Title:
Leveraging Industry 4.0 – A Business Model Pattern Framework

Authors

Jörg Weking (Corresponding author)
Technical University of Munich
Department of Informatics
Chair for Information Systems (I17)
Boltzmannstr. 3
85748 Garching bei München
Germany
Tel. +49 89 289 19500
Fax +49 89 289 19533
weking@in.tum.de

Maria Stöcker
Technical University of Munich
Department of Informatics
Chair for Information Systems (I17)
Boltzmannstr. 3
85748 Garching bei München
Germany
maria.stoecker@tum.de

Marek Kowalkiewicz
Queensland University of Technology
Chair in Digital Economy
2 George St
Brisbane QLD 4000
Australia
marek.kowalkiewicz@qut.edu.au

Markus Böhm
Technical University of Munich
Department of Informatics
Chair for Information Systems (I17)
Boltzmannstr. 3
85748 Garching bei München
Germany
markus.boehm@in.tum.de

Helmut Krcmar
Technical University of Munich
Department of Informatics
Chair for Information Systems (I17)
Boltzmannstr. 3
85748 Garching bei München
Germany
krcmar@in.tum.de
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Abstract

Industry 4.0 (I4.0), also known as the fourth industrial revolution, describes the digitalization of manufacturing industries. The transition to I4.0 is crucial for manufacturing firms to sustain competitive advantage and seize new opportunities. Most research has focused on the technological aspects of I4.0 in the form of product and process innovations. Despite I4.0’s rising attention from both researchers and practitioners, little research exists about I4.0 business model (BM) innovation, even though BM innovations can be more successful than product or process innovations. To address this research gap, we analyze 32 case studies of I4.0 BM innovators. We develop a taxonomy to characterize I4.0 BMs and derive 13 patterns of I4.0 BMs by applying the taxonomy to the case studies. Three super-patterns are identified: integration, servitization, and expertization. Integration innovates a BM with new processes and integrates parts of the supply chain. New combined products and services are the basis for servitization. Expertization is a hybrid of product- and process-focused BMs that includes consulting services and multi-sided platforms. This study contributes to research with a framework for describing, analyzing, and classifying BMs for I4.0. The findings deepen the understanding of how I4.0 impacts ecosystem roles, BMs, and service systems. Archetypal patterns show how firms can leverage I4.0 concepts and build a conceptual basis for future research. The taxonomy supports practitioners in evaluating the I4.0-readiness of their existing BM. The patterns additionally illustrate opportunities for becoming an I4.0 firm.

Keywords
Business model; Industry 4.0; Taxonomy; Patterns; Case study; Internet of Things (IoT)
1 Introduction

Gearing traditional industries toward the opportunities and challenges of digitalization is frequently discussed among researchers and practitioners around the globe. Advanced Manufacturing Partnership in the United States, La Nouvelle France Industrielle in France, Future of Manufacturing in the United Kingdom, and Made in China 2025 alongside the Internet Plus in China are just some examples of government initiatives that address the convergence of traditional industrial production with IT and new technologies, such as the Internet of Things (IoT) (Hermann, Pentek, & Otto, 2016; Liao, Deschamps, Loures, & Ramos, 2017; Ramsauer, 2013). The name of the equivalent German campaign Industry 4.0 (I4.0), has evolved as an eponym for a new manufacturing landscape based on advanced digitalization and automation (Liao et al., 2017; Pereira & Romero, 2017). All of these programs aim at bringing new technologies to traditional manufacturers, as many of these firms are digital laggards (Gallagher, 2017). Further, the manufacturing sectors are the backbones of several industrial nations. In Germany, for example, manufacturing contributes to more than 25% of GDP and employs more than one-sixth of the total workforce (Statista, 2018a, 2018b). Thus, initiatives aimed at securing competitiveness and economic wealth for the industrial nations in the long run are very important (Ramsauer, 2013).

Researchers, as well as consulting firms, have already recognized the digital innocence of manufacturers and the economic potential behind I4.0. Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries (BCG, 2015) or Manufacturing’s Next Act (McKinsey, 2015) are just a few catchy headlines of practitioner reports about I4.0. These reports promise firms economic prosperity from applying new technologies. Roland Berger (2016), for example, estimates a potential of €450 billion of net profits and capital employed in Europe due to the upgrade from Industry 3.0 (I3.0) to I4.0. Likewise, there are claims in the
literature that manufacturing firms have to innovate their business model towards servitization, cloud manufacturing, intelligent manufacturing, C2B manufacturing, and so on (Rabetino, Kohtamäki, & Gebauer, 2017; Wei, Song, & Wang, 2017).

Despite the increasing interest in and importance of the economic aspects of I4.0, research has mainly focused on its technological implications (Burmeister, Lüttgens, & Piller, 2016; Kiel, Arnold, Collisi, & Voigt, 2016). Several general studies, however, show that businesses struggle with profiting from new technologies without applying adequate business models (BM) (Abdelkafi, Makhotin, & Posselt, 2013). Further, not only product and process innovations but also business model innovations (BMI) are essential for future success (Wischmann, Wangler, & Botthof, 2015). BM innovators are even more successful than pure product or process innovators (Gassmann, Frankenberger, & Csik, 2014). “A mediocre technology pursued within a great business model may be more valuable than a great technology exploited via a mediocre business model” (Chesbrough, 2010). The inability to adapt BMs to new economic conditions can ultimately kill a firm (Gassmann et al., 2014; Wirtz, Schilke, & Ullrich, 2010).

BMI does play a minor role in I4.0 specific literature and generally the question of how new technologies affect traditional BMs is understudied (Bock & Wiener, 2017; Rayna & Striukova, 2016). The term I4.0, however, is associated with several advancements that assume the opportunity or even the requirement to change current BMs (Kagermann, Wahlster, & Helbig, 2013). Consequently, manufacturers do not know what new BMs under I4.0 can look like (Sarvari, Ustundag, Cevikcan, Kaya, & Cebi, 2018) and how to transform traditional BMs for I4.0 (Grünert & Sejdic, 2017). Firms struggle with BMI because they do not “understand their existing BM well enough to know when it needs changing – or how”
Business model patterns (BMP) are a practice-proven approach for innovating BMs systematically and efficiently (Amshoff, Dülme, Echterfeld, & Gausemeier, 2015). BMPs represent recurring building blocks of a BM that document the BM logic abstractly and generally (Amshoff et al., 2015; Rudtsch, Gausemeier, Gesing, Mittag, & Peter, 2014) and can emerge as a result of a BMI process (Massa & Tucci, 2014). Gassmann et al. (2014) show that 90% of all BMIs are simply a recombination of existing patterns. They provide a common vocabulary for systematically describing BMI options (Bocken, Short, Rana, & Evans, 2014). Scholars call for the transfer of BMPs to industries under change (Remané, Hanelt, Tesch, & Kolbe, 2017). Except for a few studies about BMPs in I4.0-related areas, for example, IoT BMPs (Fleisch, Weinberger, & Wortmann, 2014), no study has systematically analyzed BMPs for I4.0. Further, as BMs are often a combination of several atomic BMPs, insights about their co-occurrence and interactions are crucial to completely penetrating the BM logic (Amshoff et al., 2015).

For this, taxonomies are a popular means of explanation (Bock & Wiener, 2017). A taxonomy refers to a “form of classification” which is a “conceptually or empirically derived grouping” that helps researchers and practitioners to analyze, structure, and understand complex domains (Nickerson, Varshney, & Muntermann, 2013). Moreover, taxonomies support deriving patterns, as they clarify the standard and unique building blocks of BMs (Bock & Wiener, 2017). Recent studies have developed taxonomies and patterns for domain-specific BMs in I4.0-related areas, for example, for digital BMs (Bock & Wiener, 2017; Remané, Hanelt, Nickerson, & Kolbe, 2017), platform BMs (Täuscher & Laudien, 2018), or data-driven BMs (Hartmann, Zaki, Feldmann, & Neely, 2016). These taxonomies, however, are
either too general or too specific to classify I4.0 BMs. In conclusion, the extant literature provides only a small amount of conceptual guidance regarding the research question:

**RQ: What are business model patterns for Industry 4.0?**

To address this question, this paper investigates BMs in the context of I4.0. We collect and analyze 32 case studies about I4.0 BMI from scholastic and practitioner reports. We develop a taxonomy to describe the I4.0 BMs using existing BMPs. Based on the taxonomy, we derive 13 BMPs particularly for I4.0.

Our work contributes to the literature on production economics and business models with a framework for describing, analyzing, and classifying BMs for I4.0. It furthers the understanding of how I4.0 impacts ecosystem roles, BMs, and service systems. The taxonomy and archetypal patterns show how firms can leverage I4.0 technologies and concepts and build a basis for future research on I4.0. Practitioners can benefit from our work as the taxonomy can help them to evaluate the I4.0-readiness of their existing BMs. The patterns and related cases promote creativity and illustrate opportunities for becoming an I4.0 firm.

