IoT as PSS Enabler: Exploring Opportunities for Conceptualization and Implementation

Completed Research Paper

Mohammad R. Basirati

Jörg Weking

Sebastian Hermes

Markus Böhm

Helmut Krcmar

Abstract

Nowadays, product-service systems (PSS) as an integrated system of physical products and services play a crucial role in sustainable economies. In addition to high competitive global economy, emergence of new digital paradigms is supporting the shift towards servitization. Although the great potential of such paradigms are recognized by both practice and research, their implications for PSS is not clear yet. Particularly, features of Internet-of-Things (IoT) such as total connectedness and ubiquity of smart sensors and actuators provide various new opportunities for PSS. This study explores such opportunities by conducting structured literature review and 13 interviews. We formulate the findings into two folds. First, we introduce four degrees of IoT involvement in PSS business models and we elaborate the opportunities that they create for different types of PSS. Second, we present the key technologies and approaches, which IoT provides with regard to PSS lifecycle management.

Keywords: Product-Service System, Internet-of-Things, IoT Integration, Review

Introduction

Firms have to increase their share of service offerings in order to survive in the global competitive economy (Mont 2002). Products are no more the main contributors to value creation, as the value is shifting towards services. We can see this shift in gross domestic product (GDP) of most developed countries, which are more dependent on services than physical products (Meier et al. 2010). Consequently, more service-oriented business models have emerged such as product-service systems (PSS). Most definitions of PSS describe it as a system that integrates products and services in order to create a competitive solution (Beuren et al. 2013). Furthermore, some definitions also emphasize on the role of PSS for reaching sustainability with regard to environmental and social considerations (Baines et al. 2007; Maxwell et al. 2006).

Emergence of advanced digital paradigms such as Internet of Things (IoT) is providing even more opportunities for innovative service offerings and PSS design (Kowalkowski et al. 2015; Lightfoot et al. 2013; Ulaga and Reinartz 2011). IoT is a concept for network of objects, which can sense, communicate, store data and interact with the environment (Patel and Patel 2016). IoT allows not only monitoring state of the physical objects, but it establishes the ground for progressive services such as optimization and atomization of product operations and services (Adrodegari and Saccani 2017; Porter and Heppelmann 2014).

There is a consensus among previous studies on the relevance of digital technologies such as IoT on servitization, and particularly PSS (Exner et al. 2017; Marilungo et al. 2017; Shih et al. 2016). In practice, however, adoption of IoT is a challenging issue as it requires an intensive reconfiguration of existing settings (Marilungo et al. 2017). Research, on the other hand, does not provide clear guidance on how we can exploit IoT to successfully design and develop PSS despite the need (Kiel et al. 2017). Hence, this study addresses the following research question:

Research question: What opportunities does IoT provide for PSS design and development?

We focus on two important aspects of PSS development: (1) Integrating IoT in PSS business models (2) Integrating IoT in PSS lifecycle. To get a wide-ranging understanding of IoT and PSS in research and practice, we use a structured literature review (Webster and Watson 2002a) and expert interviews (Gläser and Laudel 2010). The results provide a comprehensive overview on ideas and practices that IoT delivers for innovative PSS design and development. With regard to business development aspect, a framework elaborates the implications of different degrees of IoT involvement for different types of PSS. Furthermore, we present the core concepts and technologies, which IoT enables and can be employed to facilitate PSS lifecycle management.

Theoretical Background

PSS

PSS refers to a strategic business model design intended to integrate and combine products, services and communication based on changing costumer and stakeholder demands (Beuren et al. 2013). The concept was introduced in 1999 as a promising business model for "sustainable economic growth" (Baines et al. 2007; Maleki et al. 2017). Most articles investigating PSS rely on the definition of Goedkoop et al. (1999), who stress: *"A Product-Service System is a marketable set of products and services capable of jointly fulfilling a user's need. A Product is a tangible commodity, manufactured to be sold. A Service is an activity (work), often done on a commercial basis and for others with an economic value. A System is a combination of elements including their relations."*

Table 1 . PSS Types According to Reim et al. (2015)

	Product-oriented	Use-oriented	Result-oriented
Value Creation	Provider takes responsibility for the contracted services.	Provider is responsible for the usability of the product or service.	Provider is responsible for delivering results.
Value Delivery	Provider sells and services the product sale and service (e.g., maintenance or recycling).	Provider assures the usability of the physical product along with service.	Provider actually delivers result.
Value Capturing	Customer pays for physical product and for the performed services.	Customer can make continuous payments over time (e.g., leasing).	Customer payments are based on outcome units; that is, they pay for the result.

The PSS literature has recognized the importance of implementing integrated product-service offerings, considering them as a powerful source of competitive advantage and sustainability (Ardolino et al. 2016; Schuh et al. 2016). PSS has proven to provide advantages such as higher profit margins, new growth opportunities in saturated markets and long-term customer relationships. Besides advantages for PSS providers, PSS also benefits consumers, the environment and the society (Beuren et al. 2013). Nonetheless, PSS implementation can be challenging and lead to inconsistencies among heterogeneous teams and developing artefact (Basirati et al. 2018). Moreover, PSS adoption into existing business models is not a straightforward procedure and requires applying proper strategies (Weking et al. 2018).

Within the PSS research stream, three types of PSS have emerged. Namely, product-oriented, use oriented and result-oriented PSSs (Baines et al. 2007; Tukker 2004; Yang et al. 2009). This classification is widely accepted in the literature. Table 1 describes the three different categories of PSS with regard to their underlying business model elements (Reim et al. 2015).

Another way of looking at the three types of PSS is how far they are on the innovation scale: result-oriented PSS is the most innovative and product-oriented PSS is the least innovative. To evolve from product-oriented to result-oriented PSS, there are incremental paths and radical paths. Incremental innovation in this context means that product-oriented PSS evolves slowly to use-oriented and then further to result-oriented. This happens through a slow and steady continuous improvement process. Radical innovation, on the other hand, means that product-oriented PSS transforms directly into result-oriented PSS, skipping the use-oriented stage. This often involves a radical shift in technology and leads to a total reconfiguration of the PSS (Jing, 2012, p. 791).

