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Exploring Opportunities of IoT for Product–Service System Conceptualization and Implementation

Mohammad R. Basirati[a,*], Jörg Weking[b], Sebastian Hermes[c], Markus Böhm[d], Helmut Krcmar[e]

[a] *Research associate and Ph.D. student, Chair for Information Systems, Technical University of Munich (TUM), Germany*
[b] *Research associate and Ph.D. student, Chair for Information Systems, Technical University of Munich (TUM), Germany*
[c] *Research associate and Ph.D. student, Chair for Information Systems, Technical University of Munich (TUM), Germany*
[d] *Research Group Leader, Chair for Information Systems, Technical University of Munich (TUM), Germany*
[e] *Chair Professor, Information Systems, Technical University of Munich (TUM), Germany*

A B S T R A C T

Product–service systems (PSS), integrating physical products and services, currently play a crucial role in sustainable economies. In addition to the highly competitive global economy, the emergence of new digital paradigms is supporting the shift toward servitization. Although the great potential of such paradigms is recognized by both practice and research, their implications for PSS are not yet clear. In particular, 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 organize the findings in two folds: First, we introduce four degrees of IoT involvement in PSS business models and elaborate the opportunities that they create for different types of PSS. Second, we present the key technologies and approaches that IoT provides concerning PSS lifecycle management.

Keywords: Product–Service System, Internet of Things, IoT Integration, Review, Expert Interview

Ⅰ. Introduction

Firms have to increase their share of service offerings in order to survive in today's competitive global economy (Mont, 2002). Products are no longer the main contributors to value creation, as the value is shifting toward services. We can see this shift in the gross domestic product of most developed countries, which are more dependent on services than physical products (Meier et al., 2010). Consequently, more service-oriented business models, such as product–service systems (PSS), have emerged. Most definitions of PSS describe it as a system that integrates products and services in order to create a competitive

*Corresponding Author. E-mail: mohammadreza.basirati@tum.de Tel: 498928919598

solution (Beuren et al., 2013), while some definitions also emphasize its role in reaching sustainability with regard to environmental and social considerations (Baines et al., 2007; Maxwell et al., 2006).

A frequently cited example of a PSS is that of the Xerox company (Baines et al., 2007). Traditionally manufacturing print and copy machines, now Xerox provides print and copy solutions that comprise more service-side than product-side elements. A starting point for such a change was developing a pay-per-copy system, in which the machines were sold at a low price and copy function was seen as a service provided by Xerox. More recent and widespread examples of PSS are car-, bike-, and e-scooter-sharing systems. In such a PSS, the value is created by providing mobility as a service to the customer instead of selling a physical product such as a car.

At the same time, the emergence of advanced digital paradigms such as the 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 describing the networking of objects, which can sense, communicate, store data, and interact with the environment (Patel and Patel, 2016). IoT allows not only monitoring the status of physical objects but also establishes the basis for progressive services such as optimization and automization 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 to servitization, particularly PSS (Exner et al., 2017; Marilungo et al., 2017; Shih et al., 2016). In practice, however, the adoption of IoT is a challenging issue, as it requires an intensive reconfiguration of existing settings (Marilungo et al., 2017). However, past research has not provided 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:

What opportunities does IoT provide for PSS design and development?

We focus on two important aspects of PSS development: (1) integrating IoT into PSS business models, and (2) integrating IoT in the 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, 2002) and interview experts (Gläser and Laudel, 2010; Miles and Huberman, 1994). The results provide a comprehensive overview of ideas and practices that IoT delivers for innovative PSS design and development. With regard to the business-development aspect, a framework elaborates the implications of different degrees of IoT involvement for different types of PSS. We also present the core concepts of IoT and the technologies it enables, which can be employed to facilitate PSS lifecycle management. We extend a previously published study (Basirati et al., 2019) in two steps: First, we cover related prior research more comprehensively, and second, we provide real-world PSS cases for every aspect of IoT opportunity for PSS business models.

Ⅱ. Conceptual Background

2.1. Product–Service Systems

PSS refers to a strategic business-model design intended to integrate and combine products, services, and communication based on changing customer 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 definitions by Goedkoop et al. (1999):

"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."