2 Related Work

2.1 Defining Industry 4.0

To analyze I4.0 BMs, we first clarify I4.0. There is no consensual definition of the term I4.0 or dissociation of its predecessor, I3.0 (Hermann et al., 2016; Pereira & Romero, 2017). Some authors define I4.0 as (1) the process “toward the increasing digitization and automation of the manufacturing industry” (Brettel, Friederichsen, Keller, & Rosenberg, 2014; Oesterreich & Teuteberg, 2016), and some as (2) a new stage or paradigm for industrial production (Kagermann et al., 2013; Pereira & Romero, 2017), focusing on the outcome of a transformation process. Other authors mix both perspectives (i.e. transformation process and
its outcome) or use I4.0 as (3) an umbrella term for new technologies and concepts (Hermann et al., 2016; Pfohl, Yahsi, & Kurnaz, 2015). Thus, the term I4.0 covers both, the digital transformation of (process perspective), and a new manufacturing paradigm for (outcome perspective), traditional industries. To analyze I4.0 BMs as the outcome of BMIs, we follow the outcome perspective and see I4.0 as the fourth stage of industrial production.

In the first stage, water and steam power enabled mechanical production at the end of the 18th century (Industry 1.0). The intensive use of electrical power and the division of labor in assembly lines allowed mass production at the end of the 19th century and the beginning of 20th (Industry 2.0). The use of IT and electronics and the introduction of programmable logic controllers enabled automated production in the second half of the 20th century (I3.0). Cyber-physical systems (CPS), IoT, and smart factories permit smart production nowadays (I4.0) (Hermann et al., 2016; Kagermann et al., 2013; Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014; Pereira & Romero, 2017). “Smartness” covers the ability to communicate and cooperate in real time, to make decisions autonomously, and to steer oneself based on information obtained (Pereira & Romero, 2017). Thus, the speed of change is getting faster.

The term Industrial Internet of Things (IIoT) is often used to denote the international description of I4.0 (Arnold, Kiel, & Voigt, 2016; Huxtable & Schaefer, 2016; Kiel, Arnold, & Voigt, 2017). It describes the application of the IoT in the industrial context, that is the connection of devices in a factory (Gierej, 2017). Additionally, it stands for the vision of a new manufacturing landscape with real-time communication of smart machines, smart objects, and people (Arnold et al., 2016; Huxtable & Schaefer, 2016). Technically speaking, the IoT is a fundamental part of the fourth stage of industrial production, but I4.0 also involves other elements (Gierej, 2017).
CPS, IoT, and smart factories are fundamental technical enablers of I4.0. CPSs are technological systems consisting of physical parts, embedded sensors and actuators, and digital parameters, whose physical and virtual components are merged so that they “cannot be differentiated in a reasonable way anymore” (Lasi et al., 2014). CPS’s internet connection form the foundation of the IoT (Pereira & Romero, 2017). The IoT connects physical objects, people, systems, and IT, allowing things to communicate and control each other (Oesterreich & Teuteberg, 2016; Pereira & Romero, 2017). Devices connected to the IoT and equipped with memory are called smart objects, and these can interact with each other in real time. They can make decisions and perform actions independently and autonomously based on obtained information (Pereira & Romero, 2017). CPS and IoT when integrated in manufacturing enable smart processes, products, machines, systems and factories (Hermann et al., 2016). A smart factory contains the manufacturing resources of an entire production site that can independently communicate and exchange information with itself, trigger and control the next actions, and steer production (Brettel et al., 2014; Lasi et al., 2014; Pereira & Romero, 2017; Ramsauer, 2013). “Context-aware, the factory can assist people and machines in execution of their tasks” (Hermann et al., 2016), by drawing on information from the physical and virtual world.

2.2 Business Models
To identify BMPs for I4.0 as results of BMI, we first differentiate the general concepts of BM, BMI and BMP without relating them to I4.0. Despite enormous research about BMs, no commonly accepted interpretation or definition has yet been established (Foss & Saebi, 2017; Massa, Tucci, & Afuah, 2017; Schneider & Spieth, 2013). Massa et al. (2017) distinguish between three interpretations of BMs, that is as “attributes of real firms,” as “cognitive/linguistic schemas,” and as “formal conceptual representations.” We use BMs as formal conceptual representations to abstract from single cases to generalizable BMPs. In this
interpretation of BMs, its definition converges on four components and their relations using different terminology: *value proposition*, *market segments*, *structure of the value chain*, *value capture mechanisms* and “how these elements are linked together in an architecture” (Foss & Saebi, 2017; Saebi, Lien, & Foss, 2017). Other common approaches, such as Teece (2010), and practitioner-oriented approaches, such as the Business Model Canvas (Osterwalder & Pigneur, 2010) or the Business Model Navigator (Gassmann et al., 2014), confirm these four elements, on which this paper builds (see Table 1).

| Foss and Saebi (2017), Saebi et al. (2017) | Teece (2010) | Osterwalder and Pigneur (2010) | Gassmann et al. (2014) |
|------------------------------------------|--------------|---------------------------------|------------------------|
| Market segments                          | Customers    | Customer segments               | Who is the target customer? |
| Value proposition                        | Value        | Value proposition                | What does the customer value? |
| Structure of the value chain             | Value creation | Key partners, Key activities, Key resources, Customer relationships, Channels | How is the value proposition built and distributed? |
|                                         | Value delivery |                                  |                        |
| Value capture mechanisms                 | Value capture mechanisms | Revenue streams, Cost structure | Why is the BM financially viable? |

The research stream of BMI covers changes in a firm’s BM, such as innovating from a traditional BM to an I4.0 BM. BMI recognizes the BM as a potential source of innovation that is distinct from product, service, process and organizational innovation (Foss & Saebi, 2017; Zott, Amit, & Massa, 2011). “BMIs are designed, novel, nontrivial changes to the key elements of a firm’s business model and/or the architecture linking these elements” (Foss & Saebi, 2017). This commonly used definition allows us to capture BMIs that result in I4.0 BMs. “Designed” implies that BMI is a deliberate change to a current BM, for example, towards I4.0. “Novel, non-trivial changes” excludes minor adoptions of the existing BM, such as adding a new supplier. BMI changes the BM more radically, such as innovating towards I4.0 (Foss & Saebi, 2017).
To systematically and efficiently support BMI, applying BMPs is a practice-proven approach (Amshoff et al., 2015). Thus, we build on BMPs to describe and analyze I4.0 BMs resulting from BMI toward I4.0. Patterns describe both a recurring problem and the core of its solution in such an abstract way that they can be reused for several issues multiple times (Alexander, 1977). Transferring this to BMs, a BMP captures the core of a recurring BM design problem and the corresponding BM design solution in such an abstract way that it can be applied in BMs of various firms from different industries and markets. Firms can reuse BMPs at different times by applying the abstract pattern to the firm’s specific requirements (Abdelkafi et al., 2013; Amshoff et al., 2015; Osterwalder & Pigneur, 2010; Remané, Hanelt, Tesch, et al., 2017). BMPs represent a systematic and efficient approach for all phases of the BMI process (Amshoff et al., 2015; Gassmann et al., 2014; Remané, Hanelt, Tesch, et al., 2017). For example, BMPs help firms to understand and describe their own BM and the dominant industry logic. Additionally, they serve as inspiration for new BMs by transferring patterns from other firms and industries to a firm’s own BM (Gassmann & Csik, 2012; Remané, Hanelt, Tesch, et al., 2017). By aggregating previous work, Remané, Hanelt, Tesch, et al. (2017) present a database of 182 distinct, generally applicable BMPs. This collection is the foundation for our work of identifying I4.0-specific BMPs.

2.3 Business Models in Industry 4.0-related Areas

Although research on BMs for I4.0 is immature, research on BMs for some I4.0-related topics has been well explored. This subsection summarizes work on BMs in I4.0-related areas: open innovation (OI) and crowdsourcing, mass customization, product service systems (PSS), and IoT. These types of BMs are strongly linked to I4.0 BMs because all of them are enabled and/or supported by the fundamental technical enablers of I4.0 BMs: CPS, IoT, and smart factories.
2.3.1 Open Innovation and Crowdsourcing Business Models

CPS, IoT, and smart factories, as fundamental technical enablers of I4.0 BMs, intensify internal and external communication, which enables open innovation and crowdsourcing BMs. Global competition, rising research and development (R&D) and technology costs, and shorter product life cycles require firms to open their innovation processes, shifting from closed innovation toward OI (Chesbrough, 2007; Saebi & Foss, 2015). OI covers two directions: outside-in and inside-out. Outside-in OI describes innovation activities that include external expertise, for example, from suppliers, customers, or other organizations. Inside-out OI means selling underutilized or unused ideas to other parties (Chesbrough, 2012). An OI strategy changes traditional BMs to open BMs (Chesbrough, 2007; Saebi & Foss, 2015). “An Open Business Model is a BM characterized by the active search and exploitation of external ideas and/or licensing internal technologies and ideas to other firms” (Chesbrough, 2007). Thus, OI covers various innovation activities, such as buying or licensing technology, hosting innovation contests, engaging in crowdsourcing, or forming R&D alliances or joint ventures (Saebi & Foss, 2015).

Crowdsourcing is a subtype of OI (Kohler, 2015; Saebi & Foss, 2015) and describes outsourcing a task once performed by employees to an undefined, vast network of ordinary people. Jobs can be completed collaboratively or by individuals (Djelassi & Decoopman, 2013). Crowdsourcing affects several aspects of traditional BMs. The customer role changes from a passive consumer and purchaser to a value co-creator and key partner (Djelassi & Decoopman, 2013; Kohler, 2015). Crowdsourcing can open new customer segments, as individuals can take part who are not yet a customer (Djelassi & Decoopman, 2013).
2.3.2 Mass Customization Business Models

Regarding mass customization, fundamental technical enablers of I4.0 BMs, such as CPS, IoT, and smart factories, enable small lot sizes and, thus, mass customization. Mass customization describes the production of individually adapted goods for a large sales market at costs comparable to standard goods (Bullinger & Schweizer, 2006). It provides the benefits of both mass production and handicraft (Bullinger & Schweizer, 2006). Advancements in IT enable this production paradigm. For example, computer-aided design software allows customers to adapt product features before buying and gives visual feedback about the modified product in real time (Grimal & Guerlain, 2014). IT enables the immediate translation of product orders into a list of materials and transfers the required tasks to the production system (Grimal & Guerlain, 2014). Mass customization typically requires IT in the form of e-commerce and online shops for the necessary interaction with customers and suppliers (Bullinger & Schweizer, 2006; Grimal & Guerlain, 2014).

