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RESEARCH PAPER

Recombinant Service Systems Engineering

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Abstract Although many methods have been proposed for engineering service systems and customer solutions, most of these approaches give little consideration to recombinant service innovation. Recombinant innovation refers to reusing and integrating resources that were previously unconnected. In an age of networked products and data, we can expect that many service innovations will be based on adding, dissociating, and associating existing value propositions by accessing internal and external resources instead of designing them from scratch. The purpose of this paper is to identify if current service engineering approaches account for the mechanisms of recombinant innovation and to design a method for recombinant service systems engineering. In a conceptual analysis of 24 service engineering methods, the study identified that most methods (1) focus on designing value propositions instead of service systems, (2) view service independent of physical goods, (3) are either linear or iterative instead of agile, and (4) do not sufficiently address the mechanisms of recombinant innovation. The paper discusses how these deficiencies can be remedied and designs a revised service systems engineering approach that reorganizes service engineering processes according to four design principles. The method is demonstrated with the recombinant design of a service system for predictive maintenance of agricultural machines.

Keywords Service engineering · Recombinant innovation · (Product-)service system · Design science research · New service development

1 Introduction

The structured design of value propositions – also referred to as Service Engineering or Product-Service Systems (PSS) Engineering (Becker et al. 2009c; Böhmann et al. 2014; Cavalieri and Pezzotta 2012) – has been a focal area of the Service Science discipline since the 1980s. Ever since, a plethora of methods has been proposed for designing 'services' or 'customer solutions' that consist of services, products, and information technology (Cavalieri and Pezzotta 2012). Following the properties of 'service' as the core unit of exchange (Vargo and Lusch 2008b), we will henceforth refer to all these methods as 'service engineering'. Most service engineering methods prescribe service design as a top–down engineering process that spans from idea management to offering a value proposition on the market. Subsequently, service is co-created by service providers and service customers, thereby generating value-in-use for the stakeholders involved.

While the relevance of service engineering has increased (Fähnrich and Opitz 2006), our understanding of service engineering has also shifted conceptually. In particular, the advent of smart products has enabled companies to offer value propositions that rely on context-specific field data

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that are made available in (near) real time. Discussed under the buzzwords 'Internet of Things' or 'Internet of Services', a new era of (smart) service systems engineering is ushered in. These trends are increasingly focused on designing integrated conglomerates of products, services, and information technology, which jointly provide value propositions based on which service and value-in-use are co-created (Vargo and Lusch 2008a, b; Maglio et al. 2009).

However, as opposed to the considerable body of knowledge of service engineering, the value and applicability of the available methods is questionable for two reasons. First, many methods seem complex, over-engineered, overwhelmingly cumbersome to use, and require large investments to be made before a value proposition can be offered on the market (Becker et al. 2009c; Meyer and Böttcher 2011). Second, most approaches implicitly assume an inside-out perspective that is based on defining (modular) value propositions that service providers offer to their clients (Becker et al. 2011a; Meyer and Böttcher 2011). In contrast, service as value co-creation explicitly highlights the need to include resources of customers and third parties in service innovation and design.

Due to the progressing availability of smart products and smart data, Brynjolfsson and McAfee (2014) suggest that many future innovations will be recombinant. Recombination refers to systematic reutilization and combination of existing resources that were previously unconnected to achieve an innovative solution (Cecere and Ozman 2014). Uber (Uber Technologies Inc. 2017) is a well-known example for a recombinant service innovation. With about 40 million monthly riders worldwide (Kokalitcheva 2016), Uber matches car owners with customers on an online platform to co-create a transportation service. A recombinant innovation is not designed and brought to market by means of a top–down engineering process, but is developed by recombining existing resources and solutions supplied by different stakeholders. Therefore, recombinant innovation intrinsically supports the outside-in perspective of service innovation and design. The purpose of this paper is to conceptualize recombination as a type of service innovation and – based on this conceptualization – to assess and enhance existing service engineering methods in order to foster this type of innovation. More specifically, we review service engineering methods vis-à-vis mechanisms of recombination and other constructs and design a conceptual method for recombinant service systems engineering. The method itself is a recombination, since it rearranges existing service systems engineering approaches according to four design principles.

The remainder of this paper is structured as follows. In Sect. 2, we review and discuss related literature on service engineering, new service development, and (product-)service systems engineering, as well as literature on service innovation and service modularization. In Sect. 3, we explain and justify our research method. In Sect. 4, we analyze existing methods for service systems engineering. In Sect. 5, we design a method for recombinant service systems engineering and demonstrate its application with a scenario for predictive maintenance of agricultural machines. Section 6 concludes the paper.

2 Related Research on Service Engineering and Innovation

2.1 Developing/Engineering (Product-)Service (Systems)

First approaches covering the development of services were published under the banner of "New Service Development" (NSD) in the Anglo-American literature of the 1980s (Meiren and Barth 2002). Johnson et al. (2000) argue that "NSD research mirrors that in NPD" (New Product Development) and focuses on success factors, which "address what should be done, not how it should be done" (Johnson et al. 2000, p. 9). NSD mainly focuses on particular aspects of service development, e.g., quality (Edvardsson and Olsson 1996; Ramaswamy 1996), prerequisites for services (Edvardsson and Olsson 1996), processes (Shostack and Kingman-Brundage 1991), or enablers for service development (Johnson et al. 2000). The approaches often contain frameworks or (partial) processes without presenting detailed methods or tools for service development (Johnson et al. 2000). Also, they often focus on a service management or service marketing perspective (Meiren and Barth 2002; Edvardsson and Olsson 1996).

