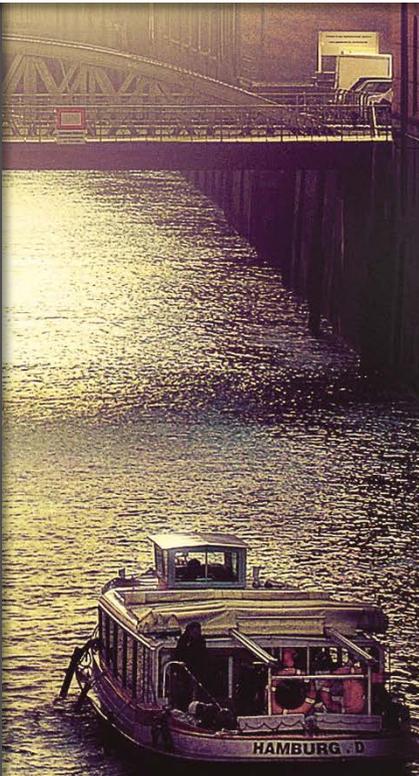


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IoT-coordinated Logistics in Product-Service Systems

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Product-Service Systems (PSS) enable new value to customers compared to traditional selling of goods, e.g. through new business models such as Performance-based contracting (PBC) and Pay-per-use (PPU). This turns the manufacturer into a service provider, which has to perform maintenance, repair and operation (MRO) tasks for the products provided in a PSS. Therefore, the service provider must organize the logistics of the equipment, spare parts, and consumables in a timely manner. In this paper, we evaluate the impact of Internet of Things (IoT) technology for the support of logistics-related tasks in PSS. More specifically, the required tasks with relevance of logistics are identified using case studies and existing literature. For each task, we derive trigger events and how they can be discovered automatically. Based on this, we propose a generalized architecture for IoT-enabled logistics processes in PSS, which can be used to better understand the operation of such systems and support their design.

Keywords: product-service systems; cyber-physical systems; Internet of Things; Performance-based contracting

1 Introduction

The proliferation of Internet of Things (IoT) technologies and ongoing servitization efforts in manufacturing companies break ground for new business models, such as pay-per-use (Weinberger, Bilgeri and Fleisch, 2016). One of the most frequently cited example for this principle is the “power-by-the-hour” concept of Rolls-Royce for aircraft engines (Neely, 2008). The concept of combining goods and services into an integrated offer is called Product-Service System (PSS). In more elaborate usage-based or results-based PSS, the task of managing and operating equipment is shifted from the user to provider (Elmazoski, et al., 2016). While this reduces the risk, required knowledge and maintenance resources at the customer, it causes uncertainty about the overall cost as it is usage-dependent. For the provider, which takes over the responsibility for maintaining the equipment, this model offers continuous revenue through long-time contracts, customer lock in and other benefits (Lockett et al., 2011).

The main aspect of PSS in regard to logistics is that products are not being sold but instead provided as a service or as part of service (Cavaliere and Pezzotta, 2012). Therefore, the provider strives to keep the contracted equipment running for two reasons: First, the revenue depends on the usage, and second, any penalty payments due to service level agreement (SLA) violations have to be avoided. To increase usage fees and prevent penalty payments for SLA violations with PBC, the service provider aims to perform all required activities to maintain high availability at the lowest possible cost. The employment of IoT-technology for products in PSS offers large efficiency potentials in their operation. For example, spare parts, consumables, and technicians need to be provided in timely manner to fulfill the agreed upon SLAs. Consequently, the physical processes should be coordinated efficiently through the IoT-enabled products in PSS. The major challenge is to employ IT in a way that provides high availability for the user and efficient servicing for the provider at the same time. However, the link between the concept of PSS and underlying technology for it has just recently emerged in literature (Ardolino et al., 2017; Sala et al., 2017).

In this paper, the role of information technology for the coordination of logistics processes for PSS is investigated. Using several case studies as well as existing literature, we identify information demand and data sources required for the logistics tasks as part of the overall equipment servicing. Based on that, a generalized architecture for a cyber-physical system (CPS) is proposed, which integrates information flows required to coordinate material flows for products equipped

with IoT-technology. From a technology perspective, IoT-data and events from the product are processed with analytics in the cloud to trigger the execution of business processes in the transaction systems at the service provider.