The shift from mass production to mass customization affects BMs. Coordination between demand and supply tighten and information-sharing between organizations become standard (Bullinger & Schweizer, 2006). Linear supply chains transform to digitally connected value networks (Bullinger & Schweizer, 2006). Firms need to more closely involve customers into their production process (Grimal & Guerlain, 2014). IT will continue to decrease transaction costs and time-to-market (Grimal & Guerlain, 2014).

2.3.3 Product Service Systems Business Models

PSS is another BM type that is enabled by fundamental technical bases of I4.0 BMs. The service component of PSS heavily builds on data from CPS, IoT, and smart factories. PSSs describe a combination of tangible products and intangible services that jointly fulfill certain customer needs (Reim, Parida, & Örtqvist, 2015; Tukker, 2004), whereas servitization means
integrating or increasing the share of service components in a firm’s portfolio (Foss & Saebi, 2017; Witell & Löfgren, 2013). PSSs describe a particular type of servitization in the manufacturing industry (Gerrikagoitia, Unamuno, & Sanz, 2016). PSS-based BMIs are popular among manufacturing firms that are aiming at closer customer contact, more stable revenue streams, and improved resource utilization (Reim et al., 2015; Velamuri, Bansemir, Neyer, & Möislein, 2013; Witell & Löfgren, 2013). Shifting from product sellers to customer problem-solvers or solution providers (Remané, Hanelt, Tesch, et al., 2017), firms provide new customer value by mitigating risks and improving operating performance or asset effectiveness (Velamuri et al., 2013). Tukker (2004) identifies eight archetypical PSS BMs and groups them into three main categories: product-oriented, use-oriented, and result-oriented PSS. Table 2 provides an overview.

| Business Model | product-oriented | use-oriented | result-oriented |
|----------------|------------------|--------------|----------------|
|                | Product-related  | Advice and consulting | Product lease | Product renting or sharing | Activity mgmt./ outsourcing | Pay per service unit | Functional result |

### 2.3.4 Internet of Things Business Models

IoT itself is a fundamental technical enabler of I4.0 BMs. Related BMs, IoT BMs, show the value proposition as the most important element (Dijkman, Sprenkels, Peeters, & Janssen, 2015; Ju, Kim, & Ahn, 2016; Metallo, Agrifoglio, Schiavone, & Mueller, 2018; Rong, Hu, Lin, Shi, & Guo, 2015), particularly in the industrial context (Arnold et al., 2016; Kiel et al., 2017). A new value proposition can be a holistic solution that solves a customer’s problem (Dijkman et al., 2015; Kans & Ingwald, 2016), or an increased convenience (Dijkman et al., 2015). Additionally, the IoT affects customer relationships, key resources and key partners (Arnold et al., 2016; Dijkman et al., 2015; Kiel et al., 2017). IoT BMs integrate customers in the product engineering and design process (Arnold et al., 2016; Dijkman et al., 2015; Gierej, 2017; Kiel et al., 2017). Software and human resources with IT qualifications (e.g., data
analytics or software development) become key resources of IoT BMs (Arnold et al., 2016; Gierej, 2017; Ju et al., 2016; Kiel et al., 2017). The employee’s role changes from operator to problem solver (Arnold et al., 2016). Typically partnerships with suppliers of IoT devices and IT partners become crucial for IoT BMs (Arnold et al., 2016; Dijkman et al., 2015; Gierej, 2017; Kiel et al., 2017). Fleisch et al. (2014) introduce eight BMPs for the IoT, which we include in our analysis (e.g. remote usage and condition monitoring and digitally charged products). However, none of the concepts above cover all of the specific characteristics of I4.0 BMs. Thus, this paper investigates BMPs particularly for I4.0.

3 Research Approach

To analyze I4.0 BM as a “contemporary phenomenon in its real-world context”, a case-based approach with many I4.0 cases is most fitting (Yin, 2014). Qualitative, multiple case studies allows to gain in-depth understanding (Yin, 2014) as well as generalizable, cross-sectional analyses, such as in case surveys (Larsson, 1993). Our approach has two phases. First, we set up a case base comprising 32 I4.0 BMI cases. The unit of analysis of these cases is the BM at the level of a strategic business unit (Cao, Navare, & Jin, 2018). Thus, we can focus solely on I4.0 BMs. For example, we analyzed Daimler Mobility Services as a case without considering Daimler’s traditional BM of vehicle manufacturing. For smaller firms with one strategic business unit, the level of analysis correlates with the whole organization’s BM, for example, Local Motors, Ponoko, or Shapeways. Second, we develop a taxonomy in three iterations, derive I4.0 BMPs based on the case studies and the taxonomy, and empirically and theoretically evaluate both results. A taxonomy and related BMPs allow us to collect and provide a structured overview of characteristics of various I4.0 BMs. Thus, we can visually show which BM attributes are archetypal for I4.0 BMs.
3.1 Case Base (Empirical Foundation)

We used the databases EBSCOhost, ScienceDirect, Scopus, Springer Link, IEEE Explore, and the Web of Science, Google Search, and practice reports (e.g., McKinsey, BCG, Accenture, Microsoft) to find case studies about I4.0. We also considered IIoT and data-driven cases that fit the I4.0 definition. Our inclusion criteria were:

- The BMI of the case forms a final BM that matches our understanding of an I4.0 BM.

- The case provides sufficient information to characterize its BM including value proposition, market segments, structure of the value chain, value capture mechanisms and “how these elements are linked together in an architecture” (Foss & Saebi, 2017; Saebi et al., 2017).

- The case description includes the firm name, so that we can search for additional information and thus support data triangulation (Yin, 2014).

We obtained an initial set of 39 use cases with several references each. To augment the case data and to support data triangulation (Yin, 2014), we manually searched for additional information on the firms’ websites, in newspaper articles, publicly available interviews, and press releases and gathered it in a case base (Yin, 2014). Finally, we checked all cases again for sufficient information about the case’s BM. This resulted in 32 cases with two degrees of detail: category A and category B. The 15 instances of category A provide rich information on various dimensions of their BMs, which is necessary for developing a BM taxonomy and archetypal BMPs. The 17 cases of category B provide less information, but enough detail to evaluate both the taxonomy and the patterns (see Table 3 and appendix A for analyzed sources).
| No. | Category | Firm                            | Main empirical study                      | Analyzed sources |
|-----|----------|---------------------------------|------------------------------------------|-----------------|
| 1   | A (rich data) | Adidas                            | Plattform-i40 (2017)                      | 11              |
| 2   |           | Atomic                           | Lassnig et al. (2017)                     | 5               |
| 3   |           | AVL                              | Lassnig et al. (2017)                     | 4               |
| 4   |           | Caterpillar                      | Schaefer, Walker, and Flynn (2017)       | 5               |
| 5   |           | Claas – 365Farmnet               | Bauernhansl et al. (2015)                | 7               |
| 6   |           | eMachineShop                     | Bauernhansl et al. (2015)                | 4               |
| 7   |           | GE Digital                       | Schaefer et al. (2017)                   | 7               |
| 8   |           | KAESER Compressors               | Kaufmann (2015)                          | 6               |
| 9   |           | Konecranes                       | Wortmann, Bilgeri, Weinberger, and Fleisch (2017) | 5               |
| 10  |           | Local Motors                     | Bauernhansl et al. (2015)                | 7               |
| 11  |           | Ponoko                           | Gassmann et al. (2014)                   | 4               |
| 12  |           | Shapeways                        | Bauernhansl et al. (2015)                | 5               |
| 13  |           | Texa CARe                        | Microsoft (2017a)                        | 4               |
| 14  |           | TRUMPF – AXOOM                   | Grünert and Sejdić (2017)                | 7               |
| 15  |           | Zumtobel                          | Lassnig et al. (2017)                    | 4               |
| 16  | B (lesser data) | ABB Marine Systems              | Wortmann et al. (2017)                   | 2               |
| 17  |           | ABT Power Management             | Microsoft (2018)                         | 2               |
| 18  |           | Biesse Group                     | Accenture (2018)                         | 2               |
| 19  |           | Bosch Engineering                | Wortmann et al. (2017, p. 12)            | 3               |
| 20  |           | Daimler Mobility Services        | Bauernhansl et al. (2015)                | 8               |
| 21  |           | GE Fuse                          | BCG (2017)                               | 6               |
| 22  |           | GE Taleris                       | Daugherty, Banerjee, Negm, and Alter (2015) | 4               |
| 23  |           | Hilti                            | Wortmann et al. (2017)                   | 7               |
| 24  |           | Michelin                         | Daugherty et al. (2015)                  | 4               |
| 25  |           | New Balance                      | BCG (2017)                               | 4               |
| 26  |           | Pirelli                          | Schaefer et al. (2017)                   | 6               |
| 27  |           | Rolls-Royce                      | Microsoft (2016)                         | 4               |
| 28  |           | Samudra LED                      | Microsoft (2017b)                        | 3               |
| 29  |           | Schlotterer                      | Lassnig et al. (2017)                    | 5               |
| 30  |           | Siemens                          | Plattform-i40 (2018)                     | 1               |
| 31  |           | ThyssenKrupp Elevator            | Microsoft (2014)                         | 2               |
| 32  |           | Würth Industrie Service          | Bauernhansl et al. (2015)                | 5               |

### 3.2 Taxonomy and Patterns

We applied the method suggested by Nickerson et al. (2013) to systematically develop a taxonomy for I4.0 BMs. This method allows to combine theoretical findings about BMs with the empirical results of case studies (Remané, Nickerson, Hanelt, Tesch, & Kolbe, 2016). We conducted three iterations (see Figure 1) (Nickerson et al., 2013).
First, we specified meta-characteristics that “serve as the basis for [the] choice of characteristics in the taxonomy” and the ending conditions for terminating the iterative approach (Nickerson et al., 2013). We chose four generally accepted BM components as meta-characteristics: target customer, value proposition, value chain, and value capture (Gassmann et al., 2014). Each dimension and characteristic of the taxonomy must relate to these characteristics, which help to identify and organize relevant dimensions (Remané et al., 2016). We used the eight objective and five subjective ending conditions suggested by Nickerson et al. (2013), following Bock and Wiener (2017).