IoT

The term "Internet of Things" was introduced by Kevin Ashton in a presentation in 1998 (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014) and is now a technological concept with wide areas of application (Tao et al. 2014). However, there is yet no standard definition for IoT due to the fact that research about IoT is still in its infancy. Building of the seminal work of Gubbi et al. (2013), we define IoT as: *"Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless large scale sensing, data analytics and information representation using cutting edge ubiquitous sensing and cloud computing." (Gubbi et al. 2013).*

The concept of Internet of things (IoT) includes both technology and services that are based on connected objects and the use of the collected data (Čolaković and Hadžialić 2018). Everyday objects can be equipped with sensors and actuators to communicate, generate and process data (Whitmore et al. 2015). Usually an object, also called a thing, communicates over network protocols with a service in the cloud (Guth et al. 2018).

We elaborate the essential components of IoT comprised within a four-layered technology stack, which comprises the insights of Bandyopadhyay and Sen (2011), Porter and Heppelmann (2014; Vuppala and Kumar (2014), Lee et al. (2013), Georgakopoulos and Jayaraman (2016), Mazhelis et al. (2012) and Wortmann and Flüchter (2015). Table 2 illustrates the multiple technology layers. The layers are independent, which means that all components can be developed independently. The communication between the components ideally proceeds through well-defined interfaces and a shared cloud-based platform. In general, the two lower layers are responsible for data capturing, where the data is generated and collected by the low-end sensor nodes. The two upper layers are contributing to data processing and data utilization in applications.

Table 2 – Four Layers of IoT Components

Application Services	Services	Analyze and Learn	Respond
Cloud Computing	Store	Process	Share
Sensor Network	-	Capture	Transmit
Physical Layer	-	Hardware	Software

IoT for PSS

There are few studies, which addressed the relationship between IoT and PSS. Predominantly, the studies investigated application of IoT for PSS development in case studies. For example, Seregni et al. (2016) analyzed three commercial PSS cases, which incorporated IoT technologies into their systems. Based on available public information about the cases, they compared which new services IoT enabled for the PSS cases. They analyzed the cases with regard to four categories, namely, identity-related services, information aggregation services, collaborative-aware services and ubiquity services. Moreover, they investigated whether IoT supported delivery or order phase of the PSS and whether the customer side or the PSS provider side. Nevertheless, the study does not dive deep into the subject and only presents a preliminary analysis.

Another cases study is conducted by Elia et al. (2016) on integrating IoT in a PSS solution for waste collection. The main contribution is the performance evaluation of such a solution and comparing it to traditional non-PSS solutions. The study shows that IoT-enabled PSS is significantly better than traditional methods for waste collection; however, the study rarely focuses on IoT aspects and does not expose any IoT integration insights.

Zancul et al. (2016) propose a method for adopting IoT-enabled PSS regarding its business model. Their method consists of two parts. First, they follow the failure mode and effect analysis (FMEA) approach in order to analyze which features of IoT should be integrated with the product. Second, they use a PSS business strategy configurator that assists PSS providers to positions themselves during the innovation planning. They merge the results of configurator with FMEA approach and determine what product features and PSS processes must be implemented with the help of IoT. They apply and evaluate their method in a case study.

Similarly, Shih et al. (2016) propose a PSS design method that extends visual mapping methods for service creation such as (Matzen and McAloone 2009) and (Moritz 2009) with the aim of incorporating IoT technologies. They introduce a new concept called “pseudo-actor”, which stands for an IoT-enabled object with sensors and actuators. Their method tackles selecting IoT technology alternatives for customer value creation. The method mostly focuses on design of PSS for engineers and the study does not cover general IoT potentials for PSS.

In summary, the existing studies on the integration of IoT in PSS are mostly application-oriented and partially cover the ways, in which IoT support PSS. Particularly, there is lack of knowledge on what general opportunities IoT can provide for PSS in general. Hence, in this study, we build a first theoretical framework to integrate different views on the opportunities of IoT for PSS.

Study Design

To gain a deeper understanding of opportunities of IoT for PSS from a theoretical and a practical perspective, we conducted a structured literature review based on Vom Brocke et al. (2009) and Webster and Watson (2002b) and expert interviews based on Gläser and Laudel (2010), Mayring (2010) and Miles and Huberman (1994). We employed such a mixed-method approach with the purpose of ‘completeness’ (Venkatesh et al. 2013). We aimed to reach a complete picture of the phenomenon of interest by mixing evidences from the literature and practice.

Systematic Literature Review

To analyze opportunities of IoT for PSS from literature, we applied the approach and instructions based on Vom Brocke et al. (2009) and Webster and Watson (2002b). Table 3 gives an overview of this process and resulting numbers of analyzed publications. We used the databases IEEE, SpringerLink, ScienceDirect and Scopus. We applied the following research string: (Lifecycle OR Life-cycle OR “Life cycle”) AND (Development OR Manufacturing OR Production OR Deployment) AND (Interdisciplinary OR Multidisciplinary OR “Product Service System” OR “Cyber Physical System”) OR IoT OR “Internet of Things” OR Servitization OR Digitalization. We included all types of scientific literature and did not confine to a specific publication year range or ranking.

For the analysis, we first analyzed title and abstracts and removed duplicates. We selected only relevant publications based on sets of inclusion and exclusion criteria. The exclusion criteria consists of papers with main focus on IoT implementation or tools. The inclusion criteria are papers, which addressed lifecycle management in the context of IoT and PSS, and IoT integration in business. This selection reduced the number of possible relevant publications to 160. In the second screening, we studied the full text of the papers and evaluated their relevance to our research question. We ended up with 72 relevant papers.

Table 3. Outcome of Database Search

Database	*Initial search*	*Title and abstract screening*	*Full text screening*
IEEE	124	25	17
SpringerLink	1127	72	20
ScienceDirect	53	21	16
Scopus	683	42	19
Total	1987	160	72

Expert Interviews

As the literature review reveals some gaps, we enriched our data with expert interviews based on Gläser and Laudel (2010), Mayring (2010). For the sampling of interviews, we looked for enterprises and start-ups across different application fields of IoT. We chose business managers that consider or involve IoT in their processes, consultants that offer IoT solutions, and start-ups working in the field of IoT. We conducted 13 semi-structured interviews, which their details are presented in Table 4.