Recognizing the importance of implementing integrated product–service offerings, PSS literature has considered them 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 the advantages for PSS providers, PSS also benefits consumers, the environment, and society (Beuren et al., 2013). Nonetheless, PSS implementation can be challenging and lead to inconsistencies among heterogeneous teams and developing artifact (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: product-oriented, use-oriented, and result-oriented PSS (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 in terms of their underlying business-model elements (Reim et al., 2015).

Another way of looking at the three types of PSS is to consider what point they have reached on the innovation scale; result-oriented PSS is the most innovative, and product-oriented PSS is the least innovative. For a PSS to evolve from product-oriented to result-oriented, it may take incremental steps and/or a radical path. 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.

The Xerox case, introduced in the previous section, is a typical product-oriented PSS example. All manu-

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

	Product-oriented	Use-oriented	Result-oriented
Value creation	The main responsibility of provider is service delivery.	The main responsibility of provider is the usability of the product or service.	Results are the main responsibility of provider.
Value delivery	Provider delivers extra services in addition to sold products (e.g., maintenance or recycling).	Provider focuses on service usability along with product usability.	The results are counted as the main deliverables instead of products or services.
Value capturing	Customer pays for the product and extra delivered services.	The payment is performed over usage phase continuously (e.g., leasing).	Customer pays based on outcome units instead of pay-per-use or pay-per-product.

facturers that provide maintenance and recycling services besides their products can be considered examples of the product-oriented PSS type.

Car-sharing and bike-sharing cases belong to use-oriented PSS type. In such cases, the price is calculated based on the units of usage. For example, BMW car-sharing service DriveNow[1] and Daimler car-sharing service car2go[2] charge the users based on a per-minute basis. The users can take any available car in the city and park it for free anywhere in the city. The cars (physical products) are typical car models manufactured by BMW and Daimler. However, these car manufacturers do not sell their cars in the PSS, but they use their physical products as a means to deliver mobility services to the users.

Result-oriented PSS has the highest level of servitization, in which the service-side creates more share of value than the product side (Yang et al., 2010). If a washing machine manufacturer provides its machines for free and charges the users on a pay-per-use basis, this would be a use-oriented PSS. It is possible to incorporate more servitization in such a PSS by delivering laundered clothes, i.e. the result, instead of the machines (Baines et al., 2007). Such a system would be a result-oriented PSS. A real-case advanced example of result-oriented PSS is Lufthansa's AVIATAR digital power platform[3], which provides various apps and services for airlines and their suppliers and partners. For instance, the airlines can create networks with each other and share their airplanes' spare parts with the purpose of increasing the availability.

1) https://www.drive-now.com
2) https://www.car2go.com
3) https://www.lufthansa-technik.com/aviatar

2.2. Internet of Things

The term "Internet of Things" was introduced by Kevin Ashton in a presentation in 1998 (Perera et al., 2014) and is now a technological concept with widespread applications (Tao et al., 2014). However, there is as yet no standard definition for IoT, as research about IoT is still in its infancy. Building on the seminal work of Gubbi et al. (2013), we define IoT as follows:

"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."

The IoT concept 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 within a four-layered technology stack (<Table 2>), which we based on the insights of several others earlier in this decade (Bandyopadhyay and Sen, 2011; Georgakopoulos and Jayaraman, 2016; Lee et al., 2013; Mazhelis et al., 2012; Porter and Heppelmann, 2014; Vuppala and Kumar, 2014; Wortmann and Flüchter, 2015). <Table 2> illustrates the multiple technology layers, including the physical, sensor network, cloud computing services and application services layer.

<Table 2> Four Layers of IoT Components

Application services	Analyzing data, learning and responding
Cloud computing	Storing, processing and sharing data
Sensor network	Transmitting data
Physical layer	Providing hardware infrastructure

The four layers are independent, which means that all components can be developed independently. Communication between the components ideally takes place through well-defined interfaces and a cloud-based shared platform. In general, the two lower layers are responsible for data capturing (data generation and collection) by low-end sensor nodes, while the two upper layers contribute to data processing and utilization in applications.

Each of the four layers (<Table 2>) has distinct capabilities, operations, and costs. The physical layer provides the infrastructural hardware components, such as embedded sensors, processors, and data storage. Connectivity among these components is reflected in the sensor-network layer, in which the data are transmitted by various technologies, such as Bluetooth, Ethernet, or RFID. To store and process the huge amounts of data captured in the physical layer and transmitted in the sensor-network layer, the cloud-computing layer provides mechanisms to aggregate and normalize the data. This layer also makes available the main attributes of the data for detailed analysis and may connect external sources of data (e.g., traffic and weather data). This layer can be considered as a platform that supports heterogenous devices, data privacy and security, and total integration within a bigger ecosystem (Marques et al., 2017). In the highest layer in the IoT technology stack, the application-services layer, the unit of analysis and operations is large in scale compared to the cloud-computing layer. On the basis of the other three layers, this layer provides a deep analysis of data and appropriate services.