### 3.2.1 1st Iteration: Conceptual Development

Second, we developed the taxonomy with three iterations. The first iteration was conceptual-to-empirical and derived dimensions and characteristics of I4.0 BMs from literature. We used
findings about BMs and I4.0, which the related work section outlines. We derived 11 dimensions with two to nine characteristics each based on 55 papers (see Table 4).

| Meta-Dim. | Dimension | Characteristics |
|-----------|-----------|-----------------|
| Target Customers (Who) | Market | B2B (37) | B2C (25) | B2B and B2C (22) | B2G (5) |
| Value Proposition (What) | Product | Physical (23) | Digital (22) | Hybrid (41) |
| | Digital Degree | Digital (27) |
| | As a Service | Software as SaaS (9) | Infrastructure as SaaS (6) | Data-aggregation as SaaS (13) | Analytics as SaaS (11) |
| | Value Proposition | Solution Provider (27) | Scalability (14) | Cost efficiency (30) | Financial risk reduction (10) | Time savings (13) | Sustainability (17) | Transparency (15) | Customization (26) | Matching (10) |
| Value Chain (How) | Innovation | Open innovation (32) | Open source (7) |
| | Production | Modularization (10) | Mass customization (9) | From-push-to-pull (14) |
| | Sales Channel | Direct selling (16) | E-commerce (24) |
| Value Capture (Why) | Revenue Model | Sales (19) | Revenue sharing (16) | Licensing (13) | Rent/lease (16) | Usage fee (15) | Subscription (14) |
| | Payer | User (10) | Customer (29) | Third party (11) |
| | Pricing | Pay-per-use (24) | Fixed price (23) | Free (7) | Flatrate (8) | Freemium (10) |

The number in brackets indicates the number of papers supporting this characteristic.

3.2.2 2nd Iteration: Empirical Development

The second iteration was empirical-to-conceptual by applying the taxonomy from the first iteration to the 15 case studies of category A. We randomly chose an instance and conducted a qualitative structured data analysis (Miles, Huberman, & Saldana, 2013). We coded the case information with BMPs from the literature (Remané, Hanelt, Tesch, et al., 2017) and empirically derived characteristics (within-case analysis) (Yin, 2014). Then, we classified the case within the taxonomy and, if necessary, added further characteristics and dimensions to the taxonomy until all cases were included. Here, we split the component of value creation into two meta-dimensions: value chain and key elements – to improve the structure. We dropped and synthesized characteristics and dimensions to keep the taxonomy lean without losing discriminative power.
To derive I4.0 BMPs, we applied our taxonomy to the 15 cases in the form of a within-case analysis (Yin, 2014). We found that some cases do not follow one specific BM but apply a mix of different BMs. Thus, more than one characteristic per dimension could apply for each BM innovator, which differs from Nickerson et al. (2013). Second, we generalized from the cases classified by the taxonomy and conducted a qualitative cluster analysis as a cross-case analysis (Yin, 2014) using constant comparison (Eisenhardt, 1989; Eisenhardt & Graebner, 2007), following Cao et al. (2018). We initially identified 10 patterns with each covering cases with similar BM characteristics. To ensure clarity and applicability, we again conducted a qualitative cluster analysis as a cross-case analysis (Yin, 2014) with the 10 patterns to inductively generate overarching patterns. This resulted in three super-patterns, which cover common characteristics of their underlying sub-patterns. Altogether, we identified 13 patterns: Three super-patterns and 10 underlying sub-patterns.

3.2.3 3rd Iteration: Empirical and Theoretical Evaluation

The third iteration also followed the empirical-to-conceptual approach. We used the taxonomy to code the 17 lower-information cases of category B (Miles et al., 2013). The taxonomy enabled us to search pointedly for missing information. Additionally, we applied the 13 patterns to classify the 17 lower-information cases. Again, we used multiple sources and triangulated the data to corroborate results (Yin, 2014). The taxonomy and patterns did not need any changes in this iteration, which terminates the development process and starts the evaluation (Nickerson et al., 2013).

To empirically evaluate the taxonomy and identified patterns, we built on two settings, one with researchers and one with practitioners. First, we conducted a confirmatory focus group with five research associates and one author as moderator (Tremblay, Hevner, & Berndt,
We selected the participants according to their research field of digital business models. The focus group took 65 minutes and had three main parts. (1) The moderator explained the goal of this paper and its understanding of the main concepts, such as I4.0 BMs. (2) The group discussed the BM taxonomy and all its elements. (3) The group discussed the BMPs including definitions and examples. The focus group was recorded, transcribed, and analyzed (Tremblay et al., 2010). This led to minor changes in the taxonomy’s elements, such as rearranging the elements of one dimension in existing ones and renaming and removing some elements. Second, we used the BMPs in three commercial research projects, where we co-designed I4.0 BMs for three industry incumbents. The project team used the BMPs to support creativity and inspiration for new I4.0 BMs and developed several BM ideas for each of the three established firms. The project teams consisted of approximately five managers (e.g., innovation manager, digital marketing manager, or information systems manager) and five researchers (i.e., professor, postdoc, two PhD students, and one master student). In one case, we worked with an established firm operating in the construction industry, an area which barely shows I4.0 BMs. The new BMs and venture ideas that were created based on the BMPs included a software platform connecting all stakeholders in the construction ecosystem (based on product-related platformization), a new digital service model (based on mass customization), and a crowdsourcing platform for developing new solutions (based on crowdsourced innovation). The suggested solutions were well-received and endorsed by the CEO of the organization for further development in-house. In these two ways, we ensured consistency and demonstrated the applicability and usefulness of our taxonomy and BMPs (Bock & Wiener, 2017).

For theoretical evaluation, we used two guidelines: Nickerson et al. (2013) and Rich (1992). First, we used the objective and subjective ending conditions according to Nickerson et al. (2013). All eight objective conditions are met: (1) We could classify all cases with the
taxonomy and the patterns, (2) no cases had to be merged or split to fit to the taxonomy or patterns, (3) each characteristic of the taxonomy and each pattern describe at least one case, (4) to classify all cases, no new characteristic or pattern had to be added, and (5) no element had to be merged or split. Finally, (6–8), every taxonomy dimension, characteristic, super-pattern, and sub-pattern is unique. Similarly, all five objective conditions were met (Nickerson et al., 2013): Based on the cases, the taxonomy and patterns are (1) concise, (2) robust, (3) comprehensive, (4) extendable, and (5) explanatory. Second, we used the criteria for organizational taxonomies and classifications according to Rich (1992) to evaluate the identified BMPs. He introduced seven criteria, which are all met by the patterns: (1) The patterns cover a broad range of firms, (2) have a clear meaning for business, and (3) provide sufficient depth to cover real-life phenomena, namely I4.0 firms. (4) The BM literature serves as a theoretical basis, and (5) the taxonomy serves as a means to measure the patterns’ characteristics. Finally, based on the cases, (6) the patterns are complete and logical, and (7) recognizable, as they mirror the real world, namely I4.0 BMs. In conclusion, we used two empirical evaluations, one with practitioners and one with researchers, and two theoretical evaluations to demonstrate the applicability and usefulness of the BM taxonomy and BMPs for I4.0.