Our results are to help practitioners to design and manage PSS based on CPS. They could also serve as a basis for services fourth-party logistics providers (4PLs), which can then be contracted as part of the overall PBC-PSS service system by the service provider. As a theoretical contribution, we aim to improve the conceptual basis for smart service systems at the intersection of service science, cyber-physical systems, logistics and big data (Demirkan et al., 2015; Medina-Borja, 2015).

2 Conceptual Foundation

The key concepts of this research are product-service systems, business models, IoT and cyber-physical systems, which are briefly introduced in this section.

The combination of tangible physical goods and intangible services into an integrated offer is called a product-service system (PSS) (Mont, 2002; Baines, et al., 2007). PSS take a marketing oriented perspective as they describe what companies offer and what value customers can gain from these offers. According to a popular classification proposed by Tukker (2004), PSS can be subdivided into product-oriented, use-oriented and result-oriented PSS. The first category involves the selling of product and the offer of accompanying services. Use-oriented services still focus on the product but the product remains in the ownership of the provider and it is billed on a per use basis. In result-oriented PSS, the consumer and the provider agree on a defined result without the involvement of any pre-determined product (Tukker, 2004). A trend contributing to the emergence of PSS is the so-called “servitization”, which refers to the transformation of product-oriented offers into services (Neely, 2007).

In contrast to the selling of goods, PSS allow for business models, in which the product remains property of the service provider, while the user pays for the actual service. Typical variants are pay-per-use and performance-based contracting. In pay-per-use (PPU) models, the user is charged for the metered usage of a good, e.g. by the hour as in car sharing services like Car2Go (Gassmann, Frankenberger and Csik, 2014). Performance-based contracting (PBC) refers to the “the contractual approach of tying at least a portion of supplier payment to

performance” (Selviaridis and Wynstra, 2014). In their survey of 241 papers on PBC, Selviaridis and Wynstra (2014) recognize “performance specification and evaluation, payment scheme design and its impact on supplier behavior and, to a lesser extent, risk allocation and attitudes” as the main aspects in PBC research. A comprehensive review of PBC from a business perspective is provided by Essig et al. (2016).

The integration of Internet of Things technology into physical products has been identified as basis for innovative business models (Allmendinger and Lombreglia, 2005; Herterich, Uebernickel and Brenner, 2015). This particularly holds true for PBC and PPU a, which are both identified as business models benefitting from IoT, especially from the “Remote Usage and Condition Monitoring” component in the “digitally charged products” pattern (Fleisch, Weinberger and Wortmann, 2015). The “IoT-enabling” of products constitutes of them being equipped with sensors, embedded computation and communication capabilities to turn them into smart products (Porter and Heppelmann, 2014; Valencia et al., 2015; Barbosa et al., 2016). The remote access to the product status, operation conditions etc. for monitoring and control provide the basis for data-driven product-related services (Herterich, Brenner and Uebernickel, 2016; Kagermann, Riemensperger and Weckesser, 2016). To support the servicing of PSS, it is therefore key to integrate IoT devices and the events they generate with business processes, which has emerged as topic in the recent years, e.g. by Schief et al. (2011) and Meyer, Ruppen and Magerkurth (2013).

The theoretical foundation for these systems are Cyber-physical systems (CPS), denoting the integration of computing with physical processes, which can affect each other (Lee, 2008). In a more comprehensive understanding, CPS are socio-technical systems, consisting of sensors, actuators, embedded systems, digital networks, Internet services as well as coordination and management processes (Broy, Cengarle and Geisberger, 2012). CPS can be considered as the technical implementation of a PSS with smart, connected products (Sala et al., 2017).

In summary, within this research, we assume that all PBC and PPU business models for technical products create a PSS. Furthermore, we consider CPS as the conceptual basis for the implementation of such PSS with IoT-enabled technical products, as CPS integrate physical goods, processes, people and information technology into a holistic system.

3 Research Goal and Methodology

The research goal of this paper is to identify how logistics processes in PSS can be coordinated through IoT-enabled products. For that, the following methodology is applied: Based on existing literature and several real-world cases, main logistics tasks are identified. These tasks are consolidated into a framework, which relates information demands, data sources and analytics to these logistics tasks. From this, a generalized CPS architecture is derived to describe the coordination of logistics processes in IoT-enabled PSS.