In parallel to NSD, another research stream started in the 1990s, transferring know-how from engineering disciplines and software development to service development (Fähnrich and Opitz 2006). The aim was to build on advantages of engineering processes like improved efficiency, reduced development time and costs and increased quality for service development (Meiren and Barth 2002). A center of activities in Service Engineering was in Germany, where the term "service engineering" was used since the mid-1990s (Fähnrich and Opitz 2006). Here, initiatives, conferences, and publicly funded projects were initiated since 1994 to strengthen research activities in structured service development (Fähnrich and Opitz 2006). From the funding program *Dienstleistungen für das 21. Jahrhundert* (Services for the twenty-first century), service engineering emerged as an independent focus topic (Fähnrich and Opitz 2006).

Several process models for service engineering have been designed (Jaschinski 1998; Botta 2007; Klein 2007).

Early approaches feature three to seven steps that can be repeated iteratively. These approaches have close references to product engineering approaches and, therefore, consider service as a product without taking into account other aspects, such as organizational or social impacts (Böhmann et al. 2014; Meiren and Barth 2002; Jaschinski 1998; German Standards Institute 1998).

More recent research extends the point of view from designing a value proposition to designing a service system. Scheuing and Johnson (1989, p. 32) already highlight the necessity to convert "the new service concept into an operational entity" (Scheuing and Johnson 1989, p. 32). Klein (2007) develops a systems engineering approach based on considering the service engineering system as a social system. Becker et al. (2009c) identify different conceptualizations of product-service systems. Böhmann et al. (2014) "conceptualize a service system as a socio-technical system that enables value co-creation guided by a value proposition", including "not only data and physical components, but also layers of knowledge, communication channels and networked actors" (Böhmann et al. 2014, p. 74). Engineering service systems comprise defining service architectures (i.e., modules of a service system and their interactions), designing interactions in service systems, and mobilizing human, physical, and information resources (Böhmann et al. 2014). Selected core concepts that constitute the Service Science discipline are briefly defined in Table 1.

2.2 Recombinant (Service) Innovation

Innovation, in general, can be defined as a discontinuous change and describes a new solution or renewal of an existing solution (Toivonen and Tuominen 2009). As opposed to mere invention, innovation has practical or commercial value (Cooke 2016).

The existing literature emphasizes the evolving character of innovation by describing its processes as either planned, intentional, or unintentional (Gremyr et al. 2014). Innovation processes can be described through six different modes: radical innovation, improvement innovation, incremental innovation, ad hoc innovation, recombinant innovation, and formalization innovation (Gallouj and Weinstein 1997). In theory, most innovations are based on recombination (Cooke 2016), since hardly any innovation is entirely new (Wirth et al. 2015). Therefore, we will focus on recombinant innovation here.

Recombinant innovation relies on combining existing elements to generate a new relationship between previously uncombined resources (Fleming 2001). There are three basic mechanisms of recombinant innovation, namely, dissociation, association, and addition. Uncombined elements can be accessed from internal and external resources,

Table 1 Selected core concepts of the service science discipline defined

Concept	Definition
Service	Service is "the application of specialized competencies […] through deeds, processes, and performances for the benefit of another entity or the entity itself" (Vargo and Lusch 2008b, p. 26). Service does "not result in a transfer of ownership from seller to buyer" (Lovelock and Gummesson 2004, p. 37) but offers "benefits through access or temporary possession, instead of ownership" (Lovelock and Gummesson 2004, p. 37). Therefore, service refers to operant and operand resources that are made available to/are accessed by external actors in a service system
Service system	A service system is "a configuration of people, technologies, and other resources that interact with other service systems to create mutual value" (Maglio et al. 2009, p. 395). It is a socio-technical system (Böhmann et al. 2014). Product-Service Systems are particular service systems that include a transfer of physical items as well as temporary access to resources
Service science (management and engineering)	"Service science is the study of service systems, aiming to create a basis for systematic service innovation. Service science combines organization and human understanding with business and technological understanding to categorize and explain the many types of service systems that exist as well as how service systems interact and evolve to co-create value." (Spohrer and Maglio 2008, p. 18)
Value proposition	Value propositions are "invitations from actors to one another to engage in service" (Chandler and Lusch 2015, p. 6). If a value proposition is accepted, service providers and service customers access and combine each other's resources to co-create value-in-use
(Operand and operant) resources	"Constantin and Robert (1994) define operand resources as resources on which an operation or act is performed to produce an effect […] operant resources […] are employed to act on operand resources (and other operant recourses [sic!])" (Vargo and Lusch 2008a, p. 2)
Value-in-use	Value-in-use highlights that value is created in interactions of service providers and service customers. As opposed to value-in-exchange, value-in-use is based on the co-creation of value that is based on integrating the actors' operant and operand resources (see Vargo and Lusch 2008a)

spanning as an orthogonal dimension across the three mechanisms of recombinant innovation (Fig. 1), which enable and constrain recombinant innovation (Cecere and Ozman 2014). The mechanisms can be concatenated to build more complex innovation patterns. Recombinant innovation has also been claimed as a role model for service innovation (Gremyr et al. 2014) that can lead to incremental improvements as well as radical changes (Cecere and Ozman 2014). Conceptualizing innovation as a recombination of resources is also in line with basic principles of service science; for instance, Service-Dominant Logic states that all companies are resource integrators and that resources of service providers and service customers are integrated with each other in order to create mutual value (Vargo and Lusch 2004; Vargo et al. 2010).