4 Findings

The 32 identified cases have very different I4.0 initiatives and related BMs. Table 5 provides an overview of the general characteristics of the cases and their I4.0 initiatives.

| No | Name         | Type                  | Employees  | Year | Industry 4.0 Initiative                                                                 |
|----|--------------|-----------------------|------------|------|-----------------------------------------------------------------------------------------|
| 1  | Adidas       | Sportswear manufacturer | 57,000     | 2015 | Customized shoes and flexible smart factory (Speedfactory) with production times of hours |
| 2  | Atomic       | Winter sports manufacturer | 600        | 2015 | Customized skis and local smart factory with lot size of one.                           |
| 3  | AVL          | Powertrain            | 9,500      | 2016 | Smart service concept including predictive                                                |
| Manufacturer | Industry       | Year | IoT Description                                                                                                                                                                                                                                                                                                                                 |
|--------------|----------------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Caterpillar  | Construction   | 2016 | Data analytics platform for predictive diagnostics for remote fleet monitoring based on IoT sensor data                                                                                                                                                                                                                                         |
| Claas –      | Agricultural    | 2013 | Cloud-based software for farm management with IoT-based tracking, partner modules (two-sided platform) and freemium pricing                                                                                                                                                                                                                   |
| 365Farmnet   | machinery      |      |                                                                                                                                                                                                                                                                                                                                            |
| eMachineShop | Machine parts   | 2012 | Online factory for customized parts (CNC machining, injection molding, and 3D printing)                                                                                                                                                                                                                                                        |
| GE Digital   | General Electric| 2015 | Cloud-based industrial IoT platform (Predix) and consulting for industrial digital transformation                                                                                                                                                                                                                                           |
| KAESER       | Compressors    | 2006 | Selling of compressed air with IoT sensors, remote monitoring, and predictive maintenance                                                                                                                                                                                                                                                 |
| Konécranes   | Cranes         | 2015 | Remote monitoring and all-inclusive renting                                                                                                                                                                                                                                                                                                |
| Local Motors | Vehicle        | 2007 | Rapid digital development and production with developer community and 3D printing                                                                                                                                                                                                                                                        |
| Ponoko       | Manufacturing   | 2007 | On-demand, distributed, digital manufacturing platform connecting designers, fabricators, suppliers, and buyers                                                                                                                                                                                                                           |
| Shapeways    | 3D-printing    | 2007 | Product 3D printing service, online-shop and community for entrepreneurs and designers                                                                                                                                                                                                                                                     |
| Texa CARe    | Diagnostic      | 2017 | IoT device to remotely monitor cars and automatic emergency alerts using a freemium model                                                                                                                                                                                                                                                |
| TRUMPF –     | Machine tool    | 2015 | Trading platform for machine tool process parameters and consulting for digital transformation                                                                                                                                                                                                                                           |
| AXOOM        |                |      |                                                                                                                                                                                                                                                                                                                                            |
| Zumtobel     | Light solutions | 2016 | IoT-based, intelligent, and energy-efficient light solutions using continuous revenues                                                                                                                                                                                                                                                     |
| ABB Marine   | Ship engine     | 2013 | Remote monitoring and diagnostics with IoT sensors using service contracts                                                                                                                                                                                                                                                               |
| Systems     |                |      |                                                                                                                                                                                                                                                                                                                                            |
| ABT Power    | Battery         | 2002 | Remote monitoring of forklift batteries and offering of guaranteed power supply for forklifts                                                                                                                                                                                                                                              |
| Management   | management      |      |                                                                                                                                                                                                                                                                                                                                            |
| Biesse Group | Machine        | 2017 | IoT platform for remote performance monitoring offered with a pay-per-use model                                                                                                                                                                                                                                                         |
| Engineering  |                |      |                                                                                                                                                                                                                                                                                                                                            |
| Daimler      | Vehicle        | 2008 | Free-floating car rental on a pay-per-use model (Car2Go), mobility services platform (Moovel)                                                                                                                                                                                                                                              |
| Mobility     |                |      |                                                                                                                                                                                                                                                                                                                                            |
| Services     |                |      |                                                                                                                                                                                                                                                                                                                                            |
| GE Fuse      | 3D printing     | 2016 | Rapid-prototyping and small-batch manufacturing with 3D printing based on crowdsourcing                                                                                                                                                                                                                                                    |
| GE Taleris   | Service         | 2013 | Predictive maintenance for jet engines and fleet optimization services for airlines based on IoT                                                                                                                                                                                                                                         |
| Hilti        | Construction    | 2014 | Tools on demand with guaranteed availability (Fleet Management) and cloud-based asset management (ON!Track)                                                                                                                                                                                                                              |
| Michelin     | Tire            | 2013 | IoT sensors and platform to track and monitor trucks fleets and optimize fuel costs (EFFIFUEL)                                                                                                                                                                                                                                           |
| New Balance  | Footwear        | 2013 | Automated smart factory based on IoT sensors with 3D printing and customization                                                                                                                                                                                                                                                         |
| Pirelli      | Tire            | 2017 | IoT sensors and platform to monitor tire conditions and reserve garage appointments (Conesso)                                                                                                                                                                                                                                            |
| Rolls-Royce  | Aero-engines    | 2002 | Power-by-the-hour business model (since 1962) and IoT sensors to remotely monitor engines                                                                                                                                                                                                                                                |
| Samudra LED  | Light solutions | 2015 | Remote monitoring and control of lights for optimizing energy efficiency based on IoT                                                                                                                                                                                                                                                     |
| Schlotterer  | Sun protection  | 2011 | Automated, customized, on-demand production with                                                                                                                                                                                                                                                                                           |
| 30 | Siemens  | Industrial manufacturer | 379,000 | 2016 | Renting of drive technologies with guaranteed availability based on remote monitoring |
| 31 | ThyssenKrupp Elevator | Elevator manufacturer | 50,000 | 2014 | Remote monitoring and predictive maintenance based on IoT sensor data |
| 32 | Würth Industrie Service | Logistics provider | 1,500 | 2013 | Intelligent Kanban box (iBin) monitors inventory levels and automatically orders, if needed |

### 4.1 Taxonomy for Industry 4.0 Business Models

The derived taxonomy for I4.0 BMs consists of five meta-dimensions and 19 dimensions with two to six distinct characteristics each (see Table 6). Marked characteristics (*) refer to the extensive list of BMPs of Remané, Hanelt, Tesch, et al. (2017). Complete I4.0 BMs are combinations of the taxonomy’s characteristics. Thus, not every single characteristic is new in I4.0. However, these characteristics are needed to comprehensively describe I4.0 BMs.

The 19 dimensions show common characteristics of I4.0 BMs. The dimensions of market and segments highlight how I4.0 can change target markets and customer segments, as seen in the case of Texa. The value proposition strategy shows new directions of I4.0 BMs. The dimension of factory of the value chain emphasizes that in I4.0 some firms step back from mega-factories and transform into several local micro-factories, as seen in the cases of Adidas, Local Motors, Shapeways, and Ponoko. The dimension of platform captures different types of I4.0 platforms. The value capture dimension differentiates between revenue (how?) and sales models (what?). Hence, it distinguishes between innovative ways to generate revenues (e.g., freemium or usage-based) and parameters that determine the payment amount (e.g., usage or result of a product).
Table 6: Taxonomy of Industry 4.0 Business Models  
*Marked characteristics (*) based on Remané, Hanelt, Tesch, et al. (2017)*

| Meta-Dim. | Dimensions | Question | Characteristics |
|-----------|------------|----------|-----------------|
| **Target Customers (Who)** | Market | To which market does the firm sell? | B2B only (22) | B2C only (6) | B2B & B2C (4) | Multi-sided market * (8) |
| | Segments | Does the firm target new customer segments due to the I4.0 transformation? | Existing customer segment only (13) | New customer segment only (8) | New and existing customer segment (11) |
| | Contact | How does the firm interact with its customers? | Hybrid (intermediary and direct) (4) | Direct selling * (28) |
| | Channel | Which channel is used for interacting with customers? | Offline (7) | Bricks & clicks * (20) | Online * (5) |
| **Value Proposition (What)** | Strategy | Which general value proposition strategy does the firm use? | Add-on * (10) | Lock-in * (15) | Aikido * (5) | Make more of it * (12) |
| | Product | What is the good the firm produces and makes money with? | Physical only (10) | Physical, digitally charged * (19) | Digital only (10) |
| | Service | What is the content of the service offering? | Repair & maintenance (2) | Monitoring & predictive maintenance * (17) | Product (9) | Production (3) | IT (9) | Advice & consulting * (8) |
| **Value Chain (How)** | Development & Design | Who develops and designs the products that the firm sells? | Hired or employed experts (16) | Customer/ user designed * (3) | Development community/ crowdsourcing * (4) |
| | Customization | How individualized is the product? | Mass production (7) | Mass customization * (14) | Mass individualization (5) |
| | Push/Pull | What kind of production paradigm is used? | Pull/ on-demand * (8) | Push and Pull (1) |
| | Factory | What is the size of the operating factories? | Mega-factory (4) | Micro-factory (5) |
| | Role | Which role of the value chain does a firm focus on? | Integrator * (9) | Service and support * (20) | Intermediary * (6) |
| **Key Elements (How)** | Key Partners | Which partnerships are essential to delivering the proposed value? | Inside-sector partners (6) | Outside-sector partners (5) | Customer or community including customization * (14) |
| | Data Analytics | Where does the high-value data come from? | Internal data (4) | Customer’s data * (21) |
| | Key Employees | Which is the most characteristic job of the value creation and delivery process? | Operator & maintainer (15) | Remote monitoring (19) | Software developer & IT (10) | Consultant or trainer * (8) |
| | Platform | What kind of digital platform is an essential part of the BM, if any? | IoT (21) | Merchant only (3) | Innovation * only (2) | Merchant & innovation (3) |
| **Value Capture (Why)** | Revenue Model | How does the firm generate and manage revenues? | Sales * (24) | Revenue sharing * (2) | Freemium * (4) | Rent/ lease * (4) | Subscription * (18) |
| | Continuity | How continuous are the revenues? | Once (10) | Mixed (16) | Continuous (12) |
| | Sales Model | What does the customer pay for? | Ownership/ service delivery (24) | Use/ availability (11) | Result (3) |

The number in brackets indicates the number of cases that apply this characteristic.
4.2 Business Model Patterns for Industry 4.0

We identified three super-patterns and 10 sub-patterns of I4.0 BMs. The super-pattern integration innovates its BM around new processes, servitization around new products, and expertization around a hybrid of products and processes. The case studies illustrate the I4.0 BMPs and their relations. Table 7 gives an overview of the patterns. Table A2 in the appendix provides more details.

| Super-patterns | Sub-patterns |
|----------------|--------------|
| Integration (9) | Crowdsourced innovation (2) | Production as a service (3) | Mass customization (6) |
| Servitization (18) | Life-long partnerships (12) | Product as a service (6) | Result as a service (3) |
| Expertization (13) | Product-related consulting (5) | Process-related consulting (3) | Product-related platformization (5) | Process-related platformization (5) |

The number in brackets indicates the number of cases that apply this business model pattern.

