Industrial Services as a Research Discipline

Ralf Gitzel[*,a], Björn Schmitz[b], Hansjörg Fromm[b], Alf Isaksson[c], Thomas Setzer[d]

[a] ABB AG, Corporate Research Center Germany, Wallstadtler Straße 59, 68526 Ladenburg, Germany
[b] Karlsruhe Institute of Technology, Karlsruhe Service Research Institute, Englerstraße 11, 76131 Karlsruhe, Germany
[c] ABB AB, Corporate Research Center Sweden, Forskargränd 7, 72178 Västerås, Sweden
[d] Karlsruhe Institute of Technology, Institute of Information Systems and Marketing, Englerstraße 14, 76131 Karlsruhe, Germany

Abstract. *Services in the industrial sector—commonly referred to as industrial services—are an important source of profit, differentiation and future growth for their providers. This sector includes industries such as heavy equipment manufacturing, energy production, chemical production and oil and gas. Despite its importance, neither the term industrial service(s) nor its concrete subareas are unambiguously defined. The goal of this paper is to motivate research which addresses the challenges currently faced in the industrial sector with regard to service. For this purpose, we review existing definitions of industrial services and identify the services in scope as well as the scientific disciplines that can contribute. The main part of the paper is a list of relevant current and future challenges which have been encountered by the authors during their daily practice.*

Keywords. Industrial Services • Research Discipline • Research Challenges • Research Trends

Communicated by B. Hofreiter and E. Proper (Guest Editors). Received 2015-06-24. Accepted after 1 revision on 2015-12-20.

1 Introduction

In recent years, services have played an increasingly important role in corporate strategies of companies in the industrial sector (Baines et al. 2009; Quinn et al. 1990; Vandermerwe and Rada 1988; Wise and Baumgartner 1999). These so called industrial services range from maintenance and spare parts management to technology-focused services in industrial automation and mobile technologies to the handling of entire processes for clients in full service contracts. In developed economies many industrial goods manufacturers generate more than half of their profits with industrial services and services are considered an attractive market to operate in (Strähle et al. 2012).

* Corresponding author.
E-mail. ralf.gitzel@de.abb.com
Note: This article revises and extends an earlier conference publication, cf. Schmitz et al. (2015).

Despite these impressive figures, industrial service is still an underresearched topic. Industry—and research even more so—have only lately recognized the huge untapped potential for future growth in industrial service. As a result, there is still a lack of methods, standardization and suitable approaches to successfully exploit the service potential. In addition to this, we observe massive technological advancements (e. g. in form of increased connectivity and intelligence of devices) which will affect the way in which industrial services are delivered and consumed. Technology will also promote innovation in the development of industrial equipment, vehicles, production processes and entire factories, i. e. it will change the service objects themselves. All these developments will result in new economic, organisational and technical requirements which will need to be addressed in the future.

1.1 Purpose and Contribution

The purpose of this paper is to stimulate industrial service research in the fields of computer science and business informatics. For this purpose, we aim to discuss the definition of industrial service and to provide a pragmatic delineation of scope for the establishment of a research area on *industrial services* for both academics and industrial researchers (Sect. 2). Following this discussion, we outline different fields of industrial service that we have encountered in our daily practice (Sect. 3). The main part of the paper lists challenges which need to be addressed by researchers in order to push forward the field (Sect. 4).

Thus, the academic contribution of this paper is two-fold: We propose a definition of industrial services which can serve as a basis for industrial service research. Subsequently, we put forward a collection of challenges which need to be addressed in order to stimulate future research.

1.2 Scope of Study and Research Strategy

The scope of the literature study are articles which provide a definition of industrial services or of their inherent characteristics. The review was based on a forward/backward keyword search according to Webster and Watson (2002). Using Google-Scholar, we searched for contributions with the following keywords: 'industrial service(s)', 'industry service(s)'. Although a plethora of articles containing one of the keywords was returned, only a very limited number of these provide a comprehensive definition of the term industrial service or discuss their immanent properties. Consequently, the focus was set on *central and relevant* contributions to the topic. Leading questions considered to determine the relevance of identified articles were as follows:

1. Does the article provide an explicit definition of the term industrial service?
2. Does the article outline one or more characteristics of industrial services?
3. Does the article study industrial services from a particular academic perspective?

Based on the obtained results, definitions and characteristics have been sorted and clustered according to the characteristics mentioned. Second, we have further discussed the results of the analysis with experts from industry and academia in the field in order to complement our findings and to account for the latest developments in the field.

The list of challenges is the result of years of discussions with people in the industrial service business by several of the authors. Two of us work for a major asset vendor and service provider in the fields of power and automation and have been confronted with these challenges in our daily work. There is often no source in the academic literature for those—which in fact is the motivation to compile this list in the first place.

2 Definition of Industrial Services

Industrial services can be (and have been) studied from various perspectives and academic disciplines. In order to contribute to the establishment of a research field on *industrial services*, this paper aims to establish a holistic perspective on the characteristics commonly related to industrial services by reviewing the literature.[1] Developing a shared understanding of research problems and corresponding activities in the field of industrial services will promote the development of methodologies and solutions which may be applicable for a wider range of problems and application scenarios.

In literature, there is no common definition of the term *industrial service* nor of the types of activities that are part of the field of industrial services. Organizing identified articles of interest along their underlying concepts and perspectives, four major streams of definitions have been identified (see Tab. 1). Some of the articles identified contain a detailed definition and characterizations of industrial services (see Tab. 2 in Appendix). They are thus mentioned in multiple categories.

Market-Focused Definition: One way of defining industrial services builds on the characterization of markets. On a conceptual level, two

[1] An earlier version of this section was published in Schmitz et al. (2015).

Author	Market	Asset	Process	IHIP
	Concept			
Jackson and Cooper (1988)	√	√	√	√
Morris and Fuller (1989)				√
Cooper and de Brentani (1991)	√			
de Bretani (1995)	√			
Boyt and Harvey (1997)				√
Homburg and Garbe (1999)	√	√		
Mathieu (1999)		√	√	
Mathieu (2001)		√		
Oliva and Kallenberg (2003)	√	√	√	
Henkel et al. (2004)			√	
Johansson and Olhager (2004)		√		
Paloheimo et al. (2004)	√		√	
Brax (2005)	√			
Ivens (2005)	√			
Karandikar and Vollmar (2006)		√	√	
Kowalkowski (2006)	√		√	
Meier et al. (2010)	√	√		
Kowalkowski et al. (2011)		√	√	
Datta and Roy (2011)			√	
Ojanen et al. (2011)		√		
Reen (2014)	√		√	

Table 1: Concepts used to characterize and define industrial services.

lines of argumentation can be differentiated: One view is that industrial services are services marketed to industrial clients as opposed to consumer clients (Brax 2005; Jackson and Cooper 1988; Kowalkowski 2006; Meier et al. 2010; Paloheimo et al. 2004) (*receiver view*). Other articles define industrial services based on the entity providing a service (*provider view*). They state that industrial services are those services which are provided and developed by manufacturers of industrial equipment (Brax 2005; Homburg and Garbe 1999; Reen 2014). Complementing, it should be mentioned that there is no clear consensus whether providers or recipients of industrial services are restricted to *manufacturing companies* (see e. g. Oliva and Kallenberg 2003). In marketing, the term industrial service is also frequently used as a synonym for business-to-business services (Cooper and de Brentani 1991; de Bretani 1995; Ivens 2005). The latter cover a broader range of services and may also include financial services, communication services, or consulting. However, as this paper discusses services from the industrial sector, we would not regard every business-to-business service as an industrial service. The benefit of market-focused definitions is that it is easy to identify companies which provide or receive industrial services. Thus, they are quite useful for high-level studies about industrial services. The drawback is that they do not provide a tangible description of the activities which are part of an industrial service.