Dissociation refers to designing a new value proposition by splitting up an existing service, isolating specific characteristics or a subset of operations, categorizing them, and turning those elements into marketable value propositions (Gadrey et al. 1995). Resources that have been split up can be combined or integrated with other resources that were unconnected before (Cecere and Ozman 2014). *Association* refers to designing a new value proposition by combining (or "associating") two or more existing resources. Theoretically, any resource can be recombined with any other resource (Fleming 2001). This nexus indicates that the number of new combinations is a combinatorial function of the number of existing resources (Tsur and Zemel 2007). Association also describes the transfer of an existing resource into another context for which it was initially not designed (Toivonen and Tuominen 2009). Another mechanism of recombination is the *addition* of new value propositions (Tsur and Zemel 2007).

Service refers to (re-)combining *internal and external resources*. Internal resources refer to the capability to recombine a company's internal procedures in storing, retrieving, and processing knowledge (Gallouj and Weinstein 1997). Externally, firms can draw on resources through their relationship with customers, suppliers, and other stakeholders that are involved in a service system (Gallouj and Weinstein 1997). Their relationships give them access to valuable resources that cannot be generated internally. If resources possessed by the involved parties are similar, they can be recombined efficiently leading to innovations, which, however, are rather incremental (Antonelli et al. 2010). Integrating distant resources can result in innovative breakthroughs, but presupposes that the

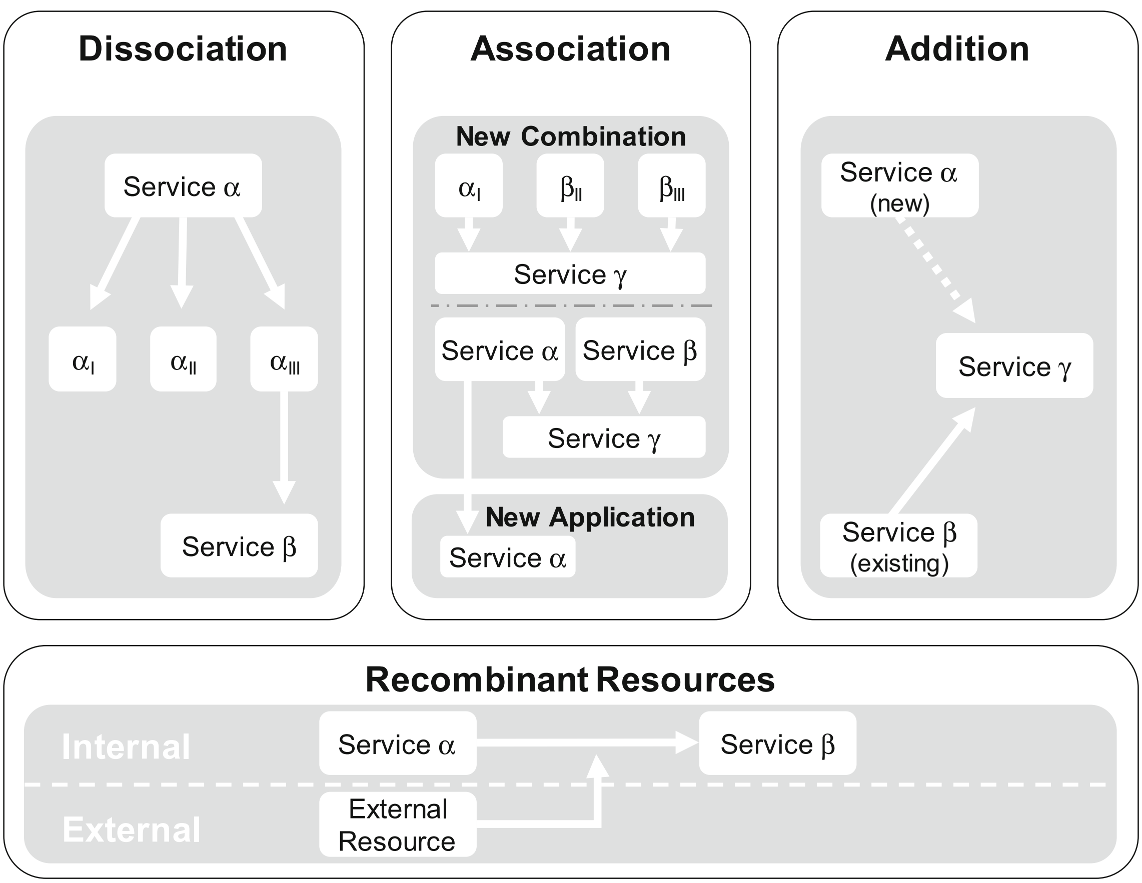

Fig. 1 The basic mechanisms of recombinant innovation

actors can overcome cognitive disparities to absorb resources efficiently.

The basic mechanisms of recombinant innovation rely on four assumptions. First, it is assumed that a resource can be broken down into clearly identified and defined elements (Gallouj and Weinstein 1997). Second, it is assumed that organizations can maintain variety, i.e. that they have the capability to access and recombine elements from different domains of unrelated or distant resources that are retrieved internally and externally (Cecere and Ozman 2014). Variety is a prerequisite for designing an innovative value proposition that is significantly different from existing ones, thereby distinguishing from incremental improvement or refinement of an existing resource (Cecere and Ozman 2014). Third, recombinant innovation presupposes a concatenated and cumulative creation of a value proposition by utilizing one or more existing resources, as opposed to radical innovation that is unconnected to any previously existing value proposition (Gadrey et al. 1995). Fourth, recombinant innovation presupposes specific competencies of the agents, development work, and creativity (Gallouj and Weinstein 1997). These four assumptions build the prerequisites for the three mechanisms of recombinant innovation, i.e. dissociation, association, and addition.

