EMPOWERING TECHNICAL CUSTOMER SERVICE BY CYBER-PHYSICAL INDUSTRIAL EQUIPMENT: EXPLORING RATIONALES, OPPORTUNITIES, AND IMPEDIMENTS

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Abstract

Against the backdrop of digital innovation, new opportunities to empower technical customer service (TCS) for industrial equipment are emerging. Despite the currently available technological capabilities, organizations struggle to harness the potential of industrial equipment becoming cyber-physical. Cyber-physical capabilities of industrial equipment equipped with sensors, connectivity, and actuators, play a particularly pivotal role in providing more efficient and effective TCS support systems. This paper is an attempt to shed initial light onto this emerging topic. Based on 11 explorative case studies with organizations in the industrial service ecosystem, we first recognize changing service business models, the rise of independent TCS organizations, and a shrinking workforce as major rationales for leveraging cyber-physical industrial equipment for TCS. Second, our inquiry identifies remote service, the ability to predict and trigger service activities, and the provisioning of operational equipment information to TCS staff as opportunities for application. Third, we pinpoint impediments to the fast implementation and adoption of cyber-physical capabilities to harness them for TCS processes.

We believe that these findings may help practitioners to understand the relevance and potential of the embedded emerging digital capabilities and to pave the way towards effectively harnessing cyber-physical industrial equipment by identifying key impediments to successful usage.

Keywords: Cyber-Physical Systems, (Product-) Service Ecosystem, Digital Innovation, Service Innovation, Technical Customer Service

1 INTRODUCTION

Value creation in the equipment manufacturing industry is traditionally understood as developing and producing physical goods rather than offering services for the products (Ulaga et al. 2011). With the rise of the service business and servitization in industrial equipment manufacturing, technical customer service (TCS) of industrial equipment at customer sites in the field is gaining particular importance (Daeuble et al. 2015; Matijacic et al. 2013; Ray et al. 2005). Taking the routine maintenance of offshore wind turbines as an example, different organizational entities (actors) in a service ecosystem consisting of manufacturers, service organizations and equipment operators have to work together. Taking this example, it becomes quite obvious that providing industrial service in the field is often a costly and complex undertaking. This endeavour is supported by TCS support systems that ensure efficient and effective workforce control and empower service technicians in the field. As competition is refocusing from the product to the service business (Lightfoot et al. 2013; Xu et al. 2014), efficient and effective TCS processes become a competitive differentiator. This particularly holds true for servicing industrial equipment with their long lifecycles that often span more than two decades (Becker et al. 2009; Blinn et al. 2008; Walter 2010).

Against the backdrop of digital innovation (Fichman et al. 2014; Yoo et al. 2010, 2012), the installed base as an essential part of the backstage of a TCS system is pivoting: Digital and physical components of industrial equipment lately merge to so-called cyber-physical systems (CPS) (Lee 2008; Mikusz 2014). It is predicted that organizations will make huge investments into cyber-physical components and sensing capabilities of their industrial equipment, leading to an economic impact of $2.3 trillion for the global manufacturing industry exclusively (Bughin et al. 2010). Although the digital innovation of cyber-physical industrial equipment provides new opportunities for the TCS business (Tilson et al. 2010, 2010), impediments exist to harnessing the potential of cyber-physical industrial equipment for TCS and to fueling service innovation (Lee et al. 2014). To prepare for an efficient and effective TCS business empowered by cyber-physical capabilities of industrial equipment, an in-depth understanding must exist. Hence, explorative research is needed to deepen the understanding. Despite the practical relevance, so far no research on mobile TCS support systems has taken into account the impact of cyber-physical industrial equipment (Herterich et al. 2015). To address this research gap, the aim of this paper is to explore and understand the rationales, opportunities, and impediments for leveraging cyber-physical industrial equipment for TCS. Hence, this work addresses the following research questions:

RQ1: What are the rationales behind leveraging cyber-physical industrial equipment for TCS?

RQ2: What are the opportunities of leveraging cyber-physical industrial equipment for TCS?

RQ3: Which factors impede the leveraging of cyber-physical industrial equipment for TCS?

The remainder of this paper is organized as follows: Section 2 introduces the theoretical background that we draw on within this paper. Taking this as a foundation, section 3 explains the applied methodology to answer our research questions. Section 4 presents and structures the findings of the case studies. Section 5 discusses the findings with regard to related literature. Finally, section 6 concludes our work by indicating limitations of this study and pointing out opportunities for further research.