It is important to note that there is a variety of options to configure PSS offerings (Freund and Stölzle, 2016). As Essig et al. (2016) point out, PBC is related to both industrial marketing and operations and service management (OSM). For our research, we focus on the OSM part and PSS with the following characteristics:

- The product part of the PSS is a technical product
- The PSS is offered in a pay-per-use or performance-based contracting model
- Maintenance, Repair and Operations (MRO) are at least partly contained in the offer

4 Related work

While the conceptual foundation addresses the basic concepts of this research, the related work section presents recent work at the intersection between PSS, CPS and PBC/PPU business models.

The potentials and challenges of the application of performance-based contracting in manufacturing are surveyed by Holmbom, Bergquist and Vanhatalo (2014). They find that there is a lack of empirical evidence on the improved profitability for both the provider and the user, although this is one of the key motivators the implementation of PBC. The procurement of performance in a PSS from a buyer's perspective is discussed by Elmazoski et al. (2016). They establish a framework which links payment models and service orientation to identify different PSS purchasing options for the buyer. Specifically, it discusses the incentives for buyer and provider in the various models (Elmazoski, et al., 2016).

A number existing contributions deal with the planning and configuration of supply networks for services or PSS, e.g. by Lockett et al. (2011) and Xu et al. (2016). However, they do not address the operational benefits of IoT for improved information management for servitized products. Johnson and Mena (2008) propose and integrated model for product supply chains and service supply chains in order to cater of servitized products. Furthermore, they highlight the importance of real-time information and the information flow management. Grubic (2014) discusses the importance of real-time information as a measure to mitigate risk in servitization, without relating to CPS. The value-based organization of business processes for a product-service supply chain is described by He et al. (2016).

Several existing contributions deal with various aspects of IT-supported logistics process coordination of smart products. Examples are the dispatching of technicians (Bader et al., 2017), the replenishment process (Alfathi, Lyhyaoui and Sedqui, 2015), spare parts availability (Chaudhuri and Ivceknno, 2017), replenishment policy (Hosoda and Disney, 2012). The potentials of CPS for maintenance, repair and operations (MRO) have been analyzed by Trentesaux et al. (2015) using two case studies of aircrafts and trains. They, however, do not provide a link to business models and focus on MRO tasks in general rather than PSS logistics in general. Still, the contribution of Trentesaux et al. is a helpful work to illustrate the principle of applying CPS to support maintenance in product fleets. Ardolino et al. (2017) present a very recent and comprehensive study on the application of digital technologies such as IoT, Cloud Computing and Predictive Analytics in servitization. Furthermore they introduce helpful terminology for service transformation paths such as “availability provider” (offering products in a PPU model) and “performance-provider” (offering products in a PBC model), both of which employ IoT for usage data, product performance.

With regard to related work, it can be concluded that the IoT-enabling of PSS to support new business models has been widely discussed from various perspectives in literature. However, to the best of our knowledge, we could not identify a contribution regarding the logistics of PSS and their coordination with the help of IoT-enabled information flows.

5 Case Analysis

We use publicly available information as well as scientific publications on the following cases of existing real-world IoT-enabled PSS to identify logistics requirements:

- Winterhalter provides industrial dishwashers in a “pay-per-wash” business model. The fixed price includes all detergents, water treatment, baskets, maintenance and service. There is also no minimum contract duration, which means that all the installed equipment may have to be transferred to another customer soon after the sign-up (Winterhalter, 2016).
- Canon offers document management solutions in pay-per-page contracts, which include consumables replenishment, spare parts, maintenance and technician labor (Canon Europe, 2017). Canon equipment can connect and send to the Canon eMaintenance platform data related to meters and machine status, ink levels, activity log and fault registry (Ardolino et al., 2017).
- Kaeser Compressors offer is called Sigma Air Utility, which uses a PBC business model with a fixed price per cubic meter compressed air. Users get an individual solution concept, which is build, operated and optimized by Kaeser. To enable remote monitoring of all compressors, the Sigma Telecare is employed to gather data for both predictive maintenance and energy efficient operation. Spare parts are delivered through a worldwide network of logistics partners. These measures are aimed to reduce downtimes and unnecessary onsite visits (Kaeser Kompressoren, 2017).
- Car2Go is a car sharing system, which is offered in various large cities, e.g. Berlin, Vienna, Vancouver and New York City. Users are billed by the minute, with prices depending on the type of car. Cars can be located, booked and opened via a smartphone app. Car2Go will take care of all required maintenance and cleaning, as well as paying for parking lots, insurance and other vehicle related cost. If a car has to be refueled by the user, he or she gets a credit of 10 extra driving minutes (car2go Deutschland GmbH, 2017).