2.3 Mass Customization and Modularization of Value Propositions

Mass customization (Gilmore and Pine 1997) is a strategy for efficiently dealing with heterogeneous customer demand, based on configuring (seemingly) individualized value propositions based on pre-defined modules.

Service researchers and practitioners have built on the principles of mass customization since the co-creation of value is particularly receptive to the idiosyncratic needs and resources of service providers and service customers. Most of the approaches include a service engineering process in which an initial set of goods, services, and IT modules are designed (Böhmann et al. 2008; Becker et al. 2011b). A crucial part of the engineering process is to specify modules and configuration rules with a (semi-)-formal modeling language (Becker et al. 2009b, 2011b; Razo-Zapata and Gordijn 2009). The service engineering process is concluded with publishing a modular service architecture (Dörbecker and Böhmann 2015b) that specifies the available components independent of specific customer requests. After a customer's needs, wants, and demands (Baida 2006) have been identified, individual value propositions are built based on combining a subset of the modules defined earlier. While the resulting value proposition can benefit from standardization and economies of scale – as perceived from a provider's perspective – the resulting value proposition might be regarded as unique by customers, which enables service providers to exploit their customer's willingness-to-pay (Backhaus et al. 2010).

While mass customization resembles some features of recombinant innovation, both approaches differ conceptually. Methods for service modularization and configuration (Becker et al. 2009b, 2011b; Dörbecker and Böhmann 2015a) usually presuppose that a finite solution space can be designed at built-time, therefore constraining the solution space at runtime to a combinatorial function of the specified modules. Müller (2014) refers to this approach as the *configuration shortcut* of service systems engineering. As such, mass customization focuses on developing *value propositions*. In contrast, recombinant service systems engineering – the approach taken in this paper – focuses on *designing service systems as socio-technical systems*. It considers all available operant (e.g., people, knowledge, and skills) and operand (e.g., technology and materials) resources (Vargo and Lusch 2004; Vargo et al. 2010) and value propositions in a service system. Therefore, configuring solutions based on pre-defined modules differs from the notion of *association* in recombinant innovation, which also includes integrating distributed information systems, establishing interdisciplinary work teams, integrating business processes, designing new configuration rules, or applying resources in new contexts. Finally, mass customization approaches do not usually include *dissociation* or *addition*, since both mechanisms focus on the design of new modules, not on configuration.

Likewise, recombining resources and business services for engineering socio-technical service systems – the focus of this paper – builds on the principles of recombination that have long been discussed under the headwords of Service-Oriented Architecture (SOA) (Erl 2005), e-Service and Web Service (Cardoso et al. 2008). E-Services are operand resources that exhibit well-defined interfaces by which users and software applications can invoke functionality that is encapsulated in an application system. Therefore, regarding recombination, this paper is consistent with approaches to design new software based on reusing and recombining e-Services, including Service Composition) (Traverso and Pistore 2004), Service Choreographies, and Service Orchestration (Peltz 2003). However, our paper takes a more general view by making the principles of recombination applicable to every resource (no matter if operand or operant, digital or analog) for engineering socio-technical service systems.

3 Research Method

Our research implements a multi-method approach that includes a literature review along with a conceptual analysis of existing service engineering methods and the design of a class of methods that support recombinant service systems engineering.

We performed the literature review in line with the guidelines proposed by Webster and Watson (2002), as explained in more detail in a former version of this paper (Beverungen et al. 2017). After completing an informal screening phase, we used German and English search strings to compile service engineering methods from various electronic libraries and online databases. Forwards and backward search pinpointed additional methods that remained unidentified in the initial search (Webster and Watson 2002). The search identified 24 service engineering methods.

We used a concept matrix with eight dimensions to analyze the identified methods. The dimensions included the mechanisms of recombinant innovation and four additional concepts to distinguish different methods and research streams in service engineering. The three authors individually coded all 24 methods, leading to an initial inter-coder reliability (Krippendorff 2013) that was measured as average pairwise percent agreement ($A_0 = 0.861$), Fleiss' Kappa ($\kappa = 0.676$), average pairwise Cohen's Kappa ($\kappa = 0.676$), and Krippendorff's Alpha ($\alpha = 0.677$). Since all values exceed the critical value of $\alpha_{min} = 0.667$, concordance between the coders can be assumed. Subsequently, we conducted a workshop to discuss and remedy conflicting assessments.

Four conceptual insights emerged from the review. Since conceptual research can be used to initiate theory development and to assess and enhance theory (Yadav 2010), we used these insights as justificatory knowledge to develop four design principles that methods must implement to enable recombinant service systems engineering.

Building on the design principles, we designed a new method for recombinant service systems engineering. Designing this method was recombinant innovation itself, since we dissociated and associated the detailed processes and activities identified from the 24 reviewed methods in line with our four design principles, and added new activities. In particular, the resulting method implements the three mechanisms of recombinant innovation, considers physical goods and services as resources, focuses on a sociotechnical service systems perspective, and builds on integrating internal and external resources to co-create value in service systems. In the spirit of design science research, we demonstrate the function and utility of the method with the real case of recombining resources to engineer a service system for predictive maintenance of agricultural equipment.

