Cyber-Physical Systems as Service Systems: Implications for S-D Logic

Conceptual Research Paper.
Service-Dominant Logic.

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Purpose – According to the current state of research, the present predominant understanding of cyber-physical systems (CPS) is technical and not driven by service related abstractions. To address this research gap, the author developed an alternative view of CPS in the form of a conceptual framework informed by S-D logic. It considers CPS as service systems in the sense of S-D logic. The present paper focuses on how the framework contributes to the advancement of S-D logic itself.

Design/Methodology/approach – The methodological approach of this research is conceptual and inductive in the sense that findings from the application of S-D logic to the field of CPS are passed back to the general orientation of S-D logic.

Findings – The paper provides three main implications for the general orientation of S-D logic, drawn through its application to the field of CPS: First, the service system abstraction is a proper abstraction to understand and characterize actors or resource integrators involved in value co-creation. Second, bridging S-D logic and management research on technological platforms can advance S-D logic's efforts to clarify the conceptual interplay between the service ecosystem abstraction, the value co-creation network, indirect service exchange, and value. Third, the anatomy of platform-mediated value co-creation in the framework reveals that (the overall) value-in-context consists of "indirect value-in-context", "option value-in-context", and "direct value-in-context".

Research limitations/implications – The research implications from S-D logic perspective are limited by its exploratory, inductive and conceptual nature.

Originality/value – S-D logic is often reported to be less concrete, on a level of abstraction too far away from theoretical and practical analysis, and hard to operationalize. This research is a first exploratory attempt to apply S-D logic to the field of CPS. It is an example of how S-D logic can be operationalized, i.e. applied in a concrete context and at a low level of abstraction. S-D logic's final conceptualization is still in progress. The presented implications for the general orientation of S-D logic, drawn through its application to the field of CPS, contribute to the advancement of S-D logic.

Key words – S-D logic, service system, cyber-physical system

Paper type – Conceptual research paper

1 INTRODUCTION

The advance of information technology (IT) has been one of the key events accelerating the necessity for a shift from G-D logic to S-D logic. Advancement in IT has enabled the rise of service-provisioning networks that are consistent with S-D logic principles—what S-D logic refers to as service ecosystems. One of the key reasons explaining why, closely relates to the emerging field of cyber-physical systems (CPS): With the increase in IT, tangible goods have become digitally enhanced with microprocessors and intelligence and thus can become platforms for service provision (Lusch et al. 2010, Lusch and Vargo 2014, Rust 2004).

Future cyber-physical systems (CPS) will comprise interconnected, distributed embedded systems (buildings, cars, machines etc.) that directly record physical data using sensors, combine these data with other (globally) available data and services, and, on this basis, interact with the physical and digital world. Actuators that influence physical processes via open system interfaces and standards as well as a number of multimodal human-machine interfaces, will implement the cyber-physical interaction. In this way, CPS will enable new features and services that go far beyond today's capabilities of closed embedded systems with strictly controlled behavior. Examples of such visionary CPS are systems that allow context-adaptive control of integrated traffic solutions or CPS in telemedicine and for assisted living (Broy et al. 2012).

The present state of research on CPS mainly considers them as technical systems and consequently provides views on CPS at the (technical) system architecture layer. Thus, research mainly addresses CPS through the paradigm of the traditional goods-dominant logic (G-D logic) with its roots in technological product inventions. While G-D logic prioritizes product attributes to define innovations, S-D logic, with its inherent customer focus, moves away from perspectives traditionally rooted in technological product inventions and defines an innovation with regard to its service provision. S-D logic emphasizes that service systems are dynamic configurations of resources in which value is co-created and evaluated as value in context (Vargo et al. 2008). The critical factor in this context is not how smart is the product but how it makes the beneficiary smarter (Michel et al. 2008).

The understanding of CPS as technical systems provides the right abstractions to carry out solutions for technical or engineering challenges, but less for business challenges. Taking the economists' point of view, questions regarding CPS arise regarding how to serve the need for service platforms on which value networks can be modularly configured and assembled into novel network-like business models; how can in these networks various actors as dynamic resource integrators and co-creators of value provide service. The paradigm of G-D logic falls short in answering these and other contemporary questions.

To facilitate further empirical and design oriented research on CPS in the business context, Mikusz (2015) suggests understanding CPS as complex, socio-technical service systems, i.e. as service systems in the sense of S-D logic. S-D logic emphasizes that service systems are dynamic configurations of resources in which value is co-created and evaluated as “value in context” (Vargo et al. 2008). The paper develops an alternative view of CPS in the form of a conceptual framework informed by S-D logic. The framework decomposes CPS into its single components that are essential from the service architecture perspective, and show their relationships between each other. A service architecture transforms the value proposition of a service system into a configuration of actors, resources, and activities of value co-creation (Böhmann et al. 2014). The application or instantiation of the framework shall enable the decomposition of and insights into CPS service architectures, and on this basis further empirical and design-oriented research on CPS service architecture innovations, business model innovations, novel value propositions, and collaborative and contextualized value creation.

The present contribution focuses on how this conceptual framework contributes to the advancement of S-D logic itself. The purpose of this contribution is to pass back the findings from application of S-D logic to the field of CPS to the general orientation of S-D logic. The methodological approach is conceptual on the one hand—following Yadav's (2010) encouragement about the opportunity of conceptual papers. On the other hand, this research is inductive in the sense that passing back findings from the application of S-D logic to the special field of CPS to the general orientation of S-D logic is an inductive generalization. The remainder of the paper is structured as follows.

Section 2 (Background) provides a short overview about the state of research on CPS (2.1), introduces S-D logic, and thereby clarifies why the conceptual framework uses S-D Logic as its (pre-) theoretical approach (2.2). Section 3 presents the framework along with its empirical illustration (3.1), which is done with the empirical example "BMW (i) Connected Drive" from the field of smart mobility, i.e. the intelligent interconnection of driver, vehicle and environment. There is barely another industry that shows the potential and relevance of CPS clearer than the automotive sector. Subsection 3.2 shows in what way the framework enables analyses of CPS service architectures, and on this basis facilitates further empirical and design-oriented research on CPS service architecture innovations, business model innovations etc. Sections 2 and 3 are based on previous work, presented in Mikusz (2015). Section 4 discusses how the conceptual framework contributes to the advancement of S-D logic itself. It focuses on three main implications for the general orientation of S-D logic, drawn through its application to the field of CPS. The paper concludes with limitations and directions for future research, outlined in section 5.

