Towards an Understanding of Cyber-Physical Systems as Industrial Software-Product-Service Systems

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Abstract

New forms of solutions with a declined share of mechanics or hardware and instead an increased share of software and (software-enabled) services on the overall customer value proposition, so called cyber-physical systems (CPS), have been emerging for some time now. Current research highlights the underlying technical challenges but lacks a well-founded conceptualization for CPS that reflects its character as a software-enabled hybrid solution, consisting of software as well as of service and tangible product parts. The latter may facilitate research on CPS from a business-oriented and a customer value creation perspective rather than solely from a technical perspective. For this purpose, the present contribution proposes the conceptualization of the industrial software-product-service system. It is based upon empirical findings as well as theoretical considerations on the concept of industrial product-service systems and substantiated by suggested future research directions, derived with the help of the proposed conceptualization.

1. Introduction and Problem Statement

We can observe a shift of value creation towards diverse, cross-domain cooperating business networks nowadays. Customer-oriented business models, characterized by interactive value creation with users and other external actors as well as innovation processes that are realized in inter-organizational networks are becoming key competitive factors. This facilitates cross-industry innovations, which ignore existing market boundaries and accelerate the convergence of previously separate markets. Businesses or rather manufacturers of varying sizes and industry segments increasingly cooperate with each other and with service providers, telecommunication suppliers, and software producers, in order to merge their competences, which are eventually needed to construct and operate cross-industry product innovation [1, 2].

As a consequence, new forms of cooperation and competition as well as new shapes of solutions with a declined share of mechanics and hardware on the overall customer value proposition, so called cyber-physical systems (CPS), are emerging. Particularly, previously isolated business models of the traditional goods-producing industry meld together with those of software businesses.

CPS are opened, linked-up systems that operate flexibly, cooperatively (system-system-cooperation) and interactively (human-system-cooperation). They link the physical world seamlessly with the virtual world of information technology and software, and by doing so, use various types of available data, digital communication facilities, and services. The main part of its overall customer value proposition can therefore be directly attributed to software, i.e. the manifold integration and cross-linking of data and services and, in addition thereto, their configuration and individualization capabilities [1, 2].
CPS enable a wide range of novel functions, services, and features that are far beyond the scope of today’s capabilities of embedded systems with controlled behavior. Embedded systems are either invisible to the user, especially in the case of autonomous systems, or just assist him with the automated performance of tasks but cannot be influenced by the user. In latter case, embedded systems usually allow only controlled intervention through precisely defined interaction interfaces (assistance systems). In contrast to this, CPS gather information about environmental and system conditions in real time and react to these information interactively with users, through pre- or ad-hoc defined cooperation with services and systems of the local environment as well as the internet (Internet of Things and Services) [1, 2]. Figure 1 outlines the structure of a CPS.

To illustrate the potential and the relevance of CPS, the field of industrial remote services shall serve as an example. Industrial remote service is an instrument that manufacturers have been using for several years in order to provide customers with fast and efficient support by remotely accessing and controlling machines. CPS open up new potential to deliver additional productivity gains and to move closer to the goal of no unplanned downtime. 

Technicians will no longer manually connect to the machine they are servicing. Self-monitoring, intelligent manufacturing systems transmit sensor data on their condition in real-time. The data that are received, recorded, and analyzed enable preventative maintenance and the discovery of other opportunities to lower maintenance and operating costs. Manufacturing systems will operate in networks that are similar to social networks and will automatically connect to costs. Manufacturing systems will operate in networks that are similar to social networks and will automatically connect to the relevant functions and data via standardized, secure communication links with the industrial remote service platforms [3, 4].

The above-mentioned development forces manufacturers, service providers, as well as software businesses to change. They all have to build up new competences, strategies, and business models in order to prosper and ultimately become key players in the emerging, converged markets. Research, not least from the field of industrial product-service systems (IPS²), is obliged to enable and support this with respective contributions.

From the author’s point of view the state of research necessitates the development of a well-founded conceptualization for CPS. That conceptualization shall make CPS as an object of research more accessible to research in the area of IPS². That is, it shall reflect the character of CPS as a software-enabled hybrid solution, consisting of software as well as of service and tangible product parts. For this purpose, the contribution at hand proposes the conceptualization of the industrial software-product-service system (ISPS²; section 4). It is based upon theoretical considerations (section 2) as well as empirical findings (section 3) from research in the field of product-service systems (PSS) and substantiated by suggested future research directions, which were derived with the help of the proposed conceptualization (Section 5).