4 Conceptual Analysis of Service Engineering Methods

We use a concept matrix to provide a systematic review of service engineering methods. While the matrix identifies the completeness of each method vis-à-vis theoretical concepts, any gaps and other topics are identified at the population level (Webster and Watson 2002).

Our concept matrix is built on four types of constructs (Table 2). First, we identify addition, dissociation, and association as the basic mechanisms of recombinant innovation. Since recombinant innovation is often built on integrating internal and external resources (Senyard et al. 2014), this perspective was also included. Second, we identify if a service engineering method applies to designing a value proposition – a marketable object or solution – or if it is focused on designing a service system as a socio-technical system for value co-creation. Third, the general type of process is identified as linear, iterative, or prototyping (Schneider and Scheer 2003). Linear models are characterized by discrete and consecutive process steps (Schneider and Scheer 2003). Iterative models exhibit multiple repetitions of the involved activities (Schneider and Scheer 2003). In prototyping models, a value proposition is refined through prototypes that communicate design ideas and explore the solution space, as proposed in Design Thinking (Kolko 2015). Fourth, we identify if a method explicitly refers to designing services and physical goods or if it has been designed specifically for developing services. Since both services and physical goods offer *service* – while the ownership of goods is transferred or while services make resources accessible without a transfer of ownership – it is important to include both perspectives into a service systems engineering method.

Our literature analysis of (product-)service (systems) engineering methods revealed four conceptual insights. First, few methods take a service systems perspective, but rather focus on developing a value proposition. Only ten methods explicitly consider accessing external resources, but often limit the customers' role to requirements or need elicitation. This emphasis on developing a marketable solution neglects to design the socio-technical context in which the co-creation of value in service system needs to be performed.

Second, addition, dissociation, and association are seldom included in the available service engineering methods. Twelve of the 24 analyzed approaches do not cover one of the stated operations at all, including all considered NSD approaches. Although eleven of the twelve remaining approaches include association in some respect, only four methods feature transfer, which shows the largest gap. This means that current methods strongly focus on engineering service systems anew, while disregarding existing resources – at least officially.

Table 2 Conceptual analysis of service engineering methods, in chronological order

	Addition	Dissociation	Association: new combination	Association: transfer	Accessing both internal and external resources	Model scope	Model type	Object designed
Scheuing and Johnson (1989)	–	–	–	–	x	Value proposition	Linear	Service
Shostack and Kingman-Brundage (1991)	–	–	–	–	–	Value proposition	Iterative	Service
Edvardsson and Olsson (1996)	–	–	–	–	–	Service system	Linear	Service
Ramaswamy (1996)	–	–	–	–	–	Value proposition	Linear	Service
Schwarz (1997)	–	–	–	–	–	Value proposition	Linear	Service
German Standards Institute (1998)	x	x	x	–	–	Value proposition	Linear	Service
Jaschinski (1998)	x	x	x	–	x	Service system	Iterative	Service
Johnson et al. (2000)	–	–	–	–	–	Service system	Iterative	Service
Schreiner et al. (2001)	–	–	–	–	–	Value proposition	Linear	Service
Meiren and Barth (2002)	–	–	–	–	–	Service system	Linear	Service
Morelli (2003)	–	x	x	x	–	Service system	Iterative	PSS
Schneider and Scheer (2003)	x	–	–	x	x	Value proposition	Linear	Service
Kunau et al. (2005)	x	–	x	–	x	Service system	Iterative	Service
Herrmann et al. (2006)	–	x	–	x	x	Value proposition	Linear	Service
Bullinger and Schreiner (2006)	–	–	–	–	–	Value proposition	Iterative	Service
Kersten et al. (2006)	–	x	x	–	x	Value proposition	Linear	Service
Lindahl et al. (2006)	–	–	–	–	–	Value proposition	Linear	PSS
Botta (2007)	x	x	x	–	–	Value proposition	Iterative	PSS
Tuli et al. (2007)	–	–	x	–	x	Value proposition	Linear	PSS
German Standards Institute (2008)	x	–	–	–	x	Service system	Iterative	Service
Becker et al. (2009a)	–	–	–	–	–	Value proposition	Linear	PSS
Vasantha et al. (2011)	–	–	–	–	x	Service system	Iterative	PSS
Kim et al. (2012)	x	–	x	x	–	Value proposition	Linear	PSS
Müller (2014)	x	x	x	–	x	Service system	Linear	PSS

Third, methods often do not recognize physical goods and services as equally important sources for value co-creation. Many approaches refer merely to service engineering without accounting for the design of any physical goods. However, all methods developed since 2006 (except one) include services and goods, which reveals a (laudable) trend towards including all available types of resources into the co-creation of value in service systems.

Fourth, all evaluated approaches represent sequential or iterative processes and do not feature agile or prototypical approaches, as advocated in Design Thinking and Software Engineering nowadays. As many traditional product development models are linear, it seems that some methods for service engineering implicitly replicated and perpetuated this structure.

5 A Class of Methods for Recombinant Service Systems Engineering

5.1 Design Principles for Recombinant Service Systems Engineering Methods

Based on the four conceptual insights developed in our literature review, we propose designing a new class of methods that enable recombinant service systems engineering. Subsequently, we propose four design principles that prescribe and constrain the design of these methods.

Design Principle 1 (DP1) Recombinant service systems engineering views service systems as socio-technical systems, not as marketable objects.