Asset-Focused Definitions: A second type of definitions emphasizes the close relationship between industrial services and industrial goods. Such definitions (indirectly) assume that industrial services are always provided in relation to or in conjunction with industrial goods. Today, industrial services are still frequently denoted as after-sales services (Homburg and Garbe 1999; Johansson and Olhager 2004; Kowalkowski 2006; Ojanen et al. 2011; Oliva and Kallenberg 2003). The reasoning of such definitions is that industrial services can be characterized based on the life cycle of industrial goods. For instance, Oliva and Kallenberg (2003) regard industrial services as 'product- or process-related services required by an end-user over the useful life of a product'. Johansson and Olhager (2004) see them as the 'supply of after-sales-services [. . .] related to the maintenance of industrial goods'. Ojanen et al. (2011) introduce a broader definition which relates industrial services to various phases of the asset lifecycle. Following this line of argumentation, Homburg and Garbe (1999) classify industrial services into pre-purchase, at-purchase and after-sales industrial service. In addition to the life cycle view, Jackson and Cooper (1988), Mathieu (1999), Oliva and Kallenberg (2003), Karandikar and Vollmar (2006), and Kowalkowski et al. (2011) suggest to distinguish between product-oriented and process-oriented industrial services. Product-oriented services directly support the provider's product—for instance through installation and commissioning, maintenance and repair, or refurbishment and recycling services (Oliva and Kallenberg 2003)—whereas process-oriented services aim at supporting the 'client's action in relation to the supplier's product' (Mathieu 1999) (this will be discussed separately below). Finally, there are definitions originating from research on industrial product services systems (Meier et al. 2010). They state that industrial services are part of an integrated offering of products and services which is characterized by an 'simultaneous and interfering product and service engineering'. The main drawback we see with these definitions is that they neglect or at least de-emphasize the system level. For example some services help optimizing the production system as a whole as opposed to insular assets.

Process-Focused Definitions: Complementing the argumentation above, there are definitions which underline the process view on services. They follow the reasoning that industrial services comprise all services which aim at supporting a customer's (production) processes. Oliva and Kallenberg (2003), Karandikar and Vollmar (2006), and Kowalkowski et al. (2011) speak of end user process-oriented services in this context. Such definitions can be further distinguished according to the characteristics of the processes supported. Jackson and Cooper (1988), Paloheimo et al. (2004), and Kowalkowski (2006) state that industrial services are offered for a customer's industrial production process. For instance, Kowalkowski (2006) defines industrial service as 'processes supporting customers industrial production processes, so that value for them is created in those processes'. Jackson and Cooper (1988) speak of 'production services' in this context. Others qualify this assumption stating that industrial services may target more than just the production processes of a customer (Datta and Roy 2011; Karandikar and Vollmar 2006; Kowalkowski et al. 2011; Mathieu 1999; Oliva and Kallenberg 2003; Reen 2014). For instance, Datta and Roy (2011) view industrial services as a 'series of activities connected to customer's value creating processes'. The advantage of a process-focused definition is that it provides a good description of properties an activity needs to have to be considered an industrial service. Also, it is not limited to maintenance and repair, which means it leaves room for advanced and new services found in the industrial services cube which will be introduced in Sect. 3.

IHIP-Focused Definitions: For many years, the inherent characteristics that differentiate services from goods had been subject to discussion. In the course of this debate the so called IHIP criteria (Regan 1963; Zeithaml et al. 1985) evolved which aim at distinguishing services from goods based on four characteristics: intangibility, heterogeneity, inseparability, and perishability.[2] Based on the IHIP criteria, researchers have proposed to distinguish industrial services from services in general by introducing additional criteria which they consider to be integral parts of industrial service. Examples of such industrial service specific criteria are 'specialization' (Jackson and Cooper 1988), 'technology' (Jackson and Cooper 1988), 'consumption in irregular patterns' (Boyt and Harvey 1997; Morris and Fuller 1989), and many others (Boyt and Harvey 1997; Jackson and Cooper 1988; Morris and Fuller 1989). An IHIP-focused definition has the advantage that it aligns industrial service with the overall concept of service.

In addition to the categories outlined above, many authors have cited examples of industrial services in their articles. They cover product-oriented services such as installation, repair, or retrofitting and also more process-oriented services such as process optimization, simulation, or technical consulting. References to more comprehensive collections of industrial services can be found in Henkel et al. (2004), Karandikar and Vollmar (2006), Kohtamäki et al. (2013), Kowalkowski

[2] The practical suitability of using the IHIP as a means to distinguish services from products has been subject to discussions in academic literature (see e. g. Vargo and Lusch 2004).

(2006), Kowalkowski et al. (2011), Matyas et al. (2009), Oliva and Kallenberg (2003), and Paloheimo et al. (2004).

All of the above definition categories have their merit and are suited for different situations. Our goal in this paper is to provide a pragmatic definition which stimulates, inspires, and guides industrial service research which can then be productised by industrial service companies. From this angle, a suitable definition must meet certain criteria. First, a definition has to be applicable to a particular activity in order to decide whether it is an industrial service or not. Only the last three definition types allow such application. On the other hand, a definition should not unnecessarily limit the scope. In our view, industrial services need not be limited to assets only (asset-focused definitions). In the case of IHIP, some of the points are quite philosophical and of lesser interest to industrial service providers. For example, is a standardized inspection service still heterogeneous? Does a 4h-response time service contract fulfil the criteria of inseparability with respect to immediate consumption? Is the sales of spare parts not part of service because the parts are not intangible? For these reasons, in our daily practice, we have found process-based definitions to be the most suitable for service research and to align best with the activities our and other companies offer under the label *service*.

Definition of Industrial Services: *Industrial services are activities directly supporting a customer's value creation by positively influencing their industrial production processes.*

2.1 Common Characteristics of Industrial Services

Based on our preferred definition, industrial services have a number of properties.

Industrial Scope: Industrial services are services related to industrial assets and/or systems of industrial assets. Unlike consumer goods, industrial assets are typically used by business or industrial clients as opposed to consumer clients (Jackson and Cooper 1988). Examples of industrial assets are pumps, motors, and robots. Examples of systems of industrial assets are oil refineries, breweries, and fleets of trucks.

Support Activities: The immediate association for industrial services are maintenance, repair, and overhaul activities. However, industrial services cover a range of other activities such as training, engineering, condition monitoring, predictive maintenance, advanced diagnostics, or asset and fleet management.

Strong Product Relation: Industrial services can be applied at an asset or system level. In some cases, the service is only distantly related to the industrial goods which are perceived to form the core offering of a manufacturing company (e. g. manufacturer of measurement equipment offers tank management). In this respect, industrial service research is related to research on *product service systems* which are integrated offerings of goods and services (Baines et al. 2007). Although we are not able to discuss the concept of product service systems in detail in this work we want to emphasize that industrial services establish a strong link between services and products. Following this line of thought Meier et al. (2010) state that understanding the '[m]eaning of industrial service is a necessary prerequisite to understand the nature of an Industrial Product-Service System'.

3 Fields of Industrial Service

Industrial services have been studied from a variety of angles and research disciplines. However, apart from service catalogues of industrial equipment providers, there is relatively little material as to what services and activities are part of the field of industrial services. Although some sources provide collections and examples of industrial services, they show limited overlap and seem far from complete (compare e. g. Henkel et al. 2004; Karandikar and Vollmar 2006; Kohtamäki et al. 2013; Kowalkowski 2006; Matyas et al. 2009; Oliva and Kallenberg 2003; Paloheimo et al. 2004). To the best of our knowledge, a comprehensive taxonomy to characterize the fields of industrial services is still missing.

In order to allow for comprehensive research on industrial services, we have developed a cube which allows to categorize industrial services[3] —as well as corresponding activities to develop, deliver, and manage them—along three dimensions as illustrated in Fig. 1.[4]

3.1 Functional Areas

The first dimension of the cube describes different *functional areas* which represent groups of activities that providers and customers of industrial services need to deal with.

Service Strategy: In the context of industrial service, several strategic decisions have to be made. First of all, the determination of a service strategy is the topmost task of a company undergoing a service transition and covers strategic planning at different levels. The category covers activities concerning decisions about the strategic importance of industrial services for corporate strategy. Moreover, it addresses topics of long-term planning regarding the service organisation and alignment of service activities and infrastructure for service providers and customers.

On top, companies need to decide on the overall importance of the service business and on the degree to which to *servitize* their business (Gebauer et al. 2008): Managers need to decide on the objectives pursued with services, on the amount of revenue to generate and how much profit to target with industrial services.

Regarding strategic alignment of the service organisation, equipment providers and their customers need to decide on an optimal strategy for life cycle management of assets (e. g. planning optimal time intervals for equipment replacement) and corresponding maintenance strategies (e. g. corrective, predetermined, condition-based, or predictive maintenance) as well as their integration with downstream processes in resource planning (e. g. defining a spare parts policy). In addition, they need to establish a network of partners (e. g. identifying strategic suppliers and distribution partners) and decide on a channel strategy for service sales (e. g. single channel or multi channel). Depending on the perspectives taken, such activities may either be used for internal purposes (i. e. to define a companies internal strategy) or they may be offered as professional consulting services by an external service provider.

