Industrial Marketing Management 119 (2024) 90–107

Contents lists available at ScienceDirect

Industrial Marketing Management

journal homepage: www.elsevier.com/locate/indmarman

Unlocking the potential of Industrial Internet of Things (IIOT) in the age of the industrial metaverse: Business models and challenges

Herbert Endres[a,b,*], Marta Indulska[c,d], Arunava Ghosh[e,f]

[a] Faculty of Economics and Business Administration, Chemnitz University of Technology, Germany
[b] Institute for Business Administration, University of Regensburg, Germany
[c] Business School, The University of Queensland, Brisbane, Australia
[d] ARC Centre for Information Resilience, Brisbane, Australia
[e] PricewaterhouseCoopers, Gurgaon, India
[f] Indian Institute of Management Indore, India

ARTICLE INFO

Keywords:
Industrial Internet of Things (IIoT)
Industry 4.0
value capture
IIoT business model archetypes
successful business models
business model canvas
industrial metaverse
business model performance

ABSTRACT

While the Industrial Internet of Things (IIoT) holds much promise, there is a mismatch between its potential and companies capturing value from investments in IIoT. Indeed, even when companies recognize the value of IIoT, they do not necessarily know how to grasp related opportunities and are challenged in developing a suitable business model. Accordingly, to alleviate roadblocks to capturing value from IIoT, in this paper we address the challenge of identifying suitable business models in the age of the industrial metaverse. We do so through an extensive review and classification of main IIoT business model archetypes that are successful in practice. In particular, we conduct a content analysis of IIoT projects based on over 2000 articles in industry trade magazines and newspapers. Our analysis identifies four distinct business model archetypes in the context of IIoT, *viz.* IIoT digical, IIoT service-centered, IIoT data-driven, and IIoT platform, and further explores the challenges that need to be addressed to ensure that companies can capture value from their IIoT initiatives. We explore appropriate contexts for these business model archetypes, and, in doing so, we provide actionable guidance for industrial (marketing) managers seeking to position their IIoT offerings and maximize their value.

1. Introduction

In the age of the industrial metaverse, the Industrial Internet of Things (IIoT) is becoming increasingly important for companies across different industries (Wan et al., 2016). IIoT technologies interconnect objects and systems, and enable the creation of dynamic and self-organizing cross-firm value networks. Indeed, 80% of firms expect IIoT to have an impact on their business model (BM) (McKinsey Digital, 2015). Accordingly, incumbents must adapt and innovate their BMs in relation to IIoT to stay competitive (Paiola, Agostini, Grandinetti, & Nosella, 2022), particularly because many start-ups are entering the market with innovative BMs.

While existing literature on IIoT BMs provides valuable foundational knowledge and highlights the importance of the phenomenon (Müller, Buliga, & Voigt, 2018; Schaefer, Walker, & Flynn, 2017), many IIoT innovations still experience difficulties in the search for viable BMs (Forbes, 2021; McKinsey, 2018, 2021). These difficulties often result from a lack of capabilities and knowledge (Dignan, 2018), which manifest in multiple challenges for implementation of IIoT BMs. There are also emerging stories of struggles in unlocking IIoT's full potential (e.g., challenges General Electric faced in their highly publicized IIoT initiative (Dignan, 2018)). Prior research has shown, however, that the challenges are not necessarily technological in nature but are rather related to the issue of appropriate BMs (Ehret & Wirtz, 2017; Müller et al., 2018). Yet, at this stage, the literature on IIoT BMs is still in its infancy, with a stark lack of related empirical research (Baiyere, Venkatesh, Donnellan, Topi, & Tabet, 2016).

In the industrial management and industrial marketing management fields, researchers have in recent years started to address IoT topics and focus on IIoT business models (see, for example, Leminen, Rajahonka, Wendelin, & Westerlund, 2020 and Falkenreck & Wagner, 2017). However, there is still a dearth of studies that illuminate IIoT business

* Corresponding author at: Faculty of Economics and Business Administration, Chemnitz University of Technology, Germany.
E-mail addresses: herbert.endres@wiwi.tu-chemnitz.de, herbert.endres@ur.de (H. Endres), m.indulska@business.uq.edu.au (M. Indulska), arunava.r.ghosh@pwc.com, f15arunavg@iimidr.ac.in (A. Ghosh).

https://doi.org/10.1016/j.indmarman.2024.03.006
Received 10 November 2022; Received in revised form 9 November 2023; Accepted 21 March 2024
Available online 24 April 2024

models that have been *successfully* used in practice to provide guidance to companies who are challenged with selecting an appropriate IIoT BM. The siloed view that is present in the current state of the IIoT BM body of knowledge also limits our understanding of IIoT BMs across industries and of their utility. Previous research has neither focused at a ground level to analyze IIoT-driven BM elements in successfully applied BMs nor distinguished IIoT specific aspects between start-ups and incumbents.

We are thus motivated to address this lack of knowledge due to the critical need for guidance in IIoT business model development and adoption. Indeed, prior industrial (marketing) management research indicates that companies innovate their BMs incrementally and through trial and error (Paiola et al., 2022). We see this situation as a BM design challenge that gives salience to the issue of value creation and value capture in IIoT contexts (Åström, Reim, & Parida, 2022; Kim, Cho, & Ramesh, 2019; Li, Van Heck, & Vervest, 2009; Nielsen & Persson, 2017; Reuschl, Tiberius, Filser, & Qiu, 2022; Sjödin, Parida, Jovanovic, & Visnjic, 2020). Thus, to provide specific guidance on how to unlock the value of IIoT technologies, in this paper we seek to answer the following research question: *what types of business models are used in practice to successfully unlock the potential of IIoT?* To answer this question, we conduct a qualitative analysis of articles reporting on successful IIoT projects that led to revenue generation. We found these projects in 2,139 articles published over a nine-year period (January 2011- September 2020) in industry trade magazines and newspapers that represent important business outlets for companies. Our analysis indicates there are four main IIoT BM archetypes that companies should consider, *viz*. IIoT digical, IIoT service-centered, IIoT data-driven, and IIoT platform, and explores the main BM elements through which IIoT technologies can be leveraged. Our analysis also identifies the predominant challenges that need to be addressed when using a particular IIoT BM to capture value from IIoT investments, providing insights for companies planning IIoT projects.

Through this study, we contribute to IIoT BM practice and theory. First, we contribute to the limited body of knowledge on IIoT BMs in general and build on prior studies in industrial marketing management that explored IIoT BMs through conceptual studies (e.g., Leminen et al., 2020), by providing evidence from practice on succ*essful* IIoT BMs. Based on our analysis of IIoT BMs in practice, we reveal new BM archetypes that have not been identified by prior research. Second, and in contrast to previous survey, case-study or case-based research on IIoT BMs (e.g., Arnold, Kiel, & Voigt, 2016; Dijkman, Sprenkels, Peeters, & Janssen, 2015), our analysis of the large corpus of industry publications allows us to focus on a lower level of granularity to analyze IIoT-driven BM elements and thus provide insight on related aspects, including customer loyalty for example. The IIoT projects analyzed are from a broad range of companies, across different sectors and countries, and therefore, provide a broad understanding of IIoT BMs by taking different perspectives into account. Further, the focus on BM elements in our analysis offers companies insights into concrete IIoT BM elements that lead to success in other firms and industries. Third, we distinguish between start-ups and incumbents in our analysis to enable us to provide targeted guidance. Due to organizational inertia, incumbents often have problems finding new ways to create value (Carroll & Hannan, 2000). In contrast, start-up firms are more flexible because they can design new, more radical BMs from scratch, yet are typically constrained by resource limitations. We, therefore, contribute a more nuanced understanding of which IIoT BM archetypes are relevant to which scenario. Finally, we contribute by identifying challenges that need to be understood and addressed to capture value from IIoT because the application of a BM alone does not result in value capture – companies need to be mindful of related challenges and actively seek to address them.

The remainder of this paper first provides background on IIoT and summarizes current studies on BMs in general, and IIoT BMs specifically. Next, the paper outlines our dataset and analysis approach, which is followed by an explanation of the four identified IIoT BM archetypes and their associated challenges. The paper concludes with a discussion and implications.

2. Background and related work

2.1. The Industrial Internet of Things

With the launch of the German policy initiative, Industry 4.0, IIoT related technologies have received significant attention from researchers and practitioners alike, offering an entirely new approach for creating value (Chen, Jia, Steward, & Schoenherr, 2022). IIoT[1] refers to the use of smart machines and sensors to facilitate modern manufacturing and industrial activities. It is a specialized application of the Internet of Things (IoT), which refers to "*a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies*" (International Communication Union ITU, 2015). While the number of publications on IIoT topics has increased over recent years, there is no widely accepted definition of the term "Industry 4.0" or "IIoT" (e.g., Arnold et al., 2016; Roth, 2016), owing to its interdisciplinary nature. For the purposes of this study, we adopt a definition of Paschou, Rapaccini, Adrodegari, and Saccani (2020), who provide a harmonized definition of IIoT for the industrial marketing management domain. Specifically we see IIoT as "*The integration of some technological developments whereby products and industrial equipment are connected to provide large datasets and provide insights into the status of the equipment in order to predict other kinds of occurrences and to deliver smart services (e.g., remote control, operations and optimisation, fleet management, spare parts management, and predictive maintenance)*" (Paschou et al., 2020).

The main innovation afforded by IIoT is the consistent interconnection and digitization of the whole value chain (Bischoff et al., 2015; Endres, Auburger, & Helm, 2024; Roth, 2016). Many of the technologies required to implement IIoT are not new but were previously used independently of each other. New opportunities arise, however, by joining these technologies in the industrial context (Roth, 2016). As a result, it is now possible for almost all stages of the production process to be connected, which can result in shorter lead and delivery times and the reduction of errors. These factors in turn contribute to an increase in productivity (Roth, 2016). In addition, production can be individualized due to consistent digital engineering making it cost-feasible to, in certain situations, have a batch size of one, allowing greater customer intimacy through greater customization possibilities (Arnold et al., 2016).

In addition to optimization, IIoT can be used to expand or innovate a business model. Due to IIoT's value-adding potential, companies can expand their product and service offerings. For example, by combining intelligent services, companies are able to evolve into solution providers (Roth, 2016). Indeed, IIoT is seen in general as a means for manufacturing companies to "unlock the value of their machines" (Ehret & Wirtz, 2017). It is not surprising then that in recent years IIoT deployment has seen a significant increase. For example, it has been implemented in healthcare for real-time health monitoring to prevent medical failures. In this setting, smart sensors collect health information and send it to the cloud for further access by medical professionals (Hossain & Muhammad, 2016). IIoT also plays a significant role in other industries. For example, IIoT has enabled aircraft manufacturing industries to automate and trace equipment information while processing large aircraft components assembly (Jacobson, Spence, & Ng, 2017; Szymanski, 2016). IIoT has also helped to improve the safety and the security of aircraft products by detecting the use of unapproved parts that don't meet the requirements of the aircraft design, thus preventing violation of security standards (Liu & Yu, 2013).

Several prior studies have focused on the importance and influence of IIoT, and network technologies more broadly, on value creation for an

[1] Also referred to as Industry 4.0.

organization, and for society. They found that IIoT business value is much higher than what is represented by the number of devices (Roblek, Meško, & Krapež, 2016) i.e., IIoT's potential is not yet realized. This is because, while there are many potential benefits, implementation of IIoT also brings major challenges (Müller et al., 2018). The implementation effort itself is significant (Li, Min, & Jun-Wei, 2011; Moorhead, 2013) and also requires significant investments in IT infrastructure, IT personnel, and technical training (Popescu, 2015). However, addressing these challenges does not yet guarantee a return on investment for the IIoT; the missing piece of the value creation and value capture puzzle comes from an appropriately chosen BM.

2.2. Business models and IIoT

A business model explains how a company creates and captures value (Al-Debei & Avison, 2010; Osterwalder & Pigneur, 2010; Teece, 2010) and considers both the company's activities and those of its partners, suppliers, and customers. Accordingly, BMs emphasize a system-level, holistic approach to explaining how companies 'do business' (Zott, Amit, & Massa, 2011). Over the last two decades, many authors have examined the structure of BMs and described components, elements, types, and ontologies of BMs. The majority agree that *value proposition* (products and services offered by the company; value offered to the customers), *value creation* (how the value is generated; partners, resources, processes), *value capture* (method for how the company generates profit from the offer; profit formula), and *value delivery* (how the value is delivered to the customer; distribution channel, customer segments) are key components of a BM (e.g., Ehret & Wirtz, 2017; Johnson, Christensen, & Kagermann, 2008; Osterwalder & Pigneur, 2010; Teece, 2010).