4.2.1 Integration – Process-focused Business Model

Integration BMPs aim to cover more parts of the value chain (Remané, Hanelt, Tesch, et al., 2017). Firms adopting this BMP typically transform from specializing on a single step of the value chain toward covering more activities. Thus, new processes rather than completely new products are the basis for this BMP. The super-pattern integration has three sub-patterns: crownsourced innovation, production as a service, and mass customization.

The three sub-patterns have in common that the meta-dimension value chain indicates most of the changes. Firms open their innovation processes by integrating customers or development communities in development processes. Smart production converts the production process from push to pull, and relocates production facilities from centralized mega-factories in low-wage countries to decentralized production in micro-factories close to the local markets, even in high-wage countries. New production techniques allow for small batch sizes, shifting mass production toward mass customization or even mass individualization. Moreover, shifts in
key elements and target customers characterize this super-pattern. Online channels allow firms to directly sell to customers and replace distributors.

**Crowdsourced Innovation**
A new product development and design process shapes *crowdsourced innovation*. A community of people design products (crowdsourcing) instead of hired experts only. The innovation platform becomes a key resource and the community a crucial partner. Firms move from a closed business toward an open one. New manufacturing techniques allow fast, on-demand production of individual goods in micro-factories (mass individualization). The car manufacturer Local Motors, for example, announces challenges for car engineering on its innovation platform Launch Forth and members can submit suggestions. Local Motors prints cars directly from the digital specification files in its micro-factories.

**Production as a Service**
Transforming product ideas into physical goods is core to *production as a service*. Firms undertake production from design checking until shipping as a service for their customers. The value chain shifts from producing mass-produced, expert-designed goods to mass-individualized, user-designed products. The customer becomes a key partner and can choose among a wide range of different materials and production techniques (long tail). Philips Electronics’ spin-off Shapeways.com, for example, is a platform for 3D-printed consumer goods. The firm offers a product printing service, an online shop, and a designer community. Designers can upload their 3D design, select materials, and sell products via the online shop. When receiving an order, Shapeways.com builds the product on-demand nearby the final destination and ships it to the customer.
Mass Customization
The integration of customers into the value chain characterizes mass customization. Firms shift from mass production to mass customization, which enables customers to adapt the final product to their individual taste by choosing from a range of options (long tail). However, hired experts and designers still develop and design the core product. Customization is an additional option for personalization only and not a requirement (add-on). Smart production enables profitable production of small lot sizes. For example, Adidas’s customers can personalize shoes in its online shop by changing colors or adding individual letters or logos.

4.2.2 Servitization – Product-focused Business Model
Integrating sensors into products (digitally charged products (Fleisch et al., 2014)) enables the super-pattern of servitization to provide new PSS instead of selling solely tangible products. Offering remote monitoring or predictive maintenance services for products turns these firms into solution providers. Thus, new offerings rather than new processes are the basis for this BMP, steering customers’ production toward smart production. The sub-patterns are an implementation of known PSS types in I4.0 (Reim et al., 2015; Tukker, 2004).

Life-long Partnerships
IoT-connected products enable this pattern to evolve a firm’s service portfolio from scheduled maintenance with repairs after failure to preventing breakdowns with remote monitoring and predictive maintenance throughout the whole product lifecycle. The firm becomes a solution provider and a partner for the entire product use phase. A firm still generates significant turnover by selling tangible products. However, firms add continuous revenue streams with subscription-based, life-long service contracts. AVL List, for example, is a leading provider of tailored powertrain development and test system solutions. The firm offers remote usage and condition monitoring in addition to product sales and aims to optimize product lifetime. They proactively exchange weak parts to avoid breakdowns.
**Product as a Service**
Renting instead of selling products and related services or offering them for a use-based fee shapes this sub-pattern. Customers do not pay for ownership or service delivery but for product usage and availability. Smaller but continuous fees replace higher proceeds of one-time product sales. This sub-pattern provides new customer value by guaranteeing the availability of the product. Konecranes, for example, not only sells industrial cranes but also rents them out with remote monitoring and predictive maintenance services based on a monthly fee.

**Result as a Service**
Selling the output or result of a product characterizes *result as a service*. Like *product as a service*, it turns discontinuous sales-based revenue streams into continuous ones. Firms sell full-service packages and take responsibility for safe operations and compliance. KAESER, for example, innovated from selling compressors to selling compressed air per cubic meter with its I4.0 offering Sigma Air Utility. In contrast to KAESER’s product as a service solution Sigma Flex, KAESER takes full responsibility and operates compressors at the customer’s site.

### 4.2.3 Expertization – Hybrid Business Model

![Figure 2: Expertization Sub-patterns](image-url)
This super-pattern uses a firm’s internally built expertise in products or processes (make more of it) and offers it as a new consulting service (product-related and process-related consulting) or a new platform-based product (product- and process-related platformization) (see Figure 2).

Consulting
The consulting sub-patterns shift the value chain focus from production toward service and support. Both patterns transform the meta-dimensions of value proposition, key elements, and architecture. Value capture, value chain, and target customers are not affected. Firms still focus on one-time sales of services in addition to manufacturing and selling tangible products. The consulting sub-patterns interact with existing B2B customers directly and offline.

**Product-related Consulting**
*Product-related consulting* complements product sales with advice and consulting based on the firm’s own experiences with the products. The type of product can range from purely physical to purely digital products. Firms provide new customer value by offering integrated product service solutions. The new consulting service extends the existing product/service line or is an add-on to it. Firms help their customers to make optimal use of the products. In contrast, servitization patterns focus on repair, maintenance, or operating services and not on consulting. KAESER, for example, makes use of its expertise in compressors by offering tailored system planning and consulting services for energy-saving.

**Process-related Consulting**
*Process-related consulting* makes use of a firm’s experiences in internal processes. Firms offer this know-how to external parties as advice and consulting. This new service does not involve a tangible product and contains new value beyond the traditional value proposition (do more to address the job), for example, consulting about smart production and digital
transformation. For example, GE Digital provides consulting about digital transformation, making use of GE’s own experiences. Michelin uses its experience with tires to provide advice and consulting on fuel consumption and eco-driving.

**Platformization**

A platform BM offers a new platform-based, digital product together with complementary IT services. Firms move from producing and selling physical products with at most product-related services toward digital products with related IT services. This requires employees with software development and IT skills. Customer contact takes place directly both, online and offline. I4.0 digitally upgrades pure offline channels. The new offerings address both, existing and new customer segments. The meta-dimension of value capture moves from one-time sales to continuous subscription fees, in which customers do not pay for the ownership of a physical product but for its availability. The meta-dimension value chain shifts from mass production of physical products toward mass customization of digital products. External developers thereby play a more important role in product development and design.

**Product-related Platformization**

*Product-related platformization* describes how firms use their experience from manufacturing and selling asset-intensive machinery and turn it into a new digital product. The new offering primarily addresses unsolved customer problems (do more to address the job). In the case studies, the new product is a cloud-based platform for innovating or trading goods and services among user groups. Community members become key partners. Acting as an intermediary in this multi-sided market allows firms to charge different user groups, for example, commissions from third parties. Claas, for example, extends its business scope from manufacturing and selling farm machinery to a cloud-based software solution for farm management with its spin-off, 365Farmnet. Other firms can also offer modules for
Thus, Claas uses the IoT data from tractors and addresses further pain points of its customers, such as farm management, crop planning, and paperwork.

Process-related Platformization
This sub-pattern makes use of a firm’s experience with internal processes and smart production and transforms it into a new digital platform with related services, for example, an IoT platform. In contrast to product-related platformization, the value proposition is an integrated solution of a digital product and related IT services rather than solving other customer’s problems. Firms are more focused on service and support rather than intermediating. Analyzing customers’ data becomes a key activity, while a user community is not necessary. The GE Software Center, for example, developed the IoT platform Predix as an internal solution for machine operators and maintenance engineers. It aimed to reduce GE machine downtimes and to schedule maintenance checks more profitably (Schaefer et al., 2017; Winnig, 2016). Due to continuous product improvement and market demand, they used their platform knowledge and offered the more open industrial IoT platform, Predix 2.0.

5 Discussion
Despite the importance of manufacturing firms transforming toward I4.0 BMs, research has focused on the technological aspects, and little research addresses I4.0 BMs. Therefore, we investigate BMPs for I4.0. We analyzed 32 case studies of firms that have transformed towards I4.0 BMs and developed a taxonomy and 13 patterns to characterize I4.0 BMs.