2. The Conceptualization of Product-Service Systems as a Starting Point

The realization that customers are not only interested in products or services as such, but rather expect the solution of a problem or fulfillment of a need, must be considered as the starting point of the discussion, which relates to hybrid value creation. In this sense, a solution or a PSS is a combination of products and services that offers value to the customer beyond the sum of its parts. These parts are by no means identifiable without hesitation but their attributes characterize the overall value proposition. PSS are co-produced by customer and complementors and tailored to the customers’ needs. This level of customization and integration sets PSS above standalone products or services or a classic bundle of products and services [5, 6, 7].

Arguments underpinning the increasing popularity of such product-service offerings in today’s business environment are manifold. Certainly, today’s dissemination of this concept has been enabled by preceding research on this area. Based on 169 systematically identified and analyzed publications, Velamuri et. al. [8] provide a state of the art report on research in the field of hybrid value creation. The report clusters the identified publications into eight categories, which shall serve as a rough characterization in terms of different research areas at this point. Thus, the broad research basis on PSS covers strategic, organizational, marketing, design, innovation, and business levels, as well as sustainability aspects and the macroeconomic perspective [8]. Cedergren et. al. [9] have brought research on IPS² into the focus of their systematic literature review. After final filtering, 20 publications have formed the relevant base for the study. The authors have identified five research themes which have been
predominantly focused by researchers: delivery, processes, value creation networks, knowledge sharing and management, and business models.

The above-mentioned reviews, established definitions of a solution or a PSS (see [8, 10, 11] for a couple of sets of definitions), as well as the common understanding of this conceptualization indicate that software as an explicit part of a PSS is either ignored completely or at least allocated to the tangible product or the service part. To my best knowledge only Galbraith’s [12] and, based on it, Leimeister’s [13] definition and understanding of a PSS stand alone in this regard. Galbraith argues explicitly that companies following a solution strategy bundle their products together and add software and services. Leimeister highlights explicitly that software as part of the solution carries out central integration functions.

However, in fact, research in the field of software business has pinpointed the specific economic properties of software and with it the need for a (sub) value chain framework with respect to these for a long time. There is a broad consensus among the scientific (software business) community about the dissimilarity between software and its value chain on the one hand, and the service or the (material) product value chain on the other hand. Practitioners as well as researchers require a (sub) value chain framework reflecting the industry specifics, just as a respective business model conception [14, 15, and further references there]. Pussep et. al. [14] have mapped the economic principles of the software industry to attributes of software value chain activities. Schief and Buxmann [15] have developed a software industry business model framework comprising 20 elements, based on 43 specific economic properties of software which were retrieved from other sources. The software economic property “ease of replication”, for instance, refers to 14 business model elements – e.g. the pricing model, the degree of standardization and the operating model are highly dependent from this economic property. A selection of these properties is presented below:

- Intangibility
- Ease of replication and modification
- Ease of individualization
- Software as network-affected good
- Software as an experience good
- Non-rivalry of software
- Utility-dependent value
- Low importance of rationalization in production
- High fix costs, high economies of scope
- High opportunities for differentiation
- Ease of access to global markets
- High importance of intermediaries
- High importance of platform concepts
- High change barriers for customers
- Integration of external factors (at least) in case of individual software development
- Iterative, incremental, high risked development process

Porter [16] has defined activities within the value chain as the physically and technologically distinct activities a firm performs and by which a firm creates a product valuable to its buyers. In this regard he has suggested that activities should be isolated and separated that

- have different economics,
- have a high potential impact on differentiation, or
- represent a significant or growing proportion of cost.

All three mentioned points are indicative that software should be considered an explicit part of a PSS instead of allocating it to the tangible product or the service part and to their underlying (sub) value chains.

After elaborating on the (neglected) role of software in the research field of PSS (incl. IPS2), the industrial software-product-service system (IPS2) conceptualization as a possible understanding of cyber-physical systems will be presented. In naming so, the character of IPS2 as a conceptualization explicitly regarding software as an equal part alongside service and tangible product parts shall be highlighted. Only in so doing the increased share of software on the overall customer value proposition can be conceptually reflected.