The Business Model Canvas by Osterwalder and Pigneur (2010) also relies on these key components. Osterwalder, Pigneur, and Tucci (2005) and Osterwalder and Pigneur (2010) see the BM as a "conceptual tool that contains a set of elements and their relationships" and "describes the rationale of how an organization creates, delivers and captures value." The Business Model Canvas is the most widely applied BM framework (Aagaard, 2019) and consists of nine interrelated building blocks that are categorized into four pillars of a BM: product (value proposition), customer interface (customer segments, channels, and customer relationships), infrastructure management (key resources, key partnerships, and key activities), and financial aspects (cost structure and revenue streams).

Several prior studies have focused on BMs in the context of the Internet of Things, such as the works of Leminen, Rajahonka, Westerlund, and Siuruainen (2015), and Turber and Smiela (2014). However, IIoT specifically, as opposed to Internet of Things broadly, has differing challenges and offers differing opportunities due to its focus on machines, manufacturing and production (i-Scoop, 2019). The research field of IIoT specific BMs is still in relative infancy. While the majority of existing studies focus on the technological aspects of IIoT (Arnold et al., 2016; Emmrich et al., 2015), in recent years several authors have begun to address the impact of IIoT on BMs (e.g., Arnold et al., 2016; Arnold, Kiel, & Voigt, 2017; Dijkman et al., 2015; Ehret & Wirtz, 2017; Paiola et al., 2022; Paiola & Gebauer, 2020; Porter & Heppelmann, 2014, 2015).

Despite the literature on IIoT BMs being relatively sparse, several studies have attempted to categorize relevant BMs. Dijkman et al. (2015) develop a framework to facilitate the selection of BMs for IIoT based applications and identify value proposition as the most significant factor for IIoT BM selection, followed by customer relationships and key partnerships. Kiel, Arnold, Collisi, and Voigt (2016), on the other hand, conducted a literature review of successful adaptation of BMs related to manufacturing industries and concluded that key resources is a widely used factor for IIoT BM selection, followed by key activities and then value proposition. In another classification study, Prause (2015) classified IIoT BMs into *open innovation models, network approach models* and *service design models* based on different business areas catered by the industries for new BMs. Ehret and Wirtz (2017) also categorized IIoT-enabled BMs on the basis of innovation methods. Their categorization includes groups of *provision of manufacturing assets; maintenance repair, and operation; innovative information and analytical services* (for example, artificial intelligence (AI) and big data analytics); and *services for end users* (for example, providing customization by integrating end users into the manufacturing chain. Taking a different angle, Leminen et al. (2020) identified four distinct types of IIoT BMs in the machine-to-machine (M2M) context *viz.* company-specific business models, systemic business models, value designs, and systemic value designs, and explored the characteristics and differences in the value potential between these four. Arnold et al. (2017) suggested that IIoT-triggered BMs are grouped into Cloud-based BMs, Process-oriented BMs, and Service-oriented BMs. In their classification, cloud-based BMs facilitate an online virtual infrastructure and act as a channel for customers in delivering the required value without any physical presence of sophisticated hardware. Process-oriented BMs focus on reducing machinery downtime in manufacturing industries. Service-oriented BMs focus on leveraging the power of data, which can be used to provide service to customer like increased availability, and predictive maintenance.

The shortcoming of these classification studies is in their scope and source of data. The latter is in particular a shortcoming because the data is often limited and does not consider implementation success. Yet, there is a need to provide guidance to companies on what works, to reduce their trial-and-error approaches to IIoT business model development, and further explore characteristics that are relevant to a particular BM. In our study, we build on the works of Dijkman et al. (2015), and Leminen et al. (2020) and their focus on value derived from each BM. According to Behrendt et al. (2021), an industrial ecosystem should have a captivating value proposition which is suitable for its business needs. Any successful industrial ecosystem's strategy is dependent on understanding the areas where value lies. Value proposition is the key reason why a conventional industry decides to move to IIoT in the first place. Hence, we build our work by taking value proposition as the approach for identifying the archetypes of *successful* IIoT BM implementations. We distinguish our work from the works of other as outlined in Table 1, where we summarize core differences in our study design and focus.

As shown in Table 1, our study considers a finer grained focus on BM elements. This finer grained analysis is important because, ultimately, market dynamics influence the BM that the specific company should follow at a given point in time. It is therefore expected that an IIoT based company will evolve its BMs as and when required due to the changes in BM elements such as value proposition, customer segments, key activities, channels, key resources and key partners, cost structure, revenue streams, and customer relationships (Gierej, 2017). This makes the Business Model Canvas a good foundation for our study of successful IIoT BMs, as per Arnold et al., 2016 and Dijkman et al., 2015. Specifically, IIoT is thought to trigger the following changes to the eight Business Model Canvas components:

Value proposition: Value proposition is the primarily influenced BM element that leads to the evolution amongst all examined industries. Value proposition can change, for instance, due to the increasing amount and higher availability of data (Arnold et al., 2016; Kiel et al., 2016).

Customer Segments: Manufacturing companies integrating IIoT into their value chain need to create new markets that didn't exist previously but require IIoT products. Automotive manufacturers use IIoT technologies to develop a new market segment for an enhanced driving experience for their customers. Tesla, for example, uses IIoT technologies to produce driverless cars, marking a new era in the automated driving technology (Gierej, 2017).

Key Activities: This BM element is the reason for the evolution in the medical engineering industry sector, electrical engineering sector, and information and communications technology (ICT) sector. Key activities are the critical actions a company must undertake to develop and

Table 1
Differences in study design and focus for key related literature

	Research Design				**Study Focus**						
	Conceptual	Qualitative	Large-scale qualitative	Cross-Industry/Firm -Perspective	IoT BMs	IIoT BMs	New BM archetypes	BM Process-focused	BM Actionable Guidance	Organizational Context for BMs	BM Challenges
Arnold et al., 2016		✔		✔		✔		✔			
Arnold et al., 2017	✔			✔		✔	✔				
Chen et al., 2022	✔				✔	✔					
Dijkman et al., 2015		✔			✔				✔		
Leminen et al., 2015		✔			✔					✔	
Leminen et al., 2020	✔					✔	✔				
Paiola & Gebauer, 2020		✔				✔		✔			✔
Paiola et al., 2022		✔			✔			✔		✔	
Paschou et al., 2020	✔					✔					
Our Study			✔	✔		✔	✔		✔	✔	✔

maintain their competitive advantage. Therefore, key activities help to realize IIoT industry value through improving systems, services and processes to create a competitive edge over competitors (Gierej, 2017).

Channels: Companies use channels such as social media and online communities to deliver value of IIoT technologies. Keeping in mind the opportunities that can be gained through e-commerce, companies utilize e-commerce sites to track potential clients and deliver value to them. Key partners and potential clients need to be updated in real-time about the new developments in the IIoT field (Gierej, 2017).

Key resources and key partners: Value creation networks are the critical resources for the evolution of any industry that enable an enterprise to produce flexible value proposition. An automated and intelligent connectivity system linking manufacturers, suppliers, and customers via cloud platforms is crucial as it delivers cost reduction and efficiency. IIoT implementation requires compatible infrastructure and software resources. For an IIoT-based company, customers are also the collaborative partners that have led to open innovation processes. Therefore, they are also key partners in any IIoT sector.

Cost structure: When it comes to the financial aspects of a BM, the cost structure element is the most affected one. ICT production costs are most affected when there is a financial investment surge in the software platform, for example, implementing IIoT technologies to automate the software platform incurs additional costs (Arnold et al., 2016; Laudien & Daxböck, 2016). Software-defined IIoT architecture has been suggested to manage the industrial manufacturing units, and the software platform provides an interface for information exchange. The software platform also allocates the network resources to the manufacturing units as and when required (Wan et al., 2016).

Revenue streams: Integration of physical and digital components along with IIoT solutions will alter the revenue stream of a company. The company can then increase its number of product lines and evolve into different industrial manufacturing sectors to increase their profit (Kiel et al., 2016; Schaefer et al., 2017).

Customer Relationships: Customers can have volatile demands that may change frequently. This can hamper the implementation of IIoT solutions. Hence, individual customer demands in such cases can lead to lower standardization in the production cycle, reducing the net value that can be derived. The evolution of customer relationships can, therefore, have impacts on the value proposition BM element. Thus the issues in one BM element can lead to issues in another (Li et al., 2017).

3. Data and method

3.1. Data collection

Our paper focuses on revealing levers from practice to capture the potential of IIoT and aims to provide guidance on the main IIoT business models that have been successfully applied in practice. Thus, similar to Bohnsack, Pinkse, and Kolk (2014), our data collection and analysis is based on industry trade and business magazine articles rather than on academic sources. These practical papers provide insights into industry and firm perceptions and offer rich descriptions of technologies and associated business models.

To investigate IIoT specific BMs, we identified IIoT projects of key industry players in the period January 2011–September 2020. The starting point of 2011 was chosen because the term “Industry 4.0” was first mentioned at the world's leading industrial technology show HANNOVER MESSE in that year. We stopped collecting data over the COVID period as many companies were adversely affected and redirected resources. Like Bohnsack et al. (2014), we conducted a content analysis of nine German and international industry trade magazines and newspapers offering different perspectives on IIoT. We mainly focused on German outlets because Germany is a pioneer in IIoT due to its strong mechanical engineering industry (Arnold et al., 2016).

We included five industry trade magazines in our dataset because they pay particular attention to IIoT affected industries, such as manufacturing (Maschinenmarkt, VDI Nachrichten) and IT and telecommunication (Computerwoche, Markt und Technik). Most of these magazines have special sections about innovative technologies and business strategy. VDI Nachrichten, for instance, has an “IIoT and digitization" section, that focuses on topics of automation, additive manufacturing, or big data. In all magazines, IIoT and the underlying technologies and BMs are a central pillar of the coverage. We also included several mainstream business publications in our search, namely The Financial Times, The Economist, Handelsblatt, and Wirtschaftswoche, because they are high-quality business magazines with a particular focus on in-depth information about business and marketing strategy and the wider business context. Our selected publications provide insights into different industries and firm perspectives.

The articles we collected from Handelsblatt, Wirtschaftswoche, Maschinenmarkt, VDI Nachrichten, Computerwoche, Markt und Technik are in German. The articles from The Financial Times and The Economist are in English. We used these two international business publication sources as a counterbalance to the German sources, while knowing they contain fewer details on the manufacturing industry.

To create our dataset we performed a keyword search for the relevant period using search terms referring to Industry 4.0 and IIoT, using the following keywords: "Industry 4.0", "Industrial Internet", "Industrial Internet of Things", "cyber-physical systems", "batch size one", "predictive maintenance", or "smart factory". We selected these keywords because such keywords are most often associated with IIoT (Mauerer, 2017), and also added the keyword "Integrated Industry" because we could see through our literature review that this is also a commonly used term. Our keyword search resulted in a set of 6,875 articles. Because our specific focus is on IIoT BMs that are known to have been successful in practice, we limited our data set to articles where we could infer from mentions some measures of success, e.g., gaining new customers or revenue growth. To identify these, we screened the articles for indications of success as well as terms associated with BM elements from Osterwalder et al. (2005) and Osterwalder and Pigneur (2010). By doing so, we excluded all articles not related to BM elements, and those that were related but not explicitly indicated to be successful in revenue generation. This process resulted in 2,139 relevant articles remaining. We coded the articles according to the companies mentioned - Table A.1 in the Appendix provides an overview of the identified companies and the respective number of articles per year.

Because more than one company is addressed in some articles (e.g., cooperation between companies), one article may be coded to more than one company. Overall, these companies were mentioned 2,961 times in a total of 2,139 articles. We then analyzed the content of the articles using qualitative data analysis software NVivo (v12) with the coding scheme explained in the following section and shown in Appendix A2. For reliability, we undertook a dual coder analysis and calculated interrater reliability. One of the authors iterated through all articles to complete the coding. Once coding was finished and the node structure was stable, we engaged a second coder who used the final nodes to code all articles independently. The coders then met to discuss and reach a final consensus on any discrepancies. The initial interrater agreement resulted in an acceptable value for Cohen's Kappa of 0.6 (Fleiss, Levin, & Paik, 2013; Landis & Koch, 1977a,b). Ultimately, the coders discussed any coding discrepancies until 100% consensus was reached. We used German codes for the German articles and translated the same codes in English to code the English articles.

3.2. Data coding

We based our content analysis on the BM ontology of Osterwalder et al. (2005), i.e. the Business Model Canvas. We created a code for each BM element, which consists of various search terms related to the respective element (e.g., the search terms: mass customization, risk reduction, cost reduction, convenience, or batch size 1 were used for the value proposition element). These search terms were derived from existing literature in the area of BMs and IIoT (e.g., Arnold et al., 2016, 2017; Dijkman et al., 2015; Osterwalder & Pigneur, 2010) and enabled us to trace the changes in each BM component. Table A.2 in the Appendix provides an overview of the coding structure we applied to analyse our data set of successful IIoT BMs. Four of our five first order nodes (*product, customer interface, infrastructure management, financial aspects*) reflect the four pillars of BMs and an additional *challenges* node was designed to capture various types of challenges mentioned in the articles. Each first order node has a number of second order nodes that relate to the BM building blocks within each BM pillar, as well as a finer grained typology of challenges (technological and business development) in the case of the fifth node. Associated with each second order node is the third order node, our finest grain of analysis, which represents the search terms we used.