5.1 Supporting Technologies and Concepts
The taxonomy and BMPs show different ways how firms can leverage I4.0 technologies and concepts to yield competitiveness. In the following, we discuss the relation of OI, mass customization, PSS and IoT with the taxonomy and the 13 BMPs.
The taxonomy and patterns show how open innovation and mass customization can be leveraged. For outside-in OI, the taxonomy shows that firms can build their value chain on a development community or crowdsourcing, and that partners, customers, or a community can become key partners, resulting in an open BM. Further, the taxonomy identifies two forms of customization, that is, mass customization and mass individualization. The BMPs crowdsourced innovation and mass customization show how firms can respond to customers’ demand for individualized products and active participation (Djelassi & Decoopman, 2013). The BMP of mass customization directly builds on the identically named concept. Online shops enable direct communication with a smart factory (Bullinger & Schweizer, 2006; Grimal & Guerlain, 2014), which allows for efficient mass production of individual products on demand. For inside-out OI, the characteristics of advice and consulting services, production as a service, or make more of it in the taxonomy and expertization patterns illustrate how firms can benefit from offering internal know-how externally. Hence, OI and mass customization support I4.0 BMs in different ways.

The taxonomy shows several ways for utilizing PSS. The dimensions of value proposition, service offering, and revenue and sales models reveal different ways to profit from PSS in I4.0. Besides, the three patterns of servitization, that is, life-long partnerships, product as a service, and result as a service demonstrate how to exploit the three general types of PSSs (Tukker, 2004). Thus, I4.0 and related technologies, such as IoT, are closely linked to servitization and PSS, and foster these PSS BMs.

The taxonomy reveals many options for how to leverage IoT with I4.0 BMs. Firms can offer monitoring and predictive maintenance, guaranteed availability, product or even production as a service, building on IoT, and become a solution provider or full-service operator. Moreover, providing an IoT platform enables partners to offer these services. All 13 patterns provide
distinct BMs that profit from IoT. Integration patterns illustrate how IoT devices work as CPS in a provider’s smart factory and enable efficient production. Servitization patterns leverage IoT devices as CPS to support a smart factory at the customer’s site. Additionally, IoT enables servitization itself with remote monitoring and predictive maintenance. Expertization patterns show how providers can learn from IoT data, and offer this know-how externally (i.e., product- and process-related consulting), create a market for IoT data (i.e., product-related platformization), and connect IoT devices (i.e., process-related platformization). Thus, IoT is an important foundation for I4.0 BMs and can be exploited in different ways.

5.2 Theoretical Implications
This research contributes to the literature by showing what I4.0 really means for BMs and what important elements a BM under I4.0 should have. This has important implications for the literature on production economics and BMs.

5.2.1 Production Economics and Management Literature
We contribute to production economics in three ways. First, we develop a taxonomy for describing, analyzing, and classifying BMs for I4.0. General BM frameworks or general BM patterns do not cover the complexity and specific characteristics of the manufacturing and I4.0 context (Gassmann et al., 2014; Osterwalder & Pigneur, 2010; Remané, Hanelt, Tesch, et al., 2017; Taran, Nielsen, Montemari, Thomsen, & Paolone, 2016). These frameworks provide a high-level structure, that is, four dimensions of BMs, whereas our taxonomy implements this structure and further considers detailed contextual design elements, that is, 19 dimensions with two to six characteristics each. Moreover, we derive 13 archetypal BMPs for I4.0. In this way, we respond to the call of Zott et al. (2011) to generate BM typologies for specific industries. Thus, we are able to build on all three levels of BMs: BM elements (taxonomy), BM patterns describing common configurations of the elements, and instances of
real firms. With this use, the BM concept is most powerful (Osterwalder, Pigneur, & Tucci, 2005).

Second, we explain how I4.0 impacts BMs, service systems, and the roles of manufacturing firms. Whereas prior research mainly focused on technological implications (Burmeister et al., 2016; Kiel et al., 2016) and lacked BMs and their emerging roles for manufacturing firms, this paper reveals how I4.0 leads to new BMs and new service systems for manufacturing firms. The taxonomy for I4.0 BMs shows how I4.0 changes BMs and the role of manufacturing firms in their ecosystems. The 13 BMPs illustrate new roles of manufacturing firms. Additionally, the results reveal new service systems. All 13 patterns show different forms of service systems and value co-creation, and illustrate how new services provide customer value. Patterns indicate strategies for enabling value co-creation in an industrial setting and illustrate how I4.0 and related new digital technologies affect service systems.

5.2.2 Business Model Literature
This study contributes to the BM literature in two ways. First, the results contribute to the growing field of enterprise classifications based on BMs (Täuscher & Laudien, 2018). In the context of I4.0, the extant literature does not structure strategic options and BMs. The taxonomy as a common vocabulary facilitates the systematic description and the intuitive knowledge of I4.0 BMs, and opens options for I4.0 BMI without oversimplifying their complexity. Moreover, the 13 archetypal BMPs structure I4.0 BMs and support their classification. We follow the call for analyzing pattern-based BMI in industries under change with existing BMP collections as the basis for our taxonomy (Remané, Hanelt, Tesch, et al., 2017). Further, we shed some light on the understudied topic of how to make traditional BMs fit for new technologies and, specifically, for I4.0 (Bock & Wiener, 2017; Grünert & Sejdić, 2017; Johnson et al., 2008).
Second, our research method illustrates how to derive an industry-specific BM taxonomy, and shows BMPs utilizing case study, case survey, and taxonomy development approaches as guidelines. Case studies provide extensive and in-depth analyses (Yin, 2014), whereas case surveys show generalizable, cross-sectional analysis (Larsson, 1993). Taxonomy development adds a systematic approach to structuring and interpreting empirical findings as well as integrating conceptual research (Nickerson et al., 2013). One technique was to distinguish cases by the richness of their information. We use cases with rich information for building the taxonomy patterns, and build on cases with less information for one evaluation of the taxonomy and patterns. Finally, we use four approaches to evaluate both results. By building on these methods, we show how to systematically derive an industry-specific BM taxonomy and BMPs. The results show both in-depth information and generalizability for a specific industry. We again build on all three levels of BMs: real-world instances (cases), BM elements (taxonomy), and patterns (Osterwalder et al., 2005) and leverage the full potential of BMs.

5.3 Practical Implications
For practice, this paper addresses the lack of guidance for BMI under I4.0 (Laudien & Daxböck, 2016). We show what new BMs under I4.0 look like (Sarvari et al., 2018) and guide firms in leveraging I4.0, including its technologies and concepts, such as OI, mass customization, PSS, IoT, CPS, and smart factories. Practitioners can characterize their current BM by using the taxonomy to assess its I4.0 readiness. Moreover, characterizing their BM with the taxonomy supports inspiration. Each dimension provides opportunities for transforming toward I4.0 in terms of characteristics and related cases. The characteristics and case examples allow managers to discover opportunities for progressing BMIs toward I4.0 and directly communicate new ideas with the taxonomy. Similarly, the taxonomy can be used to analyze competition, compare BMs, and identify white spots in the market. The 13 patterns
further provide inspiration for I4.0 BMIs and case examples for I4.0 BMs. Similar to Gassmann et al. (2014), practitioners can use patterns and underlying cases in an ideation phase to support thinking out of the box. To stimulate creativity, practitioners can use questions such as: What would our firm look like when applying the pattern result as a service? Organizations can further assess the implementation of the pattern in the firm’s context because each pattern specifies the BM dimensions it affects most. Overall, the taxonomy and patterns support communicating and modelling new ideas and the current BM, and stimulate creativity and inspiration with the taxonomy’s characteristics, BMPs, and related cases.

5.4 Limitations
Our study faces some limitations. First, the taxonomy and the archetypal BMPs are based on and dependent on the 32 case studies. BMs and technologies innovate quickly. We could only consider cases that were available when we wrote the paper. We only searched and considered German and English cases due to language barriers. It would be interesting to investigate BMIs that resulted from governmental initiatives comparable to Industry 4.0 of other countries such as the Chinese Made in China 2025 or the French La Nouvelle France Industrielle. Second, the qualitative approach may restrict our findings. We developed both – the taxonomy and the BMPs – by building on a qualitative content analysis of data from existing case studies and secondary data. Therefore, it was a challenge to conduct the analysis objectively. However, Nickerson et al. (2013) have already noted that taxonomies are never perfect, but exist to provide an appropriate solution in a specific context. Third, from a practical perspective, BMI must be aligned with a firm’s strategy and its competitive landscape. Successful BMI requires both expertise and creativity (Remané, Hanelt, Tesch, et al., 2017). Managers should avoid superficial analogies (Gavetti & Rivkin, 2005). Thus, our
findings are a starting point for BMI; however, managers must carefully evaluate their firm’s context before applying these BM patterns (Abdelkafi et al., 2013).

5.5 Future Research

Our research enables several avenues for future research. Rich taxonomies and typologies are the basis for theory building (Doty & Glick, 1994; Rich, 1992). Future research can build on our taxonomy as well as archetypal BMPs to develop theories. The taxonomy and the patterns provide a solid foundation for qualitative as well as quantitative studies. Qualitative research can analyze patterns or specific dimensions of the taxonomy regarding their success factors and key challenges. Quantitative studies can analyze BMPs or specific dimensions or configurations of the taxonomy concerning their market performance (similar to Weill, Malone, & Apel, 2011), their profitability, or their influence for competitive advantage in different contexts. Moreover, future research can investigate the dominant transition paths from one pattern or taxonomy configuration to another. Furthermore, the taxonomy and patterns can be extended toward an I4.0 maturity model.