2 THEORETICAL FOUNDATIONS

Following the paradigm of service-dominant (S-D) logic (Vargo et al. 2004, 2008), value creation focuses on competences and processes instead of tangible goods exclusively. A service is conceptualized as the application of resources including competences, knowledge, and skills (Maglio et al. 2009). Within this logic, service systems in general are conceptualized as “value co-creation configurations of people, technology, value propositions connecting internal and external service systems between service providers and service customers” (Maglio et al. 2008 p. 18). This leads to a higher complexity as service ecosystems emerge in line with the S-D logic (Barrett et al. 2015). Such systems can be conceptualized as “self-adjusting systems of loosely coupled social and economic (resource-integrating) actors connected by shared institutional logics and mutual value creation through service exchange” (Lusch et al. 2014 p. 161). In line with Meier et al. (2010), we focus on three key actor groups — namely, *TCS organizations*, *industrial equipment manufacturers*, and *industrial equipment operators* — that are predominant in the context of the industrial equipment manufacturing industry. Despite the servitization trend in manufacturing (Lightfoot et al. 2013; Oliva et al. 2003), manufacturing industry products (i.e., industrial equipment) is still the major focus. Hence, drawing on the general concept of service systems, the concept of product-service systems (PSS) is widespread (Aurich et al. 2006; Meier et al. 2010). PSS describe customer life cycle oriented combinations of products and services, realized in an “extended value creation network” (Aurich et al. 2006 p. 1483). Within this paper, we understand TCS scenarios as PSS. Since industrial equipment is characterized by long lifecycles, TCS in particular plays a key role to monetize the operations phase of these groups of industrial PSS (Becker et al. 2009; Blinn et al. 2008; Walter 2010). Tangible products (i.e., industrial equipment) are increasingly seen as service end-points (Xu et al. 2014). Due to the high complexity of service activities, service technicians more and more rely on TCS support systems to provide them with current information about the entire service process, documentation on the industrial equipment, and other relevant data for service provisioning (Daeuble et al. 2015; Legner et al. 2011; Matijacic et al. 2013; Ray et al. 2005). The importance of leveraging information systems (IS) to empower TCS has already been recognized in prior work (Herterich et al. 2015) focusing on the impact of technology use on service performance (Agnihothri et al. 2002; Legner et al. 2011; Ray et al. 2005), proper integration of existing IS (Fellmann et al. 2011), and requirements elicitation (Matijacic et al. 2013). With the trend of miniaturization and consumerization, field service technicians are getting equipped with mobile devices such as smartphones, tablets, or wearable devices (Agnihothri et al. 2002; Dutta 2008; Fellmann et al. 2011; Herterich et al. 2015; Thomas et al. 2007). Drawing on the perspective of Glushko and Tabas (2009), service systems can be divided into a *front stage* comprising interaction between actors in the service ecosystem as well as a *back stage*, consisting of supporting (backend) IS. Both stages are separated by the “line of visibility.” Research on TCS so far primarily focuses on the front stage and especially on leveraging mobile technology for field service technicians (Falk et al. 2014; Herterich et al. 2015). Focusing on the back stage of service systems, industrial equipment offer novel functions with more and more embedded digital capabilities (Yoo et al. 2010). Such product innovations are termed as ‘digital innovation’, involving digital and physical components. The emerging capabilities can be harnessed to create innovative service offerings, resulting in new challenges and opportunities (Yoo et al. 2010).

The term cyber-physical systems (CPS) has emerged as a concept that describes the integration of computation and physical processes (Lee 2008). In his pivotal study, Lee (2008) classifies technical requirements of CPS and identifies them as being a cornerstone of the 20th century IT revolution. In addition, Dworschak and Zaiser (2014) identified technical as well as organizational competences and critical success factors that are crucial to implement CPS in manufacturing. In IS literature, the concept of CPS is likewise on the rise (Böhmann et al. 2014). CPS can be defined as “systems with embedded software [...] which:

- directly record physical data using sensors and affect physical processes using actuators;
- evaluate and save recorded data, and actively or reactively interact both with the physical and digital world;
- are connected with one another and in global networks via digital communication facilities (wireless and/or wired, local and/or global);
- use globally available data and services;
- have a series of dedicated, multimodal human-machine interfaces” (acatech 2011 p. 15).

Drawing on this concept, we recognize the work of Mikusz (2014) and use the term cyber-physical industrial equipment for addressing PSS (Meier et al. 2010) equipped with cyber-physical capabilities in an industrial context.

3 METHODOLOGY

This paper builds on the above-mentioned theoretical foundations. The goal of this study is to identify rationales, opportunities for application, and impediments for leveraging cyber-physical capabilities of industrial equipment for TCS. Since no comprehensive research on the real-world phenomenon of industrial equipment getting cyber-physical exists, we choose an explorative qualitative research design (Eisenhardt 1989; Myers 1997, 2013; Yin 2008). As we are interested in an in-depth understanding of leveraging cyber-physical industrial equipment in TCS processes, we use a multiple case study approach (Yin 2008). As qualitative research is often criticized for limited transparency and generalizability, we follow a highly structured and stringent methodology. We applied theoretical sampling (Lincoln et al. 1989) to cover all relevant actor groups in an industrial PSS context (Meier et al. 2010). We selected 11 diverse and revelatory cases varying in terms of turnover and employees as well as their industry. To gain insights on the relationships between actor groups, we furthermore paid attention that active business relationships exist between most cases across service ecosystem actor groups. Table 1 provides an overview of the case organizations.