During our dual coding process, we recognized that our data varied with regard to IIoT challenges, the organizational context (incumbents vs. start-ups) and IIoT use (IIoT user vs. IIoT vendor). We therefore added additional codes to capture these aspects in our content analysis in the second round. For IIoT challenges, we coded all verbs and subjects associated with "challenge", "issue" or "problem" in relation to IIoT. For the organizational context (incumbents vs. start-ups), we coded based on the age of the particular company, which we extracted from the DAFNE database or the relevant company's website. For IIoT use, we coded based on the description available in the article, either as "IIoT user" or as "IIoT vendor". We define companies that provide the technologies and infrastructure needed to connect machines, products, processes, and people are classified as IIoT vendors. On the other hand, IIoT users make use of this technology and infrastructure and integrate it into the value chain to optimize existing processes or pursue new BMs.

3.3. Data analysis

Following our coding, we conducted a cluster analysis, using Nvivo's inbuilt cluster analysis functionality to derive BM archetypes as well as main categories of challenges faced by the relevant companies. The Nvivo cluster analysis feature is an exploratory technique that can be used to show patterns in data by grouping sources or nodes. The sources or nodes in an Nvivo cluster analysis can be clustered by similarities such as word similarity. Therefore, Nvivo uses a similarity metric; a statistical method used to calculate correlation between items (Nvivo, 2020). Because Arnold et al. (2016) show that value proposition is the most often affected BM element by IIoT, we derive our BM archetypes by distinguishing between the types of value proposition that result from the merging of the physical and the digital world in the context of IIoT (Vermesan et al., 2016). We therefore applied the commonly used word similarity measure based on the Pearson correlation coefficient for our keywords related to value proposition. Keywords that have a higher degree of similarity based on the occurrence and frequency of words are clustered together (Nvivo, 2020).

As second step, we used NVivo queries to connect the other eight BM building blocks to the particular type of value proposition and the associated challenges. We applied the Compound query that is designed to find content that is close to other content (Nvivo, 2020). This provided information not only about the interconnected elements of the business model types but also about challenges, the organizational context, and IIoT use associated with the particular BM archetype. We also performed a frequency analysis to identify the most common challenge(s) industrial managers need to address when using a particular BM. In this paper, we report on predominant challenges, i.e., challenges that were most frequently identified (using a frequency cutoff of 3).

Table A.3 in the Appendix provides a summary of our analysis on the basis of the second order nodes[2]. To increase insights from this summary, we show the coding per company and with relevance to the four clusters of value proposition.

[2] We provide our coding summary on the basis of second order nodes in the interest of brevity as the full table is significant in size. Full coding summary can be obtained from the authors on request.

4. IIOT business model archetypes

Our analysis resulted in four clusters of value proposition. These are the *digical solutions* - a combination of physical and digital solutions, *service-centred solutions* – where the focus is on selling services, *data-driven solutions* – the focus lies on data collection, processing and analysis, and *platform solutions* – the focus is on the possibilities of platforms. Accordingly, these gave rise to our four IIoT BM archetypes: (a) IIoT Digical, (b) IIoT Service-centered, (c) IIoT Data. The IIoT projects analyzed in our content analysis capture 467 references to IIoT digical, 1,867 to IIoT Service-centered, 3,833 to the IIoT Data-driven, and 206 to IIoT Platform -driven, and (d) IIoT Platform. IIoT BMs. Accordingly, the four archetypes can be the basis of guidance for other companies, but to do so we need a more nuanced understanding of their characteristics. Fig. 1 summarizes the value propositions for the four IIoT BM archetypes and the key characteristics that define them. Table 2 takes a more detailed look at the composition of the business models and their core characteristics. Specifically, we focus on the relevant organizational context (incumbents vs. start-ups), the type of IIoT use (user vs. Vendor; as defined earlier), and Osterwalder and Pigneur (2010) four BM pillars. In the following four subsections, we explain each IIoT BM archetype and include practical examples from the companies in our dataset. We also provide direct quotes from our dataset to highlight core challenges relevant to each IIoT BM archetype.[3]

4.1. IIoT – digical business model

The IIoT Digical BM is characterized by a progressive evolution of an existing BM, with no radical change that might alter the industry logic (Emmrich et al., 2015). The model is primarily suited to industrial companies (e.g., traditional engineering companies, automobile manufacturers) that use IIoT technologies to optimize their existing value creation processes. Mostly, there is still no complete and consistent digitization of the entire value chain, the focus is on particular sub-areas. Therefore, the extent of change is limited in this BM type. Companies gradually seek to cover multiple layers of the value creation layer model by increasingly adding digital elements and connectivity to physical products. The value proposition itself remains largely similar and is not fundamentally questioned, but it is improved by increasing digitization of products or processes.

The model is suitable to a machine manufacturer, for example, who still retains a primary focus on the sale of the machine, but includes additional IIoT driven functions that extend existing hardware or software offerings. The BM archetype therefore is suitable in situations of purely physical products, that can be equipped with sensors, actuators or communication systems to enable them to become hybrid products, which we call "digicals". Digicals are a combination of physical and digital components that are customizable, expandable and can communicate. Digicals enable companies to offer numerous product-related digital services, such as remote maintenance. These extra features help to improve the overall market valuation of the company's products or services. A good example from our dataset is that of BMW. BMW is one of the leaders of digitization in the automotive industry. They offer additional digital services such as real-time traffic information, security warnings, or maintenance service. Schneider Electric is another example. They use digital transformation to achieve more yield with less energy, fewer raw materials and fewer labor hours (Maschinenmarkt, 2018a,b, 2019, 2020). In addition to these exemplified enhancements, companies who take the opportunity to optimize internal processes through IIoT use can achieve shorter delivery times, better product or service quality, or greater flexibility (e.g., greater degree of customization).

In this BM archetype, companies have the opportunity to collect additional data about user behavior and, therefore, can track customer behavior. This is because while the sale of a physical product (asset sale) is still at the center of the BM, it has digital components that create data. The data can be used for product improvements and additional services (Hui, 2014). In addition, communicating regular relevant updates or new functionalities can enhance customer loyalty (Hui, 2014). A company from the machine engineering sector, for instance, could use the generated data to offer the customer predictive maintenance. Plant manufacturers can — and have to — extend their core competencies (not solely production, but also data analysis and consulting) to generate additional revenue. Moreover, providers can create a *digital lock-in* by integrating digital components in their products and limiting their compatibility (Fleisch, Weinberger, & Wortmann, 2015).

In our analysis of BM elements aligned with the IIoT Digical BM, a high proportion of the customer interface BM element is connected to increasing individualization (78%) and customer integration in the value creation process (65%). The most discussed topics related to the infrastructure management BM element are process optimization due to the integration of new technologies and the digitalization of the value chain (42%), investment in technology factories (32%), development of comprehensive software know-how (56%), and acquisitions and cooperation (42%). Of the references reporting on the financial aspects BM element, 68% indicate that revenues are still mainly generated with the product sale, 46% indicate an improved value proposition allowing companies to set higher prices, and 32% report that additional revenues are generated due to higher number of product-related services.

The predominant challenge relating to IIoT digical BMs is standardization for physical-digital interfaces. There has been an increasing trend in interactions between the physical and the digital world. Unified or tiered interfaces and viable IIoT networks might lead to increased production efficiency, which in turn reduces the interaction complexity. Computerwoche (2014), VDI Nachrichten (2015) and Computerwoche (2018) highlighted this issue. For example:

> *Cisco: "The interface between the digital and the physical world is a huge challenge for the entire industry, with many implications of various kinds."* (Computerwoche, 2014, p. 48)

> *Pilz GmbH: "The challenge is bringing together and standardizing the requirements of both worlds to create practicable solutions. Networking increases functional diversity and brings about interactions. The variety of functions increases, and with it the corresponding interactions."* (VDI Nachrichten, 2015, p. 12)

> *Software AG: "The challenge is to capture data from machines of different manufacturers and production vintages and make it available via open interfaces to third-party systems for corporate planning (ERP/SAP) as well as systems for PLM, CAQ, tool management, predictive maintenance or artificial intelligence (AI)."* (Computerwoche, 2018, p. 34)

4.2. IIoT – service-centered business model

Compared to IIoT Digical, the IIoT Service-centered BM archetype doesn't use sensors just as an add-on or an extra service feature. Instead, the service-centered business model is focused on the selling of services completely based on IIoT technology. This archetype is characterized by a high service-orientation. Service-orientation can, in general, be categorized in two manifestations: (1) creating a product-service-system, where in addition to the core product sold, additional services are created and commercialized (this is aligned with the "Digical BM" above) and (2) selling the product as a service, where the customer only pays for usage. This second manifestation of service orientation is

[3] Where quotes originate from German publications, they are provided in the paper translated into English. The translation was carried out by the lead author.

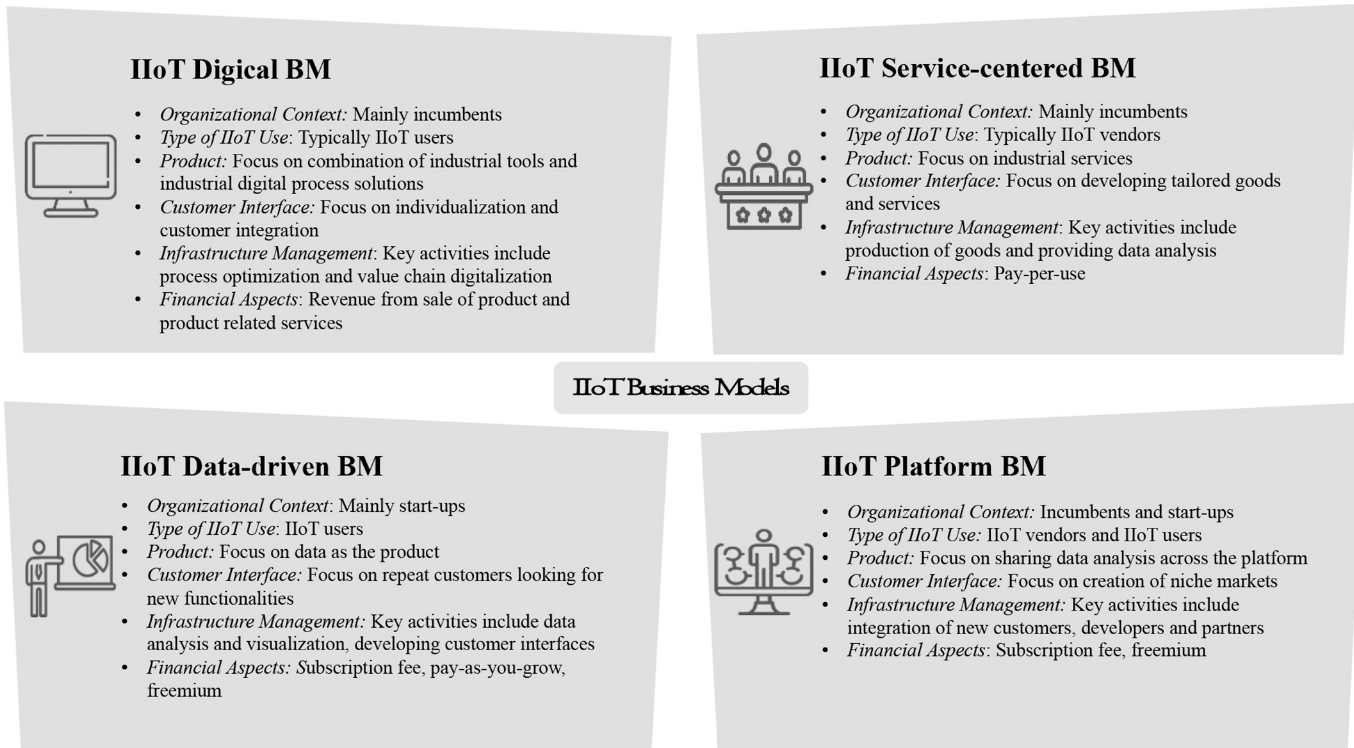

Fig. 1. Overview of the summarization of the four business models

aligned with the Service-centered BM archetype.