- Hewlett Packard offers the “Instant Ink” program for toner cartridges, which are charged in a cost-per-page model. Different plans with various numbers of included pages for a monthly subscription are offered for occasional, moderate and frequent users. To participate, the user must own an Instant Ink compatible HP printer, and register for the “HP connected” service, which facilitates the transmission of usage information from the user to HP over the internet. The user receives new toner cartridges automatically via postal mail before the ink runs out. Also, empty cartridges are returned to HP partners for recycling via postage-paid shipping material (HP Development Company, 2017).

From these cases, we can derive the following main logistics processes: Delivery, Maintenance, Replenishment and Recycling (see table 1). As Delivery is a process that takes place before the actual operational logistics support begins, we do not further discuss it in this research. However, it is obviously a process that is part of the provider’s fleet management and can be also supported using IoT data.

Table 1: Logistic requirements of the selected cases

Case	Model	Delivery	Maintenance	Replenishment	Recycling
Winterhalter	PPU (per Wash)	Machine included	Included	Detergents	(unclear)
Canon	PPU (per Page)	Setup by Canon	Labor, spare parts, maintenance kits, print heads	Ink	
Kaeser Compressors	PBC (per m ³ compressed air)	By Kaeser, incl. setup	Labor, spare parts	n/a	n/a
Car2Go	PPU (per Minute)	Pickup by User	Cleaning, maintenance	Refueling by User	n/a
HP Instant Ink	PPU (per Page)	Parcel	n/a	Ink	Empty cartridges

6 A Framework for PSS Logistics

In this section, the results from the case analysis and related work are consolidated into a general framework for PSS logistics. The main focus is the identification of provision of information that is required to allow for a timely conduct of logistics processes. First, we propose the following terms to generalize the logistics of a PSS:

- Equipment: a product, machine or device that performs the desired service
- User: the entity that requires the performance of an equipment
- Provider: the company that provides the PSS and takes care of its servicing
- Service Level Agreement (SLA): an agreement between user and provider on quantifiable properties of a service, e.g. availability.
- Consumables: any physical goods, which are used up by the equipment during operation, such as ink in a printer, lubricants in machines etc.
- Spare Part: any component, which has to be replaced during the use of the equipment
- Replenishment: any physical operation that is required to provide the equipment with consumables.
- Maintenance: any physical operation that is required to improve the reliability and longevity of equipment, which can also be determined through safety laws and regulations, e.g. calibration of measurement devices. Examples for maintenance are cleaning, inspection, and replacement of wearing parts.
- Repair: any physical operation that is required to restore the correct function of an equipment
- Recycling: the return of any unwanted physical material that is created during the operation of the equipment.

To conduct the identified processes as efficiently as possible, IoT-enabling is employed to create a CPS which provides automation for the individual steps from physically identifiable demand, digitally detected demand, data transmission, event processing, workflow initiation, physical provisioning of material, delivery to operation site, and local operations to fulfill the demand.

For each of the operational logistics processes, the following characteristics are thus required to propose a generalized CPS architecture: To perform the process, one or multiple workflows have to be performed at the service provider. This creates a demand for information, which helps to decide, when these workflows have to be triggered. To fulfill these demands, data on usage, condition, location etc. is needed from the equipment. This data is then processed using analytics, which mainly fall in the category of predictive analytics or machine learning algorithms (Ardolino et al., 2017). The consolidated characteristics for PSS logistics process support are shown in Table 2.