New Service Offerings: Whenever a company decides to move from traditional, product-centric, and reactive services towards advanced, customer-oriented, proactive services, corresponding offerings need to be identified, developed and economically evaluated. New service offerings do not only cover product-related services which are predominantly designed to maintain or restore the initial condition of an asset. Activities in this category address the development of proactive, customer-oriented, value-added services which aim at generating value beyond maintenance of the status quo. As mentioned in Sect. 2, such services may be more independent and only distantly related to industrial goods.

New service offerings range from warranty extension, remote service, and cyber-security, to services built on technologies such as data engineering, software as a service, and cloud-based offerings, to engineering of advanced solutions, process and environmental safety, energy efficiency, and other services which generate value beyond maintaining the status quo of industrial equipment. Additionally, for each of these offerings, providers need to decide on the bundling and packaging of products and services, on payment models, terms and conditions of contracts, and consequences for institutional and organisational change.

Customer Support: The third functional area, customer support, deals with all activities needed to provide *information* to customers, e. g. via phone support, in personal meetings, or as online documentation. Information provided as an industrial service is any information needed to

[3] The industrial service cube was developed by the authors in conjunction with a senior ABB service manager and complemented with input from service researchers from multiple universities across Europe.
[4] A more concise version of this section was published in Schmitz et al. (2015).

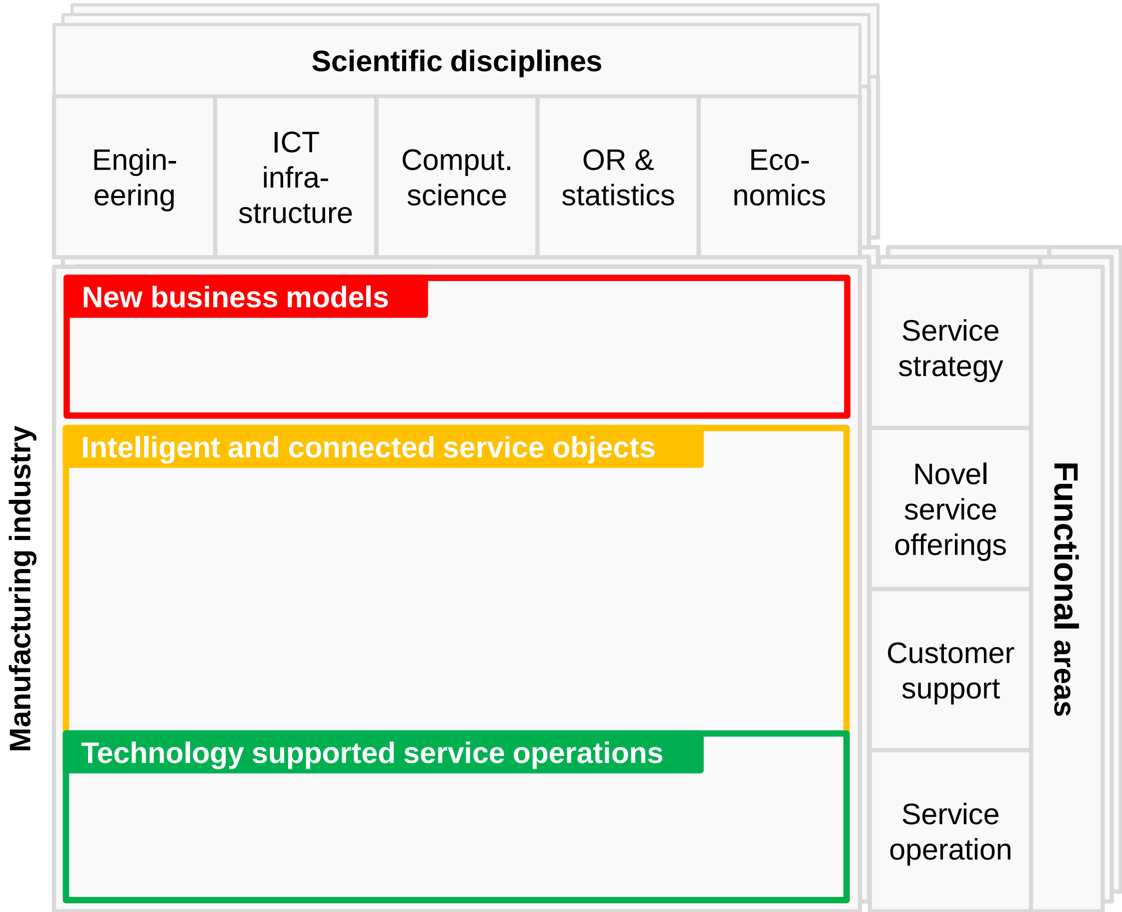

Figure 1: Fields of industrial service

properly operate and maintain industrial equipment and any information needed to properly make use of other industrial services. Examples are technical consulting (e. g. for plant maintenance), trainings, e-learning (e. g. for machine operators), and maintenance and performance audits.

Service Operation: As opposed to service strategy, service operation happens on an operational level and builds the functional *backbone* of the service business. It deals with the provision of supporting activities for the customer's asset throughout its life cycle as well as planning, organising, executing, and controlling the service delivery process.

This category covers services such as spare parts and consumables, installation and commissioning, inspection, maintenance, repair, reconditioning, performance upgrades, decommissioning, etc. Tasks may either be offered for an individual asset or for an entire fleet of assets (asset management). These service offerings need to be integrated with the service delivery process which may cover activities such as human resources planning (e. g. scheduling of service technicians), inventory planning (e. g. determination of economic order quantities and frequencies for parts), planning of transportation and reverse logistics, maintenance scheduling, etc.

3.2 Scientific Disciplines

The cube's second dimension shows different key *scientific disciplines* which describe the knowledge and capabilities necessary to develop, deliver, and manage industrial services and to address corresponding research problems. Disciplines of major importance are economics (e. g. knowledge about business and pricing models and business administration), operations research and statistics (e. g. expertise in data quality, data analytics, and reliability engineering), software-focused computer science (e. g. knowledge about information systems, data management, and software development), hardware-focused information, and communication technology (e. g. knowledge about cyber-physical systems, mobile devices, ubiquitous computing) as well as various engineering disciplines (e. g. understanding of technical properties of assets).

3.3 Industry Domains

The fields of scientific disciplines and functional areas of industrial services are complemented by a third dimension describing different *industry domains*. While the previous two dimensions allow us to describe typical service topics, solutions will vary slightly by industry. For example, certain activities are governed by industry-specific standards (such as the International Railway Industry Standard (IRIS)), specialised safety requirements and technical differences. A technical solution developed for the chemical industry may not readily apply for waste water management or car manufacturing, for example.

The main function of the cube presented in this section is to illustrate the multitude of service functions as well as the highly inter-disciplinary nature of industrial service research. In the next section, we present some of the main challenges associated with the areas of the cube.

4 Future and Current Industrial Service Challenges

We have identified industrial service as a critical field of business in Sect. 1 to motivate a deeper discussion of the topic. In this section, we present a series of challenges (in particular in Sect. 4.3) that we feel remain in the field of industrial service and/or are bound to emerge in the future. Furthermore, we show the trends currently affecting industrial services and their effects on the industrial services cube. When discussing the challenges, we will show how these effects will reinforce or weaken the challenges. It should be noted that we see these challenges through the lens of potential commercial use with all the advantages and problems this implies.

4.1 Current Trends in Industrial Services

Increased Interest in Industrial Manufacturing: As an aftermath of the financial crisis in 2008, there is currently a strong desire to (re-)strengthen the industrial base in the developed world (see e. g. European Commission 2012a,b; Ministry of Industrial Renewal France 2013; Popkin and Kobe 2010). In Europe, promoting *industrial leadership* is one of the focal points of research and innovation initiatives to achieve the strategic goals of the agenda Europe 2020. While the majority of research projects currently aim at the development of *technologies and (product) innovation* (see e. g. European Commission 2012b), complementary research and innovation in industrial services are needed to maintain technological leadership of the European industry and to achieve sustainable growth of the European economy in a globalized world. In fact, all technological innovations promoted through European and national research initiatives such as *Industry 4.0* (German Federal Ministry of Education and Research and Federal Ministry of Economics and Technology 2012), *Factories of the Future* (European Commission 2013a), *Sustainable Process Industries* (European Commission 2013b), *The New Industrial France* (Ministry of Industrial Renewal France 2013), and many others require an equal advancement in research and innovation on industrial services to maintain and extend industrial leadership. Increased interest in industrial production automatically increases the importance of industrial service.