On the basis of the extent to which each layer is configured and implemented, IoT can provide different PSS opportunities. Although the physical and sensor-network layers exist in every IoT system regardless of configuration, the cloud-computing and service-application layers may be absent. Therefore, the level of realization of each discussed layer can reflect the extent to which IoT can affect PSS design and development.

2.3. Internet of Things for Product–Service Systems

Few studies have addressed the relationship between IoT and PSS. Most are very recent and mainly use case studies to investigate the application of IoT-for-PSS development. For example, Seregni et al. (2016) analyzed three commercial PSS cases that incorporated IoT technology into their systems. Available information about the cases indicates that they compared which new services IoT-enabled for the PSS cases. They analyzed the cases with regard to four categories—identity-related, information-aggregation, collaborative-awareness, and ubiquity services. They also investigated whether IoT-supported the delivery or order phase of the PSS and whether on the customer side or the PSS provider side. Nevertheless, the study does not go into the subject at depth, instead presenting only a preliminary analysis. Another case study, conducted by Elia et al. (2016) looked at integrating IoT in a PSS solution for waste collection; its main contributions are an evaluation of the performance of such a solution and its comparison 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 the IoT aspects and does not mention any IoT-integration insights. Bressanelli et al. (2018) conducted an explorative case study to understand how IoT can ease the challenges of PSS development. The case is a household-appliance retailer that provides a use-oriented PSS. The customers use the appliances by a subscription-based mechanism without buying them. The PSS is realized by using IoT components, but the study provides only limited information about out how IoT can facilitate the usage phase and PSS maintenance.

Another group of studies has shown ways to use IoT in PSS business-model development. Zancul et al. (2016) propose a method for using IoT-enabled PSS in its two-part business model: First, they apply failure mode and effects analysis (FMEA) to decide which features of IoT should be integrated with the product. Second, they use a PSS business-strategy configurator that assists PSS providers with positioning themselves during innovation planning. They merge the results of the configurator with the FMEA approach to 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 incorporating IoT technology (e.g., Matzen and McAloone, 2009; Moritz, 2009). Shih et al. (2016) introduce a new concept called "pseudo-actor," which stands for an IoT-enabled object with sensors and actuators. Their method follows a six-step procedure and tackles selecting IoT technology alternatives for customer value creation. The method mostly focuses on PSS design for engineers and the study does not cover general IoT potential for PSS.

Several studies have addressed the use of IoT-for-PSS implementation. For instance, a framework for implementing industrial IoT-enabled PSS is presented by Alexopoulos et al. (2018) in support of PSS development with regard to lifecycle management and service implementation using IoT. The framework consists of various IoT-related elements selected to facilitate the service-side implementation of PSS. In a pilot case study, the framework is mapped into a real case and implementation of the IoT framework is presented. Because the focus of the framework is on IoT implementation for PSS, they do not provide an analysis of the overall capabilities of IoT-for-PSS. Similarly, Espíndola et al. (2012) address the convergence of IoT and PSS implementation by providing a conceptual design that comprises both IoT and PSS elements. In addition, they propose a middleware architecture that can realize IoT implementation with the purpose of PSS enablement. In general, the study tackles implementation details for incorporating IoT in PSS. Although this group of studies does not address overall opportunities of using IoT-for-PSS, they complement our work as they detail the implementation.