Service ecosystem actor group	**Case organization**	**Industry**	**Employees**	**Turnover**	**Respondent role [Respondent ID]**	**Location**
TCS organizations	Alpha	General facility services	>500,000	>10 bn €	Head of Facility Operations [1]	Europe
	Beta	Equipment-specific TCS	>2,000	>500 mn €	Branch Manager and Director of Service Operations [2], Director of TCS [3]	North America
	Gamma	Equipment-specific TCS	>2,000	>500 mn €	Head of Development and Processes [4]	Asia
	Delta	Equipment-specific TCS	>2,000	>500 mn €	Vice-President of Service Support [5], Head of Technical Service [6]	Middle-East
	Epsilon	Equipment-specific TCS	>10,000	>1bn €	Head of Service [7]	Europe
Industrial equipment manufacturers	Zeta	Large-scale engines	>15,000	>3 bn €	Head of Information Management Department [8]	Europe
	Eta	Metal and mineral processing equipment	>5000	>1 bn €	Director of Corporate Development [9]	Europe
	Theta	Industrial materials handling	>8,000	>1500 mn €	Senior Service Innovation Manager [10], Service Innovation Manager [11]	Europe
	Iota	Automated guided vehicle industry	>500	>100 mn €	Head of R&D Product and Service [12]	Europe
Industrial equipment operators	Kappa	Public transportation	>6,000	>1,100 mn €	Head of Operations [13]	Europe
	Lambda	Services	>60,000	n.a.	Head of Facility Management and Shared Services [14]	Europe

Table 1. Profile of case study participants clustered among actor groups of the industrial service ecosystem

For the sampling, we furthermore paid attention to cover all relevant actor groups in the TCS ecosystem (Meier et al. 2010) — namely, *TCS organizations*, *industrial equipment manufacturers*, and *industrial equipment operators* — that are about to harness cyber-physical capabilities for TCS purposes. The sampling yields in a generalizable, robust, and parsimonious understanding of the real-world phenomenon.

3.1 Data collection

To obtain in-depth insights, explorative interviews with managers responsible for the service business and innovation managers in the relevant organizational types in the service ecosystem are our primary source. To prepare for the interviews, detailed research regarding current trends and challenges in the respective industry was conducted. Furthermore, an interview guideline was developed based on the recommendations of Schultze and Avital (2011). When needed, additional sub-questions were asked to gain additional insights and ensure comparability of cases. The interviews were conducted by two senior researchers. Interviews lasted between 63 and 104 minutes and averaged 82 minutes. Interviews were anonymized and transcribed, resulting in 241 pages of text.

3.2 Data analysis

For data analysis, we used grounded theory techniques (Strauss et al. 1997). Coding of the transcripts was based on an inductive approach utilizing open, axial, and selective coding, which is widely used in qualitative research (Strauss et al. 1997). Due to the huge amount of data collected, we used a computer-supported evaluation (CAQDAS) for systematically analyzing the data (Alam 2005; Sinkovics et al. 2005). For the coding based on Miles and Huberman’s descriptive, interpretive, and pattern coding, the software NVivo 10 was used (Miles et al. 1994). In addition to the transcripts, we compiled individual case write-ups (Yin 2008). Similarities and differences were identified by using cross-case analysis. Cross-case analysis is based on a variable-oriented strategy resulting in the identification of similar and reoccurring themes across cases (Yin 2008). The analysis resulted in elements of 519 individual codes without pushing existing concepts from the literature onto the data. Due to the novelty of the topic, categories were developed inductively based on aggregation of emerging codes. We further triangulated our findings from the interviews by also reviewing supplementary internal documents provided by the case study participants.

4 RESULTS

In the case studies, rationales, opportunities, and impediments of using cyber-physical industrial equipment for TCS are identified. Table 2 provides an overview of the identified rationales, opportunities, and impediments of leveraging cyber-physical industrial equipment for TCS.

Perspective	**Identified factors**
Rationales	Shrinking workforce and skilled labor shortage
	Changing service business models
	Greater competition due to the rise of independent TCS organizations
Opportunities	Remote services
	Predict and trigger service activities
	Provide operational equipment information to TCS staff in the field and the back office
Impediments	Insufficient master data about the installed base of industrial equipment
	Weakly integrated IS and insufficient information flow within the TCS ecosystem
	Legacy industrial equipment

Table 2. Identified rationales, opportunities, and impediments of leveraging cyber-physical industrial equipment for TCS

4.1 Rationales for leveraging cyber-physical industrial equipment for TCS

The service business is characterized by a pivotal change due to macroeconomic trends and changing service business models (Bughin et al. 2010; Lee et al. 2014; Özcan et al. 2014; Zolnowski et al. 2011). Case studies indicate that TCS organizations are motivated to leverage technological capabilities embedded into industrial equipment for TCS by three rationales. First, a *shrinking workforce and skilled labor shortage* (4.1.1). Second, *changing service business models* resulting in outcome-oriented contracts (4.1.2). Third, *the rise of independent TCS organizations* results in greater competition for TCS 4.1.3).