3. Literature Review on the Conceptualization of Product-Service Systems and the Role of Software

In order to reveal the role of software as an explicit part of PSS (here and in the following incl. IPS2) beyond definitions, a comprehensive literature review has been conducted. The three premier research databases Business Source Premier, Academic Search Premier and EconLit were searched using a compound search term. The search has resulted in a set of 78 publications, whose titles have contained “String1† – in order to capture only publications from the broader field of research on PSS. In addition to that, the abstracts of these publications have had to contain the string “product* AND service* and software*” – in order to capture only those publications from the defined ones above that consider PSS as hybrid solutions consisting of the two mentioned parts and additionally software.

In the second step all 78 publications were analyzed based on their abstracts and, for uncertain cases also based on the full text, whether they correlate with PSS as a field of research. Furthermore, the publications also had to consider PSS in the mentioned threefold way. A significant number of publications were excluded as they in fact did not correlate with PSS research. In most cases these publications have been about software in the context of SOA (Service Oriented Architecture, a software architecture paradigm) or SaaS (Software as a Service, a cloud computing based software

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* See http://www.ebscohost.com/titleLists/buh-journals.htm, http://www.ebscohost.com/titleLists/aph-journals.htm, http://www.aecaweb.org/econlit/journal_list.php for the journals included on this databases.

† “String1†: ["product* OR "service* OR "software"] AND ["solution* OR "combinat* OR "integrat* OR "system* OR "servitizat* OR "PSS* OR "IPS2" OR "custom* OR "individual* OR "product service system* OR "hybrid* OR "value* OR "bundle* OR "co-produce* OR "cooperat* OR "tailor* OR "goods* OR "tangibl* OR "dematerializ* OR "productizat* OR "extended product* OR "functional product"]
delivery model). Also publications were excluded that indeed could be assigned to research on PSS, but for our case the term software has been mentioned in a not relevant context. In addition, crucial citations referenced within the remaining four publications [17, 18, 19, 20] were examined, as well as all 169 citations referenced by Velamuri et al. [8]. Just one applicable paper [21] has been included within this step. Thus in the end, a mere five publications have met both conditions and were to be further examined. In the author’s opinion, a research gap has become apparent already at this point.

Lindström et. al. [17] propose a conceptual development process to manage the PSS (referred to as functional product) development, including “hardware, software [and] service support system[s]”. The authors consider the development process for a PSS as complex and highlight the need to coordinate, monitor, control, and share information as well as to communicate properly among the parties involved in the process. Isaksson et. al. [18] perceive PSS as “combinations of hardware, software, and services”. The objective of their paper is to examine consequences that a manufacturing firm’s movement towards PSS has on the overall development process. More specifically, Isaksson et. al. address two main research questions: Firstly, how is the engineering work affected and how can it be enhanced in order to account for business models for PSS. Secondly, what competences are required in development work, in particular in the solution design team, for the manufacturing firm to become more capable of providing successful PSS.

Both publications argue based on a conceptual separation of the involved value chains, i.e. the software value chain among others. Alone due to the fact that PSS are typically developed and provided by (inter-organizational) networks such conceptualization is indeed required and is in line with the present paper.

As to the question at hand the synopsis of the three remaining publications can be kept briefly. Zhu et. al. [19] have developed a prototype named mtiPSS as the software part of an industrial product-service system for a CNC machine tool. Tien et. al. [20] have developed a healthcare service system. In doing so they considered a healthcare system to be an integrated and adaptive set of people, processes, and products, while the latter one is characterized among others explicit by its software part. Although Denkena et. al. [21] have presented a business concept for cooperation of machine manufacturers, software manufacturers, and engineering consultants, they conceptualize a PSS twofold without incorporating software.

4. Cyber-Physical Systems as Industrial Software-Product-Service Systems

The added value of CPS in the industrial context is manifold and by no means restricted to the field of industrial remote services (see the industrial remote services scenario in Section 1). In order to exemplify it in a more generalized way, the following scenario covers the machinery and plant engineering industry [1, 2, 3].