Incorporation of Cyber-Physical Systems and Mobile Technologies: In today's discussions at industry conferences and in German government publications, the vision of production systems incorporating cyber-physical systems (CPS) (Lee 2006, 2008) has a strong presence (see e. g. German Federal Ministry for Economic Affairs and Energy 2012, 2014). The introduction of a CPS results in massive changes in almost every aspect of industrial services. The *service objects*, industrial products, are becoming more and more *intelligent and connected*. They can sense and monitor their condition, they can predict and analyse failures, and they can configure, manage, and heal themselves. They are connected via networks (e. g. the Internet) with other systems or service centers. They know which part needs to be replaced and can order the required spare part by themselves. The recent developments in mobile technologies ensure that service personnel can also be connected to the CPS.

New Ways of Providing Service: On the business side, we see changing customer expectations and the demand for new business models (Kindström and Kowalkowski 2009; Meier et al. 2010; Ostrom et al. 2010; Reen 2014; Sakao et al. 2009). Due to the ever increasing complexity of industrial products and services, customers are willing to buy more and higher value services from the supplier than they did in the past. On the other hand, customers want to avoid the risk of unpredictable service costs (Meier et al. 2010; Neely 2008) and more and more customers go over to requesting service offerings which guarantee performance or outcome via performance-based or full-service contracts (see e. g. Huber and Spinler 2014; Hypko et al. 2010; Kim et al. 2007).

4.2 Effects on the Subfields of Industrial Services

We postulate that these trends will have three major (and probably a series of minor) effects on the way industrial services are offered and delivered (cf. Fig. 1).

New Business Models: Due to the digitalisation of production and the increased interaction between customer and service provider as well as new business model developments in fields such as IT, one area of change is the emergence of new business models.

Intelligent and Connected Service Objects: The development towards CPS will imply that assets and other objects to be serviced become more complex. New sources of failure (i. e. the new connections and supporting infrastructure) are introduced which sometimes require a new skill set. Product life cycles change due to the utilization of components from the consumer market. In other words, maintaining a CPS will introduce new challenges that are best addressed at an early stage where possible.

Technology Supported Service Operations: Regardless of how industrial production systems do or do not change, the service operation itself can significantly be *improved and supported by technology*. Service technicians are nowadays equipped with smart phones or hand-held devices that can automatically guide them to the point of service and can give them any information necessary to perform the service task. Augmented reality devices (e. g. eyeglasses) can display information (labels, instructions) in the field of view of the technician to support his or her work. Intelligent diagnosis systems can assist service personnel by quickly and automatically analysing symptoms of a failure or malfunction and identifying probable causes that can explain these symptoms. With new technological advances around the corner, there will be new applications in industrial service as well (see e. g. Aleksy and Rissanen 2014; Aleksy and Stieger 2009; Tesfay et al. 2013).

4.3 Challenges

All these developments underpin that industrial service will play an important role in industry and academia for the years to come. Exploiting its potential will require an interdisciplinary approach in order to account for the diverse nature of industrial services. In this section, we look at existing and new challenges in more detail. These challenges were identified during years of industry project work and discussions with practitioners from multiple companies.

4.3.1 Tracking the Installed Base

In many of the mature markets, there is only a small potential for growth in the product business. However, the large amount of products already sold, called the installed base, is a very lucrative market for service business. For example, machines might need preventive maintenance, inspections, repair or configuration. However, this service need is not always recognized by customers. Even if it is, the business does not necessarily go to the vendor. For this reason, the service units of industrial product vendors see knowledge of the installed base as a key enabler for service business today. To our knowledge, there is little academic research addressing the tracking of the installed base (with few exceptions such as Borchers and Karandikar 2006), even though it is an important topic for practitioners (e. g. Balle 2013).

Tracking the installed base is a major challenge. Very often, products such as motors are sold to Original Equipment Manufacturers (OEM) which use them as components in their own products. Naturally, OEM are not interested in passing on information about the end-users of their assets as they covet doing the service themselves. Other products are sold to resellers. Even if products are directly sold to an end user, it might be unclear where they end up. For example, the global sourcing strategy of a major German chemical company means that many products will be sold to their main site and are then distributed around the globe without knowledge of the vendor. Tracking the installed base will become simpler with the introduction of CPS, where products are connected to networks and could potentially register themselves.

4.3.2 Proof of Value Proposition

Today, there is an increasing desire on the vendor side for value-based pricing approaches, especially for remote service offerings and advanced services. In the industrial field, the core enabler of value-based pricing is the ability to measure the benefit of a service. For example, a software service might be used to improve the scheduling at a steel mill. The improved scheduling might allow for slabs (i. e. blocks of steel) to be sent directly to the hot rolling mills more often which reduces the cost of energy for reheating. The reduced energy cost is the benefit provided by the service and the provider of the service can be paid a fraction of these savings.

However, despite the general enthusiasm, instances of successful implementations of this business model are rare. The most prominent example is the Rolls Royce ‘Power by the Hour’ model (e. g. Smith 2013), but most people would be hard-pressed to name a second one. Also, many solutions such as Hilti’s fleet management offer called ‘Hilti Flottenmanagement’ go only marginally beyond equipment rental.

Our explanation is that, while this approach sounds simple in theory, it does not take into account the open system boundaries encountered in the real world. Typically, the service provided will not be the only change on an industrial site. There might be other improvement initiatives, changed demand patterns, and many other factors that can influence the same metric as the value-priced service. Experience has shown that this can lead to lengthy cause-and-effect discussions between provider and customer.

There are two main reasons why it is hard to accurately map cause and effect. First, there is a lack of data. While a good selection of sensors exists today, the challenge is to measure the right information at an adequate price. Second, the high complexity of modern production systems makes it expensive to model all relevant factors in an adequate way. If a cost-effective way is developed to incorporate CPS into production systems, the lack of data will be reduced and the system’s driving factors will be better understood. To our knowledge, there is no meaningful research being done to address this topic specifically.

4.3.3 Life Cycle Management and Obsolescence

Today’s consumer market is driven by fashion and technological change. New equipment is more powerful than existing one that is not very old yet. For this reason, there is little incentive for vendors to support old equipment and only a minority of consumers seems to worry about this fact. The situation is different in an industrial environment. Industrial equipment is often quite costly and technological capability not necessarily a production bottleneck.

On the other hand, replacing the old asset with a state-of-the-art product requires a time of shutdown which can result in massive cost of opportunity due to missed production. Also, the complexity of modern production systems means that upgrades often lead to a series of other upgrades due to incompatibilities. Consider the example of an operator station in a chemical plant running WINDOWS XP. Upgrading to a new WINDOWS version might require new hardware (due to missing drivers) and new operator station software. The new machines will probably no longer have a serial port, leading to a cascade of further changes. It is not surprising that a large number of industrial customers are reluctant to upgrade even though XP is no longer supported.

This mind-set results in a series of challenges which are only partially solved today. On the one hand, service strategies have to be developed that help support obsolete equipment. This requires the securing of relevant spare parts (which might also be obsolete and thus are no longer manufactured) and understanding the changes to inspections and preventive maintenance schedules. The increased cost of such measures needs to be quantified and balanced against the likewise substantial cost of new investments. This requires improved life cycle costing models that are not too complex but still effective. This is a challenge which is likely to increase in importance with the introduction of CPS or other new technologies and might partially be mitigated by farsighted business models. There are already publications which propose proactive approaches to obsolescence management (e. g. Bartels et al. 2012) or which allow the analysis of life cycle cost (Gitzel et al. 2011). However, to our knowledge this prior art is not applied to the design of CPS nor are there any publications in major journals or at important conferences which even consider the problem of electronics obsolescence in future production systems.

4.3.4 Failure Prediction

Today, there are success stories of equipment being monitored by new sensors whose data output is used in prediction models to anticipate failures. The benefit of this approach is reduced downtime of assets and reduced repair cost. Despite the many methods already available (see Si et al. (2011) for an overview), there is still a lot of work to be done to make failure prediction a wide-spread solution. The main challenges for failure prediction are related to the sensors and the prediction models.