4.1.1 Shrinking workforce and skilled labor shortage

In terms of labor, field TCS organizations are confronted by an aging workforce as well as a skills shortage, which is particularly true for TCS organizations in Asia. This might increase pressure on finding adequate field staff for TCS. At the same time, TCS organizations have to reckon with an increasing percentage of non-experts within their workforce. Furthermore, due to the increasing complexity of industrial equipment, higher service complexity emerges as the intricacy of machinery and plants rises. This implies that a higher information-intensity is necessary (Legner et al. 2011; Lehtonen et al. 2012). Hence, operational information about the industrial equipment is needed to empower service technicians effectively and perform highly specialized service.

> *"The trends in general are recruiting workforce and the struggle to do that. I think you have some idea that some 70% of the global installation activities happening in Asia-Pacific are in terms of new installation, which is a huge drain to have to find qualified people to not only install those elevators but also to service them, which is the challenge as well."* (Head of Service Development and Field Processes [4], Gamma)

> *"Although the weak education level of the average, field service technicians in Asia-Pacific are responsible for providing maintenance service in 20, 30, 50 story buildings at a rate of around 1,000, 2,000 dollars per year salary."* (Head of Service Development and Field Processes [4], Gamma)

Having the ability to obtain insights based on operational equipment data provides unanticipated opportunities to increase service efficiency and come up with service innovation to counteract the shrinking workforce. Actionable insights can be derived by processing operational sensor data of cyber-physical industrial equipment. Hence, it becomes necessary that service processes are simplified and TCS gets effectively empowered by mobile work support systems based on operational equipment information.

4.1.2 Changing service business models

The service business for industrial equipment is traditionally characterized by high margins and steady revenue streams for TCS organizations. It is a frequent practice that TCS organizations charge equipment operators for individual service activities. Consequently, inefficient service processes as well as insufficient and inadequate empowerment of the mobile workforce can be passed easily onto the customers of the TCS organization.

> *"What I'm seeing is a consistent push to optimize the work force. We've had a long history of an optimized workforce, and that we're not managing what the mechanic does, from a process load, from when he starts, until the time he finishes his day. I see a huge movement now to try to optimize that, and manage that down to the minutes, what they're doing, where they're at, basically to deliver and understand what we're delivering to the customer, but also be able to verify what we're delivering to the customer. It's really been inconsistent in our industry; it's a systemic industry issue."* (Director of TCS [3], Beta)

This immediate positive effect of the amount of service provided on revenue of the TCS organization can be considered as the origin of the servitization trend in the equipment manufacturing industry (Lightfoot et al. 2013; Neely 2008). Due to a more competitive environment, however, market characteristics for maintenance, repair, and overhaul (MRO) services for industrial equipment as well as service agreements are changing. In cases where individual equipment of the installed base needs an increased level of service (e.g., follow-up visits since spare parts have to be ordered and installed), less revenue is generated due to changing service agreements such as performance contracting. Consequently, with changing service business models, TCS organizations face an enormous pressure to increase their operational efficiencies and successfully solve the problems at the point of service in a short period of time. Furthermore, a trend towards output-based services can be identified in which organizations compete on their ability to deliver quantifiable results instead of just industrial equipment with loosely coupled service contracts.

> *"Currently, our customers pay for the presence of field service technicians at their site. They do not pay for the actual 98 or 99% availability of the elevator. This will change in the future."* (Head of Service [7], Epsilon)
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> *"Taking the example of air conditioning in an office building: In the past, maintenance was carried out twice a year. Today, more and more customers expect a comfortable temperature in the building. From the perspective of the service organizations, those are totally different things."* (Head of Service [7], Epsilon)

The service business undergoes a shift from selling products and services to selling outcomes. With the traditional approach of focusing on the front stage of the PSS and better mobile TCS support systems, the required operational efficiency increases can barely be realized. Cyber-physical industrial equipment provides the foundation for predictive maintenance scenarios to happen and to offer remote maintenance, resulting in measureable outcomes such as a specified uptime or equipment utilization.

4.1.3 Greater competition due to the rise of independent TCS organizations

Case studies indicate that independent TCS organizations that are not devoted to industrial equipment manufacturers are on the rise and challenge traditional TCS organizations. By focusing on dedicated use contexts (e.g., facility management or electrical power plants) and developing capabilities to service different kinds of industrial equipment (e.g., elevators, air conditioning, heating in the context of facility management), independent TCS organizations aim to exploit economies of scale by pooling service providing. This results in lower costs for service provisioning. Traditional TCS organizations associated with industrial equipment manufacturers scout for opportunities to generate unique selling propositions and competitive advantage. Cyber-physical industrial equipment provides an opportunity to create additional lock-in effects for TCS organizations.