This BM archetype is relevant to technology and machine vendors who change from the traditional model where products are sold once for a fixed price, to a pay-per-usage model where the payment is dependent on product use. In other words, the product is fully sold as a service. In such a model, the machine manufacturer remains the owner and is responsible for the operation of the machine (Obermaier, 2016). The new value proposition is the availability of the product at a given time. One example from our dataset is Siemens, who provides trains to various operators (e.g. in Spain) using a service-centered BM. Instead of selling trains or maintenance agreements, Siemens sells availability (Markt & Technik, 2016). By using a service-centered BM, and associated non-ownership contracts, customers can reduce uncertainty and "reap the benefit of manufacturing performance as an input for their own value creation" (Ehret & Wirtz, 2017, p. 119). Another notable example in our dataset is that of Deutsche Telekom. Deutsche Telekom. offers customers complete systems as a service, providing the entire system as a bundled service starting right from the antenna to the edge computing set-up on which the data is processed (Handelsblatt, 2019).

This particular IIoT BM archetype is also suitable in cases where the machine can be used by more than one customer, i.e. during inactive times of one customer the machine can be used by another customer (McKinsey Digital, 2015). This enables companies to increase their customer base. Increasing service-orientation enables companies to generate recurring instead of one-time revenues. Key resources in the service-centered BM are value creation networks and machine specific know-how needed to develop new services. Key partners are companies whose core competency lies in data analytics (e.g., Endres & Helm, 2015).

In our analysis of BM elements aligned with the IIoT Service-centered BM archetype, a high proportion of the customer interface BM element is connected to the B2B target group (72%), to gaining insights into customer behavior and therefore developing customer-tailored, additional services (58%), and to the importance of long-term customer relationships (42%). Of the references reporting on the infrastructure management BM element, 74% emphasize the production of goods as well as data analysis as key activities. The other topics that are covered by the references in this BM element are software specialists (27%), acquisitions and cooperation (48%), IIoT vendors, such as analytics companies, as key partners (37%), and operation and maintenance of the product as key activity (technicians at customer site) (53%). The most discussed topics in terms of the financial aspects BM element are pay-per-use-model (63%), recurring, variable revenues (55%), and usage of customers to reduce fixed costs (29%).

The predominant challenge relating to IIoT Service-centred BM is identifying suitable partners and setting up strategic collaborations to meet the complex technological infrastructure and IIoT environment. Working with an IIoT partner helps companies address strategic challenges with services, allowing clients to ensure that they have the culture, technology, and capabilities in place for achieving the required outcomes. Maschinenmarkt (2017) highlighted this issue. For example:

> *Connyun: " […] with the complexity of industry 4.0, strategic partnerships will become favourable, if not necessary […]. A circle of partners needs quickly to be found to be able to meet this challenge together."* (Maschinenmarkt, 2017, p. 18)

4.3. IIoT — data-driven business model

The basis of the IIoT Data-driven BM archetype is a new method of data collection and usage, which is enabled by integration of sensors. The efficient usage and analysis of data is the main success factor of such a BM (Porter & Heppelmann, 2015). Unlike the Digical business model and the Service-centered business model, the IIoT Data-driven business model is suitable only for companies that invest in IIoT sensors and collect data on behalf of their clients. To create a data-driven BM, companies must define what they want to achieve with big data and how the data can be generated. Furthermore, it is essential to know how the data will be monetized and what barriers will arise while putting in place the BM.

Start-ups in particular use predominantly pay-per-usage (fee for the

Table 2
IIoT Business model classification and key characteristics

	IIoT Digical	*IIoT Service-centered*	*IIoT Data-driven*	*IIoT Platform*
Organizational context	Mainly incumbents	Mainly incumbents	Mainly start-ups	Incumbents and start-ups
Type of IIoT use	Mainly IIoT-users	Mainly IIoT-users	Mainly IIoT vendors	IIoT-users and IIoT vendors
Product	Value proposition: New product-related digital services	Value proposition: not the product itself but the availability of the product is offered through services that are completely based on IIoT technology; producer remains machine owner and operates the machine	Value proposition: the efficient usage, analysis and processing of IIoT data	Value proposition: efficiency enhancement of the entire value chain; IIoT data is combined and processed to identify new IIoT BMs in the cloud- enables the creation of a value creation network
Customer Interface	Target group: B2B and B2C	Target group: especially B2B	Target group: B2B and B2C	Target group: B2C (mainly transaction platforms) and B2B (integration platforms)
	Customer benefit: increasing individualization of the products	Customer benefit: companies gain insights into the user behavior of the customer => customer-tailored, additional services can be developed	Customer benefit: customers gain new insights into their machines and processes and can improve their business outcome	Customer benefit: customers are enabled to exchange products, services, and information via predefined communication streams
	Customer relationships: customer integration in the value creation process	Customer relationships: long-term	Customer relationships: high customer loyalty due to lock-in and new functionalities	Customer relationships: can develop new target groups since former competitors often become important customers in platform BM
Infrastructure management	Key activities: process optimization due to the integration of new technologies and the digitalization of the value chain; development of comprehensive software know-how	Key activities: production of the goods as well as data analysis; operation and maintenance of the product (technicians at customer site)	Key activities: data generation, processing, aggregation, analysis, and visualization; development of suitable interfaces for the customer systems and software updates	Key activities: integration of new customers, developers and partners in order to increase the attractiveness of the platform; platform integration
	Key resources and key partners: acquisitions and cooperation; investment in technology factories	Key resources and key partners: software specialists; acquisitions and cooperation; IIoT vendors (e.g., analytics companies)	Key resources and key partners: sensors; adaptable algorithms; efficient IT-infrastructure;	Key resources and key partners: investments in platform development and integration; platform partners and developers
Financial aspects	Revenue models: revenues still mainly generated with the product sale but increased due to higher number of product-related services	Revenue models: pay-per-use-model (e.g., operating hours of the machine, produced quantity)	Revenue models: subscription fee, pay-as-you-grow pricing and freemium models, with additional revenue from consulting activities	Revenue models: subscription fee and freemium models
	Implications and costs: improved value proposition allows companies to set higher prices	Implications and costs: recurring, variable revenues; customers can reduce fixed costs	Implications and costs: low fixed costs (less physical assets, no production facility necessary); but development costs for software and algorithms	Implications and costs: low fixed costs (less physical assets, no production facility necessary); costs for development and maintenance of the platform
Key challenges when using the particular BM type	Standardizing of physical-digital interfaces	Identifying suitable partners and establishing strategic collaborations	Securing IIoT data networks against unauthorized interference; integrating data	Maintaining direct customer relationships

use of a particular service) or subscription fee (fee for the use of the service) revenue models, where the data are at the center of the BM (Porter & Heppelmann, 2015). The companies charge a fee for the generation, preparation, aggregation, or analysis of the data. The main difference to service-centered BMs is that data generating products are not the focus here, instead data is the core of the BM. In the literature, the term "*sensor as a service*" BM is used as a synonym (Fleisch et al., 2015).

In the industrial context, data-driven BMs can be successful and are likely to be increasingly used in the future, because they help companies to handle the enormous volume of data generated by connected products. IIoT creates new opportunities beyond the factory floor because companies can use new capabilities, like industrial clouds or various big data analysis approaches, to exploit information available worldwide for raising productivity. The integration of data from different areas and sectors (e.g., industrial data, service market data, data from the micro- or macro-environments) in turn enables new BMs. One such example from our dataset is GE. GE, for instance, processes important information from weather forecasts or energy markets and sells the data to their customers.

Our analysis of BM elements aligned with the IIoT Data-driven BM archetype indicates that, from a customer interface element perspective, the model is used mainly by IIoT users, who apply data analytics for process optimization or for the development of new BMs (67%). Further, the references relating to this BM element indicate higher customer loyalty due to lock-in and new functionalities (44%). A high proportion of the references relating to the infrastructure management element are about data generation, processing, aggregation, analysis, and visualization as key activities (72%), descriptive/predictive/prescriptive analysis (48%), sensors, adaptable algorithms and efficient IT-infrastructure as key resources (57%), and development of suitable interfaces for the customer systems and software updates as key activities (77%). The references relating to the financial aspects' element discuss mainly subscription fee (71%), pay-as-you-grow pricing and freemium models (34%), development costs for software and algorithms (47%), low fixed costs (less physical assets, no production facility necessary) (71%), and additional revenues due to consulting activities (42%).

There are two key challenges relating to this BM archetype, *viz.* data security and integration. From a security perspective, firms have to ensure that their IIoT data networks are guarded against unauthorized interference. This is particularly critical for organizations that use Data-driven IIoT BMs because they need to build trust by providing safe data security systems. Numerous references referred to this challenge. For example:

> *Cisco - "Another challenge will be the security and integrity of data transmission."* (VDI Nachrichten, 2017, p.28)

> *Weidmüller - "Securing the industrial 4.0 network against unauthorized interference of any kind will be a particular challenge."* (Maschinenmarkt, 2014, p. 14)

From a data integration perspective, the challenge lies in converging complex industrial process data with ERP systems and tools. This raises the need for standardized transfer, processing and storage of data. Numerous references made mention of this challenge. For example:

> *Cisco - "The greatest challenge will be the definition and implementation of uniform structures and standards for the transfer, processing and storage of data."… "It is also necessary to adapt the underlying ERP systems. Instead of today's central systems, decentralized systems are more necessary, which unfold their functionality on site."* (VDI Nachrichten, 2017, p.28)

> *Daimler - "Industry 4.0 is certainly a special challenge for tool and machine manufacturers, because of converging the process data in a tool and the machine."* (Maschinenmarkt, 2015, p. 35)

4.4. IIoT — platform business model

The IIoT Platform BM archetype is particularly suitable for companies that can provide ready-made platforms with interfaces to use the data released by customers or users of the platform. Platforms can support companies in the implementation of the Data-driven BM because they connect market players and enable the exchange of best practices (Evans & Gawer, 2016). Hence, firms often apply a Platform BM together with a Data-driven BM. One example from our dataset is Relayr. Relayr enables industrial customers to analyze the data generated by their machines. The data is combined and processed to identify new BMs in the cloud. Schindler services its elevators with the help of Relayr (Handelsblatt, 2016). Relayr's BM is solely based on the provision and processing of data and the associated consulting activities. The company operates in the industrial sector without producing a physical product other than manufacturing and using sensors which they use to generate the data). The data itself and the analysis of it are the central value proposition of Relayr.

In the context of IIoT, different sectors are growing together more strongly. Companies try to establish product-service-systems, where products and services of different sectors are integrated because they aim to create a holistic solution for customers (Porter & Heppelmann, 2014). Therefore, companies should use open-innovation approaches and platforms in their BMs to integrate external and specific knowledge in the production process (BMWi, 2015). In our dataset, the case of the agricultural engine producer Claas illustrates how this can work. Claas established an open platform structure called 365Farm Net, where Claas and other companies (from various sectors) offer their services. The chemical firm Bayer, for instance, provides agricultural information relating to weather and provides advice about which plant protection products should be used and at what time. The farmers share their experiences about fields, harvests and pest infestation. All the information is collected in a virtual cloud. Currently, over 2000 farmers are using the chargeable platform. This example shows how a successful platform between key business partners and customers can be created (365FarmNet 2017).

The incorporation of IIoT via a platform enables vendors to create niche markets with new customer segments. Due to the increasing service-orientation, products are becoming more interesting for other customers, because they do not have to buy the whole product, but only pay for the usage. Moovel, a subsidiary of Daimler, exemplifies this in our dataset. The platform sells mobility as a service and offers different means of transport via a mobile application to customers. Moovel has shares in *MyTaxi, Carpooling.com* or *Flixbus* and has created an extensive partner network. Serving as a mediator for means of transport, Moovel broadens the portfolio of Daimler (Emmrich et al., 2015; Moovel, 2017). Apart from selling cars (target group: mainly affluent, 40+) Daimler additionally takes on the role of the mobility provider, which enables the company to reach different customer segments (young people) and build long-lasting relationship with them, potentially leading them into a different target group in the future.

The importance of platforms as a communication and distribution channel is increasing in the IIoT context because it enables firms and customers to exchange products, services, and information via predefined communication streams. First, platforms can be used to increase attention about, and awareness of, new products (McKinsey Digital, 2015). Second, these channels can be used for machinery and plant engineering. On a technology platform, various companies from one sector (and also external firms) could offer diverse services and solutions (e.g., availability of production capacity, an efficient configuration of production lines, training) to customers. Third, platforms can support customers during the buyer decision process. In the manufacturing industry, there is a tendency towards "contract manufacturing," where companies predetermine the desired parts with the help of CAD models (McKinsey Digital, 2015). Based on these specifications, the machine manufacturer realizes the production of the parts. SLM Solutions, a producer of 3D printers, and the software company Atos, for instance, have started a pilot project for the development of an integrated B2B platform for 3D printing (Atos, 2014). The aim of this project is the creation of a production network, where the machines are connected via the Internet and orders can be produced with an optimal operating rate.