Table 4. Interview Details

Interview ID	*Job Description*	*Industry*	*Employees*	*Duration (Minutes)*
Participant 01	Business development manager	Global e-commerce & cloud computing	~566 000	~35
Participant 02	IoT evangelist & business development manager	Global e-commerce & cloud computing	~566 000	~15
Participant 03	Machine Learning Expert	Research institute	~200	~40
Participant 04	Data scientist for rail transportation	Industrial manufacturing	~372 000	~10
Participant 05	Hardware product developer	Start-up in the field of automatization solutions	~12	~20
Participant 06	Innovation manager	Manufacturer of braking systems for rail and commercial vehicles	~25 000	~35
Participant 07	Chief Technology Officer	Start-up in the field of digital gastronomy	~12	~45
Participant 08	Consultant for innovation & product lifecycle management	Global IT consultancy	~120 000	~50
Participant 09	Product manager for digital lab and smart home	Global automotive manufacturer	~125 000	~25
Participant 10	Digital E-Care	Global telecommunication company	~ 1800	~70

Participant 11	IoT consultant and app developer	IoT consultancy and software house	~ 124 000	~35
Participant 12	Product manager for industrial communication	Industrial manufacturing company	~372 000	~20
Participant 13	Consultant and developer	IoT consultancy	~10 000	~50

The interviews were based on a semi-structured interview guideline with open questions (Gläser and Laudel 2010) to ensure some common topics and leave room for specific aspects of every expert. Every expert was asked about general opportunities of IoT and realized applications of IoT (I), opportunities and realized applications resulting from new data (II), and opportunities and realized applications for their specific processes, products or product service systems (III). For data analysis, all interviews were transcribed and openly coded according to Corbin et al. (2014). Our coding is shaped around two core concepts, IoT enablement for PSS business model and IoT enablement for PSS implementation.

IoT as PSS Business Model Enabler

Table 5. Framework of IoT-PSS Business Model Opportunities

		Product-oriented PSS	**Use-oriented PSS**	**Result-oriented PSS**
IoT-Driven PSS	**Transforming**	Autonomous Product and Manufacturing	Continuously Improving Advanced Services	Proactive Smart Results
	Optimizing	Efficient Product and Manufacturing	Personalized Services	Smart Results
IoT-Supported PSS	**Interacting**	Smart Product	Engaging Services	Engaging Results
	Tracking	High Product Quality; Advanced Sales	High Service Quality; Lower Maintenance Cost;	Customized results

As the first part of the results, we present the framework of IoT-PSS business model opportunities (depicted in Table 5). The horizontal axis of the framework stands for three general types of PSS introduced by Tukker (2004). The vertical axis presents the levels of IoT involvement in PSS concept. The four levels are inspired by capability levels of smart products introduced by Porter and Heppelmann (2014) and cover a wide range of IoT implications from simple sensor-enabled products to complex product and service connectivity with autonomous behaviors. The first two levels, namely tracking and interacting, enable IoT-supported PSS. The other levels, namely, optimizing and transforming, enable IoT-driven PSS. While an IoT-supported PSS is a PSS enhanced with IoT technologies, IoT fundamentally affect PSS design and implementation in an IoT-driven PSS. In other words, IoT is the main value creator in an IoT-driven PSS. The inner text of every cell in the framework encapsulates the potential added-value by IoT for each PSS type. However, the value can be derived from many aspects, which we will discuss in this section.

Tracking

Tracking is the lowest level of IoT integration in PSS business models. It enables tracking primary product, service, user and their attributes such as quality and performance metrics. The tracking capability increases awareness of not only the system, but also the environment, in which the PSS is functioning (Lee et al. 2013). For instance, we can even track complex parameters such as frost risk and humidity using smart water sensors (Participant 13). Therefore, the provider would be able to add extra value by improving the quality in use for the users and decrease the maintenance costs (Beuren et al. 2016; Zancul et al. 2016). An important implication of tracking is reflected in product delivery phase and logistics (Barbosa et al. 2016; Papakostas et al. 2016; Porter and Heppelmann 2014). An example of result-oriented PSS enabled by IoT is a wireless connected single-function button that allows customers to order products or services (Participant 02; Participant 01). Tracking and storing processes into these buttons enable us to ask for the result instantly by a click of the button. Another example would be location-based services to users, which is enabled by tracking capabilities of IoT. Therefore, we would be able to improve the customer experience and increase the usage or purchase rate (Participant 07).

Interacting

As the next level, IoT enables a PSS to not only track and report PSS-related data, but also have some degree of action. This can be realized using an event-based scheme or direct interaction with the user. For example, in case of a smart home PSS – in which the home devices and appliances are owned by the PSS provider and the usage is sold to the customer - the lights of a smart home can be turned on or off automatically due to the outside light or the user can directly control them remotely. Similarly, the product would be able to react proactively to a particular condition. The idea is that the product has some degree of self-diagnosis and is able to interact with the user or provider. For example, the user will be informed to replace a part in case of an error. Such an ability increases the customer engagement with the PSS (Participant 13). In general, according to the interviews, interacting capabilities of IoT allows PSS providers to introduce new field services (Participant 04; Participant 06; Participant 07). Connected devices, simple interaction abilities with the environment and conditional clauses – provided by IoT – realize new advanced services for a PSS (Participant 10; Participant 03; Participant 04).

Optimizing

The interviewees argue, although tracking and interacting capabilities added by IoT support creating new business models, they are not sufficient (Participant 03; Participant 13). Thus, we need to involve IoT more into the development of PSS business models and the next step is optimizing capability, which is built upon the preceding capabilities. The collected and processed data during tracking and interacting allows advanced analysis of products and services, particularly in the usage phase. This empowers PSS providers in order to increase the performance of products and services, decrease their costs and identify new opportunities for extending their business models (Vuppala and Kumar 2014). Optimizing capability allows the smartness of a PSS to be dynamic and to evolve through the lifecycle (Barbosa et al. 2016). For instance, sales services become much more intelligent by analyzing the usage data in an IoT-supported PSS (Herterich et al. 2015; Zancul et al. 2016). In addition, pricing can be continuously be calculated in a real-time manner (Zancul et al. 2016). Interviewees perceived great opportunities based on machine learning algorithms, which are able to improve the system functions continuously (Participant 01; Participant 03; Participant 12). They believed such machine learning techniques combined with connectedness of products and services over a PSS enabled by IoT provides opportunities to automate processes and create advanced solutions (Participant 07). Many interviewees emphasized the importance of optimizing with regard to control of PSS failure behavior (Participant 04; Participant 03).