The present paper makes several contributions to the current state of research on S-D logic:

- S-D logic is often reported to be less concrete, on a level of abstraction too far away from theoretical and practical analysis, and hard to operationalize. This work is a first exploratory attempt to apply S-D logic to the field of CPS. Section 3 shows an alternative view of CPS in the form of a conceptual framework informed by S-D logic. It further shows how this framework can provide useful insights into service architectures of CPS. Both the empirical example and the evaluation indicate that insights gained by this framework can be translated to an empirical situation. All in all, the present work is an example of how S-D logic can be operationalized, i.e. applied in a concrete context and at a low level of abstraction.
- S-D logic is a thinking framework in a pre-theoretic stage and its final conceptualization is still in progress. Section 4 provides three main implications for the general orientation of S-D logic, drawn through its application to the field of CPS: First, the service system abstraction is indeed a proper abstraction to understand and characterize actors or resource integrators involved in value co-creation, especially when considering IT-enabled service-provisioning networks such as those in the field of CPS. Second, bridging insights from the field of management research on technological platforms with the perspective of S-D logic can advance S-D logic's efforts to clarify the conceptual interplay between the service ecosystem abstraction, the value co-creation network, indirect service exchange, and value. Third, a close look into the anatomy of value and platform-mediated value co-creation in the framework reveals that (the overall) value-in-context consists of "indirect value-in-context", "option value-in-context", and "direct value-in-context".

2 BACKGROUND

2.1 State of Research on Cyber-Physical Systems

As stated in the introduction, the present state of research mainly addresses CPS through the paradigm of the traditional goods-dominant logic (G-D logic) considering CPS as technical systems as well as ascribes inventions to technological product attributes. To get evidence that supports this assertion, the author conducted two interrelated and comprehensive literature reviews (Mikusz 2015). Since the present paper primarily aims to contribute to the current state of research on S-D logic, the synopsis of the literature analyses can be kept briefly.

The first literature review is based on the most influential publications on CPS and has the purpose of identifying the present predominant understanding of CPS, i.e. to reveal the extent to which it is technical, or more driven by business or service related abstractions. The most widely used characterization of CPS originates from Lee: „CPS [are] integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa" (Lee 2006; Lee 2008). Lee's technical understanding of CPS goes hand in hand with his interest in CPS system design challenges. In his opinion, new paradigms and abstractions are necessary to realize the full potential of CPS. Research will have to rebuild computing and networking abstractions that will have to embrace physical dynamics and computation in a unified way (Lee 2006; Lee 2007; Lee 2008).

Also Rajkumar et al. (2010) exclusively address technical aspects regarding to design, development, certification, and evolution of CPS with their much-noticed work on scientific foundations and challenges in the CPS domain. Accordingly, they define CPS as physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core. Likewise, they consider CPS to be a confluence of embedded systems, real-time systems, and a variety of distributed (wired and wireless networks) smart sensor systems and actuators. Broy et al. (2012) characterize the prospective evolution of CPS towards increased openness, complexity, autonomy and intelligence or smartness by five capability levels built on one another:

- CPS fuse the physical and virtual world, especially by using intelligent sensors and actuators as well as real-time control systems;
- Depending on task and situation, CPS (temporarily) build systems of systems with dynamically changing system boundaries;
- CPS can adapt to its environment and the according requirements (context-adaptability) and thereby act fully or partially autonomous;
- CPS are globally interconnected, cooperative systems with distributed and possibly changing control;
- Extensive human-system cooperation becomes an inherent part of CPS—they are systems in which humans are passive or active elements of the system behaviour (e.g. traffic control systems which enable coordinated convoy driving).

The further highly influential contributions to CPS also address challenges or research needs that lie in the technical system engineering area. They are followed by various proposals for CPS system architectures, CPS modeling approaches, solutions for security issues etc. Overall, it is not surprising that throughout all above-mentioned influential contributions, CPS are characterized from a technical point of view. The used constituent elements and characteristics are in descending order of occurrence: information technology integration, integration of physical and ICT system components, intelligent actuators, intelligent sensor technology, embedded system, distributed system, high scalability or system of systems capability, real-time system, intelligence or “smartness”, and concurrency. Interesting elements and characteristics from the business or, in particular, the service architecture point of view would rather directly address value propositions and value co-creation issues.

In conformity with these results, the second literature review of 159 publications has revealed that the consideration of and research on CPS as complex, socio-technical service systems is currently rare. The term “service" plays a central role in numerous publications, but always in the context of research on service-oriented CPS architectures. “Service” in this regard lies on the (technical) system architecture layer and do not addresses CPS service architecture aspects like value proposition and value co-creation issues etc. Overall, current research on CPS involves neither “services” in the sense of G-D logic nor service in the sense of S-D logic. In particular, no research could be identified that applies S-D logic or service science to CPS, or that considers CPS as service systems. Assuming that it provides a fruitful approach to the study of CPS service architectures, a research gap has already become apparent at this point.

2.2 Service-Dominant Logic

In essence, S-D logic says that value can only be created contextually and by cooperation. According to S-D logic, service generation is a cooperative, interactive value creation process in which different actors (resource integrators) use a number of different resources to support the value-adding processes of the customer. Here, only consistent alignment and adjustment of the service provision to a given customer’s context of use (value-in-context) creates customer value. In this collaborative and interactive value added process, the distinction between producer and consumer increasingly dissolves (value co-creation). This also means that the customer is a co-creator of value (Böhmann et al. 2014; Vargo and Lusch 2008). All actors (producers, partners or complementors, customers etc.) form a value co-creation network (Lusch et al. 2010).

To illustrate its understanding of service, which differs considerably from service defined in the traditional sense in terms of co-production, heterogeneity, perishability, and inseparability, S-D logic differentiates between the following two types of resources: Operand resources are usually tangible and static resources that require some action to make them valuable (Wieland et al. 2012), e.g. factory, equipment, or a vehicle. Operant resources on the other hand are usually intangible and dynamic resources that are capable of acting on operand and other operant resources to create value (Wieland et al. 2012), e.g. skills, knowledge, organizational processes, relationships with complementors, suppliers and customers. From the perspective of S-D logic, added value can result only from the application of operant resources that may be directly transmitted or through operand resources or goods (Vargo et al. 2008). Operant resources lie at the center of a firm’s competitive capabilities. S-D logic, in this regard, draws on contributions from knowledge management and the resource-based view (Mele et al. 2014). This distinction of resource types eventually leads to S-D logic’s service understanding—service provision is conceptualized as the ongoing combination of resources, through integration, and their application, driven by operant resources (Wieland et al. 2012).