Our analysis reveals that many service engineering methods implicitly take a goods-dominant logic perspective, in which "services", "customer solutions", or "product-service systems" are treated as marketable objects (Vargo and Lusch 2008a, b). This perspective is in line with methods for product engineering, foremost with the VDI-Standard 2221 (VDI 2221, 1993), according to which many service engineering methods were designed. Even in Service Science, early papers defined a product-service system as "a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs" (Tukker and Tischner 2006). As a result, current "service engineering models, methods, and tools rarely focus on the development of service architectures" (Böhmann et al. 2014).

We argue that with the proliferation of information technology in all societal sub-systems, integrating fragmented resources in socio-technical service systems will be increasingly crucial to provide superior value-in-use. In line with this claim, the service-dominant logic of marketing (Vargo and Lusch 2008a, b) posits that companies cannot offer *service* per se, as they can only offer *value propositions* that are enacted through a value co-creation of service providers and service customers, creating value-in-use for the actors involved. "Service systems comprise service providers and service clients working together to coproduce value in complex value chains or networks" (Spohrer et al. 2007). Later, service systems were coined the basic abstraction in Service Science and defined as "a dynamic configuration of resources, including people, organizations, shared information (language, laws, measures, methods), and technology, all connected internally and externally to other service systems by value propositions"(Maglio et al. 2009; Spohrer et al. 2007). (Product-) service systems are socio-technical systems that enable co-creation of value by service providers and service customers (Becker et al. 2009c; Böhmann et al. 2014).

We argue that engineering service systems has to take a broader account than just specifying the value propositions offered. It should also focus on the organizational and technological context that is required to turn a *value proposition* into *value-in-use*. Organizational and technological contexts comprise assets and core competencies. Those are brought to bear on the co-creation of value by (networks of) service providers and (networks of) service customers, including people, assets, processes, information systems and data, money, and relations with other actors that participate in a service (eco-)system. Since implementation refers to building up resources internally, this view is beyond an abstract 'implementation' phase, as included in many current methods.

Design Principle 2 (DP2) Recombinant service systems engineering relies on associating, dissociating, and adding to existing internal and external resources.

Our analysis reveals that few of the reviewed service engineering methods implement the three basic mechanisms of recombinant (service) innovation. Instead, numerous methods seem to perceive service engineering as a genuinely creative process that is conducted to design new value propositions from scratch, while not explicitly reusing or integrating solutions that are available in the service (eco-)system. As opposed to this finding, Brynjolfsson and McAfee (2014) argue that in our *Second Machine Age* most innovations will be created based on recombining existing resources, such as data, information systems, and mobile apps.

In line with addition, dissociation, and association as the three basic mechanisms of recombinant innovation and the orthogonal dimension of recombining internal and external resources, we argue that service systems engineering methods should explicitly identify the properties of current service systems as well as the value-propositions that can be designed and co-created with the available resources. This relational approach (Dyer and Singh 1998) goes beyond many current service engineering methods, most of which focus on requirements elicitation and analysis. We argue that this perspective is inherently goods-dominant, since it does not put assets and core competencies of the involved stakeholders center stage. As a result, requirements analysis is often not described as a relational process, but as an activity that is performed by a service provider on behalf of a customer.

Based on the socio-technical properties of service systems, a relational view on service systems engineering would fit assets and core competencies of the involved actors together (association), further advance and detail existing assets and core competencies (dissociation), engineer new value propositions and transform the service system (addition), and apply resources outside their intended context of use (transfer).

Design Principle 3 (DP3) Recombinant service systems engineering includes both, access to external resources and transfer of ownership of physical goods.

Our analysis revealed that many methods in NSD focus on designing immaterial value-propositions, while Service Engineering often explicitly integrates physical goods and services. Service research in the latter stream has come a long way from hybrid value-creation (German Standards Institute 2009) to cyber-physical systems that view smart objects as resources in service systems.

Since we expect that many future service systems will be based on data and functionality that are provided by smart objects, we strongly argue that service systems must be designed to explicitly consider all available resources for recombination. Supporting this view, service-dominant logic (Vargo and Lusch 2008a, b) has long advocated that physical goods be distribution mechanisms for service since they stem from operant resources that stakeholders contribute to service systems. The rental-access paradigm (Lovelock and Gummesson 2004) has highlighted that the core of service (as opposed to transferring ownership of products) is temporary access to external resources.

Design Principle 4 (DP4) Recombinant service systems engineering is an agile process.

The analysis revealed that many methods conceptualize service engineering as a linear or iterative process, but seldom consider agile and prototypical approaches. Service engineering methods, in particular, prescribe many activities before a value proposition is offered to a customer. Sequential approaches seem worthwhile if complex systems are developed from scratch. However, they seem less useful if service systems are designed by recombining existing resources, such as data, information systems or other immaterial resources.

Recent innovation literature states that innovation is emergent and can even happen unintentionally or unplanned (Gremyr et al. 2014). Recently, the Design Thinking movement has argued strongly for organizing engineering as an agile process, in which each iteration ends with developing a prototype. Similar approaches have been applied in software engineering for some time, including SCRUM and other agile methods. Agile approaches are also in line with the basic tenets of Design Science research that conceptualize design as processes of building and evaluation (March and Smith 1995), complemented by processes of organizational learning, as advocated in Action Design Research (Sein et al. 2011).

5.2 A Service Systems Engineering Approach for Recombinant Innovation

In line with the four design principles, we instantiate a method for recombinant service systems engineering (Fig. 2). The method is recombinant innovation itself since we reorganized parts from the reviewed 24 methods according to the four design principles. In particular, we dissociated and associated existing processes and activities and added further activities in line with the mechanisms of recombinant innovation (see the paper's online attachment for details, available via http://link.springer.com). The resulting method considers a service system as a socio-technical system (DP1). To emphasize this system's view, the method comprises three basic sub-processes, named Service System Analysis, Service System Design, and Service System Transformation. The method provides a maximum process, providing an opportunity to leave steps out, if appropriate.