Transforming

Built on the entire IoT technology stack, transforming capability of IoT for PSS is realized by high level of autonomous operations and seamless communication with other networks (Gigli and Koo 2011; Porter and Heppelmann 2014). Transformation for the smart home example means that the home appliances track their usage, perform analysis and accordingly change their behavior, interact with the user as well as other devices and the PSS provider. Therefore, there is a total connectedness and interaction among the people and machines with the aim of maximizing the products performance and quality of services (Participant 09). The products and service provision as well as the customer's experience can significantly be reshaped by total IoT integration (Participant 01). With regard to the autonomy aspect, edge processing - processing power at the edge of the network – is a key ability. It allows local decision makings for every object in the system by collecting raw sensor data, filtering the data and processing the data at its source by intelligent devices (Barbosa et al. 2016; Haller et al. 2008). During the maintenance phase, the system would be able not only to warn the provider or the user, but also to enable the provider to employ a predictive maintenance scheme as well as a real-time autonomous decision making (Zancul et al. 2016). To create more value, it is necessary to establish a combination of machine-learning methods with real-time and cloud-based infrastructure as well as communication across the system's network (Participant 10; Participant 03).

IoT as PSS Lifecycle Management Enabler

Based on the literature and the interviews, we identified the related core potential concepts, which are presented in Figure 1. IoT involvement leads to an increasing amount of data of the PSS and PSS development. The data can be exploited continuously for production improvement and closed-loop lifecycle management reflects this capability. The second aspect tackles collaboration issues in PSS development, which is inherently challenging because of variety of involved disciplines. IoT supports collaboration by enabling communication among machines and humans. Another implication of IoT for the PSS development is the higher degree of autonomy for the PSS development. In addition to the overall concepts, IoT enables specific technologies and paradigms regarding every phase of PSS development. Regarding the PSS development phases of PSS, we follow general accepted differentiation between beginning of life (BOL), middle of life (MOL) and end of life (EOL) phases. These phases present respectively the design, manufacturing, logistics, use, maintenance, reuse and recycling (Beuren et al. 2016; Terzi et al. 2010). Along these phases, we identified four underlying opportunities, namely, digital twin, smart logistics, predictive maintenance and remanufacturing.

Closed-loop Lifecycle Management (CLLM) stands for ubiquity of product-relevant information at any point in the lifecycle (Wiesner et al. 2015; Wuest et al. 2014). Such omnipresence enables stakeholders to track and manage the data even during the use (Kiritsis 2011). In traditional lifecycle management, considerable amount of relevant data is either lost or acquired with high cost. Consequently, there is a limited visibility of products and services for the PSS provider (Basselot et al. 2017; Igba et al. 2015). IoT tracking capabilities overcome such a challenge by low-cost collecting of relevant data among lifecycles of PSS product parts and PSS services (Basselot et al. 2017). Moreover, incorporating IoT into the PSS development would solve challenge of low interoperability among heterogeneous working units that prevents CLLM realization (Basselot et al. 2017; Igba et al. 2015). The interviews reflected the same argument that with the help of IoT, we would collect and manage PSS-related data necessary for CLLM (Participant 01; Participant 06). PSS providers would be able to increase the quality of their product and services continuously. In addition to tracking status of a product, i.e. product-focused data, Matsas et al. (2017) introduce user-focused data, which reflect only usage information and attributes perceived by the user. Utilizing these two types of data can

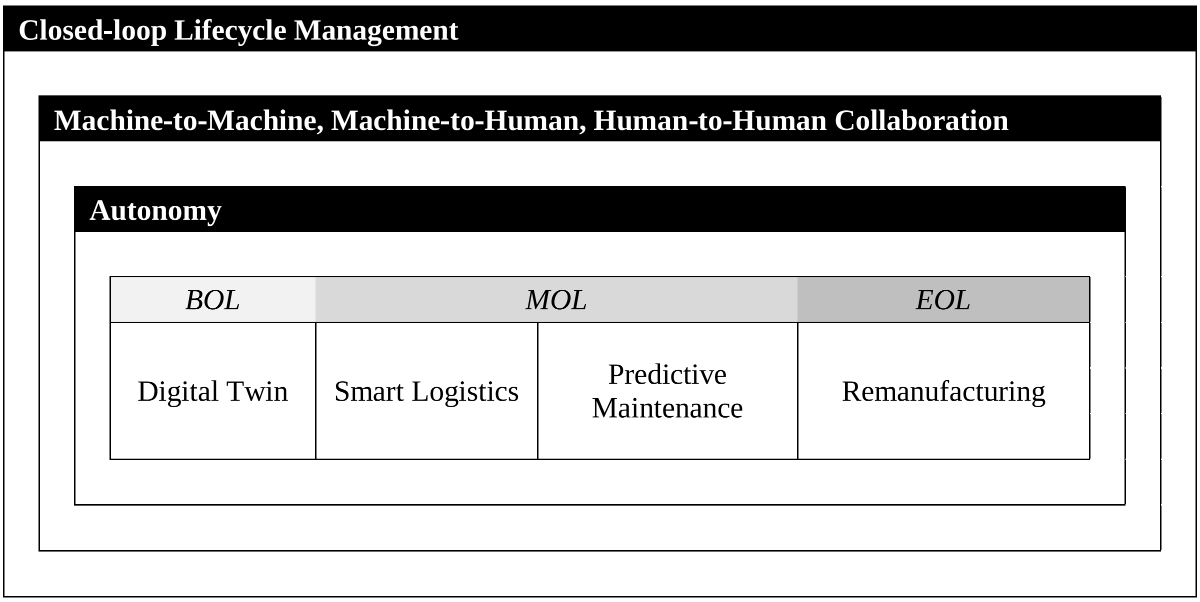

Figure 1 – Opportunities of IoT for PSS Lifecycle Management

significantly support requirements elicitation and management for PSS' products and services and even introducing new ones (Gudergan et al. 2017; Wuest and Wellsandt 2016; Yang et al. 2009).