Table 1 shows the ten foundational premises (FPs) of S-D logic (Vargo and Lusch 2008). One can interpret them as a very compressed representation of S-D logic. They make well clear that both service providers and goods-producing companies can follow S-D logic; the transformation from a purely manufacturing company to a provider of product service systems is not the same as the transformation from G-D logic to a proponent of S-D logic (Kowalkowski 2010, p. 288).

As Lusch and Vargo (2014) have stated recently, there are four FPs in particular that capture the essence of S-D logic—FP1, FP6, FP9, FP10—and from these the other FPs could arguably be derived.

These four FPs most notably contradict the G-D logic and thus S-D scholars have considered them the four axioms of S-D logic. The right column of table 1 shows beforehand, how the developed conceptual framework in the next section uses the premises of S-D logic.

FPs	Foundational premise	Explanation	Usage in the framework
FP1	Service is the fundamental basis of exchange	The application of operant resources as defined in S-D logic is the basis for all exchange. Service is exchanged for service	Particular focus on operant resource exchange in the framework
FP2	Indirect exchange masks the fundamental basis of exchange	Because service is provided through complex combinations of goods, money, and institutions, the service basis of exchange is not always apparent	CPS platform in order to uncover (indirect) exchange. Context-aware services are considered as multi-channel services with interlinked interaction channels
FP3	Goods are a distribution mechanism for service provision	Goods derive their value through use—the service they provide	Interaction channel "Goods as a vehicle"
FP4	Operant resources are the fundamental source of competitive advantage	The comparative ability to cause desired change drives competition	CPS platform is considered as a conglomerate of operant resources
FP5	All economies are service economies	Service is only now becoming more apparent with increased specialization and outsourcing	CPS value co-creation network consists of several, specialized resource integrators
FP6	The customer is always a co-creator of value	Implies value creation is interactional	CPS themselves, including their human being parts, are value co-creation network members
FP7	The enterprise cannot deliver value, but only offer value propositions	Enterprises can offer their applied resources for value creation and collaboratively create value following acceptance of value propositions, but cannot create and/or deliver value independently	Atomic cyber-physical service systems receive and possibly accept value propositions through several defined interaction channels
FP8	A service-centered view is inherently customer oriented and relational	Because service is defined in terms of customer-determined benefit and co-created it is inherently customer oriented and relational	The context sensitive value propositions are ultimately always received by the human as part of the CPS and must support his value-adding processes
FP9	All social and economic actors are resource integrators	Implies the context of value creation is networks of networks (resource integrators)	All actors in the framework are resource integrators. CPS' ability to form Systems of Systems and to act as globally interconnected, cooperative systems requires a value co-creation network
FP 10	Value is always uniquely and phenomenologically determined by the beneficiary	Value is idiosyncratic, experiential, contextual, and meaning laden	CPS as the most complex service system design, co-creating location-based and context-aware value propositions—coinciding with S-D logic's understanding of value-in-context

Table 1. Foundational premises of S-D logic (Vargo and Lusch 2008) and its usage in the framework (Mikusz 2015)

Overall, S-D logic is a thinking framework in a pre-theoretic stage—a lens through which to look at or a mindset that conceptualizes value creation and service innovation from a service-based perspective

(Karpen et al. 2012; Vargo and Lusch 2008). The more specific, S-D logic of marketing is the result of using this lens to refocus on the particular issues related specifically to marketing (Vargo and Lusch 2008). S-D logic is in fact rooted originally in marketing, but its orientation is not limited to this special field. More recently, the applicability of S-D logic had been extending and some of the expanded applicability is occurring in conjunction with the development of service science. As Maglio and Spohrer (2008) assert, S-D logic provides the right perspective, vocabulary, and assumptions on which to build a theory of service systems, their configurations, and their modes of interaction (Maglio and Spohrer 2008). The general orientation of S-D logic applies to any service system (Vargo and Lusch 2008)—with service science (and with S-D logic) thought of as a dynamic value co-creation configuration of resources, including people, organizations, shared information, and technology, all connected internally and externally to other service systems by value propositions (Maglio et al. 2009).

An atomic service system is one that uses no other service systems as resources. Atomic service systems and other resources can be combined to form a composite service system—i.e. service systems are dynamic: composing, recomposing, and decomposing over time. Possible composite structures include hierarchies and market-based structures (Maglio et al. 2009). Specifically for service systems, Vargo et al. (2008) define value simply in terms of an improvement in system well-being, i.e. its ability to fit in its environment (Vargo et al. 2008).

Vargo et al. (2008) see the service system as a useful abstraction for understanding value and value co-creation in the way of S-D logic. Especially service science's systems orientation provides a powerful perspective for the analysis of dynamic service exchange and value co-creation that are so central to S-D logic (Lusch and Vargo 2014; Vargo and Lusch 2008; Wieland et al. 2012). In order to more fully develop a complex, dynamic system framework, S-D logic scholars have also used the term service ecosystems. A service ecosystem is a relatively self-contained, self-adjusting system of resource-integrating actors connected by shared institutional logics and mutual value creation through service exchange. Worded in general terms, S-D logic refers to service-provisioning networks that are consistent with S-D logic principles as service ecosystems (Lusch and Vargo 2014). Though there are nuanced differences, the core conceptualizations of S-D logic's service ecosystem and of the composite service system, primarily used by service science, are similar in form and intent (Wieland et al. 2012).

All things considered, the framework uses S-D Logic as its (pre-)theoretical approach for the following reasons: S-D logic with its understanding of service generation as a cooperative and interactive value creation process within value co-creation networks provides a fruitful approach to the decomposition of CPS into single components and relationships from the service architecture perspective. S-D Logic is especially appropriate for studying service innovation as it moves away from perspectives traditionally rooted in technological product inventions (Michel et al. 2008). Instead, it nests both services and tangible goods into an integrated, overarching service view (Vargo and Lusch 2008). S-D logic's normalized actor concept, and first and foremost its systems orientation through the service system conceptualization, fit very well with main CPS characteristics. CPS' capability to temporarily build systems of systems with dynamically changing system boundaries, its characterization as globally interconnected, cooperative systems with distributed and changing control, and the human-system cooperation as inherent part of CPS—all can be well represented by atomic and composite service systems as defined above. Lastly, S-D logic's understanding of value—value can only be created contextually (value-in-context); value for service systems as its ability to fit in its environment—corresponds with CPS' ability to adapt to its environment and the according requirements (context-adaptability) and thereby act fully or partially autonomous.