Service System Analysis is started to identify a problem or to realize an opportunity by (re-)designing a service system. An opportunity might be enabled by recombining resources in existing service systems (DP2). As suggested by several existing methods, this step comprises an analysis of the market (Morelli 2003; Scheuing and Johnson 1989) to identify the target group and understand customers' needs (Vasantha et al. 2011; Tuli et al. 2007). The needs are then prioritized by relevance for a customer (Ramaswamy 1996). In Idea Management, different ideas are identified or generated (Kersten et al. 2006; Meiren and Barth 2002) considering also a recombination of resources in existing service systems (DP2) and taking into account the access to external resources and transfer of ownership of physical goods (DP3). Subsequently, the ideas are evaluated to identify those ideas that are worth pursuing (Meiren and Barth 2002; Schreiner et al. 2001). An initial service concept is designed, comprising basic functions and attributes (Jaschinski 1998; German Standards Institute 2008). To check the feasibility of the preliminary concepts, an internal analysis is performed (Schneider and Scheer 2003; Edvardsson and Olsson 1996), including a pre-clarification with the involved departments (Jaschinski 1998). In addition, similar or related value propositions are identified (Morelli 2003). Further, an analysis of customers, competitors, and institutions is performed to evaluate the potential and viability of the idea on the market (e.g., Edvardsson and Olsson 1996; Schreiner et al. 2001; Meiren and Barth 2002; German Standards Institute 1998). In the

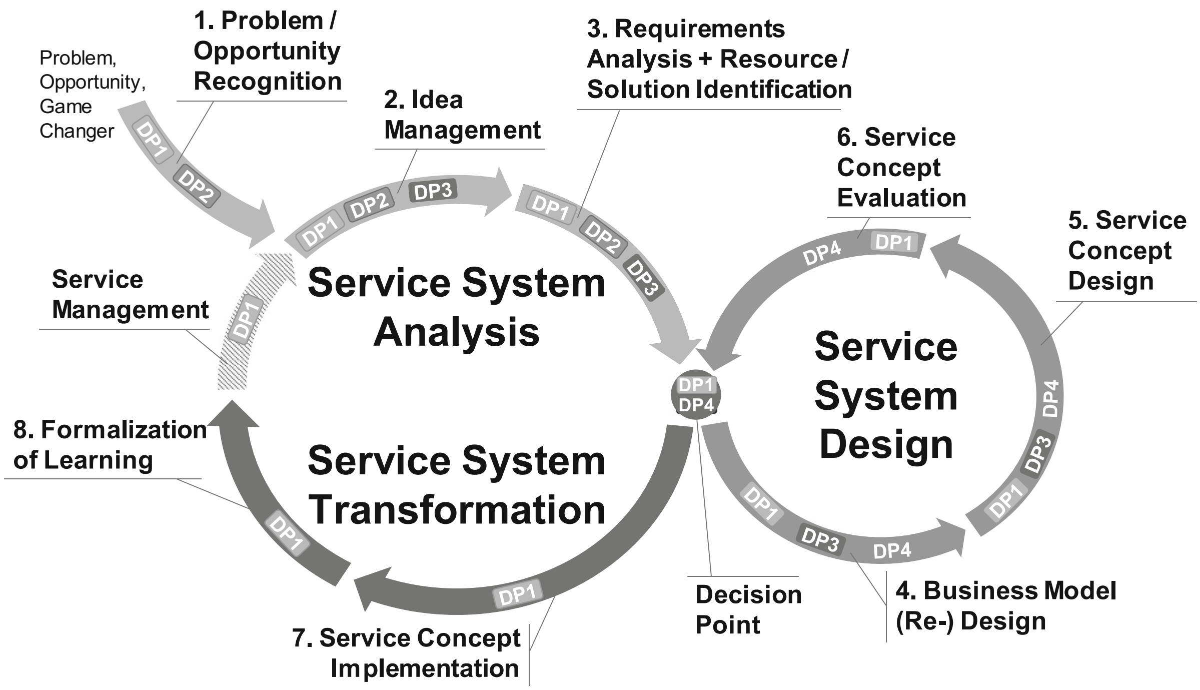

Fig. 2 A method for recombinant service systems engineering

next step, an extensive Requirements Analysis is performed, which identifies specifications of customers (Kersten et al. 2006), the market (Meiren and Barth 2002), the company (Meiren and Barth 2002; Herrmann et al. 2006), and the environment regarding legal, economic, and cultural aspects (German Standards Institute 1998). In order to extend current methods that define capabilities, functions, and tasks needed to provide the service as well as technological and environmental limitations (such as Ramaswamy 1996 and Vasantha et al. 2011), a Requirements Analysis explicitly identifies all crucial operant and operand resources in a service system, enabling the involved actors to recombine their assets and core competencies cooperatively (DP2, DP3).