Collaboration-related aspects are challenging for PSS development as PSS development involves high number of teams and disciplines, whose tools and methods differ (Gopsill et al. 2011). IoT capabilities mitigate the severity of such a challenge in collaborations among humans and machines. First, IoT-enhanced machines would be able to transfer their information and adjust their conditions to be aligned with each other. Hence, **Machine-to-Machine (M2M)** collaboration would take place without the human intervention (Lee et al. 2013). With regard to **Human-to-Human (H2H)** collaboration, interviewees from a global e-commerce enterprise highlighted that employing IoT makes the relationship among manufacturers deeper as it increases the interoperability and the supply chain performance can be monitored nearly real-time (Participant 01; Participant 02). Interviewees also agreed that unleashing the potential of a complete IoT solution lead to engagement with new partners, vendors and platforms (Participant 11; Participant 03; Participant 01). Particularly, tools and development platforms in the context of IoT allow a wider range of developers to access the innovative capabilities and build up their knowledge collaboratively (Participant 03). Consequently, companies can focus on their core competence and core business activities (Participant 07).

M2M collaborations enabled by IoT establish new opportunities for process and factory automation by minimizing the human intervention (Ardolino et al. 2016; Gerpott and May 2016; Lee et al. 2013). Interviews showed cases in which IoT could automate the complete supply chain processes from an order on the website to final delivery. This led to cost reduction and improved customer experience (Participant 01; Participant 02). Moreover, incorporating advanced machine learning techniques based on data collected and filtered by IoT empowers **autonomous** decision-makings, self-coordination and self-diagnosis abilities (Porter and Heppelmann 2014), which is confirmed by the interviews (Participant 11; Participant 03). However, the interviewees argued that there are several challenges that impede realizing high autonomy. For example, yet there are no advances in automated self-criticism, in which the system recognizes its mistakes (Participant 03). In addition, there is still lack of trust in automation operations, which does not allow its full integration into the lifecycle management (Participant 03).

Digital twin or product avatar refers to digital equivalent of a physical product. Integrating actual physical data with the virtual replication of a product enables a better design, validation and verification of engineering artefacts (Goto et al. 2016). In general, there is a trend towards use of digital twin enabled by IoT capabilities (Participant 08). Digital twin can be engaged for predicting, optimizing and verifying the products along the lifecycle. However, it plays a significant role in BOL phase by incorporating feedbacks from MOL and EOL phases into improving the design and simulating different options (Participant 01; Participant 02). For instance, a digital presentation of a product supports evaluating performance of the product in diverse environments. Moreover, applying a change in PSS can be first reflected in the virtual setting and the results can be used to realize PSS more efficiently (Participant 02; Participant 08). Another important ability of digital twin is that we can present the system thoroughly and more easily to different stakeholders along the entire lifecycle (Participant 02; Participant 08). Use of digital twin reduces the delays, increases the overall development efficiency and transparency of customers' processes (Meneghetti et al. 2016).

Smart logistics is enabled by tracking and optimizing abilities of IoT. IoT establishes an overall connectivity of all devices and product parts, which empowers efficient delivery of products and integrated services (Vuppala and Kumar 2014). For instance, IoT supports activities such as resource allocation (Barbosa et al. 2016) and inventory management (Papakostas et al. 2016). Moreover, with the help of IoT, autonomous vehicles would be able to optimize transportations during the manufacturing and facilitate distributed orders (Mueller et al. 2017). Based on the interviews, such capabilities of IoT are currently in use in several manufacturing leaders (Participant 01).

Predictive maintenance is regular monitoring and analyzing of the system conditions in order to minimize the number of failures and repairs (Mobley 2002). Since IoT provides valuable insight with regard to the PSS and its usage, it can minimize the time for error diagnosis (Lerch and Gotsch 2015). For example, with the help of IoT sensors and analysis of the collected usage data, we would be able to elicit spare part requirements (Herterich et al. 2015; Zancul et al. 2016) Several interviewees reported that they have experienced considerable savings by incorporating IoT capabilities into the maintenance activities (Participant 01; Participant 08; Participant 05). Moreover, they stated that increased availability resulted from a more efficient maintenance led to higher customer satisfaction.

Remanufacturing stands for the industrial process, in which we restore and recover used products into a good condition (Lindkvist and Sundin 2016). Hence, experiences of later stages of lifecycle would be employed in the earlier stages (Igba et al. 2015). Realizing remanufacturing necessitates tracking, controlling and analyzing the product, the condition of the product and the usage of product, which can be enabled by means of IoT (Chierici and Copani 2016). Ideally, there is a feedback loop between each lifecycle phases.

Discussion

IoT paradigm can transform the industry and be as influential as the Internet was in the 1990s. Our findings showed that practitioners assert high potential of IoT for facilitating new business models, designing new products and providing advanced services. In conformance with this fact, the prior research emphasized on transforming abilities of IoT and the big impact that IoT can have on businesses (Čolaković and Hadžialić 2018; Gubbi et al. 2013; Porter and Heppelmann 2014). Particularly, IoT can play a crucial role for PSS (Seregni et al. 2016; Shih et al. 2016; Zancul et al. 2016). Due to challenging nature of PSS, which transforms merely product or service businesses into an integrated enterprise of product and service provision, more connectedness and communication among heterogeneous elements is necessary (Vasantha et al. 2012; Wiesner et al. 2015). Strengths of IoT matches to the difficulties that PSS design and development confront.

The existing studies on IoT and PSS relationship limit to single case applications of a particular method for adopting IoT in PSS development (Shih et al. 2016; Zancul et al. 2016). We extend the current literature by establishing a comprehensive view on the opportunities that IoT can provide for PSS. We presented the framework of IoT-PSS business model opportunities that introduces four levels of IoT involvement in PSS. Based on the framework, there is a wide range of IoT integration into PSS. It starts from basic IoT-supported tracking abilities in PSS to transformed IoT-driven PSS with IoT as its core value creator. The framework assists PSS providers in positioning themselves, identifying the extent, to which they have already benefited from IoT and the possibilities, which they have not realized yet. Furthermore, we identified and highlighted the core IoT-enabled opportunities, which facilitate PSS lifecycle management. Although the concepts vary largely from M2M collaboration to digital twin and remanufacturing, they are mutual in terms of being enabled by IoT and advancing PSS lifecycle management. Nevertheless, diving deep into the details of implementing such technologies in the domain of PSS was out of scope of this study and can be investigated in future research. We argue that our study provides the fundamentals for advancing PSS and IoT integration research. Future studies can build new concepts, methods and tools upon the established frameworks of this study.