<Table 3> summarizes prior work on the relation between IoT and PSS. Existing case studies on the integration of IoT in PSS are mostly application-oriented and only partially cover the ways in which IoT supports PSS. The studies of IoT-for-PSS business-model development propose processes and methods but do not comprehensively cover all the implications of IoT-for-PSS. We found that prior

<Table 3> Summary of IoT–PSS Studies

Study Type	Study	Main Contribution
General Case Studies	Seregni et al. (2016)	Identifying IoT-enabled Services of PSS
	Elia et al. (2016)	Performance Evaluation of IoT-enabled PSS
	Bressanelli et al. (2018)	Identifying PSS challenges that IoT could overcome
IoT for PSS Business Model	Zancul et al. (2016)	A method for adopting IoT in PSS business model based on FMEA and PSS business strategy configurator
	Shih et al. (2016)	PSS design method that extends visual mapping methods for service creation by incorporating IoT
IoT for PSS Implementation	Alexopoulos et al. (2018)	IoT Framework for PSS service implementation
	Espíndola et al. (2012)	A conceptual design and a middleware architecture for incorporating IoT in PSS implementation

studies of IoT-for-PSS implementation do not consider the big picture and the use of IoT to enable PSS business models. In general, there is a lack of knowledge of what opportunities IoT can provide for PSS in general. Hence, in this study, we first build a theoretical framework that integrates different views of the opportunities for use of IoT in PSS.

Ⅲ. Study Design

To gain a deeper understanding of opportunities for use of IoT in 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 (2002) as well as expert interviews based on Gläser and Laudel (2010), Mayring (2010), and Miles and Huberman (1994). We used this mixed-method approach for completeness (Venkatesh et al., 2013), aiming to provide a comprehensive picture of the subject of interest by mixing evidence from the literature and from practice.

3.1. Systematic Literature Review

To analyze IoT opportunities for PSS from the literature, we applied the approach and instructions based on Vom Brocke et al. (2009) and Webster and Watson (2002). In this process, we used the IEEE, SpringerLink, ScienceDirect, and Scopus databases (<Table 4>). 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 without confining ourselves to a specific publication year range or ranking.

For the analysis, we first analyzed the title and abstracts and removed duplicates. We selected only relevant publications based on sets of inclusion and exclusion criteria. The exclusion criteria consisted of papers with their main focus on IoT implementation or tools. The inclusion criteria were papers addressing lifecycle management in the context of IoT and PSS and of IoT integration in business. This selection reduced the number of possibly 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. As a first result, we saw that only a few papers combine IoT with PSS or servitization. To cope with this issue, we interviewed experts.

3.2. Expert Interviews

As the literature review revealed some gaps, we enriched our data with expert interviews based on Gläser and Laudel (2010), Mayring (2010), and Miles and Huberman (1994). For interview sampling, we looked for leading enterprises and startups across different IoT-application fields. We chose business managers who consider or involve IoT in their processes, consultants who offer IoT solutions, and startups working in the IoT field. We conducted 13 semi-structured interviews (<Table 5>).

The interviews were based on a semi-structured

<Table 4> The 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

<Table 5> Interview Details

Interview ID	Job description	Industry	Employees	Duration (min)
Participant 01	Business development manager	Global e-commerce & cloud computing	~566000	~35
Participant 02	IoT evangelist & business development manager	Global e-commerce & cloud computing	~566000	~15
Participant 03	Machine Learning Expert	Research institute	~200	~40
Participant 04	Data scientist for rail transportation	Industrial manufacturing	~372000	~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	~25000	~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	~120000	~50
Participant 09	Product manager for digital lab and smart home	Global automotive manufacturer	~125000	~25
Participant 10	Digital E-Care	Global telecommunication company	~1800	~70
Participant 11	IoT consultant and app developer	IoT consultancy and software house	~124000	~35
Participant 12	Product manager for industrial communication	Industrial manufacturing company	~372000	~20
Participant 13	Consultant and developer	IoT consultancy	~10000	~50

interview guideline with open questions (Gläser and Laudel, 2010), to ensure some common topics and leave room for the specific aspects of every expert. Every expert was asked about general opportunities of IoT and applications in which IoT has been realized (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. For data analysis, all interviews were transcribed and openly coded according to Corbin et al. (2015). Our coding is shaped around two core concepts, IoT opportunities for PSS business model and IoT opportunities for PSS implementation.

The semi-structured interviews were based on guidelines (Gläser and Laudel, 2010), that both ensured some common topics and allowed for open questions, leaving room for specific aspects pertaining to each expert. Every expert was asked about general IoT opportunities and applications in which IoT has been realized, about opportunities and realized applications resulting from new data and/or pursued for their specific processes, and about products or PSS. For data analysis, all interviews were transcribed and openly coded according to Corbin et al. (2015). Our coding is focused on the two core concepts of IoT opportunities for PSS business models and for PSS implementation.