> *"We have the obvious trend that prices are going down and there are a lot of competitors, there are a lot of alternatives in the market. What our customers are expecting from us is good service and clear information; they need to trust us and, of course, expect a good price."* (Vice-President of Service Support [5], Delta)
>
> *"The other trends aim at higher service efficiencies. I believe we need to be more efficient in order to take this company a little bit further, and also I'm talking generally about the sector, but what I feel inside [Delta] is that we sometimes are not so efficient. We don't have exactly the data that we need for making a good job and giving good service to the client, and I would say that the client is starting to require this kind of efficiency."* (Head of Technical Service [6], Delta)

Hence, the trend of independent TCS organizations is an additional rationale for implementing cyber-physical capabilities and leveraging them for providing service.

4.2 Opportunities of leveraging cyber-physical industrial equipment for TCS

Across different actor groups in the service ecosystem, data from case organizations confirm that cyber-physical industrial equipment provides myriad opportunities for various actor groups in the service ecosystem. Against the backdrop of servitization in manufacturing as well as the rationales identified in 4.1, special opportunities emerge for the TCS business. We understand opportunities as clusters of application for cyber-physical industrial equipment in the context of TCS leading to a relative business advantage compared to other solutions (Porter et al. 1985). In particular, we can identify three areas of opportunity in which cyber-physical industrial equipment can provide an added-value for TCS. First, field service activities can be replaced by *remote services* (4.2.1). Second, *service activities can be triggered or even predicted* by using sensor data (4.2.2). Third, the *TCS workforce can be empowered* by harnessing operational equipment sensor data via mobile TCS support systems (4.2.3).

4.2.1 Remote services

If the installed base in the field consists of cyber-physical industrial equipment, an increasing amount of service activities can be performed remotely without sending expensive field service technicians to the customer's site. Sensor data can be analyzed from remote locations. Based on the insights from this data, further activities can be undertaken more accurately. Besides sensors, CPS also involve the ability to remotely control industrial equipment. Hence, field service technicians only have to visit the site to resolve mechanical breakdowns or exchange broken parts of the machinery.

> *"It eliminates us having to actually go to the jobsite and carry out that work. It also allows us to do some remote resets, which likewise eliminates having to make the trip to those jobsites."* (Service Development and Processes [4], Gamma)

Particularly with the shift from traditional service business models (see 4.1.2) to performance contracting and guaranteed uptime of industrial equipment, low costs for service provisioning are becoming highly important. Furthermore, the ability to analyze operational data and identify the cause of failures remotely results in more efficient and solution-oriented service activities of field service technicians. In some industries, more pressure exists, resulting in already implemented remote diagnosis functionality. In other industries, managers think about implementing the embedded technological capabilities.

> *"Also, an ability to start remotely, more efficiently to support our customers. That's what I mean by this digitalization if we grouped 'internet of things' and 'machine-to-machine' together. That's basically one of our big strategic futures."* (Director of Corporate Development [9], Eta)

> *"Maybe that remote understanding is the key, that you don't always have to go near the machine, but you can see the situation far away; that helps."* (Head of R&D Product and Service [12], Iota)

> *"Well it will basically be an online monitoring system. It will basically be a remote monitoring center. It will be to initial troubleshooting early warning if something becoming broken."* (Director of Corporate Development [9], Eta)

Above all, in the case of large and highly complex industrial equipment such as elevators, large combustion engines, or bucket wheel excavators, field service technicians spend vast amounts of their time with problem identification and diagnosis instead of actually solving the problem. Having the ability to perform these activities from remote service centers results in higher overall efficiency of TCS and counteracts the shrinking workforce and skilled labor shortage.

4.2.2 Predict and trigger service activities

Technological capabilities embedded in the back stage of industrial PSS allow for predicting and triggering various kinds of service activities. Service intervals can be optimized based on the condition of the equipment, resulting in lower service costs and higher equipment uptime.

> *"There is a big difference between those. With these kinds of systems, like remote systems [...] we can put 90% of technicians in those 10 expert levels, who then give experienced advice."* (Head of R&D Product and Service [12], Iota)

> *"With the new system, there is no longer a fixed schedule for service technicians performing planned maintenance and unplanned emergency maintenance. Instead, a remote service center gets notified about breakdowns and potential service incidents based on operational equipment data. In the future, the system might suggest potential solutions. In the best case, these solutions can be performed remotely by the system itself. In a case where the problem cannot be solved remotely, a field service activity is scheduled based on the dedicated problem. After ordering the right spare parts in the warehouse, service technicians and spare parts are sent to the equipment operators' site to fix the problem."* (Head of Service [7], Epsilon)

The ability to autonomously predict and trigger service activities serves as the foundation for outcome-based business models that are identified as a rationale in section 4.1.