3 CONCEPTUAL FRAMEWORK FOR CPS FROM THE S-D LOGIC PERSPECTIVE

3.1 Framework and its Empirical Illustration

Service systems combine and integrate value created in different design contexts. Glushko (2010) derives seven design contexts in which each successive scenario builds on the previous ones to define a progressively more complex service system. His work on design contexts of service systems is the starting point for the framework presented in figure 1 and hereinafter.

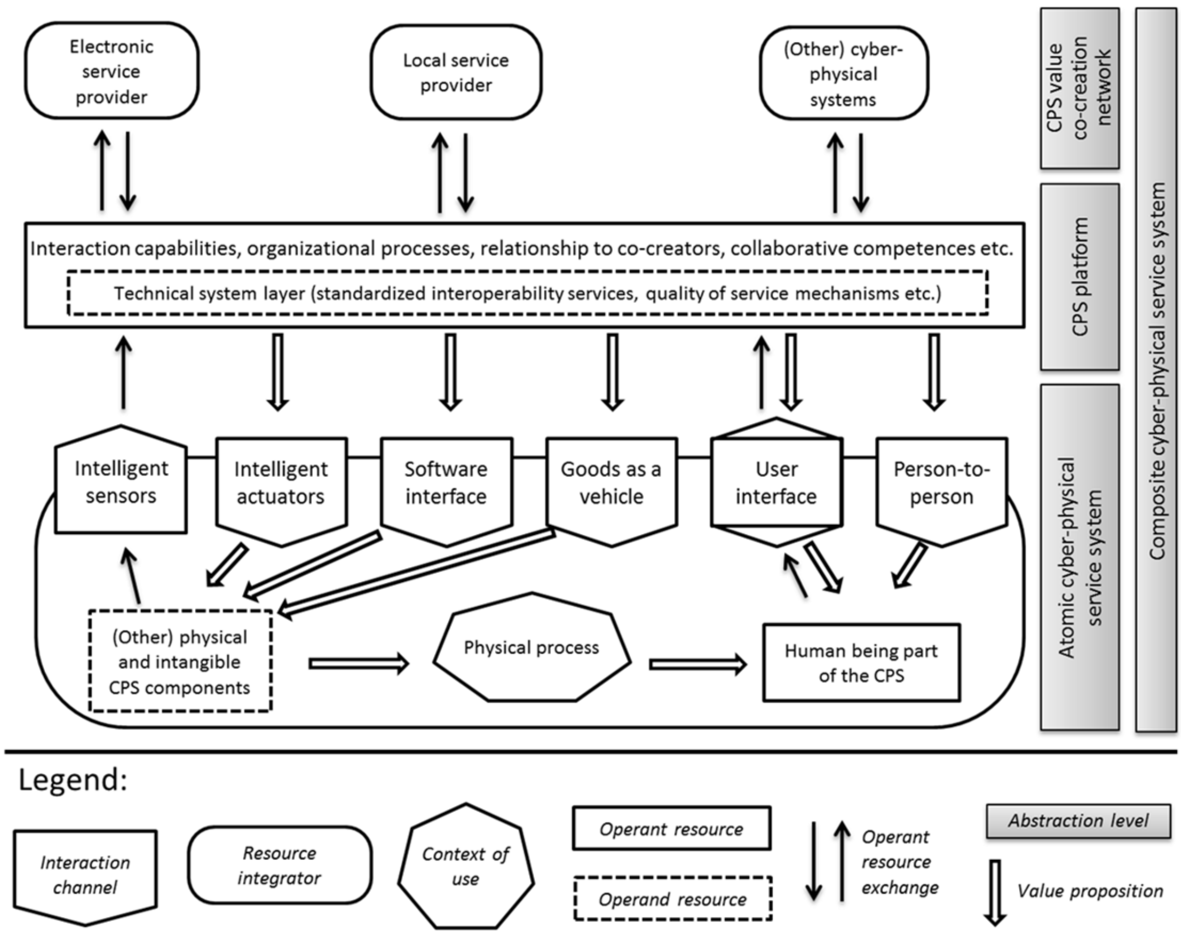

Figure 1. Conceptual Framework for CPS from the S-D Logic Perspective

The framework considers CPS as the most complex service system design, co-creating location-based and context-aware value propositions (context 7. "Location-based and Context-aware Service"; Glushko 2010). It coincides with S-D logic's understanding of value—value can only be created contextually, i.e. through consistent alignment and adjustment of the service provision to a given customer's context of use (value-in-context). Location is the most obvious context attribute, but not the only one—also identity, status or activity, and time characterize a situation. This open-ended definition of context information is bounded only by the variety and capabilities of the sensors by which context information can be acquired from the environment, and by the willingness of people to allow service providers to use information about their context (Glushko 2010).

As to CPS, the context of use is determined by the physical process that embeds the CPS at the time of consideration. The illustrative example "BMW (i) Connected Drive" understands the vehicle including occupants as a CPS. Besides the intelligent sensors and the interaction channels that will be described later, the "(i) Connected Drive"-software and hardware including the SIM-card integrated in the vehicle belong to the essential CPS components. The physical process at the time of consideration could be for example moving from A to B, being involved in an accident and others. The context sensitive value propositions that are ultimately always received by the human as part of the CPS must be aligned to this usage context in order to generate added value, in other words to support the value-adding processes of the customer.

In the empirical example various context information is transferred with the help of intelligent sensors. For example, next to GPS data that is the basis context information for each value proposition, “Tele-Services” (see www.bmw.com for detailed information on this and the following services) is provided with a remote access to vehicle state related sensor data (e.g. check-control-messages). The current car battery level is crucial context information for the inter-modal “i-Connected Drive Navigation Services”. Based on sensor data regarding airbag triggering the “Intelligent Emergency Call” can automatically execute an emergency call while other sensor data allow a remote analysis of accident type and severity, e.g. if an overturn happened. The direct exchange of sensor data of driving assistance systems (radar, ultra sound etc.) with other traffic participants will probably increase with the progress in (semi-) autonomous driving.

For further differentiation an essential property of context-aware services is considered—these are multi-channel services while the interaction channels are interlinked (Glushko 2010). The channels through which, in terms of S-D logic, value propositions are received are according to the framework presented here on the one hand "intelligent actuators", "software interface" and "goods as a vehicle", and on the other hand "user interface" and "person-to-person". While in the latter two the human being part of the CPS directly receives the value proposition, in the first three interaction channels the value proposition is first “refined” via the (other) physical and intangible CPS components. In this way, the offerer and the (direct) receiver of a value proposition can be a system or a person.