Ⅳ. Internet of Things as Product–Service System Business-Model Enabler

For the first part of the results, we present the framework of the IoT–PSS business-model opportunities (<Table 6>), which entails two dimensions: the horizontal axis stands for three general types of PSS introduced by Tukker (2004). The vertical axis presents the levels of IoT involvement in the 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 transforming and optimizing levels enable IoT-driven PSS, while the interacting and tracking levels enable IoT-supported PSS. While an IoT-supported PSS is a PSS enhanced with IoT technologies, IoT fundamentally affects PSS design and implementation in an IoT-driven PSS. In

<Table 6> The 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

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 values added by IoT for each PSS type. These values can be variously derived, as will be discussed in this section below. Also, for every concept of the framework, we provide PSS real cases.

4.1. Tracking

Tracking is the lowest level of IoT integration in PSS business models. It enables tracking of 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 decreasing the maintenance costs (Beuren et al., 2016; Zancul et al., 2016). An important implication of the 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 wirelessly connected single-function button that allows customers to order products or services (Participant 02; Participant 01). Tracking and storing processes in these buttons enables us to request for the result instantly with a click of the button. Another example would be location-based services to users, which are enabled by the tracking capabilities of IoT. Th, we would be able to improve the customer experience and increase the usage or purchase rate (Participant 07).

There are plenty of PSS cases that have already realized the tracking abilities of IoT into PSS. For instance, many transportation companies that provide fleet management services have integrated IoT into their system for real-time monitoring of the vehicles and their status. These fleet management cases can be of all three types of PSS depending on their grounding business model. <Table 7> presents a real PSS case for every type of PSS. These PSS cases are built upon tracking abilities of IoT. HP Instant Ink is a result-oriented PSS that focuses on delivering the right amount of ink for HP printers. This PSS charges customers based on the number of successful prints, i.e. the desired result, instead of ink usage.

4.2. 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 the 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 from 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 instructed to replace a part in the event of an error. Such an ability increases customer engagement with the PSS (Participant 13). In general,

4) https://www.proglove.com/
5) https://www.samsara.com/uk/customers/empyre-builders
6) https://instantink.hpconnected.com
7) https://www.olimpiasplendid.com/home-automation/aquad

<Table 7> IoT Tracking-supported PSS Examples

Product-oriented PSS		Use-oriented PSS		Result-oriented PSS	
PSS Case	Description	PSS Case	Description	PSS Case	Description
ProGlove[4)]	Enhancing regular gloves with barcode scanners to track information faster	Empyre Builders[5)]	Using IoT-tracking to monitor construction vehicles and their movements	HP Instant Ink[6)]	A system of delivering the right amount of ink whenever is needed

<Table 8> IoT Interacting-supported PSS Examples

Product-oriented PSS		Use-oriented PSS		Result-oriented PSS	
PSS Case	Description	PSS Case	Description	PSS Case	Description
AQUADUE® control[7)]	System of the air-conditioning//heating installation that works smartly using IoT sensors and actuators	QIVICON[8)]	Providing an IoT platform that connects various smart home devices with the monitoring and interaction features	Phillips ‘Pay-per_Lux’[9)]	Providing the adjusted correct amount of light (light as the result instead of selling the light bulbs)

according to the interviews, the 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).

<Table 8> provides examples of IoT-supported PSS cases realized by interacting capabilities. As discussed, smart home solutions are common examples of this level of IoT integration that automatically react and control the situations of a house. Nevertheless, PSS providers that have incorporated interacting abilities of IoT, often do not stop at this level and utilize higher levels of IoT integration.

4.3. Optimizing

The interviewees argue that, although the tracking and interacting capabilities added by IoT support the creation of 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 data collected and processed during tracking and interacting allows an advanced analysis of products and services, particularly in the usage phase. This empowers PSS providers 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 real-time (Zancul et al., 2016). Interviewees perceived great opportunities based on machine learning algorithms, which can improve the system functions continuously (Participant

ue-control
8) https://www.qivicon.com/
9) https://www.innovationservices.philips.com/news/philips-transition-linear-circular-economy/

<Table 9> IoT Optimizing-driven PSS Examples

Product-oriented PSS		Use-oriented PSS		Result-oriented PSS	
PSS Case	Description	PSS Case	Description	PSS Case	Description
glassbeam's Medical Device Serviceability with IoT Analytics[10)	Remote visibility and analytics leading to higher efficiency for a medical equipment provider	Rolls-Royce 'Power-by-the-Hour'[11)	Engine maintenance system that uses IoT to track and analyze engines for better maintenance	ABT Power Management[12)	Adjusting and optimizing the precise amount of power provision (right amount of power is the desired result)

01; Participant 03; Participant 12). They believed such machine learning techniques combined with the 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).

