

HOW TO IMPLEMENT INDUSTRY 4.0?

AN EMPIRICAL ANALYSIS OF LESSONS LEARNED FROM BEST PRACTICES

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ABSTRACT

The new manufacturing paradigm 'Industry 4.0' or 'Industrial Internet of Things' (IIoT) refers to digitized and connected industrial value creation. In this context, future value creation is located in completely digitized, intelligent, connected, and autonomous factories and production networks. This development is assumed to yield extensive industry-spanning opportunities, e.g., increases in efficiency, quality, and flexibility. However, exploiting these opportunities requires a targeted implementation of the IIoT. The goal of this study is to generate a deeper understanding of relevant implementation actions that need to be taken in the digital era. In doing so, we aim at throwing light upon the complex IIoT implementation process in order to tap its full potential. Current research aims at providing companies with purposeful and effective guidelines for implementing the IIoT. The given recommendations are mostly general, highly aggregated, and difficult to grasp. Yet, specific and concrete actions that need to be taken to accelerate the realization of the IIoT are essential.

Our study is of exploratory nature since research lacks a comprehensive and systematic investigation of the research object. We apply a multiple case study approach, which uses semi-structured in-depth expert interviews as primary source of empirical data. Between April and June 2016, we conducted 13 interviews with managers from IIoT-experienced German manufacturing companies. All interviews are transcribed and serve as text material to be examined according to the qualitative content analysis.

Our study reveals valuable insights regarding relevant and targeted aspects for IIoT implementation. The most important aspects are the development of IIoT-specific know-how, securing financial resources, integrating employees into the implementation process, and establishing an open-minded and flexible corporate culture. Further aspects that appeared to be important are, among others,

comprehensive planning processes, external cooperations, proper handling of data interfaces, interdisciplinary communication, an adaptable organizational structure, and data security.

Our article develops a comprehensive framework providing necessary and effective actions to be taken when implementing digital and connected future industrial value creation. Thus, we trigger further research on success factors and implementation strategies in today's digital and connected world. Our study supports responsible managers to effectively implement the IIoT within their organizations and consequently benefit from the IIoT's entire set of opportunities. Moreover, we contribute to research concerning the management of technology and innovation implementation in the highly dynamic digital era.

Key words: Industry 4.0, Industrial Internet of Things, Implementation, Qualitative research, Case study, German companies

INTRODUCTION

Today's world is characterized by highly globalized economies, resulting in a high degree of competition. The ongoing deregulation of markets liberates trading transactions, thereby causing vanishing industry boundaries. Additionally, doing business becomes more challenging due to strengthened volatility of global markets as well as shortened technology and innovation cycles. On top of that, global demand asks for highly individualized products and services, which increases process complexity in value streams (Bauernhansl et al., 2014; Hirsch-Kreinsen & Weyer, 2014; Spath et al., 2013). Under these circumstances, companies' survival and competitiveness depends on whether their value creation systems are flexible, efficient, and adaptable (Bauer et al., 2014), allowing to supply customized value propositions both flexibly and fast at the cost of a large-scale production (Bauernhansl, 2014; Dais, 2014).

The new manufacturing paradigm 'Industry 4.0' which is internationally better known as 'Industrial Internet of Things' (IIoT) refers to digitized and connected industrial value creation (Arnold et al., 2016; Kagermann et al., 2013). It is characterized by intelligently, horizontally, and vertically connecting people, machines, objects, and information and communication technology (ICT) systems (Bauer et al., 2014). Thereby, future value creation is located in digitized, real-time capable, intelligent, connected, and autonomous factories ('smart factories') and production networks (Hartmann & Halecker, 2015; Kagermann et al., 2013). The IIoT is assumed to yield extensive industry-spanning opportunities, e.g., increases in efficiency, quality, and flexibility (Hartmann & Halecker, 2015; Kagermann et al., 2013; Kiel et al., 2016). That is why the IIoT is considered to qualify for maintaining and enhancing companies' competitiveness and to be an appropriate solution to address the aforementioned challenges in today's global economy (Arnold et al., 2016).

Before companies are able to exploit the opportunities yielded by the IIoT and fully benefit from them, they need to implement the IIoT in a targeted and adequate way. In management research, the IIoT, its implementation, and its economic, environmental, and social implications represent a comparably young research field. Because of its technological core, current research has focused on its technical perspective, whereas economic investigations are still in their infancy (Brettel et al., 2014; Emmrich et al., 2015). So far, there is little experience in corporate practice with respect to a purposeful and successful IIoT implementation. The lack of knowledge about the implementation process is shifting

management research's focus on the implementation process since relevant expertise is vital for tapping the IIoT's full potential. Lately, academia aims at providing companies with purposeful and effective guidelines for an effective IIoT implementation.

Given the specific and complex nature of the IIoT, enterprises need to undertake appropriate implementation actions tailored to the individual design of their institutional and process organization structure (Hartmann & Halecker, 2015). Yet, up to now, literature provides corporate practice with general and highly aggregated recommendations that are difficult to grasp and usually disregard company-specific characteristics.

The goal of this article is to provide purposeful guidelines and recommendations to design the IIoT implementation process effectively. With our research, we aim at throwing light upon the complex IIoT implementation process in order to exploit its full potential and to generate a deeper understanding of relevant implementation actions that need to be taken in the digital era. The study at hand does not only provide concrete recommendations, but also enriches current research developing a conceptual model of an implementation process.

Our paper is organized as follows. First, we lay the theoretical fundament by defining the term IIoT and giving an overview of the current state of research regarding its implementation. Second, we show the qualitative research design of our study. Third, we provide the empirical results and reveal seven areas for recommendations to implement the IIoT in corporate contexts. Fourth, we discuss our results comparing them with current literature and develop a framework for IIoT implementation. Finally, we reflect on limitations of the study at hand and disclose further research areas.

THEORETICAL BACKGROUND

Industrial Internet of Things

Technological developments, progresses in the area of ICT systems, and the internet-based connection of entire value chains represent the fundament of the IIoT (Bauer et al., 2014; Dorst et al., 2015). Cyber-physical systems (CPS), comprising sensors, microprocessors, and actuators constitute the technological core of the IIoT and enable real-time data transfer. They represent the fusion of the real and the virtual world (Lee et al., 2014).