Our analysis of BM elements aligned with the IIoT Platform BM archetype, indicates that, from a customer interface element perspective the target group is mainly B2C for transaction platforms (78%) and B2B for integration platforms (66%), and companies can develop new target groups since former competitors often become important customers in platform BM (41%). For the element of infrastructure management, 78% of the identified references report that one key activity is the integration of new customers, developers and partners to increase the attractiveness of the platform. The remainder mainly talks about platform integration (42%). The references to the financial aspects for IIoT Platform BM are divided into three major topics/aspects: 67% subscription fee, 37% freemium models, and 72% costs for development and maintenance of the platform.

A key challenge relating to IIoT Platform BMs stems from the risk of companies losing direct connection to their customer base. They have primarily indirect (and impersonal) contact through external IIoT platform providers, who act as gatekeepers between the customers and the organization. Markt and Technik (2016) and Computerwoche (2018) highlighted this challenge. For example:

Phoenix Contact - "The challenge is […] that new platforms […] shift between the manufacturers and the customers: The manufacturers have the costs, the customers the money. The platforms establish themselves as gatekeepers between us and the customers. We lose the direct contact to the customers. The gatekeepers tell us what the customer orders. That is the big danger!" (Markt & Technik, 2016, p. 1)

Software AG – "The sales department has to keep getting the customer to come back to the platform. The way it has been - the deal is done for the distributor and the service takes over -, it won't be anymore. This is especially true for machine builders. These would have previously maintained a close relationship with the customer. You have to take that into account with platforms and catch up with appropriate business models." (Computerwoche, 2018, p. 32)

5. Discussion

Our study identified four main archetypes of IIoT BMs successfully used in practice, *viz. IIoT Digical, IIoT Service-centred, IIoT Data-driven and IIoT Platform,* together with core challenges relating to their use. Our use of the Business Model Canvas provided the means for a finer grained analysis of characteristics relating to specific BM elements, thus articulating the composition of BM elements that underlie the BM archetypes, as summarized in Table 1. We make a specific distinction in our analysis for IIoT vendors and IIoT users. Recall that companies that provide the technologies and infrastructure needed to connect machines, products, processes, and people are classified as IIoT vendors. On the other hand, IIoT users make use of this technology and infrastructure and integrate it into the value chain to optimize existing processes or pursue new BMs. In the below discussion we articulate this distinction where relevant to the BM archetype.

Recall that the IIoT Digical BM archetype is best suited to companies with existing physical products that can be enhanced through IIoT sensors to create additional value. Our analysis shows that, this model is best suited to companies who are IIoT users, as opposed to vendors, who aim to increase individualization and integrate customers, be it individuals or other companies, into their value creation process. Successful implementation results in improved value proposition through the evolution of physical products into hybrid (digical) products and also through process optimization, with revenue still mainly coming from the sale of products. Companies implementing this type of BM need to be mindful of either developing in-house software expertise, or potentially outsourcing software development or making related acquisitions (Endres, Huesig, & Pesch, 2022). This BM archetype is typically used by incumbents in our dataset. It is also suitable for start-ups with a new hybrid product, however resource constraints make this model more accessible to incumbents.

The IIoT service-centered BM is suitable for companies that serve customers who do not own or do not want to own products. Companies that use this BM provide IIoT technology services by supplying, for instance, the sensors to other companies as a B2B partnership. Customers or industries seeking services from such vendors only pay for the use of the sensors. The same sensors can be reused by another company and so on. Thus, a market is created for the companies operating on IIoT service-centered BMs. To address core implementation challenges, companies using this BM archetype should consider building competitive advantage by implementing IIoT solutions through long-term partner networks. As a result, they will be even better positioned to deliver the right IIoT services for their customers' needs.

IIoT data-driven BM is particularly suitable to be adopted by companies who invest in sensors and have deep data analytics expertise. While such a BM can be utilized by incumbents with the requisite expertise, it is typically used by start-ups due to the focus on analytics and lower resource requirements. Established incumbents often have legacy infrastructure, systems, and processes that can be challenging to integrate with IIoT solutions. Startups, on the other hand, are more inclined to experiment with the emerging IIoT technologies. By leveraging this data, startups can identify inefficiencies, optimize operations, and reduce costs. For example, predictive maintenance using data from IIoT sensors can help prevent equipment failures and minimize downtime. By its nature, the type of IIoT use indicates it is suited to IIoT vendors. The main value proposition comes from selling data insights, with customers being able to track their machine or process performance for a fee (typical revenue models are subscription or fremium models), but there are development costs associated with algorithm development and initial sensor outlay. Because companies employing this model use sensors to collect data on behalf of other industries/companies, who are their clients, the BM leads to B2B partnerships and is aligned with higher customer loyalty due to lock-in and new functionalities. However, challenges arise in data integration, leading to a need for standards for processing of data as well as staff training to improve technical capabilities relating to data quality and data integration.

The IIoT platform BM is suitable for companies who have requisite platforms to act as mediators between two or more companies to exchange information. The information collected by a firm registered with the platform can be shared with other companies registered on the platform. This platform is, in essence, a distribution channel and can be B2B in case of integration platforms and B2C in case of transaction platforms, allowing companies to identify new target user groups. Revenue models are the same as in the data-driven BM, and costs are associated with developing and maintaining the platform, as well as marketing activities to integrate new customers, which in turn makes the platform more attractive to others. However, companies that use IIoT Platform BMs have to consider how to also maintain and improve direct customer relationships, and need to put in place related infrastructure and services for this.

Overall, our classification and finer grained details provide useful insights for companies striving to formulate and implement an IIoT BM. Our approach to focus on successfully applied IIoT BMs in practice builds on prior conceptual studies in the IIoT domain, and also provides a finer grained lens on specific business model elements, allowing us to provide core changes relating to aspects of BMs relevant to researchers from different domains (e.g., marketing or strategy). Through our classification we also extend existing literature on value creation, value capture, and value delivery with business models (Åström et al., 2022; Kim et al., 2019; Reuschl et al., 2022; Sjödin et al., 2020) and provide new insights on how companies successfully unlock the business potential of IIoT (Baiyere, 2016; Ehret & Wirtz, 2017; Müller et al., 2018).

6. Conclusions, limitations, and future research

In this article we identified four main IIoT BM archetypes that are successfully used in practice, *viz.* IIoT digical, IIoT service-centered, IIoT data-driven, and IIoT platform. Using a fine-grained analysis based on the Business Model Canvas, and considering incumbent and start-up companies, we also contribute to the body of knowledge on IIoT BMs by providing a more nuanced understanding of the characteristics of each BM archetype. Our results add to the limited body of empirical evidence of BMs in the context of IIoT. We provide insights for researchers by highlighting existing practice and identifying which types of BMs are appropriate in which contexts. Our results are intended to guide practitioners by providing a consolidation of *successfully* used BMs and their characteristics, which can help organizations determine what

Table 3
Practical Implications illustrated with the CIMO logic

Context	Intervention	Mechanism	Outcome
Particularly IIoT-using incumbents with existing physical products	using digical IIoT BMs, where the combination of industrial tools and industrial digital process solutions is the focus	-by identifying key industrial physical products -by enhancing existing key physical products with industrial sensors or communication systems, for instance, to monitor real-time data on temperature, humidity, energy consumption, and equipment performance with revenue still coming primarily from product sales. -by having a targeted data structure in conjunction with reliable and intuitively operable industrial devices.	delivers value to customers, such as improved processes, optimized energy efficiency, improved maintenance schedules, or remote diagnostics.
Particularly companies that serve customers who do not own or do not want to own products	using IIoT service-centered BMs where industrial services are the primary focus	-as a B2B partnership, by supplying or leasing several adaptable sensors (for example) to other companies. -by using and analyzing this data generated, enhanced with machine learning -by letting the customer pay for the use of the sensors and -by overcoming implementation challenges, such as not-yet-established industrial ethernet standards, for their customers in a long-term partnership.	enables appropriate value-creating IIoT services for customers such as network utilization, traffic monitoring, or predictive maintenance to eliminate defective turnouts as a reason for delay - in an economically optimal model.
Particularly companies who invest in sensors and have deep data analytics expertise (often start-ups)	using IIoT data-driven BMs where data generating products are the focus	-by experimenting with the emerging IIoT technologies and leveraging the data. -by addressing the challenge of integrating data from different areas and sectors (e.g., industrial data, service market data, data from the micro- or macro-environments), through the creation of standards for data processing and staff training	-can identify inefficiencies, streamline the operations, and reduce costs -leads to B2B partnerships and increased customer loyalty through lock-in and new functionality.
Particularly companies that have the necessary platforms to act as intermediaries between two or more companies.	using IIoT Platform BMs where the industrial platform is the primary focus	-by developing, maintaining, and marketing the platform (B2C- transaction platform or B2B-integration platform) to integrate new customers -by maintaining and improving direct customer relationships by adding value to the customer, such as spending less time on bureaucratic activities and more time on their core business, and must build the infrastructure and services to do so. -by effectively managing the risk of the companies losing direct contact with their customer base due to the platform.	allows companies to identify new target user groups since former competitors often become important customers in platform BM

BMs might be suitable at a given point of time. Further, we identify main challenges experienced by companies implementing the identified IIoT BMs, providing insights on roadblocks to success.

6.1. Practical implications

The findings from our study highlight several implications for industrial (marketing) managers and provide insights on which IIoT BMs are appropriate and fit together along with the relevant mechanisms through which value can be created. Inspired by Van der Borgh, Xu, & Sikkenk (2020), we summarize these using CIMO (Context, Intervention, Mechanism, Outcome) logic to provide clear guidance on when and how a specific IIoT BM is likely appropriate, and how it leads to value generation.

Specifically, we view the identified IIoT business models as general interventions that help companies improve outcomes by using specific mechanisms. These mechanisms are based on BM elements that we have identified in our dataset of successful IIoT BMs, which also help to overcome the earlier identified BM challenges. We summarize these in Table 3.

In addition to these specific BM implications, we outline several general practice implications for companies considering IIoT. First, as a result of the increasing digitalization and interconnectedness of production, new core competencies are emerging and, consequently, new work requirements will arise for the workforce. Employees need more knowledge in software development as well as in data analysis as this is one of the core activities in new BMs. Second, the same software coding is being used for all products, which increases the vulnerability to piracy - as the markets for apps or digital programs illustrate. This is the reason why the so-called "all-or-nothing markets", in which one provider has a monopoly position, are increasing (Wildemann, 2016). Especially in the case of platforms, where network effects are an essential characteristic, it is important to reach the critical mass in a short period of time. Third, the creation of new organizational structures is required to support new BMs. To stay competitive in the IIoT context, established companies have to adapt or innovate their organizational structures (Endres, Weber, & Helm, 2015). Current organizational structures are often not suitable for the new business environment. Production companies are becoming a mixture of hardware and software companies due to the increasing integration of information and communication systems and the resulting intelligent, connected products (Porter & Heppelmann, 2015). Finally, we see a need for the formation of strategic partner networks. Particularly, established companies in the field of plant construction and engineering need to build up competencies in the area of data aggregation and analysis to offer new, data-driven services in addition to their products. Therefore, they should cooperate with ICT companies who have experience and knowledge in this area.

6.2. Academic implications & future research

Our study contributes to the emerging academic body of knowledge on IIoT business models. While several classifications have been proposed in prior research, our study is the first to consider *successful* IIoT BM use. It shows that such analysis results in identification of new IIoT BMs with a specific composition necessary for capturing value from IIoT that were previously not recognized in the literature – namely IIoT digical, IIoT data-driven, and IIoT platform. These are in addition to the IIoT service-centered BM, which was already identified in a prior classification by Arnold et al. (2017). Because our analysis was a fine grained one, facilitated by our focus on the elements of the Business Model Canvas, we were able to contextualize successful applications of these new BM archetypes in practice. It also allowed us to build on the work of Arnold et al. (2017) to provide a more detailed understanding of the IIoT service-centered BM, from a successful use perspective. In doing so, our work helps to inform researchers working in this domain.

There are several fruitful directions in which researchers could build on these findings. First, while data on IIoT BM implementation failures is hard to find, an important direction is a comparison of these successful cases to unsuccessful ones. It is unlikely that such data can be found at a large scale, indicating that case study research being an important avenue to compare and contrast successful and unsuccessful cases to enrich the body of literature. Second, BMs evolve over time. Our study provided a snapshot of successful IIoT BMs in practice, but we see significant potential in studying the evolution of IIoT BMs. The Business Model Canvas provides an ideal basis for such a study, as one can track changes in the underlying BM elements to uncover the evolutionary path that organizations take through these archetypes as their context changes. Third, it is important to also understand how traditional BMs have evolved following the introduction of Industry 4.0 (Paschou et al., 2020). To this end, researchers can explore how service centered BMs, for example, have evolved with advances in IIoT technologies. Finally, we see a need for large scale empirical studies on barriers and enablers of IIoT usage to better inform the researchers and the practitioners.