Most of real PSS cases, which have integrated IoT, are more concerned about optimizing capabilities, particularly, predictive maintenance and optimized service provision. Regarding product-oriented PSS cases, availability of PSS and its maintenance services are improved significantly using analytics enabled by IoT. Moreover, result-oriented can benefit the most by optimizing the result-oriented services that they provide.

4.4. Transforming

Built on the entire IoT technology stack, the transforming capability of IoT for PSS is realized by a 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 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 people and machines with the aim of maximizing the products performance and quality of services (Participant 09). Total IoT integration significantly reshapes the products and service provision as well as the customer's experience (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 making for every object in the system by the collection of raw sensor data, data filtering and data processing 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).

Complete integration of IoT into PSS allows particular intelligence for every PSS according to its history and capabilities. Such intelligence would adopt a PSS to its environmental factors, process information and usage data (Kiritsis, 2011; Porter and Heppelmann,

10) https://www.glassbeam.com/resources#casestudies
11) https://www.rolls-royce.com/media/press-releases-archive/yr-2012/121030-the-hour.aspx
12) https://www.wemanagepower.com/

<Table 10> IoT Transform-driven PSS

Product-oriented PSS		Use-oriented PSS		Result-oriented PSS	
PSS Case	Description	PSS Case	Description	PSS Case	Description
Tesla[13)]	Full autonomous driving based on connected vehicles (This is a vision and is not realized yet)	KEAZ[14)]	Using IoT to provide smart mobility and connectivity solutions	ween.ai[15)]	Providing total connectedness, autonomy, real-time predictions upon IoT devices for various solutions such as smart home or mobility services

2014) Hence, PSS providers could benefit extra value as the system autonomy and intelligence assess functionalities of the system and its components as it is running and evolving in its environment.

Few successful PSS cases could utilize the transformation ability of IoT for PSS. Many companies have envisioned such a transformation, yet it is not realized. For example, the automotive industry is working intensely on autonomous driving. The long-term vision would be the total connectedness among vehicles that smartly provide mobility services in smart cities. Although such vision has not fulfilled completely, we could not find any other real-case example for product-oriented PSS transformed by IoT. <Table 10> presents the real-case PSS cases that are driven by the transforming abilities of IoT.

Ⅴ. IoT as PSS Lifecycle Management Enabler

In this section, we address how IoT can facilitate PSS lifecycle management and implementation. Based on the literature and the interviews, we identified the related core potential concepts, which are presented in <Figure 1>. With regard to the overall lifecycle management, IoT provides three main capabilities. First, IoT involvement leads to an increasing amount of data belonging to 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 due to the variety of the disciplines involved. IoT supports collaboration by enabling communication among machines and humans. Another implication of IoT for PSS development is the higher degree of autonomy for the PSS development. In addition to the overall concepts, IoT enables specific technologies and paradigms for every phase of PSS development. Regarding the PSS development phases of PSS, we follow the generally accepted distinctions between the beginning of life (BOL), middle of life (MOL) and end of life (EOL) phases. These phases represent design, manufacturing, logistics, use, maintenance, reuse and recycling, respectively (Beuren et al., 2016; Terzi et al., 2010). Throughout these phases, we identified four underlying opportunities, namely, digital twin, Closed-loop Lifecycle Management (CLLM) stands for the 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, a considerable amount of relevant data is either lost or acquired at a high cost. Consequently, there is