While sensors have become cheaper, their added cost is still a challenge, especially for low-end equipment. Increased investment cost can be a show-stopper for these types of assets. It should also be noted that there are qualitative differences between sensors, so the cheapest solution might not provide the required level of accuracy. However, it seems that the solution to this problem is only a question of time. A more pressing challenge is to develop sensors which have a life cycle adequate for the asset monitored. The value proposition of failure prediction is that expensive downtime and maintenance effort can be reduced. However, if the sensor suite requires a lot of maintenance, this increases cost and possibly downtime as well, if sensor maintenance is not possible on a running asset.

A second aspect in need of further innovation are the prediction models, which today are too expensive. The cost driver for these models is their inherent complexity. Model creation and model use require a level of knowledge where it is neither easy nor cheap to find and employ the proper personnel. Therefore, the typical success stories actually implemented in the field are often targeting very expensive and critical equipment where large investments are considered acceptable. While one might hope to leverage economies of scale (i. e. the n+1st model will be much cheaper than the previous n models), we are pessimistic as to whether this is possible with today's technology (see Sect. 4.3.9).

Solving this challenge is one of the goals associated with the introduction of CPS on the production and on the service side. Once it is solved, the new failure prediction models can be sold as part of a series of new business models.

4.3.5 Knowledge Retention and Training

Many industrial vendors and customers are faced with a sneaking deterioration of automation knowledge. One reason is the top-heavy age structure in many companies. Especially in many service units, a substantial fraction of the employees are close to retirement. As a result, a good way of knowledge retention and transfer has to be found. On the customer side, there is currently a trend to focus on core competencies. For example, chemical companies focus on understanding their production process and are loath to invest in automation knowledge. As a result, vendors need even more people able to solve automation-related problems. Some of the key challenges arising from this development are listed below.

Capturing knowledge that exists mainly in the brains of experienced personnel without a lot of time and pedagogic experience is difficult and there is quite a bit of literature on technical training (e. g. Ledgerwood 1976; Marino 1991). In our opinion, the ideal solution to this problem would be to record and process the daily activity of employees (e. g. through process mining as proposed by Agrawal et al. 1998) and to digitize old manuals.

Storing knowledge becomes important for tasks which occur at low frequencies, e. g. the repair of legacy systems or the performance of highly infrequent maintenance tasks that occur once in a decade or even less (Haase and Tabke 2013). The main challenge in this context is to store data in such a way and format that it can be found when needed.

Efficient training should be available in a digital form and require little or no intervention from a human teacher. There are already examples of interactive e-learning tools for industrial service, however, the creation is still too expensive for wide-spread use (Haase and Tabke 2013).

Virtual Reality has long been considered a promising approach to industrial training (El-Chaar et al. 2011; Tam et al. 1999; Yang et al. 2010). However, while projects such as the Elbedom (Schenk 2001) are impressive for the visitor, the content creation cost is currently too high (Tam et al. 1999) to make widespread use of this technology. We feel that the introduction of mobile devices will be of great value for knowledge retention and information access, as described below. On the other hand, the more complex production systems of the future will make training even more important, increasing the need for further research in this field.

4.3.6 Information Access in the Field

As mentioned in the previous subsection, knowledge is a key enabler of industrial services. However, the general service knowledge also needs to be combined with case-specific information. This information relates to the design and status of assets or systems as well required actions. It can also include manuals and other documentation. Ideally, such information is short and relevant, easy to maintain, and available in the field. However, there are several factors which prevent an easy implementation of such a delivery system.

Industrial organisations have very different needs regarding their assets and thus there is a high number of products, variants, and parts available. Some are legacy products which were documented on paper or in long-obsolete systems. The large data volume and the variety of sources make it difficult to easily locate the right information. Furthermore, especially in field service, information needs to be short and relevant as there is no time to read through a lot of material and it is not convenient to browse through large texts on a small screen.

Today, many information access solutions are based on mobile devices such as smart phones or tablets. However, the industrial environment poses unique challenges (Aleksy and Stieger 2009) which limit the use of commercial off-the-shelf products. Industrial plants are often noisy and dirty places and are subject to strict health and safety rules. Consumer products such as smart phones are vulnerable to dirt, concussions, and other environmental influences found at the industrial work place. Often, service technicians wear protective clothing which makes it difficult to use touch screens (i. e. thick gloves) or to hear sound (ear protection). Voice control is made difficult by the high ambient noise. Furthermore, the ATEX 95 equipment directive places special requirements on equipment intended to be used in areas where there is a danger of explosions. These requirements are not typically met by consumer equipment.

The topic of information access for industrial service has spurned a variety of projects (Aleksy et al. 2011; Gitzel et al. 2014) and there are already tools such as the USU Knowledge Scout, to name but one. However, all of these projects are software-oriented and the challenge of producing affordable industry-ready hardware remains. In order to address this challenge, it is necessary to influence the development of commercial consumer products in such a way that they are suitable for industrial applications. A water-proof smart phone is a nice thing to have for anybody, after all. We propose that the increased complexity of CPS-based production systems will act as a driver as it makes this challenge even more pressing.

4.3.7 B2B E-Commerce

There are many similarities between B2C and B2B E-Commerce. For example, both B2B and B2C web stores need good search and navigation. Presumably, with all other things being equal, a purchaser will prefer the shop with the superior online experience. Features such as wish lists, simple checkout processes, as well as cross- and up-selling have a positive impact on both, the B2B and B2C sales volume, if web shop vendors are to be believed. However, there are also differences, especially in the context of spare parts, which we will use as an example in this section.

Selling spare parts is a very lucrative industrial service. However, an online shop for spare parts faces challenges that are different from those of a B2C web shop. Unlike a typical consumer product, spare parts are often hard to identify, with the name/ID not known to the customer. Also, industrial spare parts with similar specifications are not necessarily interchangeable in highly demanding processes. These circumstances make it very difficult to buy the right part. A good solution to this problem is to use technical diagrams of the product where the user can click on the part they want to buy.

From the vendors side, the problem is to create and update such a rich interface for all their products and even to maintain the master data. A typical industrial product vendor has to cover an astronomical number of spare parts, most of which will sell in very small quantities. Small changes in product design might not properly propagate to the parts catalogue, so the new parts will not be in the catalogue.

Finally, pricing of parts depends on long-term frame agreements, negotiations, and other factors, so an online shop has to be able to access such information and has to allow for quotes and individual changes for prices. For a discussion of further B2B E-Commerce issues see e. g. IBM (2014, p. 5).

While most of these problems could be considered solved given the availability of commercial software packages (e. g. WEBSPHERE COMMERCE or DOCUMOTO by DIGABIT), we have to consider the impact of future developments. How will spare parts selling be impacted by the changes to the industrial service cube? Arguably, more complex systems will need more parts but increased intelligence of components will probably make it easier to identify and order parts. The technology supporting the service technician might also be included in the loop, e. g. to inform technicians about parts ordered or parts possibly required with repercussions for the whole supply chain. There is also some interest by customers in no longer buying parts as spares on site, but reserving parts to buy when needed with a guaranteed delivery time. Such arrangements would need new business models to support them.

4.3.8 Effective Business Models for Advanced Solutions

When talking to customers and providers of industrial service, there is a great interest in 'advanced' solutions. A typical example is the use of specialized control and/or data analytics algorithms to improve the Overall Equipment Effectiveness (OEE) of a process industry plant. This means an improvement of plant availability, quality of the output, and/or speed of production. There are good examples for such algorithms being implemented as part of projects.

The key challenge for advanced solutions is to monetize them. Currently, advanced solutions are mainly sold via implementation projects. To us, it is an open question whether this is the most effective business model for the vendor and the customer. For the vendor, there is no opportunity to leverage economies of scale if each solution is custom-made by expensive experts. In many cases, the effort to adapt an existing solution to other sites is simply too high. For the customer, this means that maintenance of such algorithms is expensive as any change to production processes (or even the occurence of process drift) will require adjustments to the solution. This challenge is a special case of the one described in Sect. 4.3.9 in that we do not talk about general software but mathematical optimization programs. A solution to this challenge might reuse ideas from software engineering, such as dynamic software product lines (cf. Bencomo et al. 2012). However, we find it unlikely that these solutions can be transferred without major adaptations.