"Intelligent actuators" enable electronic service providers as resource integrators to remotely intervene in the control system of the CPS’ physical component parts, e.g. to remotely control a valve. "Software interface" enable electronic service providers as resource integrators to communicate and remotely intervene in the software system as intangible component of the CPS, e.g. to remotely update the firmware. "Goods as a vehicle" enable local service providers as resource integrators to provide on-site “person-to-physical CPS component parts services”, e.g. to install spare parts. Physical goods, as they for example appear in course of spare part installation, are understood as distribution mechanisms for service provision within the meaning of S-D logic. “User interface” enables electronic service providers as resource integrators to provide service via remote interaction with the human being part of the CPS, e.g. through customer self-service. “Person-to-person” enables local service providers to offer on-site services directly received by the human being part of the CPS, e.g. medical assistance in case of an accident.

The framework assumes that value-in-context can only be generated by complex service systems that are assembled from different service contexts. In other words, value-in-use can only be generated by novel and ad-hoc composed value propositions of local service providers, electronic service providers, as well as other CPS—all transmitted by the above mentioned interaction channels. Here, non-human-intensive combinations (CPS as semi-autonomous systems) are preferred based on the service design principle "information replaces interaction" (Glushko 2010).

In the empirical example the five defined interaction channels are used across all components and services. The navigation system device is the central user interface for all (sub) services related to locational context information. Although the interaction with the “Concierge Service” is mainly implemented via the built-in speakerphone, locational information, routing etc. are transmitted directly through the navigation system device. The telephone unit permanently installed in the vehicle serves all tech-enhanced person-to-person services (kind of electronic services) such as “Concierge Service”, “Intelligent Emergency Call” and “TeleServices” as an interaction channel. The software interface allows in “TeleServices” a remote repair of certain malfunctions. “i-Services for the Navigation” calculates if the destination can be reached based on several key factors such as battery level, driving style, current traffic conditions and topographical information. In case a change in the environment occurs (e.g. traffic jam), the service switches to the more efficient “ECO PRO+” driving mode via the software interface. Intelligent vehicular actuators are a quite functional safety-related interaction channel, which is currently used only for accessing interior cooling or heating, car horn as well as car doors (via a remote app or by an employee of BMW’s call center). Assuming several legal obstacles are solved, services related to (semi-)autonomous driving and car-to-car communication can be expected—all provided through intelligent vehicular actuators (e.g. controlled, cooperative emergency maneuvers). “Intelligent Emergency Call” and “TeleServices” can end up in a classic roadside assistance via the interaction channel “Goods as a vehicle” (replacement of car parts etc.); within the scope of the “Intelligent Emergency Call” rescuers potentially perform the first medical assistance for the driver or the passengers—obviously a person-to-person service.

S-D logic assumes that co-creation of value is a cooperative and interactive process. It considers all actors involved therein as resource integrators—they offer their resources for collaborative value creation as value propositions and form together a value co-creation network. A single company cannot separately and independently generate value. Lusch et al. (2010) define the value co-creation network as “spontaneously sensing and responding spatial and temporal structure of largely loosely coupled value proposing social and economic actors interacting through institutions and technology, to: co-produce service offerings, exchange service offerings, and co-create value."

The framework presented here assumes that CPS’ ability to (temporarily) form Systems of Systems (SoS) and to act as globally interconnected, cooperative systems, requires such a value co-creation network. In the formation of SoS the scenario may require ad-hoc cooperation with electronic service providers, on-site (local) service providers as well as with other, additional CPS. In analogy with S-D logic’s understanding of customer as a co-creator of added value, CPS themselves, including the human being part of the CPS, are also seen as resource integrators and thereby value co-creation network members. One may think here of fully or semi-autonomous, cooperative column driving by vehicular CPS.

The CPS value co-creation network in the empirical example consists of several resource integrators: all electronic (sub) services including tech-enhanced person-to-person (sub) services are provided by the focal company itself, i.e. BMW, or by several externally contracted service providers. The latter also provide location based information (sub) services. The framework considers besides BMW’s roadside assistance and its local service partners also local public transportation companies as resource integrators within BMW’s co-creation network, since they are integrated into the intermodal routing of “i-Services for Navigation”. The “Intelligent Emergency Call” turns even local emergency medical services into resource integrators of the CPS value co-creation network.

The “Real Time Traffic Information” takes among others also data from movement profiles of other “Connected Drive”-enabled BMW vehicles. In this way, a SoS of many vehicular CPS is created and all of them function as resource integrators by supplying the necessary sensor data. There can be a reasonable expectation that further progress in the field of (semi-)autonomous driving and vehicle-to-vehicle/environment communication will enable novel vehicular SoS scenarios. Such SoS will be probably able to run controlled, cooperative emergency maneuvers etc.

Context-awareness and cooperation, especially both combined and if taking place ad-hoc, are information-intensive value creation activities. The possibilities for this are influenced by information systems and information-based mechanisms (Böhmann et al. 2014). Here, a central role is assigned to the CPS platform, typically considered as a construct comprising hardware, software and communication systems in order to ensure basic functionality for implementation, operation and evolution of CPS on the technical system level. This includes, for example, standardized interoperability services and quality of service mechanisms.

Following S-D logic, the focus on the CPS platform is less on the technical system layer. Besides technology, the CPS platform is a conglomerate of operant resources, such as knowledge, interaction capabilities, organizational processes, relationship to co-creators, collaborative competences etc. From the perspective of S-D logic, added value can only result from the application of these operant resources. In this view, companies need to develop relevant capabilities that enable partners and customers to engage in co-creation activities—i.e. to help them to integrate their resources into the value co-creation process. In other words, companies are required to establish adequate channels for the exchange of operant resources, transcending inter-organizational boundaries (Clauß et al. 2014; Lusch and Vargo 2014). Furthermore, they need to be capable of coordinating interactions and resulting service flows among value network members. Karpen et al. (2012) refer to several interaction capabilities in this regard; Payne et al. (2008) to encounter processes—the processes and practices of interaction and exchange that take place within co-creation network relationships and which need to be managed in order to develop successful co-creation opportunities.