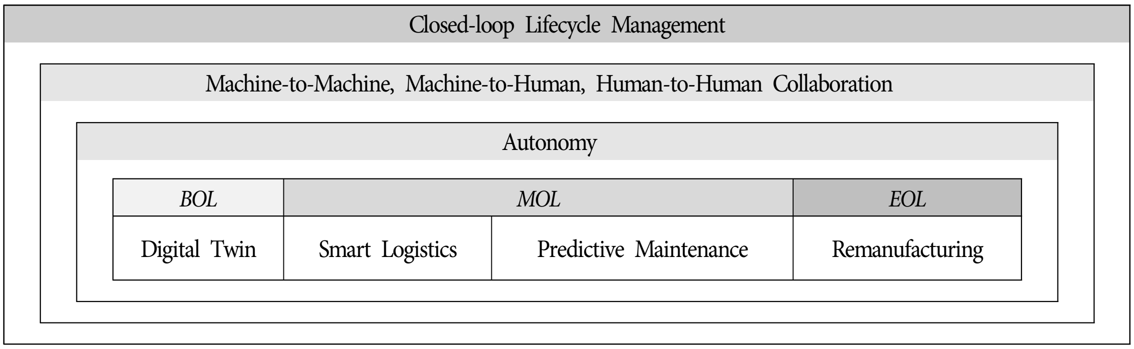
13) https://www.tesla.com/
14) https://keaz.co/
15) https://www.ween.ai/

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 life-cycles of PSS product parts and PSS services (Basselot et al., 2017). Moreover, incorporating IoT into the PSS development would solve the 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-related information and attributes perceived by the user. Utilizing these two types of data can significantly support requirements elicitation and management for PSS' products and services and even introducing new ones (Gudergan et al., 2017; Wuest et al., 2016; Yang et al., 2009).

Collaboration-related aspects are challenging for PSS development as PSS development involves a high number of teams and disciplines, whose tools and methods (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 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 almost in 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). In particular, tools and development platforms in the context of IoT allow a wider range of developers to access its 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 human intervention (Ardolino et al., 2016; Gerpott and May, 2016; Lee et al., 2013).



<Figure 1> Opportunities of IoT for PSS Lifecycle Management

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 several challenges still impede the realization of high autonomy. For example, there are as yet no advances in automated self-criticism, in which the system recognizes its mistakes (Participant 03). In addition, there is still a lack of trust in automation operations, which prevent them from becoming fully integrated into lifecycle management (Participant 03).

Digital twin or product avatar refers to a digital equivalent of a physical product. Integrating actual physical data with the virtual replication of a product enables better design, validation and verification of engineering artifacts (Goto et al., 2016). In general, a trend can be seen toward the use of digital twin enabled with 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 the BOL phase by incorporating feedback from the 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 the evaluation of product performance in diverse environments. Moreover, applying a change in PSS can first be 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 delays and increases both the overall development efficiency and transparency of customers' processes (Meneghetti et al., 2016).

Smart logistics is enabled by tracking and the optimizing abilities of IoT. IoT establishes an overall connectivity of all devices and product parts, which empowers the 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 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 in their maintenance activities (Participant 01; Participant 08; Participant 05). Moreover, they stated that increased availability resulting from 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). With this, the experiences from the later stages of a lifecycle would be employed in the earlier stages (Igba et al., 2015). Realizing remanufacturing necessitates tracking, controlling and analysis of the product, its condition and its usage, which can be enabled by means of IoT (Chierici and Copani, 2016). Ideally, a feedback loop would be in place between each lifecycle phases.

Ⅵ. Discussion

The IoT paradigm has the potential to transform the industry and be as influential as the Internet was in the 1990s. Our findings showed that practitioners assert the 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 it can have on businesses (Čolaković and Hadžialić, 2018; Gubbi et al., 2013; Porter and Heppelmann, 2014). In particular, IoT can play a crucial role in PSS development (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). The strengths of IoT match the difficulties that PSS design and development confront.

The existing studies of the IoT and PSS relationship have been limited 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 of the opportunities that IoT can provide for PSS. We have 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 and proceeds to the most-complex abilities, the 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 that they have not yet realized. 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 beyond the scope of this study but 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 frameworks established in this study.

Combining the two folds of this study's contribution enlighten the overall IoT exploitation for PSS design and development. The insightful alignment of IoT and PSS brings various added-values for both businesses and 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 continually improving products and services, which are also more customized to their usage. In addition, customers would benefit from higher availability of product and services. In the 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 the 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, allowing them to increase revenue.

Furthermore, we could identify major challenges in the use of IoT for PSS that future studies should tackle them. First, although IoT can facilitate collaboration among humans and machines, it may also add extra complexity to PSS development as IoT implementation necessitates integration and collaboration of various knowledge experts (Participant 12; Participant 04). Moreover, IoT implementation may shape new partnerships due to its technical complexity. This brings new inter-organization collaborations for PSS providers. Another challenge is finding the right methodology to develop IoT-supported and IoT-driven PSS. For example, alignment between the simultaneous development of software and hardware have difficulties for enterprises (Participant 02; Participant 09). Hence, future research should establish new methods that can tackle such challenges. Finally, huge captured, generated and collected data in IoT-driven PSS have to be managed consistently. Establishing interoperability among various tools, artifacts and data sources is a difficult goal to achieve. Therefore, future research needs to investigate interoperability in IoT-driven PSS and mechanisms to achieve it.