4.3.9 Software and Remote Service

Software is typically a product with high fixed cost and low (even close to zero) marginal cost. Security is considered important but implementation lags behind. With regard to privacy, many business models are actually based on its violation. For software within an industrial context, these assumptions have to be challenged to some extent.

First of all, industrial software often does not have a low marginal cost. In fact, the unique requirements of different customer plants make a high level of configuration necessary as part of the plant engineering. For similar reasons, operating system updates cannot just be applied automatically but must be cleared by experts beforehand to make sure there are no detrimental side effects. This problem affects most industrial software even if we ignore the special cases such as mathematical optimization software and code executed on real-time controllers (see Sect. 4.3.4 and Sect. 4.3.8). Dynamic software product lines (cf. Bencomo et al. 2012) look like a promising way to address these problems.

Security is a topic of very high importance in industrial software (Stouffer et al. 2015). Some production processes, e. g. in refineries, nuclear power plants, or steam crackers, can pose a danger to the environment and human life if disturbed by attackers. Historically, the control systems of such plants were not connected to the Internet. Concepts such as software as a service and remote service open additional entry points for attackers that need to be secured at the highest level. For similar reasons, privacy is of major importance. Many production processes are based on secret recipes or practices that a company does not want to share with others. Generic IT security measures can and are applied to industrial IT systems today. Also, there are quite interesting developments such as homomorphic encryption (Popa and Zeldovich 2015).

The three challenges mentioned in this subsection have to be taken into account when developing concepts for industrial software, remote services, or cloud-based solutions. In our opinion, the existing solutions are a good starting point, however, the introduction of CPS and more service support technology will increase the level of challenge further.

4.3.10 Maintenance of Cyber-Physical Systems

The German initiative 'Industrie 4.0' advocates the use of a CPS in production. Industry organisations like the NAMUR (an international association of users of automation technology in process industries, which is very influential in Germany) or

ZVEI (a major industrial association in Germany) are very interested in these developments and have come up with the first proposals on how to implement production processes based on a CPS. From the standpoint of industrial service, these changes mean that there are new opportunities and challenges.

On the positive side, a CPS will likely open new diagnostic opportunities due to better sensor coverage and connectivity of nodes. In fact, there are already several papers which explore the positive impact on maintenance (e. g. Herterich et al. 2015; Lee et al. 2014). However, the technical details are still open to further research and development. On the other hand, a CPS has a much higher level of system complexity. While higher system complexity does not automatically imply higher downtime, it does increase the amount of component-level failures simply due to the fact that there are more components. It also increases the difficulty of identifying the root cause of the failure. Also, maintaining a CPS requires a different skill set than maintaining a traditional production system. While some authors acknowledge the risk of CPS failure (e. g. Banerjee et al. 2012) there is currently no research how much extra effort it takes to maintain a CPS and how to best maintain a CPS technically and organisationally.

4.3.11 Management of Uncertainties and Risks

Growing the service business is an objective found in many strategic initiatives of industrial equipment providers today. While in the past they were mainly concerned with developing and selling industrial equipment in a transaction-based business, nowadays they often enter into long-term contractual relationships resulting in an increased exposure to risks and uncertainties.

Today, some customers demand extended warranties, full-service contracts and aim at contracting availability, performance and output rather than ordering single spare parts or maintenance jobs (Huber and Spinler 2014; Hypko et al. 2010; Kim et al. 2007). In this context, the management of uncertainties and risks is a key challenge in developing lasting and sustainable service business models. Providers need to decide to sell products or services separately or as a bundle, with fixed or variable pricing models while taking account of an increased sharing of customer risks and exposure to uncertainties (Van Ostaeyen et al. 2013).

Thus, growing long-term service relationships and offering corresponding agreements depend upon the development of new pricing models and methodologies to identify, quantify, and manage risks in service agreements. All of these challenges are part of the introduction of new business models which alter the distribution of risk.

5 Conclusion

The purpose of this paper is to motivate more researchers from the field of business informatics to contribute to the task of overcoming the challenges which exist or are likely to arise in the context of industrial service. According to the IEEE CBI 2015 call for papers, business informatics is ‘the scientific discipline targeting information processes and related phenomena in their socio-economical business context, including companies, organisations, administrations and society in general’ which aligns ‘core concepts from management science, organisational science, economics information science, and informatics into an integrated engineering science’. Industrial service is a socio-economical activity conducted by companies or organisations such as utilities and thus is within the targeted scope of business informatics. From the standpoint of industrial service, business informatics provides useful input because it covers many of the scientific skills we have identified, i. e. economics (which in the context of this discussion is considered to include management and organisational science) and computer science/informatics.

In summary, we see the following possible key contributions by business informatics researchers: Business data specialists might be interested in those challenges which involve the storage and analysis of data, e. g. installed base tracking, life cycle management, failure prediction, and knowledge retention. Researchers with a focus on business models will find that the technological changes lead to a need for new business models, both for advanced solutions and for traditional maintenance operations in a changing environment. New interesting architectural and modelling questions arise due to the increasing role of software, mobile devices, and intelligent assets.

We think that industrial service as a research field is attractive for two reasons. First, as can be seen by market numbers and government investments, the field is extremely relevant to society (Sect. 1). Second, due to the number of open challenges, there is plenty of opportunity to achieve visibility as a scientist. Due to the extremely multi-disciplinary nature of the field, there are many ways to contribute. We hope that this short overview will motivate interesting new research in industrial service within the business informatics community.

6 Acknowledgements

This paper would not have been possible without the many people who took the time to discuss with us their particular industrial service challenges. We would like to thank the various ABB Business Unit and Division Service R&D Managers and service technicians for their input over the years. In particular, we would like to thank Christopher Ganz (ABB Group Service R&D Manager), Guido Sand (Focus Area Manager Service Solutions), and Bernhard Eschermann (ABB PA Division Tech Manager). We would also like to thank our discussion partners for the industrial service cube Veronica Martinez (University of Cambridge), Florian Urmetzer (University of Cambridge), Liliane Pintelon (KU Leuven), and Risto Rajala (Aalto University).

References

Agrawal R., Gunopulos D., Leymann F. (1998) Mining Process Models from Workflow Logs. In: Schek H.-J., Alonso G., Saltor F., Ramos I. (eds.) Advances in Database Technology - EDBT'98. LNCS Vol. 1377. Valencia, Spain, pp. 469–483

Aleksy M., Rissanen M. J. (2014) Utilizing wearable computing in industrial service applications. In: Journal of Ambient Intelligence and Humanized Computing 5(4), pp. 443–454

Aleksy M., Rissanen M. J., Maczey S., Dix M. (2011) Wearable Computing in Industrial Service Applications. In: Procedia Computer Science 5 The 2nd International Conference on Ambient Systems, Networks and Technologies (ANT-2011)/The 8th International Conference on Mobile Web Information Systems (MobiWIS 2011), pp. 394–400

Aleksy M., Stieger B. (2009) Challenges in the Development of Mobile Applications in Industrial Field Service. In: Durresi A., Barolli L., Enokido T., Uehara M., Shakshuki E., Takizawa M. (eds.) International Conference on Network-Based Information Systems (NBIS 2009). IEEE Computer Society, Indianapolis, Indiana, USA, pp. 586–591

Baines T. S., Lightfoot H., Evans S., Neely A., Greenough R., Peppard J., Roy R., Shehab E., Braganza A., Tiwari A., Alcock J. R., Angus J. P., Bastl M., Cousens A., Irving P., Johnson M., Kingston J., Lockett H., Martinez V., Michele P., Tranfield D., Walton I. M., Wilson H. (2007) State-of-the-art in product service-systems. In: Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 221(10), pp. 1543–1552

Baines T. S., Lightfoot H. W., Benedettini O., Kay J. M. (2009) The servitization of manufacturing: A review of literature and reflection on future challenges. In: Journal of Manufacturing Technology Management 20(5), pp. 547–567

Balle U. (2013) Obsolescence Management - Auslaufende Anlagenteile managen und Migrationsdienstleistungen nutzen. Presentation at Instandhaltung 3.0+, Karlsruhe, Germany

Banerjee A., Venkatasubramanian K. K., Mukherjee T., Gupta S. K. S. (2012) Ensuring Safety, Security, and Sustainability of Mission-Critical Cyber-Physical Systems. In: Proceedings of the IEEE 100(1), pp. 283–299