Based on digitization, automation and interconnection, the IIoT represents a paradigm change and is believed to be the next industrial revolution (Dorst et al., 2015; Obermaier, 2016). Its goal is to connect resources, information, objects, and human beings (Kagermann et al., 2013; Obermaier, 2016). Following Bauer et al. (2014), the IIoT is defined as the "real-time capable, intelligent, horizontal, and vertical connection of people, machines, objects, and information and communication systems to dynamically manage complex systems" (p. 18). Kiel (2017) adds that the "IIoT refers to the proceeding digitization and smart connection of industrial value creation by a) integrating all corporate functions, b) across all products and services, c) across the entire value chain, d) with novel digital technologies, and e) with modified and new business models" (p. 4).

The vision of integrating the IIoT in industrial value creation leads to 'smart factories'. They are characterized by human-to-human, human-to-object, and object-to-object interactions along the entire value creation process (Wan, 2011). Therein, intelligent and self-controlling objects, so-called

'smart products', are constantly identifiable, steadily locatable, and they know their latest condition (Ramsauer, 2013; Spath et al., 2013). Further, orders guide themselves through entire value chains autonomously and machines set-up automatically, and, if an error is predicted, reschedule the production on their own (Kaufmann, 2015; Spath et al., 2013).

The IIoT implies numerous potentials and therefore helps companies to cope with the increasing competition of today's global economy. For example, it leads to an increased resource efficiency in terms of material usage, energy consumption, and human work, resulting in cost reductions (Kaufmann, 2015) and productivity increases (Saberi & Yusuff, 2011). Besides, future value creation is more flexible (Hinrichsen & Jasperneite, 2013; Kagermann et al., 2013) and decision making is optimized (Ganiyusufoglu, 2013). In addition, the IIoT paves the way to develop and market highly customized innovative products and services (Burmeister et al., 2016; Obermaier, 2016). Furthermore, the IIoT allows establishing entirely new business models (Bauernhansl, 2014; Botthof, 2015). From a social perspective, the IIoT helps to design demography-sensitive jobs, to improve work-life balance, and to create adaptive working environments (Hirsch-Kreinsen & Weyer, 2014; Spath et al., 2013).

An effective IIoT realization is the goal of national economies all over the world. In Germany, the concept is called 'Industrie 4.0' (Kagermann et al., 2013; Lasi et al., 2014), in the United States 'Industrial Internet Consortium' (Pike, 2014), in China 'Internet Plus' or 'Made in China 2025' (Keqiang, 2015), and in South Korea 'Manufacturing Innovation 3.0' (Kang et al., 2016).

Implementation of the Industrial Internet of Things

The IIoT has effects on the socio-technical system of human, organization, and technology. All three dimensions have to be considered when implementing the IIoT. We use the approach of Oks et al. (2017) to present the current state of research on the IIoT's implementation because it summarizes both these dimensions and their interfaces. Figure 1 illustrates this concept.

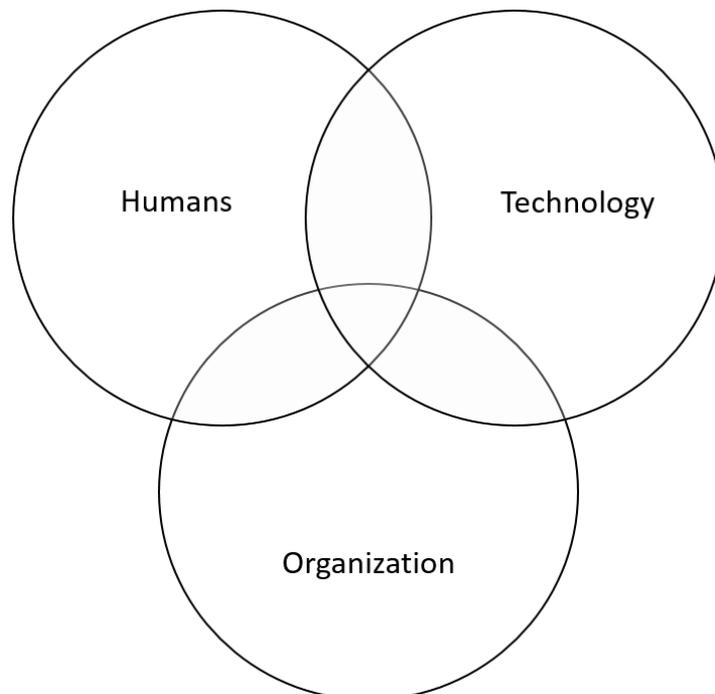


Figure 1: Humans, organization, and technology model, Source: Oks et al., 2017

Table 1 gives an overview of the main topics regarding IIoT implementation economic research has dealt with so far.

Table 1: Current state of research on IIoT implementation

Dimensions / interfaces	Key statements	Exemplary sources
Humans	<ul style="list-style-type: none"> ▪ Trainings and further education help to develop and improve vital competencies and know-how 	Darbanhosseiniamirkhiz & Ismail (2012); Erol et al. (2016); Kagermann et al. (2013); Schuh et al. (2017)
Humans – Technology	<ul style="list-style-type: none"> ▪ Assistance systems support humans in their value adding activities ▪ Matters of work safety become more important with increasing human-machine interactions 	Block et al. (2015); Deuse et al. (2015); Grote (2015); Kagermann et al. (2013)
Technology	<ul style="list-style-type: none"> ▪ Technological developments like CPS, Big Data, and cloud solutions enable future value creation in smart factories 	Jäger et al. (2016); Kang et al. (2016); Müller et al. (2016); Obermaier (2016)
Technology – Organization	<ul style="list-style-type: none"> ▪ Different hierarchical levels are connected in a vertical system integration ▪ Interactions between suppliers, customers, and partners are improved by a horizontal inter-connection 	Kagermann et al. (2013); Mosler (2017); Siepmann (2016)
Organization	<ul style="list-style-type: none"> ▪ Agile forms of organization (decentralized decision-making, flat hierarchies) ▪ Inter-firm networks and strategic cooperations ▪ Changing business models 	Emmrich et al. (2015); Hermann et al. (2015); Müller & Voigt (2017); Schuh et al. (2017)
Organization – Humans	<ul style="list-style-type: none"> ▪ Cultural change (acceptance of changes, entrepreneurial spirit, failure tolerance, democratic style of leadership, open communication) 	Burmeister et al. (2016); Saberi & Yusuff (2011); Schuh et al. (2017)

In order to be able to work in smart factories, *humans* need to have several skills and competencies. The basis of working in the digital era is confidence in technology (Erol et al., 2016). Further, humans need to have a fundamental understanding of ICT systems, automation technology, and data analysis (Erol et al., 2016; Schuh et al., 2017). Additionally, being aware of issues concerning data abuse and ICT security is critical (Schuh et al., 2017). Humans should have interdisciplinary knowledge and an understanding of interconnected systems (Erol et al., 2016; Kagermann et al., 2013). The automation of processing steps increases planning and controlling tasks, which in turn asks for further decision-

making competence of humans (Schuh et al., 2017). These skills and competencies can be developed and improved by applying trainings and education programs, e.g., scenario-based or e-learning (Darbanhosseiniamirkhiz & Ismail, 2012; Erol et al., 2016; Hartmann, 2015). All in all, companies should work closely together with schools and universities so that future staff can be provided with the skills and competencies required by new job profiles (Kiel et al., 2017).