Britsch et al. (2012, 2013) discuss an approach, namely anything Relationship Management (xRM), that could potentially expand a CPS platform (as typically considered) by the just mentioned S-D logic thought. xRM is a strategic management approach that integrates and aligns all levels of relationships. Everything is included in the relationship structures—material assets (e.g., fleet), intangible assets (e.g., contracts), and any stakeholder (e.g., customers or other co-creators). Using xRM, real and virtual entities can be linked dynamically and context-sensitive (Britsch et al. 2012). The connection to CPS is obvious—as Britsch et al. (2013) state, xRM could provide the management layer for collaborative networks and CPS (Britsch et al. 2013). The practical implementation of xRM is based on ICT. Usually an xRM solution is realized as a xRM platform (Britsch et al. 2012) that could be a CPS platform component on the technical system layer.

Since the CPS platform is attributed to the back-end area, the document analysis within the empirical example provided very limited insights. As far as can be seen, substantial amount of information exchange and service orchestration is performed, or at least assisted, by customer service or call center staff—i.e. not autonomously performed by information systems and information-based mechanisms. This argues again for the potential of xRM being an element of the CPS platform.

3.2 Exemplary Implications for CPS research

Rigorousness requires evaluation of the conceptual framework against the defined goals—i.e. to show, in what way it enables analyses of CPS service architectures, and on this basis facilitates further empirical and design-oriented research on CPS service architecture innovations, business model innovations etc. Since S-D logic is mainly criticized because of its less concrete implications, an integration of S-D logic thinking and of the business model concept is seen as highly eligible (Clauß et al. 2014). The evaluation draws on this research stream and highlights gained insights into the CPS service architecture according to two of the seven Service Business Model Canvas' (SBMC) dimensions—value proposition and channels. The value proposition dimension offers an overview about the value that is proposed to each actor—i.e. the value proposition for customers, partners and the company itself is represented; the dimension channels describe the interaction points between the actors (Zolnowski and Böhmann 2014). The presented conceptual framework leads to the following exemplary implications in respect of these two SBMC dimensions.

The framework considers CPS as the most complex service system design, co-creating location-based and context-aware value propositions through interlinked interaction channels. This understanding can be the starting point for further studies on the anatomy of CPS value propositions, e.g. in order to improve the understanding on how providers conduct service innovation by means of combining resources into value propositions (Skålén et. al. 2014) in the field of CPS. Innovation in terms of S-D logic is perceived as a process wherein co-creators together seek out ways that enable them to successfully collaborate in resource integration and fostering of value creation. The novelty of an innovation seen from S-D logic lens is not limited to be technological—it can also refer to a product being used in new ways, as in a different context, place and time (Mele et al. 2014).

The five proposed channels can serve as building blocks and facilitate the generation of novel value propositions—together with the finding that generating value-in-context may require integrable resources coming from a variety of sources—ad-hoc cooperation with electronic service providers, onsite local service providers as well as with other, additional CPS. It is through the often simultaneous integration of resources in many possible explicit and implicit combinations that value is co-created (Lusch and Vargo 2014). Discontinuous innovation often includes reconfiguring the value constellation and study how operant resources from multiple sources can form innovative value constellations (Michel et al. 2008).

In addition, the interaction channels can be the starting point for further research on collaborative and contextualized value creation in the field of CPS. Payne et al. (2008) differentiate three exchange practices or encounter types that facilitate value co-creation: 1) Communication encounters that are primarily carried out in order to connect with customers, promote and enact dialogue, and ensure an ongoing exchange of operant resources. 2) Usage encounters referring to a service that supports customer usage. 3) Service encounters which comprise customer interactions with customer service personnel or service applications. Ordanini and Parasuraman (2011) see three drivers relevant for service innovation: collaborative competences, dynamic capability of customer orientation and knowledge interfaces. They also introduce the concept of knowledge interfaces. These knowledge transfer mechanisms facilitate the transference of knowledge within and among organizations and ensure knowledge gathering and absorption as well as knowledge integration and diffusion (Ordanini and Parasuraman 2011). Bringing together the derived interaction channels and both broached research results can, for example, reveal in which ways actors in CPS-value constellations can collaborate synergistically to create networks of operant resources.

4 IMPLICATIONS FOR S-D LOGIC

4.1 Service Systems as Resource Integrators

S-D logic generally uses an actor-to-actor notation. All economic and social actors—e.g. business firms, nonprofit and government organizations, individuals, and households—have a common purpose: value co-creation through resource integration and service-for-service exchange (Lusch and Vargo 2014). This view of the normalized actor points towards the dynamic and systemic nature of social and economic exchange and helps to make the collaborative, systemic nature of value creation and its implications more salient (Wieland et al. 2012). In this sense, S-D logic's foundational premise nine (FP 9) states that all social and economic actors are resource integrators.

Vargo et al. (2008) also see the service system as a useful abstraction for understanding value and value co-creation in the way of S-D logic. They even reflected upon the service system as an alternatively appropriate term with regard to FP 9: “For present purposes, we have identified the parties involved in exchange relationships as ‘economic and social actors’. However, we are not forever committed to that term. Alternatively, ‘service systems’ [..] might be a good, S-D friendly term, but we suspect it is not yet sufficiently familiar to marketing scholars and practitioners. Therefore, the revised FP 9 is ‘All social and economic actors are resource integrators’.” (Vargo and Lusch 2008).

The presented conceptual framework speaks for seizing this idea. All actors in the framework are resource integrators. In analogy with S-D logic’s understanding of the customer as a co-creator of added value, CPS themselves, including the human being part of the CPS, are also seen as resource integrators. For example, the service “Real Time Traffic Information” (RTTI) takes among others also data from movement profiles of other “Connected Drive”-enabled BMW vehicles. In this way, all of them function as resource integrators by supplying the necessary sensor data. The service system proved to be a useful abstraction in order to cover all divergent parties involved in such a value co-creation—social and economic actors, as well as beyond as in the case of CPS.

S-D logic and service science understand a service system as a dynamic value co-creation configuration of resources, including people, organizations, shared information, and technology, all connected internally and externally to other service systems by value propositions (Maglio et al. 2009). An atomic service system uses no other service systems as resources. Atomic service systems and other resources can be combined to form composite service systems. Based on these abstractions, the presented framework understands CPS as service systems (see figure 1 in section 3): The sole CPS, understood as an atomic (cyber-physical) service system, receives and (possibly) accepts value propositions through the five defined interaction channels. Several atomic (cyber-physical) service systems and other resource integrators from the (CPS) value co-creation network can be combined to form a composite (cyber-physical) service system; just as in the abovementioned example of RTTI, where several atomic (cyber-physical) service systems and electronic services, e.g. provider of locational context information, temporarily build a dynamic value co-creation configuration.