Combining the two folds of this study’s contribution enlighten the overall IoT exploitation for PSS design and development. Insightful alignment of IoT and PSS allows various added-values for both businesses and the customers. Regarding the customer values, PSS providers would be able to establish a reliable connection with the customer, partners and suppliers by a right IoT integration. Customers can expect a continuous improving product and service, which are also more customized to their usage. In addition, customers would benefit from a higher availability of product and services. In context of the business values, IoT integration shortens the development cycles and reduces costs of development. PSS providers will have a shorter time-to-market, which is a decisive aspect in a competitive environment. Moreover, utilizing IoT decreases costs of maintenance and remanufacturing significantly. For example, there would be no need for on-site monitoring of product conditions as the sensors are continuously tracking the relevant information. At its extreme realization, PSS providers will gain autonomy and transparency during all phases of PSS lifecycle. Even though a limited integration of IoT in PSS enables PSS providers to introduce smart products and advanced services, which can lead to a higher revenue.

According to our findings from the interviews, IoT technologies have been integrated mostly on the end-customers side, despite the fact that B2B applications of IoT can have greater economic outcomes. Moreover, we observed a slow progress regarding the shift from IoT-supported PSS to IoT-driven PSS. Although, lack of infrastructural capabilities can be considered as an important factor that stops IoT integration, complicated barriers exist, which future studies need to investigate them in detail. For example, there is still uncertainty about costs and profits of IoT adoption, particularly at its highest extent. Mechanisms to analyze and estimate IoT adoption in terms of monetary parameters would significantly support the realization of IoT opportunities. Furthermore, IoT integration is fostering a collaborative ecosystem, in which many start-ups have emerged as IoT technology providers. Future studies can look more into how we can ease the integration of such start-ups' contributions into existing infrastructures. With this regard, the research should study the role of emerging IoT platforms, which will facilitate use of IoT for variety of applications.

Conclusion

In addition to empowering the existing solutions, IoT enables us to realize new ideas. Particularly, we can use the power of IoT to facilitate complexity of PSS design and development. In this study, we investigated opportunities that IoT can provide for PSS business models and lifecycle management. We provided examples for each relevant hotspot to assist PSS providers in positioning and deciding a right business model when integrating IoT in their portfolio. First, we introduced framework of IoT opportunities for PSS business models that entails two dimensions of IoT involvement level and PSS types. It evaluates which type of services IoT technologies foster for the provision of PSS. Furthermore, we analyzed IoT as a key facilitator of the lifecycle management by enabling new technologies and capabilities such as autonomy, closed-lifecycle management, digital twin, predictive maintenance and remanufacturing.

The findings of this study provide new insights for PSS providers. Moreover, this study establishes a comprehensive view on opportunistic implications of IoT for PSS, which paves the path for future studies to advance this topic. The research can complete this work by addressing on one hand, the barriers for integrating IoT into PSS and on the other hand, the challenges caused by IoT integration into PSS. Accordingly, the studies can propose solutions to overcome such challenges.

Acknowledgements

This work was supported by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) collaborative research centre 'Sonderforschungsbereich SFB 768 "Managing cycles in innovation processes – Integrated development of product-service-systems based on technical products".

References

Adrodegari, F., and Saccani, N. 2017. "Business Models for the Service Transformation of Industrial Firms," The Service Industries Journal (37:1), pp. 57-83.

Ardolino, M., Saccani, N., Gaiardelli, P., and Rapaccini, M. 2016. "Exploring the Key Enabling Role of Digital Technologies for Pss Offerings," Procedia CIRP (47), pp. 561-566.

Baines, T. S., Lightfoot, H. W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., and Tiwari, A. 2007. "State-of-the-Art in Product-Service Systems," Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture (221:10), pp. 1543-1552.

Bandyopadhyay, D., and Sen, J. 2011. "Internet of Things: Applications and Challenges in Technology and Standardization," Wireless Personal Communications (58:1), pp. 49-69.

Barbosa, J., Leitão, P., Trentesaux, D., Colombo, A. W., and Karnouskos, S. 2016. "Cross Benefits from Cyber-Physical Systems and Intelligent Products for Future Smart Industries," Industrial Informatics (INDIN), 2016 IEEE 14th International Conference on: IEEE, pp. 504-509.

Basirati, M. R., Zou, M., Bauer, H., Kattner, N., Reinhart, G., Lindemann, U., Böhm, M., Krcmar, H., and Vogel-Heuser, B. 2018. "Towards Systematic Inconsistency Identification for Product