In smart factories *humans* and *technology* act complementarily (Grote, 2015). Assistance systems help employees to operate complex systems (Block et al., 2015). On the one hand, these systems aim at physically and mentally relieving employees, automating transportation and handling processes, and taking care of monotonous tasks (Deuse et al., 2015). On the other hand, they serve as platforms providing necessary information (Kagermann et al., 2013). Assistance systems are able to identify humans via identification and visualization technologies (Schuh et al., 2017). Personal data can be collected to facilitate interactions and to design employee-focused workplaces (Block et al., 2015). In this context, guaranteeing employees' safety in human-machine interactions at any time is essential (Kagermann et al., 2013).

Technology is a key enabler of the IIoT. The usage of new technologies requires the preparation of existing systems. For instance, integrating further sensors and actuators into existing production systems and purposefully managing data is a prerequisite for CPS (Kang et al., 2016; Obermaier, 2016). Additionally, the systems need to be integrated into flexible transportation systems so that intelligent production systems can emerge (Jäger et al., 2016). Plug-and-produce solutions are designed to be quickly added to or removed from a process (Weyer et al., 2015). Also, fast and stable broadband internet infrastructure is a prerequisite, requiring respective investments. A smart factory should rely on a well-developed internal data infrastructure, e.g., based on the Industrial Ethernet (Schuh et al., 2017). Cloud systems are available to handle and process large datasets (Kang et al., 2016). Intrusion detection systems, honeypots, and firewalls help to protect data and impede unauthorized people's intervention (Hänisch & Rogge, 2017; Kagermann et al., 2013).

Applying *technologies* and changing the *organization* paves the way to develop smart factories. Creating a digital image of the value stream is a fundamental step (Siepmann, 2016). Respective software tools can virtualize entire production networks comprehensively (Schuh et al., 2014). This enables organizing the value creation process transparently and offers wide-ranging options for simulations and analyses (Hermann et al., 2015; Siepmann, 2016). Apart from the implementation on production level, the IIoT is characterized by an overall digital connection both vertically and horizontally. The vertical integration includes connecting all internal systems and interfaces as well as the data exchange between intra-firm hierarchical levels (Siepmann, 2016). For instance, enterprise resource planning systems and manufacturing execution systems need to be connected (Mosler, 2017). Horizontal integration means the inter-firm integration of customers', suppliers', and external service providers' systems into a company's system landscape (Siepmann, 2016). In order to realize the connection between internal systems and external partners, standardized interfaces, data types, and communication protocols are necessary that can be managed in a reference architecture model (Mosler, 2017). The reference architecture model integrates many perspectives by preferring incremental bottom-up as opposed to top-down approaches (Kagermann et al., 2013).

A company's *organization* structure should support the IIoT's goals. Employees face frequent and regular changes of tasks as well as changing affiliations to teams (Schuh et al., 2017). In the digital era, employees should be organized in communities, which match their competencies to work on a

common task for a certain period of time (Schuh et al., 2017). CPS provide the technical basis for decentralized decision-making as they provide decision-makers at the operational level with purposeful information (Hermann et al., 2015). Flat hierarchies and uncomplicated, less formal structures further support decentralized and optimized decision-making in smart factories (Hirsch-Kreinsen, 2014; Saberi & Yusuff, 2011). Consequently, management should adapt to unclear or changing demands by using agile management methods, e.g., the scrum approach, that are characterized by early prototypes and frequent feedback cycles with stakeholders (Schuh et al., 2017). Companies should increasingly focus on their core competencies, outsource value creation processes, and cooperate with partners (Block et al., 2015; Brettel et al., 2014; Müller & Voigt, 2017). Cooperations are to be organized in networks or flexible marketplaces (Brettel et al., 2014; Schuh et al., 2017). These aspects can change entire business models (Brettel et al., 2014). In this contexts, new customer relationships can emerge, e.g., business-to-business-to-customer ('B2B2C') (Burmeister et al., 2016). Additionally, new value propositions, such as 'product-as-a-service' and 'everything-as-a-service', can be offered, which comprise product and service solutions along the entire product lifecycle (Obermaier, 2016). Beyond that, using different revenue models, e.g., pay-per-use contracts, change the way of making money (Müller & Voigt, 2017).

The ability of a company to act agilely on a market strongly depends on the *organization* and on the *human-centered* corporate culture (Schuh et al., 2017). For this reason, several changes are required in future value creation. Established companies should have an entrepreneurial spirit, so that they have a flexible, open mentality similar to start-ups (Burmeister et al., 2016). An open communication aims at the free exchange of knowledge across all hierarchical positions and departments, enabling the acceleration of learning processes and focus on a common vision. Employees should have the willingness to continuously improve things and learn new content. Responsible managers should apply a democratic leadership style, value employees' skills, view them as part of a community, and have a failure tolerance (Schuh et al., 2017). Concrete approaches to trigger corporate cultural changes include, e.g., creativity workshops and the introduction of think tanks (Burmeister et al., 2016).

RESEARCH DESIGN

The goal of our study is to develop a conceptual framework comprising recommendations for effective IIoT implementation and to provide managers with purposeful guidelines in this context. To achieve this goal, we employ a qualitative empirical research design. This approach is particularly appropriate as current research lacks a comprehensive and systematic investigation of guidelines for IIoT implementation.