4.2.3 Provide operational equipment information to TCS staff in the field and the back office

Most importantly, case studies reveal that cyber-physical industrial equipment can be leveraged to support and empower TCS staff in the field and the back office. Operational data collected by sensors can be used to guide service technicians directly to the root of problems and defective equipment. Without these capabilities, a great amount of time is spent on problem identification and analysis. Today, service technicians in many industries are equipped with a variety of diagnostic tools that can be connected to the industrial equipment at the site of the equipment operator. However, service technicians have to be on site to read out the error codes and identify the actual problem.

> *"Yeah, some [service technicians] can fix the problems immediately. They have very high knowledge on their team. They have a long background or something from different machines even. They can create solutions by themselves very easily, but then of course, as those machines are quite difficult to find what is wrong, then it's time-consuming if the service technician cannot find that."* (Head of R&D Product and Service [12], Iota)

> *"This technician is trying to detect the problem or the root cause of the problem and he's not able. On that moment he's not able to, he's not understanding the problem properly, he's not fixing the problem properly, and perhaps based on this system you may have the possibility that this technician could be assisted or supported by a remote expert or the system."* (Vice-President of Service Support [5], Delta)

The ability to make operational equipment information available to TCS staff results in increased service efficiency and addresses the rationales identified in 4.1.

4.3 Impediments to leveraging cyber-physical industrial equipment for TCS

In this section, we discuss impediments to leveraging cyber-physical capabilities of industrial equipment in the TCS service processes that were identified in our sample. We identify insufficient master data about the installed base, weakly integrated IS, insufficient information flow within the TCS ecosystem, as well as legacy industrial equipment as major impediments to harnessing cyber-physical capabilities in TCS.

4.3.1 Insufficient master data about the installed base

Equipment manufacturers that just focus on just selling their products have limited incentives to keep track of the installed base in the field after selling the products to equipment operators.

> *"I would say that the lack of adequate installed-base data - meaning the installed base information, that whether it was originally documented properly, and had we not been in charge of running the plan, maintaining the plan before, the subsequent changes that take place. That's*

> *probably the ununiformed installed base that we have delivered ourselves, which could be seen as both a potential for additional service and a difficulty."* (Director of Corporate Development [9], Eta)

> *"Since we are in the middle of the transition from a pure product company to a services and product company, for example our installed base is not adequately documented. Because we have been traditional in the project business, we have not taken into use the mobile devices yet. There is no sufficient backbone to support them with."* (Director of Corporate Development [9], Eta)

With the trend of servitization, this mindset drastically changes. Equipment manufacturers establish TCS organizations also for monetizing the operations phase of the industrial equipment they manufactured. If these data structures are missing, it is difficult to effectively empower TCS with adequate work support systems. As industrial equipment is characterized by long lifecycles of often more than 20 years, it will take quite some time till the current installed base with the missing master data is replaced (Blinn 2012; Walter 2010). Today, breakdowns, tasks performed on routine maintenance visits, as well as changes to the industrial equipment (i.e., installation of spare parts) cannot be maintained digitally. The reason for this lies in the missing data structures such as bill of material.

> *"You don't necessarily know what the customer has done to that equipment. Quite often our technicians do not know about the status of the equipment. Every once in a while we get an assignment with a digital photo attached to it: 'We need some help with this machine. Can you please tell us what this machine is?'"* (Director of Corporate Development [9], Eta)

With sensor data and additional operational data about the industrial equipment in the field entering the game, the lack of bill of material data structures of the installed base results in even stronger drawbacks. Data structures, which digitally represent individual instances of the industrial equipment, are missing. Establishing digital representations of complex industrial equipment results in extra effort for TCS organizations and impedes fast adoption of CPS for service processes.

4.3.2 Weakly integrated IS and insufficient information flow within the TCS ecosystem

In many industries, servicing machinery and industrial equipment is highly complex and an information-intense endeavor. First, the complexity of machines and plants is increasingly resulting in higher requirements in terms of knowledge and information-intensity (Legner et al. 2011). Second, multiple actor groups in the service ecosystem must deal with specific information coming from different sources, which leads to high requirements in terms of interfaces between individual IS. The TCS ecosystem comprises several organizational actor groups. Taking a service process perspective, equipment operators traditionally create a service incident in the case of breakdowns of machinery.

> *"When a customer has noticed a disorder in the equipment, he calls the service center. He can also contact us via fax or email. After entering the incident in our workforce management system, a service visit is scheduled. This process offers great potential in terms of efficiencies and saving costs, as it is manual at the customer's side and our side."* (Head of Service [7], Epsilon)

To support TCS with relevant information, adequate IS support is needed (Matijacic et al. 2013). The integration of heterogeneous IS has already been recognized as an impediment to effective support of TCS (Fellmann et al. 2011). In practical settings, however, existing IS in the back stage (i.e., service incident management, customer relationship management, systems for material data and product lifecycle data) are often weakly integrated, leading to media breaks within the service ecosystem and limited usage possibilities of this information for TCS.