6.3. Limitations

Our study is not without limitations. First, as with any qualitative research, there is a risk of bias in the coding of our data. To mitigate this risk, we used a dual-coder approach. Second, we recognize that a large proportion of the publication outlets were German. However, the scale of publications identified (over 2000) and our inclusion of international outlets, as well as business magazines, reduces the risk of relying on a particular country context. Finally, while our analysis is based on successful implementations of IIoT BMs as outlined in industry magazines, it would be beneficial to further empirically validate it. We did so informally through conversations with seven practitioners with an average of six years senior industrial manager experience. While they offered supporting examples from their own knowledge or experience in the field, which helped us to confirm the archetypes, we note the need for a broader evaluation.

Funding

This research was partially supported by the ARC Industrial Transformation Training Centre for Information Resilience (project number: IC200100022).

Data availability

The data that has been used cannot be published for legal and confidential reasons.

Acknowledgements

We would like to thank the editors and the reviewers for their very valuable feedback, which helped us to improve our paper significantly. We would also like to thank Stefan Broser and the participants of the European Marketing Academy (EMAC) Annual Conference and the International Conference on Information Systems (ICIS) for their valuable contributions.

Appendix

Eq. (A.1) Articles per firm in 2011-2020

Company	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020 (01-09)	Total
Established companies											
Daimler	-	2	8	10	22	28	13	7	13	4	**107**
BMW	-	-	3	1	14	14	6	11	16	3	**68**
Audi	-	-	3	4	13	11	5	15	6	4	**61**
Siemens	1	4	15	26	42	53	21	40	45	8	**255**
Bosch	-	1	5	8	22	27	16	20	30	4	**133**
Phoenix Contact	-	-	3	11	6	14	7	11	9	5	**66**
ABB	-	1	4	7	15	26	12	11	13	2	**91**
GE	-	-	6	6	14	23	6	12	3	2	**72**
Festo	-	1	3	9	11	5	7	13	12	3	**64**
Pilz GmbH	-	-	3	6	11	16	5	7	9	1	**58**
Weidmüller Interface	-	-	8	9	12	9	5	12	10	4	**69**
Rittal GmbH	-	-	2	6	7	15	1	11	17	2	**61**
KUKA	-	-	4	8	19	28	12	12	5	4	**92**
Trumpf GmbH	1	2	6	6	13	24	8	12	12	6	**90**
Claas KGaA mbH	-	-	1	2	5	8	-	3	1	-	**20**
Microsoft	-	-	4	12	17	34	14	19	22	12	**134**
Google	-	-	6	16	25	21	12	21	14	4	**119**
Cisco	-	-	3	14	15	9	11	11	21	5	**89**
Deutsche Telekom	-	-	2	3	10	13	7	17	15	3	**70**
Accenture Plc	2	1	3	5	3	-	3	5	2	4	**28**
Alibaba	-	-	-	-	1	2	4	8	3	2	**20**
Amazon	2	-	-	8	3	14	29	26	22	12	**116**
Apple	-	1	-	6	2	10	9	8	9	2	**47**
Atlantik Elektronik	-	-	-	-	-	-	-	-	1	3	**4**
Basler AG	-	-	-	-	-	1	3	1	2	3	**10**
Bayer AG	-	-	-	3	-	3	2	8	6	4	**26**
Bystronic	-	-	-	1	2	-	-	7	2	2	**14**
CommScope Inc.	-	-	-	-	-	-	-	1	1	-	**2**
Continental AG	1	2	-	4	3	5	5	12	9	2	**43**

(*continued on next page*)

(*continued*)

Company	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020 (01-09)	Total
Cypress	-	-	-	2	-	2	-	-	1	2	**7**
Fujitsu K.K.	-	-	2	-	-	1	2	9	5	1	**20**
Huawei	2	1	1	-	2	6	8	11	15	3	**49**
IBM	2	2	4	9	15	18	24	14	10	5	**103**
Infineon Technologies AG	2	-	1	4	5	6	6	7	3	1	**35**
Intel	1	1	1	4	8	13	14	11	4	5	**62**
Kontron S&T AG	-	-	1	-	-	1	1	9	10	5	**27**
Kyocera K.K.	-	-	-	-	-	-	-	2	-	-	**2**
Mapal Dr. Kress	-	-	-	-	1	-	2	3	2	4	**12**
Maxim Integrated	-	-	-	3	2	2	2	5	3	3	**20**
Micron Technology Inc.	-	-	1	-	-	-	-	-	4	3	**8**
Mitsubishi	-	-	-	1	3	2	3	8	4	2	**23**
Nokia	-	-	-	1	2	4	2	6	6	1	**22**
Nvidia	-	-	-	-	1	1	4	4	14	10	**34**
Profibus & Profinet (PI)	-	-	-	3	-	2	-	12	3	6	**26**
Qualcomm Inc.	-	-	-	-	-	2	6	3	10	3	**24**
Recom Electronic	-	-	-	-	-	1	1	2	-	-	**4**
Red Hat	-	-	-	-	-	-	-	-	3	1	**4**
Rohde & Schwarz	-	1	-	-	-	1	1	2	4	2	**11**
Samsung	-	-	1	1	3	4	4	4	4	3	**24**
SAP	-	3	-	12	18	22	21	28	11	10	**125**
Schneider Electric SE	-	-	-	1	-	5	2	10	6	1	**25**
Sigfox	-	-	-	-	-	3	1	4	5	4	**17**
Software AG	-	1	-	2	3	1	11	9	5	6	**38**
STMicroelectronics N.V.	-	-	-	1	-	2	1	-	3	1	**8**
Swissbit	-	-	-	-	-	-	1	-	4	2	**7**
Telefónica Deutschland Holding	-	-	-	-	-	2	1	10	6	2	**21**
Thyssenkrupp AG	-	1	-	1	3	5	4	12	7	4	**37**
Turck GmbH & Co. KG	-	-	-	1	-	-	1	8	2	1	**13**
ZF Friedrichshafen AG	-	-	-	-	-	1	2	7	7	4	**21**
Start-Ups											
Relayr	-	-	-	-	-	-	-	5	1	1	**7**
Konux	-	-	-	2	4	7	5	-	-	2	**20**
Axoom	-	-	-	-	3	23	8	5	4	2	**45**
Cybus GmbH	-	-	-	-	-	1	1	1	1	-	**4**
365 FarmNet	-	-	-	4	1	2	1	-	1	-	**9**
ProGlove	-	-	-	-	2	7	1	2	2	1	**15**
Connyun	-	-	-	-	-	-	3	-	-	-	**3**

Eq. (A.2) Used codes for content analysis (translated to English)

Product	
Code name	**Value proposition**
Used terms	Value proposition, product, service, service, (risk | cost) reduction, mass customization, innova (tion | tive), quality, performance, update, customization, design, comfort | comfortable, user friendly, batch size (1 | one), sales pitch, price, extension, expansion, improvement, optimization, tracking, maintenance, evolution | advancement, add-on (features), orientation (service), value creation, algorithm(s), evaluation, monetization, attractiveness, exchange, ecosystem, insight(s), physical (analog) & digital (hybrid), (additional | new) service(s), store, transaction (mediator | types), machine (rent), availability, ecosystem, data evaluation, network, detail, (better) digitalization, (based on) data (analysis | insight(s)), (rather) analog, similarity, improving (previous), efficiency, radical (change)
Customer Interface	
Code name	**Customer relationship**
Used terms	Customer (relationship | loyalty | integration | involvement | support | service | portal | individualization | personalization | customization), co-creation, long-term, competitors to customers, lock-in, process optimization
Code name	**Customer segments**
Used terms	Mass market, niche, segment, B2B, B2C, customer segment, customer (tailored | fitted | adapted), insight(s), customer behavior, (new) target, IIoT-user
Code name	**Channel**
Used terms	Communication, Distribution, channel (s), Field Sales, Sales, Homepage, online (Shop | Sales | Platform | Dealer), integration platform (B2B), transaction platform (B2C), (new) business models
Infrastructure management	
Code name	**Key resources**
Used terms	Resource, Personnel, Employees, Software, Knowledge, Know-How, Technology, Data, (adaptable) algorithm(s), it-infrastructure, sensors(s) (platform), technology investment
Code name	**Key partners**
Used terms	Software (Developer | Supplier | Supplier), Partner, Cooperative | Alliance, Supplier, Data Service Provider, Hardware (Manufacturer | Supplier), Together (Work | Final), Acquisition, Cooperation, Software specialist(s), IIoT-vendor(s)
Code name	**Key activities**

(*continued on next page*)

(*continued*)

Product	
Code name	**Value proposition**
Used terms	(Software | Product | Customer) development, production, manufacturing, marketing, data (analysis | preparation | evaluation | generation | collection | processing | visualization), prescriptive, predictive, process optimization, increase attractiveness, developer integration, customer integration, partner integration, platform integration, production & data analysis, maintenance & operation
Financial Aspects	
Code name	**Revenue streams**
Used terms	Sales (electricity | flows | growth | increase | source | potential | opportunity | opportunity | rise | decline | loss), pay-per-use, pay-by-usage, license, advertising, rent | Fee | Leasing | Add-on | Sale | price, subscription, income source (product | service), higher prices, price hike, improved value proposition, additional income (service), freemium, recurring payment(s)
Code name	**Cost structure**
Used terms	Costs, Investment, economies of scale, economies of scale, economies of scope, development cost (Software & algorithm | platform), (low) fixed-costs, pay-as-you-grow (growth-dependent), maintenance cost (platform)
Challenges	
Code name	**Technological challenges**
Used terms	Interface, machine & data (combination), securing (data | access), (transfer| processing | storage) standardization, digitalization (limited | little), digital (lack | deficiency | shortage), storage saving
Code name	**Business development challenges**
Used terms	(business) partners, collaboration, keeping customer relations, fear(s), inhibition(s), (new) technology (change | uncertain(ty)), focus on (single | limited) area(s), complex (environment), in (sufficient | consistent | complete)

Eq. (A.3) References per company and value proposition cluster for the particular business model element or challenge on the basis of our second order nodes

Companies	**Clusters of Value Proposition**	**Technological challenges**	**Business development challenges**	**Value proposition**	**Key Ressources**	**Key partners**	**Key activities**	**Customer Relationship**	**Customer segments**	**Channel**	**Revenue streams**	**Cost structure**
365FarmNet	Data-driven	4	0	3	8	0	2	4	0	1	0	3
	Service-driven	0	1	7	0	4	1	0	0	0	0	0
ABB	Data-driven	20	0	24	73	0	42	17	6	1	1	3
	Platform	0	15	47	0	1	12	5	0	3	3	3
	Service-driven	0	3	42	0	3	15	1	11	0	3	0
Accenture	Data-driven	7	0	6	13	0	19	5	1	2	0	2
	Platform	0	4	32	0	1	7	5	0	1	1	1
Alibaba	Data-driven	2	0	3	7	0	4	1	0	1	0	0
	Platform	0	2	7	0	0	2	1	0	4	0	0
Amazon	Data-driven	11	0	10	51	0	53	12	0	1	1	3
	Service-driven	0	5	55	0	6	15	1	8	0	9	0
Apple	Data-driven	3	0	6	17	0	10	0	0	0	0	0
	Service-driven	0	1	8	0	1	1	0	4	0	3	0
Audi	Data-driven	10	0	16	29	0	29	16	1	0	0	1
	Digical	18	0	52	3	0	7	7	2	0	2	0
	Service-driven	0	8	39	0	4	10	4	16	0	0	1
Atlantik	Data-driven	0	0	1	4	0	1	1	0	1	0	0
	Platform	0	0	2	0	0	0	0	0	1	1	0
Axoom	Data-driven	4	0	7	21	0	23	9	0	1	0	0
	Service-driven	0	3	16	0	2	5	0	8	0	4	0
Basler	Data-driven	1	0	1	7	0	3	0	1	0	0	0
	Platform	0	0	1	0	0	0	1	0	1	0	0
	Service-driven	0	0	1	0	0	0	0	0	0	0	1
Bayer	Data-driven	8	0	13	20	0	15	8	0	0	1	2
	Digical	4	0	10	0	0	2	5	1	0	4	0
	Service-driven	0	2	14	0	7	4	1	4	0	0	0
Bosch	Data-driven	8	0	12	69	0	47	12	0	0	0	2
	Service-driven	0	3	39	0	2	7	0	9	0	11	2
BMW	Data-driven	13	0	9	36	0	40	17	0	0	0	4
	Digical	9	0	27	0	1	4	8	0	0	4	0
	Service-driven	0	4	27	1	5	15	2	14	0	11	2

(*continued on next page*)

(*continued*)