In line with the works of Edmondson and McManus (2007) as well as Eisenhardt and Graebner (2007), we apply a multiple case study approach based on inductively analyzed in-depth expert interviews for several reasons. First, case studies provide profound and deep-rooted information and help to answer 'how' and 'why' research questions, which applies to the nature of our research question (Stokes & Bergin, 2006; Yin, 2009). Second, case study research is well suited to be used in the context of ICT systems, which represent technological key enablers of the IIoT (Almeida, 2011; Dubé & Paré, 2003). Last, this approach is widely used in contexts of complex, novel, evolving, and contemporary phenomena to be studied within their real-life, social, and organizational environment, which is true for the IIoT and its implementation (Benbasat et al., 1987; Yin, 2009). The study at hand relies on

multiple cases rather than on a single one. Doing so supports accuracy, robustness, reliability, and generalizability of our results and their implications (Eisenhardt, 1991; Eisenhardt & Graebner, 2007; Yin, 2009). Semi-structured expert interviews serve as primary source of data. This kind of interview allows collecting data in a structured way, yet maintaining an adequate and necessary level of openness to allow unexpected and novel knowledge to emerge, which corresponds to the exploratory nature of our study (Cannell & Kahn, 1968; Yin, 2009).

We interviewed 13 managers from IIoT-experienced German manufacturing companies of different industry sectors and firm sizes between April and June 2016. The German economy is particularly suitable because of its representative character for a developed and industrialized nation, its economic importance for the European Union, and its advanced experiences in IIoT implementation. The sample comprises electrical engineering (n = 6; 46 %), machine and plant engineering (n = 5; 39 %), and automotive supply industry (n = 2; 15 %). These industry sectors have leading roles in implementing the IIoT and contribute significantly to the German economy in terms of the Gross Domestic Product (Federal Bureau of Statistics, 2016). The company sizes vary in number of employees and sales (see Table 2). Maintaining heterogeneity and different perspectives in the sample enables us to better generalize the results and counteract potential negative effects of sample biases. By doing so, we follow Yin's (2009) recommendation for multiple case study sampling. All experts have management positions, are closely involved in or responsible for IIoT implementation projects, and know the relevant markets and their company's strategic orientation. Consequently, the reliability of recalled issues is strengthened (Graebner & Eisenhardt, 2004; Huber & Power, 1985). The interviews lasted between 48 and 70 minutes. They were conducted in German, the native language of the interviewees and interviewers, to avoid any language or cultural barriers and to ensure comparability. The interviewees' names are anonymized for confidentiality reasons. Table 2 summarizes the characteristics of our sample.

The development of the interview guideline was informed by literature but followed the principle of openness and flexibility to allow unexpected and novel topics to emerge, corresponding to the exploratory nature of our study (Ananthram & Chan, 2013; Kasabov, 2015). In order to verify its duration, understandability, content structure, plausibility, and the value of the provided information for the research goal, we pilot tested our initial interview guide with three managers from the sample industries. After having revised minor parts, the final guideline consists of two parts. The first part deals with personal facts, e.g., company tenure and position to verify the interviewees' trustworthiness and their level of knowledge. The second part focuses on questions about relevant aspects, procedures, and best practices concerning IIoT implementation.

All interviews were audio recorded and transcribed, providing us with more than 200 pages of text material. We examined them by applying a qualitative content analysis as suggested by Miles and Huberman (1994). Whenever possible and for triangulation purposes, the expert interviews were verified using secondary data, e.g., annual reports and company websites (Maxwell, 1996; Yin, 2009). As we used secondary data exclusively to verify the experts' statements, we did not code this material separately.

Table 2: Sample characteristics

Expert interview	Management position	Tenure in years	Industry	Number of employees	Sales in Mio. Euro
E1	Middle	30	Machine and plant engineering	(0 - 5.000]	(500 – 1.000]
E2	Middle	5	Machine and plant engineering	(5.000 – 20.000]	(3.000 – 6.000]
E3	Low	2	Machine and plant engineering	(5.000 – 20.000]	(1.000 – 3.000]
E4	Top	6	Automotive supply industry	(0 - 5.000]	(0 – 500]
E5	Lower	22	Machine and plant engineering	(5.000 – 20.000]	(1.000 – 3.000]
E6	Middle	10	Machine and plant engineering	(20.000 – 50.000]	(6.000 – 10.000]
E7	Lower	5	Machine and plant engineering	(20.000 – 50.000]	(3.000 – 6.000]
E8	Middle	25	Electrical engineering	> 50.000	> 10.000
E9	Middle	13	Automotive supply industry	> 50.000	(3.000 – 6.000]
E10	Lower	16	Electrical engineering	(5.000 – 20.000]	(1.000 – 3.000]
E11	Middle	3	Electrical engineering	(0 - 5.000]	(500 – 1.000]
E12	Middle	13	Electrical engineering	(0 - 5.000]	(500 – 1.000]
E13	Lower	3	Electrical engineering	(0 - 5.000]	(0 – 500]

During the qualitative content analysis, the developed categories were partly informed by extant literature, but followed an inductive coding procedure (Gioia et al., 2013; Krippendorff, 2013). We did so to allow new concepts to emerge rather than being restricted by predefined hypotheses (Graebner & Eisenhardt, 2004; Kelley et al., 2009), as the IIoT research is still in its infancy. Likewise, inductive coding allows contributing to theory building (Edmondson & McManus, 2007) by identifying consistencies and common patterns in the collected data (Greening et al., 1996). We closely followed the well-established procedure of Gioia et al. (2013): In an initial step, first-order (informant-centric) concepts/categories were developed. Secondly, we synthesized these categories into second-order themes. These were inspired by our experiences gained from previous research on the IIoT. Thirdly, we distilled them into the dimensions of corporate culture and communication, personnel, company organization, safety and security, preparing the implementation of IIoT solutions, handling and integrating IIoT solutions, and financial feasibility. The entire process was conducted in a research team comprising the four authors of this article to increase validity and objectivity of the coding

procedure (Weston et al., 2001). The illustration of first-order concepts, second-order themes, and the aggregate dimensions in the data structure (see Table 3) increases the methodological rigor of qualitative research design (Gioia et al., 2013).

The case data was coded independently by the authors in order to serve for the calculation of the inter-coder reliability (Holsti, 1969), aiming at enhancing data reliability during the interview analysis procedure. Since it resulted in a high value, the validity of the coding process was strengthened. Additionally, potential key informant and retrospective biases were addressed using the following approaches. Firstly, we selected reliable and knowledgeable experts. Secondly, we assured all interviewees of full anonymity and confidentiality. Third, we used secondary data for triangulation reasons (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Yin, 2009). By doing so, we aim at further increasing the robustness of our results (Eisenhardt & Graebner, 2007; Yin, 2009) as well as accounting for routine criticisms in qualitative research designs (Schüßler et al., 2014).

EMPIRICAL FINDINGS

The empirical results indicate seven dimensions, which need to be considered when implementing the IIoT. Given its limited space, we only present the most important aspects in this section. Table 3 gives an overview of the dimensions and categories derived from the case material, underlined with exemplary interviewee statements.