> *"We know who called and what they called about, but there's no detailed information about what the resolution was to close the loop or even attach it to a service contract. So if another technician or dispatcher or service manager is looking at it, the history of that device or that unit is not available to them."* (Branch Manager and Director of Service Operations [2], Beta)

The weak integration and lack of interoperability of existing proprietary IS impede the use of additional IS dealing with sensor data that is obtained by cyber-physical capabilities of industrial equipment. This is due to the fact that existing data about the equipment provides the context for sensor data of cyber-physical equipment. Since service organizations are often not the owners of the industrial equipment, they often have only limited access to sensor data of the equipment.

4.3.3 Legacy industrial equipment

Another circumstance that impedes the effective leverage of CPS for the service business is the extensive lifecycle of industrial equipment (Aurich et al. 2006; Blinn et al. 2008). Often lifecycles span around 20 to 30 years. Whereas recent equipment can be retrofitted or updated with some effort, older equipment does not provide the technical requirements for implementing cyber-physical capabilities. Hence, legacy equipment in the field often cannot be retrofitted or upgraded and equipped with the adequate technology. Furthermore, different series of equipment co-exist with a variety of different controllers and bus systems, resulting in additional overhead to manage the installed base. Various equipment versions have to be connected differently to the backend systems.

> *"The majority of the installed base around the globe comprises older pieces of equipment. […] There's a requirement that if you want to have this machine-to-machine connection you need to have varying versions of what's possible because it's impossible to be able to control remotely or debug a contact relays piece of equipment when there's no process there to actually speak to."* (Head of Service Development and Processes [4], Gamma)

> *"That's probably the diversified installed base that we have delivered ourselves, which could be seen as both a potential and a difficulty for this endeavor. Then of course you have other examples, like finding skilled people, increasing the awareness of our customers of what this is all about, and so forth. Those are the practical examples."* (Director of Corporate Development [9], Eta)

Hence, little standardization among industrial equipment and a diversified installed base result in considerable additional implementation efforts and a barrier to effectively leveraging current technological capabilities.

5 DISCUSSION

Various actors in the service ecosystem of the industrial equipment manufacturing industry strive for more efficient and effective service processes enabled by digital innovation. Until now, leveraging cyber-physical capabilities of industrial equipment and mobile work support for field service mostly remains a promising yet unused potential. In line with existing literature, our case study results confirm that practitioners are interested in leveraging cyber-physical capabilities of industrial equipment for TCS (Böhmann et al. 2014; Lee et al. 2014; Mikusz 2014; Özcan et al. 2014).

First, by identifying *rationales*, our work verifies that organizations in the industrial service ecosystem are eager to leverage those new capabilities because of various reasons. Cyber-physical capabilities are a promising element to compensate the shrinking workforce and skilled labor shortage in the industrial service business. Furthermore, industrial service business models change: Service organizations might no longer be paid for their services depending on their actual efforts. Instead, equipment operators pay for availability of the industrial equipment – regardless the number of visits of technical customer service. Hence, the risk of the entire equipment operations shifts from the equipment operator to the service organization. TCS organizations are obliged to guarantee uptime of industrial equipment in lean and efficient way. Cyber-physical capabilities might serve as a promising tool to implement smart service scenarios. Actors in the industrial service ecosystem more and more focus on actual outcomes than the efforts that service organizations undertake for service provisioning. In addition, products are increasingly understood as platforms and end-points for service offerings (Xu et al. 2014). Hence, with emerging cyber-physical capabilities, the competitive situation in the service ecosystem is changing, since they generate new lock-in effects and further resource-integrating actors with skills and knowledge related to cyber-physical capabilities enter the game (Barrett et al. 2015).

Second, although CPS provide new *opportunities* for TCS, it has to be noted that with the rise of new technology, organizations focus on increasing efficiency of existing service processes – such as TCS – in the first place. Preliminary research exists on exploiting the vast amounts of operational sensor data for traditional TCS processes (Özcan et al. 2014). In addition, an increasing portion of the service activities can be accomplished remotely without sending field staff to the equipment operator's site. This opportunity has also been recognized in existing research form a business model perspective (Zolnowski et al. 2011). In line with our findings, scheduling information as well as work order request information afford efficient TCS processes with respect to the ability to predict and trigger existing TCS activities (Daeuble et al. 2015). In sum, cyber-physical industrial equipment affords service productivity gains as field service processes can be virtualized or designed to be more efficient.