Table 2: Generalized support PSS logistic processes

Process	Workflows	Information Demand	Data Sources	Analytics
Replenishment	Schedule service, schedule transport, allocate consumables	Reach of remaining consumables	Stock levels, operational data	Consumption patterns
Repair	Schedule service, allocate spare parts	Remaining lifetime of components	Equipment sensors, operational data	Predictive Maintenance
Maintenance	Schedule service	Maintenance demand	Operational hours, inspection history	Determine maintenance timeframe
Recycling	Schedule transport	Pickup demand	Current level of residuals	Determine pickup timeframe

On this basis, we can deduct a generalized architecture of a CPS to support PSS logistics. It is based on the framework for Cyber-physical Logistics System (CPLS), as proposed by (Prasse, Nettstraeter and Hompel, 2014). It also relates to the findings of Grubic (2014) with regard to the usage of real-time information and remote monitoring in servitization. The concept of cloud-based analytics for predictive maintenance has been previously described, e.g. by Johanson and Karlsson (2016).

The main elements of the proposed architecture are:

1. The equipment, which contains sensors, embedded computing and communication capabilities to record and transmit required data, such as operational status, location, fill levels etc.
2. The data is sent to an IoT Cloud, where it is stored in a database. All analytics functions can be performed using this data. Based on the outcome of the analytics functions, trigger events are created.
3. The providers' transaction systems in the backend receive the events and can initiate workflows accordingly.
4. The logistics execution within the triggered workflows can be conducted with the help of technicians for local operations and logistics service providers for delivering spare parts and consumables as well as picking up any residuals for recycling.

The proposed architecture is presented in figure 1.

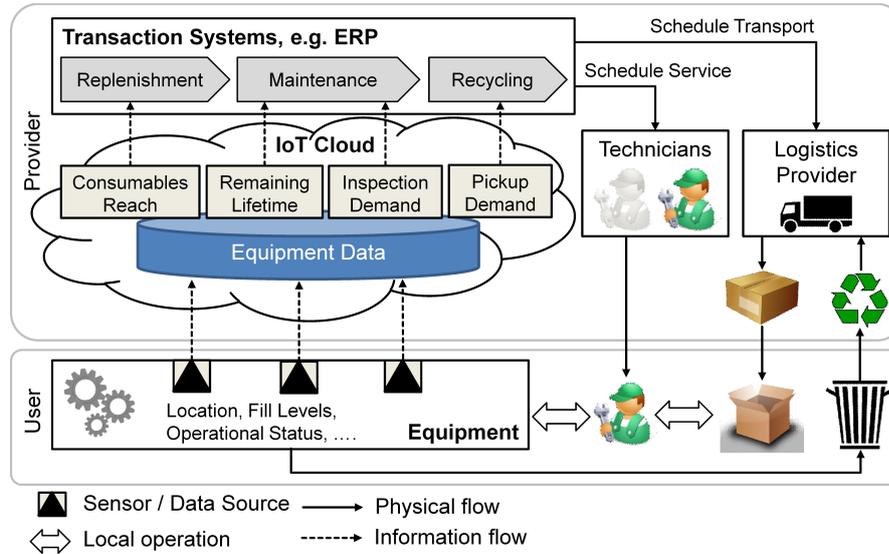


Figure 1: A generic CPS architecture to support PSS logistics

7 Discussion

This research shows that there is currently a lack of generalized knowledge on the principles and mechanisms of logistics for PSS. Given the high complexity of PSS implemented on CPS, such knowledge is required to describe, explain, and design these systems.

The results of this paper are meant to be a first step towards these goals. We found that a common basis for PSS logistics can be established, even though the analyzed cases show a wide spectrum of designs. Specifically, the processes of replenishment, maintenance, and recycling could be identified to be of relevance. Besides, a set of terms have been proposed to describe the main actors and relations.

Furthermore, the employment of IoT technology to monitor equipment either avoids error-prone and expensive manual data entry or makes the overall PSS offer economically viable in the first place. The proposed generalized architecture is a conceptual model of a CPS for PSS logistics, which shows how equipment, IoT-technology, analytics, and workflows can be combined to coordinate logistics processes for PSS. SLAs in performance-based contracted products create special requirements on the logistics process, which must be considered as part of the integrated product-service system (PSS). The use of IoT technology in physical equipment enables efficient information flow to support the fulfillment of SLAs.

Practitioners and researcher alike may use our results to get a better overall understanding of PSS logistics. For the design of equipment targeted for use in a PSS, it is advisable to consider the information demand and related data to prepare for the integration of sensors, computation and communication capabilities. It might also help logistic service providers to develop new services for PSS providers.