Corporate culture and communication

Implementing and using the IIoT requires changing the *corporate culture*. In order to conduct cultural changes, companies should apply a rather systematic approach. Management should top-down initiate cultural changes and serve as a role model, leading by example and providing an unambiguous vision. Corporate culture should rather be changed incrementally than radically in order to reduce the probability of internal resistances. Characteristics of an IIoT-adequate corporate culture are manifold: For example, high level of willingness to learn, openness to new things, promotion of creativity and idea generation, entrepreneurial mindset, and democratic leadership. In this context, the corporate culture should always focus on and empathize with the customer and his demand.

Changing the *communication* culture is another key for IIoT implementation as information is highly valuable in future value creation. There are different ways of establishing effective communication. Among others, online communication tools, such as news feeds, webcasts, and information platforms can provide employees with purposeful information. In addition, it is important to allow an open exchange of information and open discussions to aim at exchanging knowledge smoothly. This can be realized by aforementioned platforms, informal personal exchange, and interdisciplinary workshops. The communication and sharing of information should be established in daily business so it becomes self-evident for those affected. All these measures aim at allowing an open communication and exchanging information without any restrictions.

Table 3: Empirical findings and data structure

Aggregate Dimensions	Second-order themes	First-order concepts/categories	Exemplary expert statements
Corporate culture and communication	Corporate culture	<ul style="list-style-type: none"> ▪ Systematic change approach lead by management ▪ Development of entrepreneurial spirit, failure tolerance, and creative environment ▪ Consequent customer focus 	“You need a particular start-up mentality. [...] With a traditional, rigid corporate culture you will not be successful in the future.” (E13)
	Communication	<ul style="list-style-type: none"> ▪ Usage of specific tools to provide employees with accurate and relevant information ▪ Allowance of open information exchange and open discussions 	“We actively take measures to improve communication [...], such as discussion forums, discussion groups, and various forms of trainings.” (E10)
Personnel	Personnel planning	<ul style="list-style-type: none"> ▪ Considering work content changes and consequently adapting task descriptions ▪ Creation of favorable work conditions ▪ Adaption of workplace structure and characteristics 	“For instance, working in virtual teams is a prerequisite within the IIoT that will, for sure, change the way our employees work.” (E9)
	Skills and competencies	<ul style="list-style-type: none"> ▪ IT competencies ▪ Interdisciplinary competencies ▪ Personality traits, e.g., openness to change and willingness to learn 	"I need employees, who cannot only concentrate on one specific topic, but who are capable of controlling many complex topics." (E2)
	Education and training	<ul style="list-style-type: none"> ▪ Trainings ▪ Workshops ▪ Learning by doing ▪ E-learning ▪ Mentoring 	“There are trainings, projects, and research projects [...], and we teach employees by making them part of projects.” (E12)

Table 3: Continued

Aggregate Dimensions	Second-order themes	First-order concepts/categories	Exemplary expert statements
Company organization	Intra-firm	<ul style="list-style-type: none"> ▪ Establishment of a flexible and agile organization ▪ Usage of a targeted form of project organization to roll out the IIoT 	<p>“We have founded a new division to implement the IIoT [...]. In any case, that is something that needs to be separated from daily business. Otherwise it will not work.” (E5)</p>
	Inter-firm	<ul style="list-style-type: none"> ▪ Horizontal and vertical connection of the value chain ▪ Implementation of different types of cooperation 	<p>“We need a community of all suppliers to pool our strengths and to agree on how to provide our common end customers with value.” (E13)</p>
Safety and security	Data security	<ul style="list-style-type: none"> ▪ Protection of data interfaces ▪ Employment of ICT experts ▪ Data storage in clouds 	<p>“There is a router, which assigns a fixed IP address [...], the machine itself has a firewall, we set up a Virtual Private Network tunnel, and on the other side, there is another firewall. [...] It is almost impossible to get into our network.” (E4)</p>
	Work safety	<ul style="list-style-type: none"> ▪ Taking work safety actions that go beyond legislation ▪ Establishment of an institution that takes care of work safety 	<p>“Safety at work is our first priority at all times.” (E8)</p>
Preparing the implementation of IIoT solutions	Knowledge development	<ul style="list-style-type: none"> ▪ Usage of external sources of information ▪ Generation of experiences and lessons learned within the company 	<p>„We analyzed different approaches and best practices very carefully [...]. Thereof, we have derived the best path for our purposes.“ (E5)</p>
	Project teams	<ul style="list-style-type: none"> ▪ Creation of agile project teams ▪ Bringing together various disciplines and knowledge 	<p>"When it comes to disciplines in project teams to implement the IIoT, one must say that the more diverse they are, the better and the more effective it is.“ (E7)</p>
	Planning	<ul style="list-style-type: none"> ▪ Systematic approaches enriched by flexible application of trial-and-error principles 	<p>“We have learned fast from our mistakes, and to take the chance to continue quickly and better.” (E7)</p>

Table 3: Continued

Aggregate Dimensions	Second-order themes	First-order concepts/categories	Exemplary expert statements
Handling and integrating IIoT solutions	Technical preparation	<ul style="list-style-type: none"> ▪ Implementation of hardware elements ▪ Digital connection of processes ▪ Modeling interfaces 	„We had to install new sensors and new evaluation systems. [...] The generated data goes into a cloud [...], where an analysis tool reuses it.“ (E8)
	Retrofit of established infrastructure and systems	<ul style="list-style-type: none"> ▪ Adaption of existing infrastructure and production systems to the IIoT ('retrofitting'). ▪ Development of a catalogue of measures 	“We do not change a machine but adapt our systems, while they are running. [...] Never touch a running system!” (E7)
Financial feasibility	Financing	<ul style="list-style-type: none"> ▪ Usage of fixed budgets ▪ Project-specific financing 	“Before making a big hit, we set up pilot projects. [...] In doing so, we are able to assess the costs and benefits quickly. Of course, that helps us, because it keeps costs under control.” (E11)
	Performance measurement	<ul style="list-style-type: none"> ▪ Profitability ▪ Efficiency ▪ Time 	“In our company, a very important aspect is to reduce the time-to-market.” (E8)

Personnel

IIoT-related changes result in the modification of work content, work conditions, and workplace design, which in turn influence *personnel planning*. Due to an increasing automation, work content changes. Being conscious of this change and adapting employees' tasks accordingly is essential. Monotonous and physically demanding tasks are undertaken by assistance systems, leading to increasing requirements with regard to employees' mental activities and decisions. Consequently, employees should be provided with higher decision-making power allowing them to tap their creative and problem solving potential. In addition, compensation should encourage these aspects. Flexible workplaces should be offered, which support the exchange of knowledge and skills of employees. Virtual teams across geographical locations and divisions promise a similar effect. Based on the technological opportunities of connected remote control and augmented or virtual reality devices, employees do not necessarily have to control machines constantly, which enables flexible working time models. A purposeful exploitation of data and technological developments helps to tailor and specifically adapt future workplaces to employees' individual necessities. Nevertheless, as personal data is required for this purpose, data security plays a central role. Besides technical data security, good relationships that are based on trust and frequent exchanges between employees, works councils, and management are useful.