S-D logic’s basic abstraction of the service system provides a powerful perspective for understanding and analyzing service architectures of CPS. The presented conceptual framework indicates that the service system abstraction is indeed a proper abstraction to understand and characterize actors or resource integrators involved in value co-creation, especially when considering IT-enabled service-provisioning networks such as those in the field of CPS.

4.2 Bridging S-D Logic and Management Research on Technological Platforms

The presented conceptual framework assumes that value-in-use can only be generated by (ad-hoc) composed value propositions of a value co-creation network—all transmitted by the introduced interaction channels. In this regard, the CPS platform plays a central role and uncovers the indirect exchange of operant resources. The framework considers the CPS platform itself as an operant resource as well—more precisely, as a conglomerate of operant resources, such as capabilities that enable partners and customers to engage in co-creation activities, adequate channels for exchange of operant resources, organizational processes of interaction and collaboration, relationship to co-creators, collaborative competences etc. Following S-D logic, the focus on the CPS platform is less on the technical system layer (standardized interoperability services, quality of service mechanisms etc.).

The above-mentioned conceptualization of the CPS platform—briefly described through the lens of S-D logic—corresponds well to Gawer’s industry platform conceptualization (Gawer 2014) from the field of management research on technological platforms. Gawer (2014) defines industry platforms as products, services, or technologies developed by one or more firms that serve as a foundation upon which a larger number of firms, organized as a business ecosystem, can build further complementary products, technologies, or services. Industry platforms operate within the broad organizational setting of the ecosystem, whereby coordination is ensured by ecosystem governance. In this regard, platforms are distinct in that they are associated with network effects. There are increasing incentives for more providers of complementary products and users to adopt a platform and join the ecosystem as more users and complementors join. Network effects can be very powerful, especially when they are direct or same-side—between the platform and the user of the complementary innovation, or between platform and the complementors (Gawer 2014; Gawer and Cusumano 2014).

Besides complementors, the second constitutive agent of an industry platform is the platform leader. He plays a central, orchestrating role and drives industrywide innovation for an evolving system of separately developed complementary components. Industry platforms have opened technological interfaces with slight variations within the spectrum of how open these interfaces are. Potential innovators of complementary products can utilize information on the platform's technological interfaces that are disclosed by the platform leader to build compatible complements. Industry platforms therefore extend the pool of accessible innovating agents—loosely organized in an innovation ecosystem—and their innovative capabilities to a potentially unlimited extent. An interesting specificity of industry platforms is that the platform leader does not need to know ex-ante who or where innovators might be. Potential innovators of complementary products self-identify to the platform's innovation ecosystem (Gawer 2014; Gawer and Cusumano 2014).

The industry platform conceptualization is part of Gawer's integrative framework that intends to bridge two differing theoretical perspectives on technological platforms. The economics perspective sees platforms as double-sided markets, whereas the engineering design perspective understands platforms as technological architectures. While the economic perspective informs the understanding of platform competition, the engineering design perspective informs the view of platform innovation. The framework classifies technological platforms within three increasingly broader organizational settings: within firms, across supply-chains, and within ecosystems. Gawer assigns a corresponding type of platform to each of the three organizational settings: internal platform (within firms), supply chain platform (across supply-chains), and the abovementioned industry platform (within ecosystems). The platform types differ in their level of analysis, its constitutive agents and technological architecture, the nature of its interfaces, its innovative capabilities, and its coordination mechanisms.

Bridging insights from the field of management research on technological platforms with the perspective of S-D logic can advance S-D logic's efforts to clarify the conceptual interplay between the service ecosystem abstraction, the value co-creation network, indirect service exchange, and value. Several valuable contributions to this topic, especially the below-mentioned ones, provide potential links to platform conceptualizations within business or innovation ecosystems. This broad organizational setting and level of analysis corresponds well with S-D logic's service ecosystem abstraction as a relatively self-contained, self-adjusting system of resource-integrating actors connected by shared institutional logics and mutual value creation through service exchange (Lusch and Vargo 2014).

Relying upon the foundational premises of S-D logic, Lusch et al. (2007) derive propositions that shall inform marketers on how to compete through service. As to FP 9, "all social and economic actors are resource integrators", they make a proposition closely related to platform aspects: S-D logic points towards collaboration and coordination as essential approaches to innovation and competition. Both represent means for integrating (operant) resources. At one end of a coordination-integration continuum, transactional markets exist where the inherent marketplace mechanisms become the key coordination mechanism and integrator. At the other end are relational markets, i.e. long-term relationships that are highly collaborative. S-D logic embraces relational and collaborative markets. In this context, Lusch et al. (2007) raise the question who should the prime integrator be under a collaborative model of coordination. They see the value network member that is the prime integrator in a stronger competitive position. The rationale of this proposition is that the ability to effectively combine micro-specialized competences into complex services provides knowledge for increased competitive advantage. Considering this rationale, the roles of the prime integrator and the platform leader appear fairly similar.

Vargo et al. (2008) describe the interplay between co-creation of value-in-use and value-in-exchange as follows: Although S-D logic focuses on value derived and determined through use or context, value determined by exchange remains an important component in the co-creation of value—it inherently requires participation of more than one actor, and it is through integration and application of resources made available through exchange that value is created. Value-in-use can theoretically exist without value-in-exchange, but when the need to access resources from other actors arises, so does the need for value-in-exchange. To sum up, Vargo et al. (2008) state that "the process of co-creating value is driven by value-in-use, but mediated and monitored by value-in-exchange"—one can also say: mediated and monitored by a platform construct.

Chandler and Vargo (2011) explore the role of context in service provision and, more broadly, in market co-creation. They propose a conceptualization of context based on the following levels: micro-context, meso-context, macro-context, and the layer of meta-context above each of the first three levels. Micro-context frames exchange among individual actors as dyads. The important process of exchange at this level is direct service exchange. Context at the meso-level frames exchange as it occurs among dyads, i.e. actors that are not necessary directly connected in order to co-create value. The important process of exchange at this level is indirect service exchange. Macro-context frames exchange as it occurs among triads. The important process of exchange at this level is complex service, i.e., multiple simultaneous direct and indirect service exchanges in the context of a complex network. Context at the meta-level frames exchange as it occurs among complex networks as service ecosystems. The meta-level covers all other levels of service exchange and shall make salient how these levels evolve over time. A platform based conceptualization can sharpen the understanding of complex contexts of service provision like indirect service exchange or multiple simultaneous direct and indirect service exchanges in complex networks.