It should be noted, that in this research, only a relatively small number of cases was analyzed. Furthermore, all case data was gained through existing public information, mainly from the providers themselves. A larger sample of cases and additional expert interviews with providers and users will probably create a more detailed and differentiated result. However, we are convinced that the main findings of this research still hold true, and can serve as a framework for further research results.

For future research, we identified the three different directions fleet management, SLA compliance and refinement for implementation:

1. Fleet management: Within this paper, only the operational logistics of a PSS are covered. From a provider's perspective, the provisioning and operation of PSS is a fleet management task, which also includes logistics processes. Examples are the provisioning to and the return of the equipment from the customer to the provider. For these processes, the current location and status is also important, e.g. to decide whether outstanding requests can be already fulfilled with a particular equipment in the fleet. Besides the actual transport, technicians might be required to dismount and setup the equipment at the respective locations. Other fleet management tasks include the use of monitoring data for optimized operations, e.g. to reduce wear of components and energy consumption.
2. SLA compliance: While it has already been stated that SLAs can be part of the PSS operation, the adherence to these SLAs was not in scope of this research. For that, a timing perspective has to be established in the proposed framework. Another improvement could be the inclusion of additional data from the user, e.g. production schedules, shift plans etc. which can be used as additional input in the scheduling to reduce interruptions. Likewise, the process status, e.g. tracking and tracing information could be relayed back to the equipment in order to optimize its operations and provide more detailed information on the current status to the user. Along these lines are proactive business processes, which are triggered based on forecasts rather than actual events. This might be of particular value in planning and dispatching processes, e.g. to optimize management of product fleets, scheduling of technicians as well as the optimization of stock levels and order sizes for replenishment.
3. Refinement for implementation: As the proposed architecture is on a conceptual level, it needs further refinement with regard to both information logistics and infrastructure. Information logistics should describe in detail, which data has to be recorded, how it is pre-processed, when it has to be transmitted, where it is stored, how it is analyzed, and how long it has to be retained to fulfill the requirements of the PSS. Infrastructure refers to a concrete technical system with concrete sensors, communication technology, transmission protocols and IoT cloud architectures.

8 Conclusion and Outlook

The increasing importance of PSS is recognized both in academia and practice. With the emergence of reliable IoT-technology, the integration of physical and digital processes in CPS becomes a driver for further automation and thus efficiency in the operation in such systems. When technical products are offered in PBC or PPU business models, the product is combined with operational services into a PSS. Such PSS were successfully established in practice, as shown by the cases mentioned earlier. With that, the buyer of the PSS transfers the responsibility and risk for these operations to the service provider, e.g. the manufacturer of the product. While such scenarios can create a variety of positive effects for both user and provider, we focused the effects of IoT-functionality in technical products on the efficient logistics operations for PSS.

The results of this research fulfill the goal of identifying how logistics processes in PSS can be coordinated through IoT-enabled products. More specifically, the research links existing concepts from different research fields together, such as PSS, CPS, IoT, PBC and PPU business models and relates them to real-world use cases. With these results, we aim to contribute to the digitization of logistics with regard to the operation of PSS. However, we acknowledge that this can only be a starting point, as there are many open research issues, some of which were presented in the previous section.

To follow these research directions is worthwhile from our point of view. Not only because of the increasing relevance of PSS in general. Also the ongoing digitization provides new opportunities to improve efficiency and customer value of such systems. Various technological advancements within the broader concept of "Industrie 4.0" can have an enormous impact on the operation of PSS. For example, additive manufacturing (commonly known as "3D printing") might allow producing spare parts when they are needed nearby the place of operation, which reduces stock keeping and delivery times. Another relevant area of innovations is human-computer interaction. For example, augmented reality might help less experienced local technicians to get context-based instructions for repair or maintenance. Their interaction might be enriched with information from senior engineers at the manufacturer, who are able to see both the view of the technician as well as the current state of the product and its history. In summary, such developments may reduce lead times in case of failures and improve efficiency in the operations, but increase complexity of the overall system. Therefore, the

design and operation of PSS in PBC or PPU business models requires an integrated approach of technical, commercial and behavioral aspects.

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