The IIoT requires further employee *skills and competencies*, such as ICT know-how, interdisciplinary competencies, and special personality traits. Given its digital basis, knowledge and skills in ICT as well

as in data analysis are mandatory. In this context, technical and economic aspects, processes, and methods are also relevant. With regard to personality traits, the employees should be open to change, especially in terms of novel technologies. Furthermore, failure tolerance and the willingness to learn from mistakes are essential. Similarly, creativity is vital to develop new solutions and concepts. Finally, social and communication competencies facilitate interdisciplinary collaboration, teamwork, and information exchange.

In order to develop these competencies, education and trainings are helpful. Among others, adequate measures are trainings of all kinds, e.g., workshops, scenario-based learning, learning by doing, or e-learning approaches. Mentoring is a mixed form of education and training, where mentors from various disciplines help to get relevant knowledge. Training programs should be interlinked with practice and tailored to the employees' specific task as it increases learning success. Additionally, a close collaboration with universities and schools ensures that future employees acquire relevant skills for the IIoT age. However, an intuitive design of IIoT technologies and production equipment decreases the necessity of extensive, very specific trainings.

Company organization

Companies should revise their *organizational structure* to lay an adequate foundation for the IIoT. Flat, weak defined hierarchies, flexible structures and processes, and decentralized settings form an agile organization. It allows faster decision-making and promotes entrepreneurial spirit. Organizational agility is further driven by a smooth data flow based on interconnected intra-firm and inter-firm systems and interfaces. In this context, contemporary management methods are required, e.g., lean or agile project management. If it is not possible to create an organizational structure that fulfils the aforementioned requirements within the established corporate structure, it may be beneficial to spin IIoT-affected parts of the company off into independent, specialized business units. By this means, employees of the new business unit can act in a more agile and entrepreneurial way, as communication and decision-making are simplified.

Moreover, IIoT implementation is frequently advanced in individual projects, requiring a specific *project organization*. First, pilot projects should be used to test and evaluate several implementation approaches. In doing so, know-how and information can be generated centrally in order to prevent tasks from being conducted multiple times. Subsequently, the development of a global rollout roadmap standardizes implementation steps to be taken and enables transferring them to other application scenarios and contexts. This approach aims at transparent and comparable procedures to implement the IIoT in various subsidiaries, while also considering local specifics. Given the project's unique characteristics, heterogeneous teams should be formed for a distinct period and for a certain purpose.

Connecting the value chain horizontally and vertically offers the opportunity of new, strongly service-oriented business models. Here, the focus should be on end-customers during all stages of the value adding process. In order to foster R&D activities, partnerships with research institutes and other companies should be arranged. Supply chain management is optimized globally by the digital connection of suppliers and customers along the entire value chain. These changes allow novel value propositions and intensifying customer relationships.

Cooperations can be manifold. Temporary forms on a project level can help to bundle necessary resources for a while. Company networks allow sharing data via web communities and cloud-based

platforms so that key issues can be discussed in inter-firm meetings. The most intense form of cooperations represent strategic alliances that aim at long-term and partner-like collaboration. Cross-sectoral cooperations can positively influence a company's business exactly like coopetition, which pools resources and know-how of competitors. The selection of the most purposeful cooperation form depends on the company's and respective partners' goals. Generally, a consistent interconnection requires standardized interfaces and data types as well as a common way of communication.

Safety and security

The use of ICT systems and digital interconnection is in need of protection against external interferences and other issues of *data security*. The most critical interfaces are those to, e.g., external partners and customers. Their security can be increased by applying specific security systems, e.g., fixed IP addresses, firewalls, and Virtual Private Network (VPN) tunnels. Comprehensive surveillance and intrusion detection systems prevent unauthorized people from data access. Highly qualified ICT security experts are familiar with security technologies and should have leading IT positions within smart factories. In order to constantly check the security of all systems, so-called 'white hackers' can be employed who continuously search for existing security leaks. Honeypots attract cyber-attacks while distracting hackers from intervening in core systems. Cloud computing represents a secure method to store data. Nevertheless, data security issues should not lead to excessive isolation. Instead, a healthy balance between security and openness should be maintained.

The interaction between employees and machines calls for *work safety* actions at any time. Strict regulations and laws may already stipulate work safety, but further efforts are important with regard to ongoing technological developments and increasing human-machine-interactions. The design of new systems and machines should always consider aspects of work safety.

Preparing the implementation of IIoT solutions

A company should develop appropriate *knowledge* and expertise about IIoT solutions, using both internal and external sources of information. External sources can be best practice examples of other companies or academic literature as well as publications of research institutions and branch associations. Internal sources can be own R&D activities and learning from mistakes, which also generates knowledge within the company. Employees should be involved in the process as they are the ones to apply new technologies and to operate the machines.

Project teams are helpful to develop and implement IIoT solutions. Such teams should comprise different disciplines, as knowledge and expertise from different fields are mandatory. Software developers and ICT experts should be involved since software plays a vital role for the IIoT. Additionally, employees with a technical background, such as mechanical engineers, should be part of them as well. Experts in sales, marketing, and business development complement the project teams, because they are familiar with customer needs and product or service marketing. Further, people with project management knowledge are necessary. Given the variety of members, the teams must be well coordinated. At the beginning, these teams should consist of few members in order to enable short decision-making processes and agility. With implementation progress, the teams can be expanded gradually, given their increasing responsibilities and tasks.

The findings show that there are two approaches for *planning* the IIoT implementation. First, a systematic approach can be applied by following a predefined action plan. It describes objectives and

processes, includes a standardized approach, and provides the basis for a target-performance analysis. However, planning is limited, especially with regard to large and complex IIoT projects. Thus and second, flexibility should be encouraged by using trial-and-error methods. Here, it is important to learn quickly from mistakes and to test new approaches flexibly in order to develop and offer an effective solution.