Bartels B., Ermel U., Sandborn P. A., Pecht M. G. (2012) Strategies to the Prediction, Mitigation and Management of Product Obsolescence. Wiley Series in Systems Engineering and Management Vol. 87. John Wiley & Sons, Inc., Hoboken, New Jersey, USA

Bencomo N., Hallsteinsen S., Santana de Almeida E. (2012) A View of the Dynamic Software Product Line Landscape. In: Computer 45(10), pp. 36–41

Borchers H. W., Karandikar H. (2006) A Data Warehouse Approach for Estimating and Characterizing the Installed Base of Industrial Products. In: International Conference on Service Systems and Service Management (ICSSSM 2006) Vol. 1. IEEE, Troyes, France, pp. 53–59

Boyt T., Harvey M. (1997) Classification of Industrial Services: A model with Strategic Implications. In: Industrial Marketing Management 26(4), pp. 291–300

Brax S. (2005) A manufacturer becoming service provider - challenges and a paradox. In: Managing Service Quality 15(2), pp. 142–155

El-Chaar J., Boer C. R., Pedrazzoli P., Mazzola S., Maso G. D. (2011) Interactive 3D Virtual Environments for Industrial Operation Training and Maintenance. In: Xu B. (ed.) 9th International Conference on Reliability, Maintainability and Safety (ICRMS 2011). IEEE, Guiyang, China, pp. 1376–1381

Cooper R. G., de Brentani U. (1991) New Industrial Financial Services: What Distinguishes the Winners. In: Journal of Product Innovation Management 8(2), pp. 75–90

Datta P. P., Roy R. (2011) Operations strategy for the effective delivery of integrated industrial product-service offerings: Two exploratory defence industry case studies. In: International Journal of Operations & Production Management 31(5), pp. 579–603

de Bretani U. (1995) New Industrial Service Development: Scenarios for Success and Failure. In: Journal of Business Research 32(2), pp. 93–103

European Commission (2012a) A stronger European industry for growth and economic recovery. Industrial policy communication update. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. COM 582 final

European Commission (2012b) Horizon 2020 - Industrial Leadership. http://ec.europa.eu/programmes/horizon2020/en/h2020-section/industrial-leadership. Last Access: 2014.03.20

European Commission (2013a) Horizon 2020 - Call for Factories of the Future. http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/calls/h2020-fof-2015.html. Last Access: 2014.02.10

European Commission (2013b) Horizon 2020 - Call for SPIRE - Sustainable Process Industries. http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/calls/h2020-spire-2015.html. Last Access: 2014.02.10

Gebauer H., Bravo-Sanchez C., Fleisch E. (2008) Service strategies in product manufacturing companies. In: Business Strategy Series 9(1), pp. 12–20

German Federal Ministry for Economic Affairs and Energy (2012) Machine-to-Machine-Kommunikation - eine Chance für die deutsche Industrie. https://www.it-gipfel.de/IT-Gipfel/Redaktion/PDF/it-gipfel-2012-machine-to-machine-kommunikation-eine-chance-fuer-die-deutsche-industrie-ag-2-m2m-initiative-deutschland,property=pdf,bereich=itgipfel,sprache=de,rwb=true.pdf. Last Access: 2015.02.25

German Federal Ministry for Economic Affairs and Energy (2014) Smart Service Welt - Internetbasierte Dienste für die Wirtschaft. http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/smart-service-welt-internetbasierte-dienste-fuer-die-wirtschaft,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf. Last Access: 2015.02.25

German Federal Ministry of Education and Research and Federal Ministry of Economics and Technology (2012) Project of the Future: Industry 4.0. http://www.bmbf.de/en/19955.php. Last Access: 2014.01.15

Gitzel R., Dix M., Stich C. (2011) Life Cycle Cost Model for Distributed Control Systems - A Taxonomy-based Approach. In: atp Edition 53(5), pp. 56–65

Gitzel R., Klöpper B., Maczey S., Kleine B., Turrin S. (2014) Maintenance Support Through Dynamic Fault Trees. In: EuroMaintenance 2014 CONGRESS & EXPO. Helsinki, Finland

Haase T., Tabke T. (2013) Qualifizierung technischer Fachkräfte mit Methoden der virtuellen Realität. Presentation at Instandhaltung 3.0+, Karlsruhe, Germany

Henkel C. B., Bendig O. B., Caspari T., Hasagic N. (2004) Industrial Services Strategies: The Quest for Faster Growth and Higher Margins. Consultancy Report. Monitor Group. Zurich, Switzerland; Munich, Germany

Herterich M. M., Uebernickel F., Brenner W. (2015) The Impact of Cyber-physical Systems on Industrial Services in Manufacturing. In: Procedia CIRP 30 7th Industrial Product-Service Systems Conference - PSS, industry transformation for sustainability and business, pp. 323–328

Homburg C., Garbe B. (1999) Towards an Improved Understanding of Industrial Services: Quality Dimensions and Their Impact on Buyer-Seller Relationships. In: Journal of Business-to-Business Marketing 6(2), pp. 39–71

Huber S., Spinler S. (2014) Pricing of Full-Service Repair Contracts with Learning, Optimized Maintenance, and Information Asymmetry. In: Decision Sciences 45(4), pp. 791–815

Hypko P., Tilebein M., Gleich R. (2010) Clarifying the concept of performance-based contracting in manufacturing industries: A research synthesis. In: Journal of Service Management 21(5), pp. 625–655

IBM (2014) B2B Commerce Effectiveness: 5 Key Components of Successful B2B Commerce. https://www14.software.ibm.com/webapp/iwm/web/signup.do?source=swg-smartercom_medium&S_PKG=ov25530&S_TACT=101K815W&dynform=14822&lang=en_US. Last Access: 2015.02.25

Ivens B. S. (2005) Flexibility in industrial service relationships: The construct, antecedents, and performance outcomes. In: Industrial Marketing Management 34(6), pp. 566–576

Jackson R. W., Cooper P. D. (1988) Unique Aspects of Marketing Industrial Services. In: Industrial Marketing Management 17(2), pp. 111–118

Johansson P., Olhager J. (2004) Industrial service profiling: Matching service offerings and processes. In: International Journal of Production Economics 89(3), pp. 309–320

Karandikar H., Vollmar G. (2006) In-depth Observations of Industrial Service Operations. In: International Conference on Service Systems and Service Management (ICSSSM 2006) Vol. 1. IEEE, Troyes, France, pp. 739–744

Kim S.-H., Cohen M. A., Netessine S. (2007) Performance Contracting in After-Sales Service Supply Chains. In: Management Science 53(12), pp. 1843–1858

Kindström D., Kowalkowski C. (2009) Development of industrial service offerings: a process framework. In: Journal of Service Management 20(2), pp. 156–172

Kohtamäki M., Partanen J., Parida V., Wincent J. (2013) Non-linear relationship between industrial service offering and sales growth: The moderating role of network capabilities. In: Industrial Marketing Management 42(8), pp. 1374–1385

Kowalkowski C. (2006) Enhancing the industrial service offering: New requirements on content and processes. Dissertation from the International Graduate School of Management and Industrial Engineering, No. 104, Linköping University, Institute of Technology, Linköping, Sweden

Kowalkowski C., Kindström D., Brehmer P.-O. (2011) Managing industrial service offerings in global business markets. In: Journal of Business & Industrial Marketing 26(3), pp. 181–192

Ledgerwood L. W. (1976) Professional Technical Training. In: IEEE Transactions on Education 19(3), pp. 100–103

Lee E. A. (2006) Cyber-Physical Systems - Are Computing Foundations Adequate? Position Paper for National Science Foundation Workshop on Cyber-Physical-System: Research Motivations, Techniques and Roadmap October 16-17,2006, Austin, Texas, USA. Electrical Engineering and Computer Sciences Department, University of California at Berkeley. Berkeley, California, USA

Lee E. A. (2008) Cyber Physical Systems: Design Challenges. Technical Report UCB/EECS-2008-8. Electrical Engineering and Computer Sciences Department, University of California at Berkeley. Berkeley, California, USA

Lee J., Kao H.-A., Yang S. (2014) Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment. In: Procedia CIRP 16 Product Services Systems and Value Creation. Proceedings of the 6th CIRP Conference on Industrial Product-Service Systems, pp. 3–8

Marino G. G. (1991) Developing Technical Training Programs. In: Grayson L. P. (ed.) Frontiers in Education Conference, 1991. Proceedings of the Twenty-First Annual Conference. 'Engineering Education in a New World Order'. IEEE, West Lafayette, Indiana, USA, pp. 130–135