4.3 The Concepts of Indirect Value-In-Context and Option Value-In-Context

According to S-D logic's FP 7, enterprises cannot deliver value independently, but only offer value propositions which, after being accepted by customers, enable the mutual co-creation of value. Until the point of value realization, i.e. through use within customers' context, the offering is only potentially valuable. In this sense, the customer is always a co-creator of value (FP 6). Value is not created until the customer integrates and applies the offered resources for value creation with other resources that exist in his context (Vargo and Lusch 2008).

Lusch et al. (2007) call attention to the fact that there are two components of collaboration between actors involved in value creation. The most encompassing of both these components is the abovementioned co-creation of value, closely tied to value-in-use and value-in-context. The second component involves the customer's (and any other actor's) participation in the creation of the core offering itself, e.g. through shared inventiveness, co-design, or shared production. Therefore, more appropriately than value-co-creation, it is referred to as co-production.

The presented conceptual framework assumes that value-in-context can only be generated by complex service systems that are assembled from different service contexts. Ad-hoc composed and context aware value propositions of local service providers, electronic service providers, as well as other CPS—all transmitted by the introduced interaction channels—generate value-in-context, when being accepted by the beneficiary. The context of use is determined by the physical process that embeds the CPS at the time of consideration. It so far corresponds to S-D logic's understanding of value and value creation. However, drawing on the empirical illustration, a closer look into the anatomy of value and platform-mediated value co-creation in the framework reveals two issues that do not go hand in hand with S-D logic.

The value proposition of BMW's "Real Time Traffic Information" (RTTI) is to keep the driver "up-dated on the traffic situation as it develops … The system also calculates what delays are to be expected and recommends detours. This keeps [the driver] precisely informed of the traffic situation on the planned route and potential alternative routes at all times. As a result [the driver] can react to tail-backs and road closures in good time and avoid them" (www.bmw.com). In order to be as precise as possible, the system takes among others also data from movement profiles of other "Connected Drive"-enabled BMW vehicles in real time. In this way, a System of Systems of many vehicular CPS is created and all of them function as resource integrators by supplying the necessary sensor data. In other words, by driving from A to B, customers simultaneously co-create value-in-context for themselves, as well as co-produce the core offering for others by enabling precise information—i.e. they increase potential value-in-context of other customers.

The described constellation is caused by network effects that are generally associated with platform mediated value co-creation, and in the case of RTTI take effect as follows. The more users adopt the platform and co-produce the RTTI by simply using it, the more valuable the platform becomes to the platform leader and its users because of an increased value-in-context of RTTI to all customers using it. "Indirect value-in-context" might be a proper term for this effect or part of the overall value-in-context.

Hein et al. (2006) propose a similar anatomy of value (-in-use/-in-context) related to the valuation of ecosystem services. They use the following definition of an ecosystem: "the individuals, species and populations in a spatially defined area, the interactions among them, and those between the organisms and the abiotic environment" (Hein et al. 2006). Ecosystem services, e.g. recreation and nature conservation, are goods or services provided by the ecosystem to society. The authors define and discuss four value types that stakeholders can attribute to ecosystem services—among others so called indirect use values that "stem from the indirect utilization of ecosystems, in particular through the positive externalities that ecosystems provide." Positive externalities occur when the consumption or production of a good causes a benefit to a third party, which is nothing else than (positive) network effects.

Besides indirect use values, Hein et al. (2006) further introduce so called option values: "Because people are unsure about their future demand for a service, they are willing to pay to keep open the option of using a resource in the future" (Hein et al. 2006). Following this, at least parts of a value proposition can indeed be more than just potentially valuable until its realization. So the option of taking alternative routes at all times is valuable to the customer in the sense of value-in-context. Alternative routes increase the value-in-context of RTTI, no matter whether or not actually used by the customer.

Such options enable the overall value proposition of "i-Services for the Navigation"—"to make electric driving easier and more convenient" (www.bmw.com). The driver may be certain that, in any case, there will be a fast and convenient way to reach the destination. If the range assistant detects that either the charge level of the battery, driving style, topography, or current traffic conditions will prevent the driver from reaching the destination, it recommends alternative routes that consume less power, shows charging stations on the way to the destination, or even offers intermodal routing solutions including local public transportation. In this example too, the mere value propositions from of all these value co-creation network members—providers of charging stations, local public transportation companies etc.—increase or even enable the value-in-context of “i-Services for the Navigation”, no matter whether or not actually used by the customer. One can also say that their value propositions are complementary to that of i-Services for the Navigation”. “Option value-in-context” might be a proper term for this effect or part of the overall value-in-context.

According to Hein et al. (2006), the total use value equals the sum of the abovementioned indirect use and option values, as well as so called direct use value—value that arises from direct utilization of ecosystems services—and so called none-use value, which is not relevant at this point. On the analogous assumption that parts of the overall value-in-context are exclusive and may be added, the presented framework indicates that (the overall) value-in-context consists of “indirect value-in-context”, “option value-in-context”, and “direct value-in-context”. This anatomy of value-in-context can resolve the two initially raised issues.

5 CONCLUSION

In the first part, the present paper shows an alternative view of CPS in the form of a conceptual framework informed by S-D logic. It is a first exploratory attempt to apply S-D logic to CPS and to consider CPS as service systems. Thus, at this point, it is not a fully developed understanding of CPS as service systems and a fully developed conceptual framework to analyze CPS service architectures. Nevertheless, S-D logic proved to be useful when there is a need to have a complete understanding of the whole value-creating system.

In the second part, the paper focuses on how this conceptual framework contributes to the advancement of S-D logic itself. Findings from application of S-D logic to the field of CPS are passed back to the general orientation of S-D logic and result in three main implications: First, the service system abstraction is indeed a proper abstraction to understand and characterize actors or resource integrators involved in value co-creation, especially when considering IT-enabled service-provisioning networks such as those in the field of CPS. Second, bridging insights from the field of management research on technological platforms with the perspective of S-D logic can advance S-D logic’s efforts to clarify the conceptual interplay between the service ecosystem abstraction, the value co-creation network, indirect service exchange, and value. Third, a close look into the anatomy of value and platform-mediated value co-creation in the framework reveals that (the overall) value-in-context consists of “indirect value-in-context”, “option value-in-context”, and “direct value-in-context”.

The presented implications are limited by its exploratory, inductive and conceptual nature. Further research is needed in order to gain further elaboration, scrutiny, and competing views.

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