Handling and integrating IIoT solutions

Another key element of IIoT implementation is the *technical preparation*. First, a company should develop a proper understanding of new, IIoT-related technologies. Second, additional hardware components are necessary, e.g., RFID, network connections, sensors, microprocessors, and actuators, to collect machine data and to enable their analyses. Third, software adaptations are required. This includes creating a standardized connection via Ethernet, digitally connecting all processes and systems, and storing data in clouds. These measures further enable gathering and analyzing real-time data. Last, secure and standardized interfaces are created so that data can be processed without information losses.

The integration of IIoT solutions into existing value creation processes requires a *retrofit of the established infrastructure and systems*. Retrofit refers to the modernization or expansion of existing manufacturing facilities. The following steps can be recommended: First, the application context should be examined carefully and goals should be defined. Second, data of existing production systems is collected, compressed, analyzed, and managed. Third, IIoT solutions can be integrated. A catalogue of measures that specifies a standardized approach of integration for different application contexts is useful.

Financial feasibility

The empirical findings show two basic models to *finance* R&D activities concerning the IIoT and its implementation, i.e., the allocation of fixed budgets or project-specific financing. Fixed-budgets are assigned to a division or plant, where it is used for R&D activities and IIoT implementation. In corporate practice, however, this approach is mostly chosen for basic R&D activities. In contrast, the IIoT is usually implemented by employing small projects. Thus, the second option of financing projects individually seems appropriate. In advance, cost-benefit analyses are used to determine the project-specific budget, and concrete information about costs and potentials are obtained from test projects.

After the implementation, the projects' *performance* can be measured and evaluated by using three different types of *measures*. Profitability indicators are appropriate to evaluate projects monetarily. Return on investment is the most common way of assessment, but cost savings are equally appropriate. Further, efficiency indicators are useful to measure project-specific goals, e.g., scrap rates, energy and resource efficiency, and maintenance effort. Last, time indicators are purposeful as the IIoT aims at increasing process speed along the entire value chain. In this context, time-to-market represents one key indicator. However, not only the overall time-to-market, but also specific elements of it can be used as an indicator, e.g., lead-time, delivery time, and turnaround time.

DISCUSSION

Theoretical implications and contributions

Our results reveal several insights and best practices regarding an effective IIoT implementation. In the following, we discuss the most important similarities with current state of research as well as the most remarkable differences by applying the humans, organization, and technology model of Oks et al. (2017).

As far as *humans* are concerned, both existing literature and our results indicate an increasing importance of ICT competencies (Erol et al., 2016; Schuh et al., 2017). Our results show that interdisciplinary knowledge is more important than exclusive ICT competencies. Further, we emphasize that there are distinct personality traits, e.g., willingness to change and communication skills that are becoming increasingly relevant in the digital era. Despite their relevance, personality traits have not been addressed by literature so far. In accordance with Darbanhosseiniamirkhiz & Ismail (2012), the findings also show that companies frequently employ on-the-job measures to train their employees. Moreover, we reveal that new forms of learning methods, e.g., e-learning methods, are still not in wide use. Training is frequently perceived as a responsibility of educational institutions (Kagermann et al., 2013), whereas the study at hand discloses further forms of cooperations in this context, e.g., joint projects, consultations, and funding.

Having a closer look at the interplay between *humans* and *technology* reveals further insights. Work safety is already discussed in literature but rather generally (Kagermann et al., 2013). Our findings underline the need for implementing a process of work safety that goes far beyond established legal regulations.

Current research comprehensively deals with *technologies* and illustrates their applicability. We extend this basis by providing approaches for the implementation of these technologies. In addition, it is shown that retrofitting of existing production systems and equipment is a critical challenge in the context of IIoT implementation. Further, data security has to be ensured in order to prevent unauthorized third parties from data access (Schuh et al., 2017; Kagermann et al., 2013; Hänisch & Rogge, 2017).

Regarding the interplay between *technology* and *organization*, our study reveals further insights. On the company level, our results show that flat hierarchies, flexible structures and processes, and decentralized settings form an agile organization that is important when implementing the IIoT. Further, we show that not only the organizational structure, but also smooth data flow contributes to agility. Minimizing technical barriers in a company's systems guarantees data flow in this context. On an inter-firm level, it is shown that digitally interconnecting suppliers and customers helps optimizing the global value chain. This requires both the adoption of new technologies and preparation of company-specific systems, such as proper handling of interfaces and the usage of common data types. Inter-firm communication can be facilitated by using, for example, web communities and cloud-based platforms. Finally and in accordance with Mosler (2017), we confirm the importance of using a reference architecture model.

Theoretical findings about *organizational aspects* of IIoT implementation have already found their way into practice. The findings of this study emphasize the importance of an agile organizational structure, constituted by flat hierarchies and decentralized decision-making (Brettel et al., 2014; Burmeister et

al., 2016; Saberi & Yusuff, 2011). Further, we provide insights about the organization of specialized project teams, their interdisciplinary composition, and their tasks.

Research on *humans* and *organization* widely discusses work design, work content, and relationships. Our results confirm findings regarding, e.g., assistance systems and the elimination of monotonous activities (Deuse et al., 2015; Grote, 2015). Further, we emphasize the importance of an entrepreneurial spirit, which is in line with Burmeister et al. (2016), and of fault tolerance, which complies with Schuh et al. (2017). In addition, the empirical findings reveal the necessity of an adequate cultural change by using a top-down approach. In this context, open communication plays a central role (Schuh et al., 2017).

So far, research has not dealt with the interplay between *humans*, *organization*, and *technology* (Oks et al., 2017). The article at hand extends current research by making three aspects subject of the discussion, which belong to all dimensions. We reveal insights about how to generate IIoT-relevant knowledge, e.g. by using information from research institutes or branch associations. Further, we present aspects with respect to financing IIoT implementation, and recommend the use of success measures. By doing so, our study contributes to research and helps to understand how to implement the IIoT effectively.

Managerial implications

The implementation of the IIoT is a complex process within which our study provides managers with distinct recommendations. We develop a framework that consolidates and summarizes our recommendations, which is illustrated by Figure 2. The company represents the center of the framework being surrounded by partners and market players, with whom frequent exchanges and communication exist. The entire pool and ecosystem of these players is critical for IIoT implementation.