Mathieu V. (1999) Product Services Portfolio: Strategic and Marketing Insights. In: McLoughlin D., Horan C. (eds.) Proceedings of the 15th Annual IMP Conference. Dublin, Ireland, pp. 1–13

Mathieu V. (2001) Service strategies within the manufacturing sector: benefits, costs and partnership. In: International Journal of Service Industry Management 12(5), pp. 451–475

Matyas K., Rosteck A., Sihn W. (2009) Industrial Services - Corporate Practice and Future Needs for Action in Companies and in Applied Research. In: Proceedings of the 42nd CIRP Conference on Manufacturing Systems - Sustainable Development of Manufacturing Systems. Grenoble, France

Meier H., Roy R., Seliger G. (2010) Industrial Product-Service Systems - IPS^2. In: CIRP Annals - Manufacturing Technology 59(2), pp. 607–627

Ministry of Industrial Renewal France (2013) The new face of the industrial France. http://www.redressement-productif.gouv.fr/files/nouvelle_france_industrielle_english.pdf. Last Access: 2015.03.25

Morris M. H., Fuller D. A. (1989) Pricing an Industrial Service. In: Industrial Marketing Management 18(2), pp. 139–146

Neely A. (2008) Exploring the financial consequences of the servitization of manufacturing. In: Operations Management Research 1(2), pp. 103–118

Ojanen V., Ahonen T., Reunanen M. (2011) Availability and Sustainability as Value Elements in Assessing Customer Value of an Industrial Service. In: Kocaoglu D. F., Daim T. U., Anderson T. R. (eds.) 2011 Proceedings of PICMET '11: Technology Management in the Energy Smart World. Portland, Oregon, USA, pp. 2764–2774

Oliva R., Kallenberg R. (2003) Managing the transition from products to services. In: International Journal of Service Industry Management 14(2), pp. 160–172

Ostrom A. L., Bitner M. J., Brown S. W., Burkhard K. A., Goul M., Smith-Daniels V., Demirkan H., Rabinovich E. (2010) Moving Forward and Making a Difference: Research Priorities for the Science of Service. In: Journal of Service Research 13(1), pp. 4–36

Paloheimo K.-S., Miettinen I., Brax S. (2004) Customer Oriented Industrial Services. Report series. Helsinki University of Technology, BIT Research Centre. Espoo, Finland

Popa R. A., Zeldovich N. (2015) How to compute with data you can't see. In: Spectrum, IEEE 52(8), pp. 42–47

Popkin J., Kobe K. (2010) Manufacturing Resurgence - A Must for U.S. Prosperity. Study for the National Association of Manufacturers and the NAM Council of Manufacturing Associations. Joel Popkin and Company. Washington, Washington DC, USA

Quinn J. B., Doorley T. L., Paquette P. C. (1990) Beyond Products: Services-Based Strategy. In: Harvard Business Review 68(2), pp. 58–67

Reen N. (2014) The Pricing of Industrial Services. Dissertation, Åbo Akademi University, Turku, Finland

Regan W. J. (1963) The Service Revolution. In: Journal of Marketing 27(3), pp. 57–62

Sakao T., Sandström G. Ö., Matzen D. (2009) Framing research for service orientation of manufacturers through PSS approaches. In: Journal of Manufacturing Technology Management 20(5), pp. 754–778

Schenk M. (2001) EINTAUCHEN IN VIRTUELLE WELTEN. http://www.iff.fraunhofer.de/content/dam/iff/de/dokumente/publikationen/eintauchen-in-virtuelle-welten-fraunhofer-iff.pdf. Last Access: 2015.10.08

Schmitz B., Gitzel R., Fromm H., Setzer T., Isaksson A. (2015) What is "Industrial Service"? A Discussion Paper. In: Görlitz R., Bertsch V., Caton S., Feldmann N., Jochem P., Maleshkova M., Reuter-Oppermann M. (eds.) Proceedings of the First Karlsruhe Service Summit Research Workshop - Advances in Service Research. KIT Scientific Publishing, Karlsruhe, Germany, pp. 113–122

Si X.-S., Wang W., Hu C.-H., Zhou D.-H. (2011) Remaining useful life estimation - A review on the statistical data driven approaches. In: European Journal of Operational Research 213(1), pp. 1–14

Smith D. J. (2013) Power-by-the-hour: The role of technology in reshaping business strategy at Rolls-Royce. In: Technology Analysis & Strategic Management 25(8), pp. 987–1007

Stouffer K., Victoria P., Lightman S., Abrams M., Hahn A. (2015) Guide to Industrial Control Systems (ICS) Security. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-82r2.pdf. Last Access: 2015.10.05

Strähle O., Füllemann M., Bendig O. (2012) Service now! Time to wake up the sleeping giant - How services can boost long-term growth with attractive returns in industrial goods business. Consultancy Report. Bain & Company Inc. Munich, Germany; Zurich, Switzerland

Tam E. K., Badra F., Marceau R. J., Marin M. A., Malowany A. S. (1999) A Web-based virtual environment for operator training [for power systems]. In: IEEE Transactions on Power Systems 14(3), pp. 802–808

Tesfay W. B., Aleksy M., Andersson K., Lehtola M. (2013) Mobile Computing Application for Industrial Field Service Engineering: A Case for ABB Service Engineers. In: Jayasumana A., Turgut D. (eds.) The 7th IEEE Local Computer Networks Workshops on User Mobility and Vehicular Networks (ON-MOVE 2013). IEEE, Sydney, Australia, pp. 188–193

Van Ostaeyen J., Van Horenbeek A., Pintelon L., Duflou J. R. (2013) A refined typology of product-service systems based on functional hierarchy modeling. In: Journal of Cleaner Production 51, pp. 261–276

Vandermerwe S., Rada J. (1988) Servitization of Business: Adding Value by Adding Services. In: European Management Journal 6(4), pp. 314–324

Vargo S. L., Lusch R. F. (2004) The Four Service Marketing Myths - Remnants of a Goods-Based, Manufacturing Model. In: Journal of Service Research 6(4), pp. 324–335

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

Wise R., Baumgartner P. (1999) Go Downstream: The New Profit Imperative in Manufacturing. In: Harvard Business Review 77(5), pp. 133–141

Yang U., Lee G. A., Kim Y., Jo D., Choi J., Kim K.-H. (2010) Virtual Reality Based Welding Training Simulator with 3D Multimodal Interaction. In: Sourin A., Sourina O. (eds.) International Conference on Cyberworlds (CW 2010). IEEE, Singapore, pp. 150–154

Zeithaml V. A., Parasuraman A., Berry L. L. (1985) Problems and Strategies in Services Marketing. In: Journal of Marketing 49(2), pp. 33–46

Appendix A

Author	Definition of industrial service
Homburg and Garbe (1999)	Industrial services are 'services provided by a manufacturing company to organisational customers'.
Oliva and Kallenberg (2003)	*Installed base services* 'is the range of product- or process-related services required by an end-user over the useful life of a product in order to run it effectively in the context of its operating process'.
Henkel et al. (2004)	Industrial services are 'all business transactions which, subsequent to the sale\installation of a physical product, are intended to maintain and or optimize the operational process, upgrade performance and cover its resource needs throughout the entire life cycle'.
Johansson and Olhager (2004)	'The supply of after-sales services, including tangibles such as spare parts and consumables, related to the maintenance of industrial goods'.
Paloheimo et al. (2004)	Industrial services are 'services that are offered for customers' industrial production processes'.
Brax (2005)	Industrial services are 'services offered to organisations with industrial production. Industrial services are provided by manufacturers of industrial equipment or other companies which specialize in services'.
Kowalkowski (2006)	Industrial services are 'processes supporting customers' industrial production processes, so that value for them is created in those processes'.
Datta and Roy (2011)	Industrial services are 'a series of activities connected to customer's value creating processes in a business-to-business context'.
Reen (2014)	Industrial service 'is a process of exploiting the competences, knowledge, and technology base of a company's business, manufacturing, and operational processes. Industrial service can be applied for internal company's purposes of optimization, innovation, or business development or delivered to the customer in order to provide additional value as an independent offering or as a part of a solution (see definition below). Value is created through interaction between provider and consumers. The word 'industrial' emphasizes the context of service development and delivery'.

Table 2: Definitions of industrial service.