Service Systems," DS92: Proceedings of the DESIGN 2018 15th International Design Conference, pp. 2811-2820.
Basselot, V., Berger, T., and Sallez, Y. 2017. "Active Monitoring of a Product: A Way to Solve the “Lack of Information” Issue in the Use Phase," in Service Orientation in Holonic and Multi-Agent Manufacturing. Springer, pp. 337-346.
Beuren, F. H., Ferreira, M. G. G., and Miguel, P. A. C. 2013. "Product-Service Systems: A Literature Review on Integrated Products and Services," Journal of cleaner production (47), pp. 222-231.
Beuren, F. H., Pereira, D., and Fagundes, A. B. 2016. "Product-Service Systems Characterization Based on Life Cycle: Application in a Real Situation," Procedia CIRP (47), pp. 418-423.
Chierici, E., and Copani, G. 2016. "Remanufacturing with Upgrade Pss for New Sustainable Business Models," Procedia CIRP (47), pp. 531-536.
Čolaković, A., and Hadžialić, M. 2018. "Internet of Things (Iot): A Review of Enabling Technologies, Challenges, and Open Research Issues," Computer Networks).
Corbin, J., Strauss, A., and Strauss, A. L. 2014. Basics of Qualitative Research. sage.
Elia, V., Gnoni, M. G., and Tornese, F. 2016. "Assessing the Efficiency of a Pss Solution for Waste Collection: A Simulation Based Approach," Procedia CIRP (47), pp. 252-257.
Exner, K., Zimpfer, R., and Stark, R. 2017. "Maturity Model and Action Recommendation: A Pss Capability Self-Assessment Tool for Companies," Procedia CIRP (64), pp. 175-180.
Georgakopoulos, D., and Jayaraman, P. P. 2016. "Internet of Things: From Internet Scale Sensing to Smart Services," Computing (98:10), pp. 1041-1058.
Gerpott, T. J., and May, S. 2016. "Integration of Internet of Things Components into a Firm’s Offering Portfolio–a Business Development Framework," info (18:2), pp. 53-63.
Gigli, M., and Koo, S. G. 2011. "Internet of Things: Services and Applications Categorization," Adv. Internet of Things (1:2), pp. 27-31.
Gläser, J., and Laudel, G. 2010. Experteninterviews Und Qualitative Inhaltsanalyse. Springer-Verlag.
Goedkoop, M. J., Van Halen, C. J., Te Riele, H. R., and Rommens, P. J. 1999. "Product Service Systems, Ecological and Economic Basics," Report for Dutch Ministries of environment (VROM) and economic affairs (EZ) (36:1), pp. 1-122.
Gopsill, J. A., McAlpine, H. C., and Hicks, B. J. 2011. "Learning from the Lifecycle: The Capabilities and Limitations of Current Product Lifecycle Practice and Systems," DS 68-6: Proceedings of the 18th International Conference on Engineering Design (ICED 11), Impacting Society through Engineering Design, Vol. 6: Design Information and Knowledge, Lyngby/Copenhagen, Denmark, 15.-19.08. 2011.
Goto, S., Yoshie, O., and Fujimura, S. 2016. "Internet of Things Value for Mechanical Engineers and Evolving Commercial Product Lifecycle Management System," Industrial Engineering and Engineering Management (IEEM), 2016 IEEE International Conference on: IEEE, pp. 1021-1024.
Gubbi, J., Buyya, R., Marusic, S., and Palaniswami, M. 2013. "Internet of Things (Iot): A Vision, Architectural Elements, and Future Directions," Future generation computer systems (29:7), pp. 1645-1660.
Gudergan, G., Buschmeyer, A., Feige, B. A., Krechting, D., Bradenbrink, S., and Mutschler, R. 2017. "Value of Lifecycle Information to Transform the Manufacturing Industry," in Shaping the Digital Enterprise. Springer, pp. 173-194.
Guth, J., Breitenbücher, U., Falkenthal, M., Fremantle, P., Kopp, O., Leymann, F., and Reinfurt, L. 2018. "A Detailed Analysis of Iot Platform Architectures: Concepts, Similarities, and Differences," in Internet of Everything. Springer, pp. 81-101.
Haller, S., Karnouskos, S., and Schroth, C. 2008. "The Internet of Things in an Enterprise Context," Future Internet Symposium: Springer, pp. 14-28.
Herterich, M. M., Uebernickel, F., and Brenner, W. 2015. "The Impact of Cyber-Physical Systems on Industrial Services in Manufacturing," Procedia CIRP (30), pp. 323-328.
Igba, J., Alemzadeh, K., Gibbons, P. M., and Henningsen, K. 2015. "A Framework for Optimising Product Performance through Feedback and Reuse of in-Service Experience," Robotics and Computer-Integrated Manufacturing (36), pp. 2-12.
Kiel, D., Arnold, C., and Voigt, K.-I. 2017. "The Influence of the Industrial Internet of Things on Business Models of Established Manufacturing Companies–a Business Level Perspective," Technovation (68), pp. 4-19.

Kiritsis, D. 2011. "Closed-Loop Plm for Intelligent Products in the Era of the Internet of Things," Computer-Aided Design (43:5), pp. 479-501.

Kowalkowski, C., Windahl, C., Kindström, D., and Gebauer, H. 2015. "What Service Transition? Rethinking Established Assumptions About Manufacturers' Service-Led Growth Strategies," Industrial Marketing Management (45), pp. 59-69.

Lee, G. M., Crespi, N., Choi, J. K., and Boussard, M. 2013. "Internet of Things," in Evolution of Telecommunication Services. Springer, pp. 257-282.

Lerch, C., and Gotsch, M. 2015. "Digitalized Product-Service Systems in Manufacturing Firms: A Case Study Analysis," Research-Technology Management (58:5), pp. 45-52.

Lightfoot, H., Baines, T., and Smart, P. 2013. "The Servitization of Manufacturing: A Systematic Literature Review of Interdependent Trends," International Journal of Operations & Production Management (33:11/12), pp. 1408-1434.

Lindkvist, L., and Sundin, E. 2016. "The Role of Product-Service Systems Regarding Information Feedback Transfer in the Product Life-Cycle Including Remanufacturing," Procedia Cirp (47), pp. 311-316.

Maleki, E., Belkadi, F., Zhang, Y., and Bernard, A. 2017. "Towards a New Collaborative Framework Supporting the Design Process of Industrial Product Service Systems," in Advances on Mechanics, Design Engineering and Manufacturing. Springer, pp. 139-146.

Marilungo, E., Papetti, A., Germani, M., and Peruzzini, M. 2017. "From Pss to Cps Design: A Real Industrial Use Case toward Industry 4.0," Procedia CIRP (64), pp. 357-362.

Matsas, M., Pintzos, G., Kapnia, A., and Mourtzis, D. 2017. "An Integrated Collaborative Platform for Managing Product-Service across Their Life Cycle," Procedia CIRP (59), pp. 220-226.

Matzen, D., and McAloone, T. C. 2009. A Systematic Apporach to Service Oriented Product Development. DTU Management.

Maxwell, D., Sheate, W., and Van Der Vorst, R. 2006. "Functional and Systems Aspects of the Sustainable Product and Service Development Approach for Industry," Journal of cleaner production (14:17), pp. 1466-1479.

Mayring, P. 2010. "Qualitative Inhaltsanalyse," in Handbuch Qualitative Forschung in Der Psychologie. Springer, pp. 601-613.

Mazhelis, O., Luoma, E., and Warma, H. 2012. "Defining an Internet-of-Things Ecosystem," in Internet of Things, Smart Spaces, and Next Generation Networking. Springer, pp. 1-14.

Meier, H., Roy, R., and Seliger, G. 2010. "Industrial Product-Service Systems—Ips2," CIRP Annals-Manufacturing Technology (59:2), pp. 607-627.