CPS in the manufacturing environment comprise smart machines, storage systems, and production facilities capable of autonomously exchanging information, triggering actions, and controlling each other independently. This facilitates fundamental improvements to the industrial processes involved in the whole manufacturing value chain, including engineering, material usage, outbound logistics, and life cycle management. The units of such a smart factory are uniquely identifiable, may be located at all times, know their own history, current status, configuration possibilities and production conditions, and communicate independently and wirelessly with one another. Here, CPS allow individual customer requirements to be met – even one-off items can be manufactured profitably. Last-minute changes to production and flexible responses to disruptions and failures on behalf of suppliers are enabled as well.

The involved manufacturing systems are vertically networked with business processes within factories and enterprises, and horizontally connected to dispersed value networks. This provides in particular start-ups and small businesses the opportunity to develop and provide downstream services. In this regard self-organization capabilities arise. As in the industrial remote services scenario in Section 1, machines are able to autonomously control their maintenance and repair strategy depending on the degree of workload, and ensure backup capacities to maintain production in the case of maintenance-related interruptions.

The scenario described above indicates the necessity for a well-founded conceptualization of CPS from a business-oriented and a customer value creation perspective that conceptually reflects its character as a software-enabled hybrid solution, consisting of software as well as of service and tangible product parts. In the author’s point of view, such a conceptualization originating from the perspective on customer value proposition promises much deeper insights than primarily or even solely highlighting the technical realization of CPS (see Figure 1 in Section 1). For this purpose, the present contribution proposes the conceptualization of the industrial software-product-service system (ISPS²). An ISPS² meets the criteria in Table 1.

| Perspective | Criteria |
|-------------|----------|
| Solution    | Combination of software, services, and tangible product parts that offers value to customers beyond the sum of its parts |
| Value chain | Co-produced by complementors (cross-industry, software, service, tangible product part complementors) and customers |
| Software part | Explicitly regarded, conceptual equal part of the overall solution (in contrast to product-service systems) |

- Key enabler for configuration, tailoring, customization, and interactive value creation with users
- Key business differentiator, enables strategic opportunities
5. Conclusions

To substantiate the proposed conceptualization as a fruitful basis for further contributions on CPS from research in the area of IPS², the present contribution concludes with suggesting possible future research directions. With the understanding of CPS as industrial software-product-service systems (ISPS²), i.e. with having the abovementioned perspectives and respective criteria in mind, possible research directions could be proposed as shown in Table 2.

### Table 2. Possible future research directions on CPS, understood as industrial software-product-service systems

| Perspective | Possible future research directions |
|-------------|-------------------------------------|
| Solution    | With the understanding of CPS as combinations of software, services and tangible product parts that offer value to customer beyond the sum of its parts in mind: |
|             | • Research on cross-industry business model innovations, incorporating pre- and ad-hoc defined cooperation with services and systems of the local environment as well as the internet (Internet of Things and Services) |
|             | • Research on the potential of CPS-platform strategies (software part of CPS as a network-affected good) |
|             | • Research in order to deepen the understanding of customers’ requirements and based on this to develop use cases, pricing models etc. |
| Value chain | With the understanding of CPS as co-produced ISPS² by complementors and customers in mind, i.e. typically realized in (inter-organizational) networks (cross-industry): |
|             | • Research on simultaneous / integrative software-product-service engineering, in particular on integration of the service and the software value chain and on challenges due to the different life cycles of the CPS parts |
|             | • Research on the possibilities of delivering ad-hoc defined services as part of CPS |
|             | • Research on the transformation process from a single supplier to a CPS complementor |
|             | • Research on the required dynamic capabilities and on strategic positioning options of the complementors |
|             | • Research on operational issues, e.g. governance and coordination aspects |
| Software part| Assuming that the main part of the overall customer value proposition of a CPS is attributed to software and having the specific economic properties of software in mind: |
|             | • Research on enabling capabilities of software concerning changeability, configuration, tailoring, and customization of CPS |
|             | • Research on enabling capabilities of software concerning the interactive value creation with users, e.g. open innovation, mass customization, peer production etc. |

It remains to be seen how fruitful it can be to also address these or other research directions with having the presented conceptualization in mind. In this sense, it is up to future research, particularly in the area of IPS², to take up this first exploration of the topic. From the author’s point of view it may advance research on both CPS and IPS² by itself.

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