Companies	Clusters of Value Proposition	Technological challenges	Business development challenges	Value proposition	Key Ressources	Key partners	Key activities	Customer Relationship	Customer segments	Channel	Revenue streams	Cost structure
bystronic	Data-driven	2	0	2	3	0	3	4	0	0	0	0
	Service-driven	0	3	3	0	1	1	0	2	0	0	0
Cisco	Data-driven	18	0	9	46	0	55	12	0	0	0	1
	Service-driven	0	1	23	0	2	13	0	2	0	3	0
Claas	Data-driven	3	0	2	10	0	5	3	0	0	0	0
	Service-driven	0	1	4	0	2	1	0	1	0	2	0
CommScope	Data-driven	0	0	0	3	0	1	0	0	0	0	0
Connyun	Data-driven	1	0	0	1	0	5	2	0	0	0	0
	Platform	0	1	3	0	0	0	0	0	1	0	0
	Service-driven	0	0	2	0	0	1	0	2	0	0	0
Continental	Data-driven	5	0	8	22	0	9	5	0	0	0	2
	Service-driven	0	5	11	0	2	2	1	6	0	1	0
Cybus	Data-driven	4	0	4	3	0	7	1	0	0	0	1
	Service-driven	0	1	4	0	2	1	0	5	0	1	1
Cypress	Data-driven	0	0	1	4	0	0	1	0	0	0	0
	Digical	0	0	1	0	2	0	0	0	0	0	0
Daimler	Data-driven	9	0	11	39	0	26	8	0	0	0	0
	Digical	8	0	31	1	2	1	5	1	0	2	0
	Service-driven	0	8	30	0	10	12	2	12	0	6	1
Telekom	Data-driven	6	0	5	29	0	16	6	0	0	0	0
	Service-driven	0	5	20	0	1	3	0	1	0	0	0
Festo	Data-driven	10	0	8	33	0	22	7	0	0	0	0
	Service-driven	0	0	17	0	3	5	0	5	0	1	2
Fujitsu	Data-driven	0	0	3	5	0	8	1	0	0	0	1
	Service-driven	0	2	7	0	0	5	0	2	0	0	0
GE	Data-driven	9	0	10	21	0	33	6	0	0	0	2
	Service-driven	0	3	23	0	2	12	0	6	0	3	0
Google	Data-driven	17	0	19	67	0	52	8	0	0	0	1
	Service-driven	0	7	37	0	7	10	1	12	0	2	2
Huawei	Data-driven	10	0	2	17	0	7	6	0	0	2	0
	Digical	2	0	7	0	0	2	2	2	0	3	0
	Service-driven	0	0	4	2	3	2	0	7	0	4	0
IBM	Data-driven	15	0	15	47	0	62	15	0	0	0	2
	Service-driven	0	4	45	0	10	14	0	10	0	5	0
Infineon	Data-driven	5	0	8	26	0	6	5	0	0	1	1
	Service-driven	0	3	6	0	1	2	0	4	0	2	0
Intel	Data-driven	10	0	8	22	0	15	7	0	0	2	0
	Service-driven	0	4	18	0	3	7	0	5	0	0	1
Kontron	Data-driven	0	0	5	8	0	10	4	0	0	0	1
Konux	Data-driven	2	0	0	11	0	6	0	0	0	0	0
	Service-driven	0	1	1	0	1	2	0	1	0	1	0
Kuka	Data-driven	7	0	9	41	0	21	10	0	0	2	0
	Service-driven	0	6	21	0	3	9	0	1	0	5	0
Kyocera	Data-driven	0	0	1	0	0	0	0	0	0	0	0
	Digical	0	0	1	0	0	0	0	0	0	0	0
Mapal	Data-driven	3	0	2	3	0	4	6	0	0	0	0
	Digical	2	0	2	2	0	1	1	0	0	2	0
Maxim Integrated	Data-driven	2	0	3	20	0	4	3	0	0	0	0
Micron	Data-driven	1	0	1	3	0	3	1	0	0	1	0
Microsoft	Data-driven	16	0	13	52	0	49	9	0	0	0	2
	Service-driven	0	4	40	0	3	14	1	5	0	4	1
Mitsubishi	Data-driven	3	0	3	13	0	19	2	0	0	0	0
	Service-driven	0	1	18	0	1	3	0	0	0	4	0
Nokia	Data-driven	2	0	1	11	0	6	0	0	0	0	0

(*continued on next page*)

(*continued*)

Companies	Clusters of Value Proposition	Technological challenges	Business development challenges	Value proposition	Key Ressources	Key partners	Key activities	Customer Relationship	Customer segments	Channel	Revenue streams	Cost structure
	Service-driven	0	1	5	0	2	2	0	1	0	1	0
Nvidia	Data-driven	7	0	5	17	0	13	10	0	0	0	0
Phoenix Contact	Data-driven	5	0	6	29	0	13	9	0	0	0	0
	Digical	3	0	12	0	1	0	3	0	0	0	0
	Service-driven	0	1	16	0	1	1	0	2	0	0	0
Pilz	Data-driven	9	0	8	41	0	12	3	0	0	0	0
	Digical	1	0	7	0	0	2	1	0	0	0	0
	Service-driven	0	0	21	0	0	1	0	0	0	0	0
ProfibusProfinet	Data-driven	5	0	6	21	0	19	5	0	0	0	0
	Service-driven	0	2	6	0	0	4	1	2	0	2	0
ProGlove	Data-driven	5	0	1	6	0	3	1	0	0	0	0
	Digical	0	0	2	0	0	0	1	0	0	0	0
	Service-driven	0	0	2	0	0	1	0	0	0	0	0
Qualcomm	Data-driven	5	0	3	15	0	7	1	0	0	0	0
	Service-driven	0	0	6	0	1	1	0	1	0	0	0
Recom	Data-driven	0	0	1	3	0	1	0	0	0	0	0
	Digical	0	0	2	0	0	0	0	0	0	1	0
	Service-driven	0	0	0	0	1	0	0	0	0	0	0
Red Hat	Platform	0	0	2	0	0	0	0	0	0	1	2
	Service-driven	0	0	1	0	1	0	0	1	0	1	0
relayr	Data-driven	2	0	3	4	0	4	0	0	0	0	0
	Platform	0	0	5	0	0	0	0	0	0	0	0
	Service-driven	0	0	4	0	2	2	1	0	0	2	0
Rittal	Data-driven	6	0	8	18	0	20	3	0	0	0	1
	Service-driven	0	1	18	0	1	6	0	5	0	0	0
Rohde	Data-driven	0	0	0	6	0	1	0	0	0	0	0
	Digical	1	0	2	0	0	0	0	0	0	0	0
	Service-driven	0	0	2	1	0	0	0	0	0	0	0
Samsung	Data-driven	1	0	3	8	0	2	1	0	0	0	0
	Digical	3	0	2	0	0	1	0	0	0	2	0
	Platform	0	0	2	0	0	0	0	0	0	2	1
SAP	Data-driven	12	0	22	55	0	60	25	0	1	3	5
	Service-driven	0	7	54	0	8	16	0	12	0	11	1
Schneider	Data-driven	2	0	6	12	0	17	5	0	0	1	0
Siemens	Data-driven	25	0	49	109	0	117	54	0	0	0	3
	Digical	16	0	55	3	1	11	9	2	0	8	0
	Service-driven	0	6	93	2	9	34	2	20	0	13	0
Sigfox	Data-driven	6	0	0	10	0	2	4	0	0	0	0
	Service-driven	0	0	5	0	0	0	0	0	0	2	0
Software AG	Data-driven	3	0	4	17	0	16	8	0	0	0	0
	Platform	0	1	17	0	1	0	3	0	0	0	0
	Service-driven	0	2	15	0	2	3	0	7	0	0	0
STM Microelectronics	Data-driven	0	0	0	5	0	2	2	0	0	0	0
Swissbit	Data-driven	1	0	0	4	0	0	2	0	0	1	0
	Service-driven	0	0	1	0	0	0	0	2	0	0	0
TelefonicaO2	Data-driven	2	0	3	9	0	8	2	0	1	0	0
	Digical	3	0	9	1	0	0	1	1	0	1	0
	Service-driven	0	2	7	0	1	2	0	6	0	0	0
ThyssenKrupp	Data-driven	3	0	8	22	0	21	5	0	0	0	2
	Service-driven	0	4	17	0	3	7	1	6	0	3	1
Trumpf	Data-driven	8	0	11	21	0	16	6	0	0	0	0
	Service-driven	0	4	20	0	1	5	0	5	0	5	0
Turck	Data-driven	2	0	1	10	0	7	2	0	0	0	0
Weidmüller	Data-driven	6	0	15	45	0	33	14	0	0	2	1

(*continued on next page*)

(*continued*)

Companies	Clusters of Value Proposition	Technological challenges	Business development challenges	Value proposition	Key Ressources	Key partners	Key activities	Customer Relationship	Customer segments	Channel	Revenue streams	Cost structure
	Digical Service-	3	0	18	1	1	4	3	0	0	2	0
	driven	0	3	39	0	4	8	1	6	0	2	0
	Data-driven	0	0	3	12	0	6	1	0	0	1	0
ZF	Digical Service-	2	0	7	1	0	0	1	1	0	0	0
	Driven	0	0	9	0	0	2	0	1	0	0	0

References

Aagaard, A. (2019). *Digital business models*. Springer International Publishing.

Al-Debei, M. M., & Avison, D. (2010). Developing a unified framework of the business model concept. *European Journal of Information Systems, 19*(3), 359–376.

Arnold, C., Kiel, D., & Voigt, K. I. (2016). How the industrial internet of things changes business models in different manufacturing industries. *International Journal of Innovation Management, 20*(8), 1640015.

Arnold, C., Kiel, D., & Voigt, K. I. (2017). Innovative business models for the industrial internet of things. *BHM Berg-und Hüttenmännische Monatshefte, 162*(9), 371–381.

Åström, J., Reim, W., & Parida, V. (2022). Value creation and value capture for AI business model innovation: a three-phase process framework. *Review of Managerial Science*, 1–23.

Atos. (2014). Atos treibt Pilotprojekte zur Entwicklung von Industrie 4.0 Geschäftsmodellen. https://atos.net/de/2014/pressemeldungen_2014_10_07/; accessed January 5, 2022.

Baiyere, A. (2016). *Discovering the Role of Information Technology in Disruptive Innovations* (pp. 28–44). Enabler, Sustainer or Barrier.

Baiyere, A., Venkatesh, V., Donnellan, B., Topi, H., & Tabet, S. (2016). IoT–Towards a research agenda for information systems. In *Proceedings of American conference of Information Systems*.

Behrendt, A., De Boer, E., Kasah, T., Koerber, B., Mohr, N., & Richter, G. (2021). *Leveraging Industrial IoT and advanced technologies for digital transformation* (pp. 1–75). McKinsey & Company.

Bischoff, J., Taphorn, C., Wolter, D., Braun, N., Fellbaum, M., Goloverov, A., Ludwig, S., Hegmanns, T., Prasse, C., Henke, M., ten Hompel, M., Döbbeler, F., Fuss, E., Kirsch, C., Mättig, B., Braun, S., Guth, M., Kaspers, M., & Scheffler, D. (2015). Erschließen der Potenziale der Anwendung von Industrie 4.0 im Mittelstand. https://www.ipa.fraunhofer.de/content/dam/ipa/de/documents/Presse/Presseinformationen/2016/Juni/WGP_Standpunkt_Industrie_40.pdf accessed January 5, 2022.

BMWi. (2015). *Industrie 4.0: Volks- und betriebswirtschaftliche Faktoren für den Standort Deutschland*. Berlin.

Bohnsack, R., Pinkse, J., & Kolk, A. (2014). Business models for sustainable technologies: Exploring business model evolution in the case of electric vehicles. *Research Policy, 43*, 284–300.

Carroll, G. R., & Hannan, M. T. (2000). *The demography of corporations and industries, New Jersey*. Princeton University Press.

Chen, L., Jia, F., Steward, M. D., & Schoenherr, T. (2022). The role of technology in enabling circular supply chain management. *Industrial Marketing Management, 106*, A1–A6.

Computerwoche. (2014). Auch die US-Wirtschaft organisiert sich für den Wachstumsmarkt Industrie 4.0. *Computerwoche, 15*, 48.

Computerwoche. (2018). Internet of Things: Deutsche Unternehmen haben den Schatz noch nicht gehoben. *Computerwoche, 36*, 32–34.

Dignan, L. (2018). GE plans to launch independent industrial IoT company, unloads ServiceMax: Too little, too late? ZD Net. https://www.zdnet.com/article/ge-plans-to-launch-independent-industrial-iot-company-unloads-servicemax-too-little-too-late/.

Dijkman, R., Sprenkels, B., Peeters, T., & Janssen, A. (2015). Business models for the Internet of Things. *International Journal of Information Management, 35*(6), 672–678.

Ehret, M., & Wirtz, J. (2017). Unlocking value from machines: business models and the industrial internet of things. *Journal of Marketing Management, 33*(1–2), 111–130.