According to our findings from the interviews, IoT technologies have been integrated mostly on the end-customers side, even though B2B applications of IoT can have greater economic outcomes. Moreover, we observed slow progress regarding the shift from IoT-supported PSS to IoT-driven PSS. The lack of infrastructural capabilities can be considered an important factor hindering IoT integration, but the future studies should investigate in detail the existing complicated barriers exist. For example, there is still uncertainty about costs and profits associated with 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 the use of IoT for a variety of applications.

A limitation of our work was using interview and literature review in a mixed-method approach, while a mixed-method approach is most fruitful when qualitative and quantitative methods are combined. Therefore, we suggest future empirical studies to employ quantitative and qualitative methods for addressing IoT for PSS topic. To this end, researchers can conduct a quantitative analysis of successful cases of IoT and PSS integration which would be complemented by further in-detail case studies.

Ⅶ. Conclusion

IoT technologies are changing products, services and the way we develop them. 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 of each relevant hotspot to assist PSS providers in positioning and deciding the right business model when integrating IoT in their portfolio. First, we introduced the 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. The study increases their awareness regarding the potentials of IoT for PSS and their current progress of IoT realization. Moreover, this study establishes a comprehensive view on opportunistic implications of IoT for PSS, which paves the way 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.

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◆ About the Authors ◆

Mohammad R. Basirati

Mohammad R. Basirati (mohammadreza.basirati@tum.de) is a research associate and Ph.D. student at the chair for information systems at the Technical University of Munich (TUM). He holds a master's degree from TUM in informatics and a bachelor's degree from University of Tehran in computer engineering. His research focus is on system engineering, in particular requirements management with emphasis on collaboration aspects among stakeholders and resolution of emergent inconsistencies.

Jörg Weking

Jörg Weking (joerg.weking@tum.de) is a research associate and Ph.D. student at the Chair for Information Systems, Technical University of Munich (TUM), Germany. He studied Information Systems at the University of Münster, Germany, at the Turku School of Economics, Turku, Finland (TSE) and the Queensland University of Technology, Brisbane, Australia (QUT). His research focuses on business model patterns, business model innovation, value co-creation and product service systems. His work has been published in Electronic Markets, Communications of the AIS and in refereed conference proceedings such as the European Conference on Information Systems and the Americas Conference on Information Systems.

Sebastian Hermes

Sebastian Hermes (sebastian.hermes@tum.de) is a research associate and Ph.D. student at the Chair for Information Systems, Technische Universität München (TUM), Munich, Germany. He holds a Master's degree in Entrepreneurship from the University of Liechtenstein and a Bachelor's degree from the Baden-Wuerttemberg Cooperative State University. Sebastian has worked five years at Roche and co-founded Thinkfield. His work has appeared in conference proceedings such as Hawaii International Conference on System Sciences.

Markus Böhm

Markus Böhm (markus.boehm@tum.de) is research group leader at the Chair for Information Systems at Technical University of Munich (TUM), Germany. He graduated in Business & Information Systems Engineering from Friedrich-Alexander University Erlangen-Nürnberg (FAU), and holds a doctoral degree in Information Systems from TUM. His research focus is on mergers & acquisitions, business model innovation and digital transformation. His work has appeared in Management Information Systems Quarterly Executive, Electronic Markets, Communications of the AIS and several refereed conference proceedings, including ECIS and ICIS.

Helmut Krcmar

Helmut Krcmar (helmut. krcmar@tum.de) is a Chair Professor of Information Systems at Technical University of Munich (TUM), Germany. Before 2002, he was Chair for Information Systems, University of Hohenheim, Stuttgart. Helmut is an AIS Fellow and has served the IS community in many roles, including as President of the Association for Information Systems. His research interests include information and knowledge management, service management, business process management, and business information systems. His work has appeared in Management Information Systems Quarterly, Journal of Management Information Systems, Journal of Strategic Information Systems, Journal of Management Accounting Research, Journal of Information Technology, Information Systems Journal, and Business & Information Systems Engineering.

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