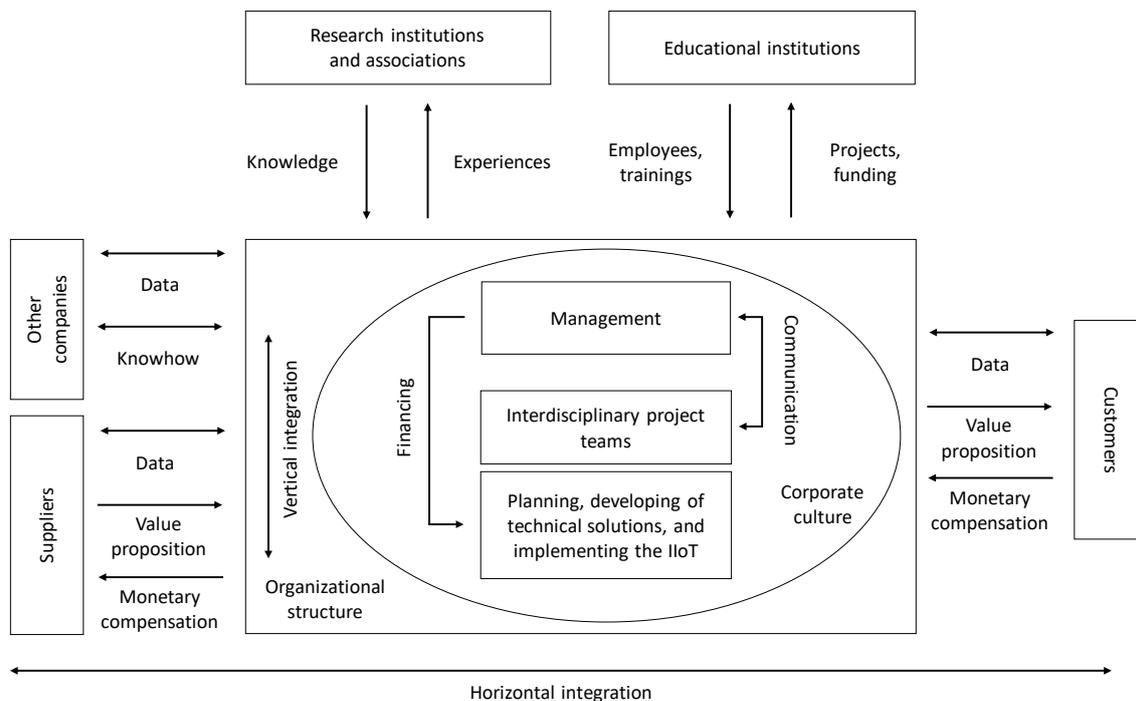


Figure 2: Framework of IIoT implementation, Source: Own illustration

The following IIoT implementation principles are recommended:

- Firstly, the future tasks of employees require further competencies. Knowledge about ICT technologies as well as interdisciplinary knowledge should be conveyed, e.g., via trainings, workshops, and further education programs. Apart from traditional training methods, emphasis should be placed on e-learning and scenario-based learning. Companies should also cooperate with educational institutions of all sorts in order to be involved in the development and design of educational programs tailored to the specific qualification needs of the IIoT.
- Secondly, IIoT-relevant knowledge should be developed by utilizing research results, experiences and recommendations of branch associations and internal experiences. Sharing knowledge with, e.g., research institutions, should be a reciprocal process.
- Thirdly, organizational changes are vital to provide an appropriate basis for the IIoT. The organizational structure should be characterized by a flat hierarchy and decentralized decision-making in order to promote agility. In some cases, it is necessary to spin-off business units to put them into an entrepreneurial environment. Furthermore, interdisciplinary project teams should be formed, which consist of software developers, engineers, and experts from the areas of sales and business development. Project organization, working time models, and compensation should encourage creativity, problem solving, and decision-making.
- Fourthly, corporate culture and the way communication is set up should support the IIoT without constraints. Among others, corporate culture should be characterized by flexibility, openness, willingness to learn, and an entrepreneurial mindset. Changes of the corporate culture should be initiated and exemplified by top management in an incremental and top-down process. Communication is to be opened up so that employees are able to freely communicate and discuss across both hierarchical levels and organizational borders.
- Fifthly, companies can start to horizontally connect the value chain. In order to optimize processes across the entire value chain, data exchange from customers to suppliers and vice versa should be allowed. The principles of openness and trust are essential in cross-company cooperation. Depending on the specific case, temporary cooperations, networks, strategic alliances, or cooptation may be adequate. These can be used to develop new business models based on novel value propositions and intensified customer relationships.
- Sixthly, the IIoT implementation process needs to be planned and technical solutions need to be developed and implemented. Pilot projects and use cases pave the way to build up knowledge centrally and later on allow transferring the IIoT to other application contexts and scenarios. Both systematic approaches and trial-and-error methods help to develop goal-oriented solutions. The new IIoT technologies and solutions should be integrated into existing machinery and production systems. In this context, key elements are integrating additional hardware and software as well as managing data interfaces in order to properly retrofit established manufacturing equipment and to digitally connect all processes and systems. This vertical interconnection should follow an incremental bottom-up approach. Therefore, uniform interface standards, data types and communication protocols are required. Last, data security and work safety are of utmost importance when implementing the IIoT.

We hope that our findings and recommendations support managerial practitioners in realizing the IIoT successfully and effectively.

Limitations and further research

Given the exploratory and qualitative nature, the study at hand faces some limitations. Qualitative case studies serve to illustrate complex topics in a detailed way, which in turn makes general theoretical contributions difficult. Yet, to be able to derive theoretical implications, we compress detailed data while maintaining the relevant informational content. In the method section, various biases are discussed, e.g., key informant and retrospective bias. As has been shown, we use several measures to reduce their impact and to achieve more reliable results. Another limitation is our focus on case studies of German companies. Even though this choice serves the purpose of this study, this limitation should be kept in mind when generalizing our results and transferring them to different countries or cultural contexts. First, different economic environments and cultural backgrounds may be the reason why implications differ. Second, transferring our results and implications to other industry sectors might be difficult due to different market environments and overall conditions. Third, we exclusively examine manufacturing companies in our sample. Thus, the results should not be directly applied to, for example, service companies without thinking.

On-going research can help to shed light on further aspects of IIoT implementation. Using different company samples, e.g., in terms of nationalities and industry sectors, contributes to verifying our results and to revealing differences across countries and industries. Due to the limited explanatory power of our study, we also recommend further differentiated analyses regarding varying company sizes, value chain positions, strategic goals, and implementation states.

Despite the presented limitations, our study reveals valuable insights and implications that serve both research and practice to better understand the process and relevant aspects of IIoT implementation.

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