Emmrich, V., Döbele, M., Bauernhansl, T., Paulus-Rohmer, D., Schatz, A., & Weskamp, M. (2015). *Geschäftsmodell-Innovation durch Industrie 4.0: Chancen und Risiken für den Maschinen- und Anlagenbau, Munich, and Stuttgart*. Dr. Wieselhuber & Partner & Fraunhofer IPA.

Endres, H., Auburger, J., & Helm, R. (2024). Industrial innovation management in the age of digital transformation: The risk of too strong selling capabilities. *Industrial Marketing Management, 117*, 371–385.

Endres, H., & Helm, R. (2015). Predictive analytics. IM+ io Fachzeitschrift für Innovation, Organisation und Management–Predictive Analytics. *4*, 59–61.

Endres, H., Huesig, S., & Pesch, R. (2022). Digital innovation management for entrepreneurial ecosystems: services and functionalities as drivers of innovation management software adoption. *Review of Managerial Science, 16*(1), 135–156.

Endres, H., Weber, K., & Helm, R. (2015). Resilienz-management in Zeiten von Industrie 4.0. IM+ io: Das Magazin für Innovation, Organisation und Management. *30*(3), 28–31.

Evans, P. C., & Gawer, A. (2016). *The rise of the platform enterprise: a global survey*. New York: The Center for Global Enterprise.

Falkenreck, C., & Wagner, R. (2017). The Internet of Things–Chance and challenge in industrial business relationships. *Industrial Marketing Management, 66*(10), 181–195.

Fleisch, E., Weinberger, M., & Wortmann, F. (2015). Business models and the internet of things. In I. Podnar Zarko, K. Pripuzic, & M. Serrano (Eds.), *Interoperability and Open-Source Solutions for the Internet of Things* (pp. 6–10). Springer International Publishing.

Fleiss, J. L., Levin, B., & Paik, M. C. (2013). *Statistical methods for rates and proportions*. John Wiley & Sons.

Forbes. (2021). Microsoft's Percept Precept: Industrial IoT Shifts from Solutions To Platforms. https://www.forbes.com/sites/moorinsights/2021/03/16/microsofts-percept-precept-industrial-iot-shifts-from-solutions-to-platforms/?sh=3cff4f565aea accessed January 5, 2022.

Gierej, S. (2017). The framework of business model in the context of industrial internet of things. *Procedia Engineering, 182*, 206–212.

Handelsblatt. (2016). Internet der Dinge: So wird Ihr Leben vernetzt. http://www.handelsblatt.com/adv/digitalatscale/internet-der-dinge-so-wird-ihr-leben-vernetzt/14884614.html accessed January 5, 2022.

Handelsblatt. (2019). Mit 5G auf der Überholspur. In *Handelsblatt (25.7.2019)* (pp. 18–19).

Hossain, M. S., & Muhammad, G. (2016). Cloud-assisted Industrial Internet of Things (IIoT) - Enabled framework for health monitoring. *Computer Networks, 101*, 192–202.

Hui, G. (2014). How the Internet of Things Changes Business Models. https://hbr.org/2014/07/how-the-internet-of-things-changes-business-models.

International Communication Union (ITU). (2015). *Internet of Things Global Standard Initiative* accessed January 5, 2022 https://www.itu.int/en/ITU-T/gsi/iot/Pages/default.aspx.

i-Scoop. (2019). The Industrial Internet of Things (IIoT): the business guide to Industrial IoT. https://www.i-scoop.eu/internet-of-things-guide/industrial-internet-things-iiot-saving-costs-innovation/ accessed January 5, 2022.

Jacobson, I., Spence, I., & Ng, P. W. (2017). Is there a single method for the internet of things? *Communications of the ACM, 60*(11), 46–53.

Johnson, M. W., Christensen, C. M., & Kagermann, H. (2008). Reinventing your business model. *Harvard Business Review, 86*(12), 57–68.

Kiel, D., Arnold, C., Collisi, M., & Voigt, K. I. (2016). The impact of the Industrial Internet of Things on established business models. In *Proceedings of the 25th international association for management of technology (IAMOT)* (pp. 673–695).

Kim, J., Cho, S., & Ramesh, B. (2019). IT-leveraged network value cocreation: a case study of the value cocreation process and value capture in the South Korean broadcast advertising industry. *European Journal of Information Systems, 28*(6), 646–662.

Landis, J. R., & Koch, G. G. (1977a). The measurement of observer agreement for categorical data. *Biometrics, 33: 1*, 159–174.

Landis, J. R., & Koch, G. G. (1977b). An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics*, 363–374.

Laudien, S. M., & Daxböck, B. (2016). The influence of the Industrial Internet of Things on business model design: A qualitative-empirical analysis. *International Journal of Innovation Management, 20*(08), 1640014.

Leminen, S., Rajahonka, M., Wendelin, R., & Westerlund, M. (2020). Industrial internet of things business models in the machine-to-machine context. *Industrial Marketing Management, 84*, 298–311.

Leminen, S., Rajahonka, M., Westerlund, M., & Siuruainen, R. (2015). Ecosystem business models for the Internet of things. *Internet of Things Finland*, 10–13.

Li, N., Min, L., & Jun-Wei, Y. (2011). Framework for industrial internet of things oriented to steel continuous casting plant MRO. *Computer Integrated Manufacturing Systems, 17* (2), 413–418.

Li, T., Van Heck, E., & Vervest, P. (2009). Information capability and value creation strategy: advancing revenue management through mobile ticketing technologies. *European Journal of Information Systems, 18*(1), 38–51.

Li, X., Wan, J., Lai, C. F., Wang, S., Vasilakos, A. V., & Li, D. (2017). A review of industrial wireless networks in the context of Industry 4.0. *Wireless Networks, 23*(1), 23–41.

Liu, J., & Yu, J. (2013). Research on the framework of internet of things in manufacturing for aircraft large components assembly site. In *2013 IEEE International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber, Physical and Social* (pp. *1192–1196*). *IEEE. 2013*.

Markt & Technik. (2016). Industrie 4.0 & Industrial Internet Summit: Lassen Sie niemanden zwischen sich und den Kunden! *Markt & Technik, 44*, 1.
Maschinenmarkt. (2014). Netz aus intelligenten Bausteinen ersetzt Automatisierungspyramide. *Maschinenmarkt, 11*, 14.
Maschinenmarkt. (2015). Bereit für den Wandel. *Maschinenmarkt, 40*, 26.
Maschinenmarkt. (2017). Konkurrent und Partner. *Maschinenmarkt, 29*, 18.
Maschinenmarkt. (2018a). Digitalisierung verspricht Umsatzwachstum. *Maschinenmarkt, 248*, 16.
Maschinenmarkt. (2018b). Immer besser in der Blechbearbeitung. *Maschinenmarkt, 25*, 18.
Maschinenmarkt. (2019). Die Fabrik denkt jetzt mit. *Maschinenmarkt, 24*, 18.
Maschinenmarkt. (2020). Wann sich Automatisierung lohnt. *Maschinenmarkt, 11*, 16.
Mauerer, J. (2017). *Studie Industrie 4.0 2017*. Hamburg: IDG Business Media GmbH.
McKinsey. (2018). *The Internet of Things: How to capture the value of IoT*. New York, NY: McKinsey.
McKinsey. (2021). *By integrating the business, the organization, and technology, manufacturing leaders can position their organizations to reap the full benefits of Industrial IoT*. New York, NY: McKinsey.
McKinsey Digital. (2015). *Industrie 4.0. How to navigate the digitization of the manufacturing sector*. Berlin, Düsseldorf, and Munich: McKinsey.
Moorhead, P. (2013). Who Wins In The Industrial Internet Of Things (IIoT)?. http://www.forbes.com/sites/patrickmoorhead/2013/10/29/who-wins-in-the-industrial-internet-of-things-iiot/.
Moovel. (2017). Ein Unternehmen für urbane Mobilität, das Städte smarter macht. https://www.moovel.com/de/de; accessed August 21, 2019.
Müller, J. M., Buliga, O., & Voigt, K. I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change, 132*, 2–17.
Nielsen, P. A., & Persson, J. S. (2017). Useful business cases: value creation in IS projects. *European Journal of Information Systems, 26*(1), 66–83.
Nvivo. (2020). www.help-nv11.qsrinternational.com accessed March 5, 2021.
Obermaier, R. (2016). Industrie 4.0 als unternehmerische Gestaltungsaufgabe: Strategische und operative Handlungsfelder für Industriebetriebe. In R. Obermaier (Ed.), *Industrie 4.0 als unternehmerische Gestaltungsaufgabe: Betriebswirtschaftliche, technische und rechtliche Herausforderungen* (pp. 3–34). Wiesbaden: Springer Gabler.
Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: A handbook for visionaries, game changers, and challengers*. New Jersey: John Wiley & Sons.
Osterwalder, A., Pigneur, Y., & Tucci, C. L. (2005). Clarifying business models: Origins, present, and future of the concept. *Communications of the Association for Information Systems, 16*(1), 1–25.
Paiola, M., Agostini, L., Grandinetti, R., & Nosella, A. (2022). The process of business model innovation driven by IoT: Exploring the case of incumbent SMEs. *Industrial Marketing Management, 103*, 30–46.
Paiola, M., & Gebauer, H. (2020). Internet of things technologies, digital servitization and business model innovation in BtoB manufacturing firms. *Industrial Marketing Management, 89*, 245–264.
Paschou, T., Rapaccini, M., Adrodegari, F., & Saccani, N. (2020). Digital servitization in manufacturing: A systematic literature review and research agenda. *Industrial Marketing Management, 89*, 278–292.
Popescu, G. H. (2015). The economic value of the Industrial Internet of Things. *Journal of Self-Governance & Management Economics, 3*(2), 86–91.
Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review, 92*(11), 64–88.
Porter, M. E., & Heppelmann, J. E. (2015). How smart, connected products are transforming companies. *Harvard Business Review, 93*(10), 96–114.
Prause, G. (2015). Sustainable business models and structures for Industry 4.0. *Journal of Security and Sustainability Issues*, 159–169.
Reuschl, A., Tiberius, V., Filser, M., & Qiu, Y. (2022). Value configurations in sharing economy business models. *Review of Managerial Science, 16*(1), 89–112.
Roblek, V., Meško, M., & Krapež, A. (2016). A complex view of Industry 4.0. *SAGE Open, 6*(2), 1–11.
Roth, A. (2016). Industrie 4.0 – hype oder revolution?. In *Einführung und Umsetzung von Industrie 4.0* (pp. 1–16). Berlin, Heidelberg: Springer Gabler, 2016.
Schaefer, D., Walker, J., & Flynn, J. (2017). A data-driven business model framework for value capture in Industry 4.0. *Advances in Transdisciplinary Engineering, 6*, 245–250.
Sjödin, D., Parida, V., Jovanovic, M., & Visnjic, I. (2020). Value creation and value capture alignment in business model innovation: A process view on outcome-based business models. *Journal of Product Innovation Management, 37*(2), 158–183.
Szymanski, T. H. (2016). Supporting consumer services in a deterministic industrial internet core network. *IEEE Communications Magazine, 54*(6), 110–117.
Teece, D. J. (2010). Business models, business strategy and innovation. *Long Range Planning, 43*(2), 172–194.
Turber, S., & Smiela, C. (2014). A business model type for the internet of things. In *Proceedings of the European Conference on Information Systems (ECIS) 2014, Tel Aviv, Israel, June 9-11, 2014*.
Van der Borgh, M., Xu, J., & Sikkenk, M. (2020). Identifying, analyzing, and finding solutions to the sales lead black hole: A design science approach. *Industrial Marketing Management, 88*, 136–151.
VDI Nachrichten. (2015). Kommunikationsfreudige Komponenten. *VDI Nachrichten, 47*, 12.
VDI Nachrichten. (2017). Softwareplattformen verknüpfen Prozesse in der Fertigung. *VDI Nachrichten, 13*, 28.
Vermesan, O., Bahr, R., Gluhak, A., Clari, F., Bösenberg, F., Hoeer, A., & Osella, M. (2016). IoT Business Model Framework, H2020-Unify IoT-Project, IoT European Platforms Initiative. http://www.internet-of-things-research.eu/pdf/D02_01_WP02_H2020_UNIFY-IoT_Final.pdf;.
Wan, J., Tang, S., Shu, Z., Li, D., Wang, S., Imran, M., & Vasilakos, A. V. (2016). Software-defined Industrial Internet of Things in the context of Industry 4.0. *IEEE Sensors Journal, 16*(20), 7373–7380.
Wildemann, H. (2016). Die digitale Chance. *Harvard Business Manager, 11*, 86–92.
Zott, C., Amit, R., & Massa, L. (2011). The business model: Recent developments and future research. *Journal of Management, 37*(4), 1019–1042, 365FarmNet. 2017. "Mein digitales Betriebstagebuch! https://www.365farmnet.com/; accessed January 5, 2022.