Meneghetti, A., Moro, S., and Helo, P. 2016. "Intermixed Product and Service Boundaries: Exploring Servitization in Sheet Metal Industry," Procedia CIRP (47), pp. 258-263.

Miles, M. B., and Huberman, A. M. 1994. Qualitative Data Analysis: An Expanded Sourcebook. sage.

Mobley, R. K. 2002. An Introduction to Predictive Maintenance. Elsevier.

Mont, O. K. 2002. "Clarifying the Concept of Product–Service System," Journal of cleaner production (10:3), pp. 237-245.

Moritz, S. 2009. Service Design: Practical Access to an Evolving Field. Lulu. com.

Mueller, E., Chen, X.-L., and Riedel, R. 2017. "Challenges and Requirements for the Application of Industry 4.0: A Special Insight with the Usage of Cyber-Physical System," Chinese Journal of Mechanical Engineering (30:5), pp. 1050-1057.

Papakostas, N., O'Connor, J., and Byrne, G. 2016. "Internet of Things Technologies in Manufacturing: Application Areas, Challenges and Outlook," Information Society (i-Society), 2016 International Conference on: IEEE, pp. 126-131.

Patel, K. K., and Patel, S. M. 2016. "Internet of Things-Iot: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges," International journal of engineering science and computing (6:5).

Porter, M. E., and Heppelmann, J. E. 2014. "How Smart, Connected Products Are Transforming Competition," Harvard business review (92:11), pp. 64-88.

Reim, W., Parida, V., and Örtqvist, D. 2015. "Product–Service Systems (Pss) Business Models and Tactics – a Systematic Literature Review," Journal of Cleaner Production (97), pp. 61-75.

Schuh, G., Salmen, M., Kuhlmann, T., and Wiese, J. 2016. "Life-Cycle-Oriented Product-Service-Systems in the Tool and Die Making Industry," Procedia CIRP (47), pp. 555-560.

Seregni, M., Sassanelli, C., Cerri, D., Zanetti, C., and Terzi, S. 2016. "The Impact of Iot Technologies on Product-Oriented Pss: The “Home Delivery” Service Case," Research and Technologies for Society and Industry Leveraging a better tomorrow (RTSI), 2016 IEEE 2nd International Forum on: IEEE, pp. 1-5.

Shih, L.-H., Lee, Y.-T., and Huarng, F. 2016. "Creating Customer Value for Product Service Systems by Incorporating Internet of Things Technology," Sustainability (8:12), p. 1217.

Tao, F., Zuo, Y., Da Xu, L., and Zhang, L. 2014. "Iot-Based Intelligent Perception and Access of Manufacturing Resource toward Cloud Manufacturing," IEEE Transactions on Industrial Informatics (10:2), pp. 1547-1557.

Terzi, S., Bouras, A., Dutta, D., Garetti, M., and Kiritsis, D. 2010. "Product Lifecycle Management-from Its History to Its New Role," International Journal of Product Lifecycle Management (4:4), pp. 360-389.

Tukker, A. 2004. "Eight Types of Product–Service System: Eight Ways to Sustainability? Experiences from Suspronet," Business strategy and the environment (13:4), pp. 246-260.

Ulaga, W., and Reinartz, W. J. 2011. "Hybrid Offerings: How Manufacturing Firms Combine Goods and Services Successfully," Journal of marketing (75:6), pp. 5-23.

Vasantha, G. V. A., Roy, R., Lelah, A., and Brissaud, D. 2012. "A Review of Product–Service Systems Design Methodologies," Journal of Engineering Design (23:9), pp. 635-659.

Venkatesh, V., Brown, S. A., and Bala, H. 2013. "Bridging the Qualitative-Quantitative Divide: Guidelines for Conducting Mixed Methods Research in Information Systems," MIS quarterly), pp. 21-54.

Vom Brocke, J., Simons, A., Niehaves, B., Riemer, K., Plattfaut, R., and Cleven, A. 2009. "Reconstructing the Giant: On the Importance of Rigour in Documenting the Literature Search Process," ECIS, pp. 2206-2217.

Vuppala, S. K., and Kumar, H. K. 2014. "Service Applications-Exploiting the Internet of Things," Global Conference (SRII), 2014 Annual SRII: IEEE, pp. 195-202.

Webster, J., and Watson, R. T. 2002a. "Analyzing the Past to Prepare for the Future: Writing a Literature Review," MIS Quarterly (26:2), pp. xiii-xxiii.

Webster, J., and Watson, R. T. 2002b. "Analyzing the Past to Prepare for the Future: Writing a Literature Review," MIS quarterly), pp. xiii-xxiii.

Weking, J., Brosig, C., Böhm, M., Hein, A., and Krcmar, H. 2018. "Business Model Innovation Strategies for Product Service Systems–an Explorative Study in the Manufacturing Industry," Twenty-Sixth European Conference on Information Systems (ECIS 2018).

Whitmore, A., Agarwal, A., and Da Xu, L. 2015. "The Internet of Things—a Survey of Topics and Trends," Information Systems Frontiers (17:2), pp. 261-274.

Wiesner, S., Freitag, M., Westphal, I., and Thoben, K.-D. 2015. "Interactions between Service and Product Lifecycle Management," Procedia CIRP (30), pp. 36-41.

Wortmann, F., and Flüchter, K. 2015. "Internet of Things," Business & Information Systems Engineering (57:3), pp. 221-224.

Wuest, T., Hribernik, K., and Thoben, K.-D. 2014. "Capturing, Managing and Sharing Product Information Along the Lifecycle for Design Improvement," Proceedings of the 10th International Workshop on Integrated Design Engineering.

Wuest, T., and Wellsandt, S. 2016. "Design and Development of Product Service Systems (Pss)-Impact on Product Lifecycle Perspective," Procedia Technology (26), pp. 152-161.

Yang, X., Moore, P., Pu, J.-S., and Wong, C.-B. 2009. "A Practical Methodology for Realizing Product Service Systems for Consumer Products," Computers & Industrial Engineering (56:1), pp. 224-235.

Zancul, E. d. S., Takey, S. M., Barquet, A. P. B., Kuwabara, L. H., Cauchick Miguel, P. A., and Rozenfeld, H. 2016. "Business Process Support for Iot Based Product-Service Systems (Pss)," Business Process Management Journal (22:2), pp. 305-323.