6 Conclusion

I4.0 as smart production enabled by the IoT, CPS, and smart factories, bears great potential for manufacturing firms to secure competitiveness and seize upcoming opportunities (Rabetino et al., 2017; Wei et al., 2017). However, applying new technologies is often not enough to succeed, additionally, a sustainable BM is needed (Abdelkafi et al., 2013). Still, especially for I4.0, extant research has mainly focused on technological questions and neglects BMs (Burmeister et al., 2016; Kiel et al., 2016). Thus, manufactures do not know how to innovate their BM toward I4.0 (Grünert & Sejdić, 2017).

Therefore, this paper analyzes I4.0 BMs and derives I4.0 BMPs to provide guidance for manufacturers and connect the technical-driven I4.0 literature with the BM research. We
collected 32 case studies about I4.0 BMs from literature and practitioner reports. For data triangulation (Yin, 2014), we enrich the case description with information from the firm websites, newspaper articles, publicly available interviews and press releases. Based on these case studies, we develop a taxonomy for I4.0 BMs consisting of 19 dimensions with two to six characteristics each (Nickerson et al., 2013). By applying the taxonomy to the case studies, we derive 13 archetypal patterns of I4.0 BMs.

The taxonomy and 13 patterns cover specific characteristics of I4.0 and can describe, analyze, and classify related BMs. The patterns are a first step toward a classification schema and a common language for I4.0 BMs. They deepen the understanding of how I4.0 impacts ecosystem roles, BMs, and service systems, and show how firms can leverage I4.0 concepts. Thus, they provide structure and accelerate the development of I4.0 BMs (Bocken et al., 2014). Practitioners can use our results to evaluate the I4.0 status of their current BM and draw inspiration for possible BMI opportunities toward I4.0. Future research can build on this typology of I4.0 BMs for theory-building and further investigate the digitization of manufacturing firms.
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Appendix A: Sources of Case Studies

Table A1: Analyzed Sources of Case Studies

| No | Firm                    | Main empirical study               | No. of sources | Further sources                                                                                                                                 |
|----|-------------------------|-----------------------------------|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Adidas                  | Plattform-i40 (2017)              | 11             | (Adidas, 2015, 2017, 2018; BMWi, 2018; Köhn, 2016; Plattform-i40, 2017; Stadler, 2015; Weitzenbürger, 2016; Wiener, 2017; Zühlke, 2015)            |
| 2  | Atomic                  | Lassnig et al. (2017)             | 5              | (Atomic, 2018; Industrie-4.0-Österreich, 2018a; Sportaktiv.com, 2017; Wörndle, 2015)                                                             |
| 3  | AVL                     | Lassnig et al. (2017)             | 4              | (AVL, 2017; Industriemagazin, 2016, 2017)                                                                                                       |
| 4  | Caterpillar             | Schaefer et al. (2017)            | 5              | (Caterpillar, 2015, 2018; Chicagobusiness.com, 2015; UPTAKE, 2018)                                                                               |
| 5  | Claas – 365Farmnet     | Bauernhansl et al. (2015)         | 7              | (365FarmNet, 2018; Brisslinger, 2016; CLAAS, 2017, 2018; Daugherty et al., 2015; Sentker, 2015)                                             |
| 6  | eMachineShop            | Bauernhansl et al. (2015)         | 4              | (Businesswire.com, 2004; eMachineShop.com, 2018; Marketwired.com, 2006)                                                                   |
| 7  | GE Digital              | Schaefer et al. (2017)            | 7              | (Bloomberg, 2016; GE, 2018a; Gutowski, 2017; Moazed, 2018; Predix.io, 2018; Winnig, 2016)                                                      |
| 8  | KAESER Compressors     | Kaufmann (2015)                   | 6              | (Bonnen, 2017; Etscheit, 2017; Kaeser.com, 2017; Nuissl, 2015; T-Systems.com, 2017)                                                          |
| 9  | Konecranes              | Wortmann et al. (2017)            | 5              | (Konecranes, 2016, 2018; Weinberger, Bilgeri, & Fleisch, 2016, p. 704; Wirtschaftsforum.de, 2018a)                                         |
| 10 | Local Motors            | Bauernhansl et al. (2015)         | 7              | (Crunchbase.com, 2017; Kilimann, 2015; Kumar, 2016; Launchforth.io, 2017; Local Motors, 2017; McKinsey, 2015)                                 |
| 11 | Ponoko                  | Gassmann et al. (2014)            | 4              | (David, 2014; McGahan, 2012; Ponoko.com, 2018)                                                                                                 |
| 12 | Shapeways               | Bauernhansl et al. (2015)         | 5              | (3D-Grenzenlos, 2017; Estes, 2014; Shapeways, 2017; Smith, 2012)                                                                            |
| 13 | Texa CARe               | Microsoft (2017a)                | 4              | (Texa, 2018a, 2018b; Wirtschaftsforum.de, 2018b)                                                                                                |
| 14 | TRUMPF - AXOOM          | Grünert and Sejdić (2017)         | 7              | (AXOOM, 2017; Feil, 2017; i40-bw.de, 2017; Nowak, 2017; TRUMPF, 2017; Weinzierl, 2015)                                                |
| 15 | Zumtobel                | Lassnig et al. (2017)             | 4              | (Industrie-4.0-Österreich, 2018b; Strölin, 2016; Zumtobelgroup.com, 2018)                                                                    |
| 16 | ABB Marine Systems      | Wortmann et al. (2017, p. 12)     | 2              | (ABB, 2018)                                                                                                                                    |
| 17 | ABT Power Management   | Microsoft (2018)                 | 2              | (ABT, 2018)                                                                                                                                    |
| 18 | Biesse Group            | Accenture (2018)                 | 2              | (Biesse, 2018)                                                                                                                                  |
| 19 | Bosch AMRA              | Wortmann et al. (2017, p. 12)     | 3              | (Bosch, 2015, 2018)                                                                                                                               |
| 20 | Daimler Mobility Services | Bauernhansl et al. (2015)       | 8              | (Bay, 2017; Car2Go, 2018; Daimler, 2017, 2018; Daugherty et al., 2015; Howard, 2016; Moovel, 2018; Muoiio, 2017)                          |
| 21 | GE Fuse                 | BCG (2017)                       | 6              | (Alpaio; Davies, 2017; Davis, 2017; GE, 2016; Kloberdanz, 2017; Scott, 2016)                                                                  |
| 22 | GE Taleris              | Daugherty et al. (2015)           | 4              | (Foster, 2013; GE, 2013, 2018b)                                                                                                                |

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### Appendix B: Business Model Patterns of Case Studies

#### Table A2: Relation of Case Studies and Business Model Patterns for Industry 4.0

| Case Studies       | SUPER-PATTERNS | SUB-PATTERNS | INTEGRATION                                                                 | SERVITIZATION                                                                 | EXPERTIZATION                                                                 |
|--------------------|----------------|--------------|------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
|                    |                |              | CROWDSOURCED INNOVATION | PRODUCTION AS A SERVICE | MASS Customization | LIFE-LONG PARTNERSHIPS | PRODUCT AS A SERVICE | RESULT AS A SERVICE | PRODUCT-RELATED CONSULTING | PROCESS-RELATED CONSULTING | PROCESS-RELATED PLATFORMIZATION | PRODUCT-RELATED PLATFORMIZATION |
| 10 Local Motors    |                |              | X                           |                              |                          |                           |                           |                               |                                   |                                   |                                   |                                   |
| 21 GE Fuse         |                |              | X                           |                              |                          |                           |                           |                               |                                   |                                   |                                   |                                   |
| 6 EMachineShop     |                |              |                              | X                           |                          |                           |                           |                               |                                   |                                   |                                   |                                   |
| 12 Shapeways       |                |              |                              | X                           | X                         |                           |                           |                               |                                   |                                   |                                   |                                   |
| 11 Ponoko          |                |              |                              | X                           | X                         |                           |                           |                               |                                   |                                   |                                   |                                   |
| 1 Adidas           |                |              |                              | X                           |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 2 Atomic           |                |              |                              | X                           |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 25 New Balance     |                |              | X                           |                              |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 29 Schlotterer     |                |              |                              | X                           |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 3 AVL              |                |              | X                           |                              |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 4 Caterpillar      |                |              | X                           |                              |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 13 Texa            |                |              | X                           |                              |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 16 ABB Marine      |                |              | X                           |                              |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 22 GE Taleris      |                |              |                              | X                           |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 28 Samudra LED     |                |              |                              | X                           |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 31 ThyssenKrupp    |                |              |                              | X                           |                           |                           |                           |                               |                                   |                                   |                                   |                                   |
| 32 Würth Industrie Services | | | | | | | | | | | | | |
|   | Company          |   |   |   |   |
|---|------------------|---|---|---|---|
| 27| Rolls-Royce      | X |   |   |   |
| 30| Siemens          | X |   |   |   |
| 24| Michelin         | X | X |   |   |
| 17| ABT Power        | X |   |   |   |
| 15| Zumtobel         | X | X |   |   |
| 23| Hilti            | X | X |   |   |
| 19| Bosch            |   | X |   |   |
| 14| TRUMPF           | X | X | X |   |
|  5| CLAAS            |   | X |   |   |
| 26| Pirelli          | X |   |   |   |
Leveraging Industry 4.0 – A Business Model Pattern Framework

Highlights

• We extend the technically-driven Industry 4.0 research with business models
• We develop a taxonomy for describing, analyzing, and classifying business models
• 13 archetypal patterns show how Industry 4.0 impacts business models
• Three areas of Industry 4.0 business models emerge:
  • Integrating parts of the value chain, servitization, and consulting or platforms