In the long-term, however, cyber-physical capabilities might be essential to effectively implement entirely new service business models and fuel data-driven service innovation (Barrett et al. 2015). Effective and efficient value co-creation (Edvardsson et al. 2011) between organizational actors beyond organizational boundaries within the service ecosystem gains in importance with the emergence pf CPS, as modular and more fragmented services for different actor groups emerge (Lusch et al. 2015). In future research, the generative potential of digital platforms should be considered as enabler to facilitate the potential for service innovation (Yoo et al. 2010). Service modularity fueled by modular digital architectures becomes increasingly important (Dörbecker et al. 2014; Hylving et al. 2013). The context of industrial service innovation provides an interesting and highly relevant context for investigating the emerging opportunities. Operational equipment data turns out to be a key asset for providing efficient and effective industrial services (Özcan et al. 2014) and affords new service business models. Design principles for digital platforms to enable service innovation become relevant.

Third, the identified *impediments* are mainly based on special ecosystem characteristics or product features of industrial equipment itself. Although existing work mentions adequate and industry-specific analytical capabilities (Chen et al. 2012) and security aspects (Lee 2008; Lee et al. 2014) as critical success factors for digitalizing tangible products (Heppelmann et al. 2014; Xu et al. 2014), from a practical perspective, the identified impediments of TCS organizations are more fundamental. Whereas existing literature suggests following an open platform approach (Heppelmann et al. 2014), reality looks quite different. Due to potential knowledge drain and the fear to lose the market position, in the service ecosystem, major barriers for information sharing exist. Instead of building open platforms for offering value-added services, actors in the ecosystem focus on isolation and a closed-system approach. Open digital platforms can be understood as IT-based boundary objects that convey between actuators in the service ecosystem and foster value co-creation. Future research is needed to identify the key characteristics of such platforms as well as the factors for use and adoption of such platforms (Tiwana et al. 2010).

6 CONCLUSION

The aim of this paper was to identify rationales, opportunities and impediments of harnessing cyber-physical capabilities of industrial equipment for the TCS business. Following the S-D logic (Lusch et al. 2014; Vargo et al. 2004, 2008) and the perspective of service ecosystems (Barrett et al. 2015; Lusch et al. 2015), we employed an explorative multiple case study approach with 11 case organizations representing major actor groups of the service ecosystem in the context of industrial equipment. Addressing RQ1, we first identified *a shrinking workforce and skilled labor shortage*, *changing service business models*, and *greater competition due to the rise of independent service organizations* as predominant rationales for harnessing cyber-physical back stage capabilities for TCS. RQ2 was answered by identifying *remote services*, the power to *predict and trigger service activities*, and the ability to *provide operational equipment information to TCS staff in the field and the back office* as key opportunities of the embedded technological capabilities for the TCS business. Despite these opportunities for practical application, *insufficient master data about the installed base*, *weakly integrated IS and insufficient information flow*, *legacy industrial equipment* and *the complexity of the TCS ecosystem* are impediments that deter harnessing the cyber-physical capabilities in the back stage of industrial PSS.

The theoretical contribution of this work is manifold: Against the backdrop of digital innovation and industrial PSS becoming cyber-physical, this work is a first step to (1) understanding the role of CPS for service innovation in the context of TCS. By (2) applying the concept of PSS, we contribute to the existing body of literature and confirm the practical relevance of the emerging context of CPS and service innovation (Lusch et al. 2015). This research is also a first step to (3) introducing the concept of cyber-physical product capabilities for (product-) service systems in the context of S-D logic and (4) identifies them as enablers for innovative (product-) service systems in the domain of TCS.

However, this study has some limitations. Since we follow an explorative research design, we do not raise a claim for completeness. Although this research provides first insights into rationales, opportunities and impediments to facilitating TCS by cyber-physical industrial equipment, the results still need further empirical validation. Beyond the obtained qualitative data, we recommend that additional research be conducted for further empirical validation. Generalization of the findings could also be enhanced by investigating a larger set of cases in more industries.

Future research is needed to enhance the understanding of smart services enabled cyber-physical systems and data. As actors in the service ecosystem struggle to harness the full potential of digitalized capabilities in the back stage of industrial (product) service systems, particularly the evolving opportunities and impediments that obstruct the successful exploitation of the digitalized capabilities have to be explored in future research. The theory of affordances (Gibson 1986; Pozzi et al. 2014) might serve as a theoretical lens for further investigation of the opportunities and affordances of cyber-physical industrial equipment. For understanding the characteristics and material properties of such systems, building a taxonomy to classify concrete application scenarios might help to better understand the requirements and emerging affordances. Based on affordances, methods for calculating the utility and profitability of data-driven services compared to traditional services are needed. The identified impediments might serve as a foundation investigating necessary foundational capabilities for the effective adoption and use of cyber-physical industrial equipment for the industrial service business. Furthermore, this work can serve as a basis for requirements elicitation in order to obtain a comprehensive view of information needs of various actor groups within the service ecosystem with respect to the cyber-physical capabilities of industrial equipment. Design principles for digital platforms (Tiwana et al. 2010) or an adequate reference architecture for cyber-physical industrial equipment-driven services should be derived. Against the backdrop of service innovation (Barrett et al. 2015; Lee et al. 2014), additional research is needed to investigate how the paradox of generativity and control in data-driven service systems can be managed.

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