator generates new revenue streams that BHS can share with partners (Stage 4 of Figure 2). Finally, data availability and the increasing demand for individualised packaging combined with smaller lot sizes leads to the development of a digital printer that can be integrated into the corrugator, i.e., digital printing in the corrugator during the manufacturing process of corrugated board.

In order to collaborate effectively, BHS has learned that high-level talks with customers must be part of an on-going process that includes developing and testing pilot installations. Data-based products and services must be seen as a benefit to all partners that does not lead to an over-dependence on certain relationships. With the experience gained, BHS is beginning to develop new services and pricing models (Stages 3 and 4 in Figure 2).

5.4 Organisational changes

Digitalisation has also had an impact on the company structure at BHS. The company formed a new business unit for digital products and for the digital development of interconnectivity of machinery and service development. The company's top management team has introduced more intensive and strictly scheduled meetings between department managers in innovation management, product management, and strategic marketing. These actions have ensured that the new digital strategy leaves a footprint in every action at BHS. Top management has also decided that the digital strategy development has to be set up at the headquarters due to the interconnectivity of past and future businesses and the proximity to the research and development of new machines. Top management explicitly decided against the establishment of a digital services development group outside the headquarters in a 'digital hotspot' such as Berlin or Munich. Furthermore, in order to better link potential partners, top management enhanced the capabilities of the department for corporate development. This department must ensure that joint ventures or acquisition activities follow the digital strategy and do so as closely as possible.

6 Discussion and implications for research and practice

Our review of the literature on Industrie 4.0 and digital business models suggests that digital technologies are changing manufacturing in Germany and around the world. On the one hand, it seems that small and medium-sized businesses in Germany often react more slowly to the necessary changes in Industrie 4.0 than larger companies, but on the other hand, we show that 'Mittelstand' businesses, especially so-called hidden champions, develop new or enhance business models along their product and process chain as well as within the ecosystem of their industry. Firms must understand not only the technologies of Industrie 4.0 as well as the challenges and possibilities (Section 2) but also the different mechanisms and drivers of different Industrie 4.0 business models. Possible pathways and relationships in the Industrie 4.0 ecosystems are highly relevant (Section 3). These theoretical implications are summarised in Figure 2 as different application options.

These options form the core of our paper and are the foundation upon which we base our practical implications. We provide medium-sized manufacturing firms with possible technological options that go beyond product adaptation through digital components. In addition, we suggest that these models will include the integration of system components and different touchpoints in the respective ecosystems. We illustrated these practical implications with a variety of company examples and in detail through the case study of BHS Corrugated. We believe that these success factors are likely to vary depending on industry and different types of competitive environments. In addition, we suggest with our data from the case study that to be successful, firms must simultaneously manage a number of internal and external drivers to develop these new types of business models. We also argue that cooperative strategies within ecosystems will be an important success factor. Our case also shows that firms will have to significantly change internal processes. Ultimately, firms will have to change their company cultures in order to develop and implement new business models.

At this stage, it is too early to recommend specific types of digital models, so we suggest further research with larger sample sizes to test which factors are the keys to success.

A limitation of our study is that we only have data from the perspective of the advisory board. Further research should include perspectives of other stakeholders inside and outside the case study company. Finally, in our paper we focus only on examples from German companies, which are all globally oriented and acting internationally. Future researchers should examine these issues in other national settings.

7 Summary and conclusions

In this paper, we first described the German Mittelstand and its importance for the German economy. Next, we discussed how digital technologies are changing manufacturing, commonly called Industrie 4.0, in Germany and increasingly around the world. These technologies are allowing medium-sized manufacturing firms, called the Mittelstand, to develop at least four types of new digital business models (see Figure 2). To be successful, firms must simultaneously manage a number of internal and external drivers to develop these new types of business models. Finally, we illustrated the application of these drivers with a case study of a typical German Mittelstand manufacturing company – BHS Corrugated. This case study suggests that although there are many challenges, Mittelstand companies can use the opportunities of digitalisation and need not fear the potential threats that some critics often emphasise. A carefully thought out and implemented business model, as we discussed above, can provide a framework for continued success.

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