Service System Design begins with Business Model (Re-) Design. This step comprises the identification of a suitable business model based on agreed resources, responsibilities, capabilities, and specifications (Vasantha et al. 2011; Müller 2014) as well as the selection of partners with appropriate skills (Kersten et al. 2006; Shostack and Kingman-Brundage 1991) and the definition of responsibilities in the service system (Edvardsson and Olsson 1996; Vasantha et al. 2011). Value-in-use should be conceptualized as based on both access to external resources and transfer of ownership of physical goods (DP3). In addition, risks (Kunau et al. 2005; Edvardsson and Olsson 1996), costs, and functional performance are evaluated (Vasantha et al. 2011 and Müller 2014). Starting from the second cycle of Service System Design, the prototype of previous cycles is evaluated to improve the business model and the service concept (DP4). Service Concept Design starts with a segmentation of resources into smaller elements (Edvardsson and Olsson 1996; Kersten et al. 2006) and tasks (Shostack and Kingman-Brundage 1991). This step includes planning interfaces of business processes, infrastructure, process organization (Jaschinski 1998), and (if applicable) the design of physical goods (DP3) (Müller 2014). Further, we include the generation and evaluation of design alternatives for the whole service and each resource (Ramaswamy 1996). Concepts for marketing (Meiren and Barth 2002), sales (Jaschinski 1998), distribution, and pricing are defined (Schneider and Scheer 2003). Subsequently, a detailed design consisting of technical realization (Jaschinski 1998) and implementation of resources, processes, products, and marketing is conducted (Meiren and Barth 2002). In Service Concept Evaluation, a pilot and testing plan is developed (Ramaswamy 1996; Jaschinski 1998; Müller 2014; Meiren and Barth 2002) to test the designed service for performance, continuity, and salability (Morelli 2003; Scheuing and Johnson 1989) based on prototypes until the final design is determined (Müller 2014). These activities are organized in cycles, in line with the Design Science paradigm that conceptualizes design as “to build” and “to evaluate” (March and Smith 1995). Additionally, each cycle of Service System Design results in a viable prototype that is used for communication and decision making at the decision point (DP4).

Service System Transformation comprises planning the introduction of a service as mentioned in Jaschinski (1998) and implementing the final Service System Concept to integrate further resources and learn additional core competencies that are required to co-create the intended value-in-use. Therefore, the service system is transformed as a socio-technical system, beyond designing value propositions. In this sub-process, a Formalization of Learning takes place by documenting and monitoring the service systems engineering process (Shostack and Kingman-Brundage 1991; Herrmann et al. 2006). Feedback loops (German Standards Institute 2008) enable a transfer of knowledge for continuous improvement (Ramaswamy 1996; Shostack and Kingman-Brundage 1991).

A Decision Point connects all three sub-processes. After the Requirements Analysis is completed, service systems engineers can decide to either recombine existing resources (transfer, association) and commence with Service Concept Implementation, or to continue with Service Concept Design (addition, dissociation). At the same time, the decision point marks the point to leave a design cycle and proceed with Service System Transformation (DP4).

5.3 Demonstration of the Proposed Service Systems Engineering Method

We demonstrate the application of our method for recombinant service systems engineering with a real predictive maintenance service system for agriculture machines (i.e., tractors). In this scenario, we cooperated with a large agriculture company.

We started Service System Analysis by identifying problems related to resource shortages during harvesting seasons, including unavailable service technicians and out-of-stock events for spare parts. These shortages caused severe delays in maintenance processes, resulting in harvesting losses for farmers and extra costs for overtime of service employees and express deliveries of spare parts. Therefore, we identified farmers and agricultural contractors as target groups for a new predictive maintenance service. Predictive maintenance is based on analyzing machine data to evaluate its condition with the target of minimizing unscheduled breakdowns and maximizing intervals between repairs at the same time (Mobley 2002). Since the agriculture company provides farmers with all goods (e.g., seeds, fertilizers, equipment) and services (e.g., consulting on growing and harvesting crops), integrating disparate data from their eight main enterprise systems (e.g., Enterprise Resource Planning, Customer Relationship Management, Product Data Management) seemed a unique opportunity to establish a recombinant data-driven predictive maintenance service.

We conducted an Idea Management workshop to identify, categorize, and prioritize ideas for predictive maintenance services. The identified ideas covered different scopes for the new service, starting from providing information on expected machine failures to the customers via a (mobile) dashboard, to including costs for maintenance and repairs (maintenance contract), to extending contracts with harvesting losses, or to leasing fully maintained machines. We decided to design a new predictive maintenance service that would prevent agricultural machines from failure in harvesting seasons, building on predictive maintenance as applied in the manufacturing industries (Groba et al. 2007). The company's IT-department and a service station reviewed and approved the preliminary service concept.

In Requirements Analysis and Resource/Solution Identification, we started with collecting requirements and then considered existing internal and external resources. We first conducted an online survey to elicit the needs of the target groups and to identify requirements towards a predictive maintenance service. We also conducted a SWOT analysis that covered market, environmental, and legal requirements. Second, we detailed our service ideas and reviewed the literature on predictive maintenance to identify the required capabilities, functions, tasks, and limitations. Third, we analyzed the current service system of machinery servicing, and we modeled all processes, tasks, organizational units, and information systems. We applied dissociation to identify available internal resources and its elements from the current service system, other service systems, and used information systems. In the current service system of machinery servicing, we analyzed processes in detail and identified the relevant resources for the predictive maintenance service system (covering mainly data from the company's ERP system). From other internal service systems, we identified customer-related data such as geolocation data of machines from a field mapping service, which we considered as relevant resources for the design of the new service system. Since our objective was the design of a data-driven service, we analyzed all available information systems in the company thoroughly to identify additional digital resources. Fourth, since field work depends on environmental circumstances, especially during harvesting seasons, we included open data (e.g., weather data and geological information) as external resources into the new service system. By combining all identified and relevant resources from the current service system, the field mapping service, and the external resources for the predictive maintenance service system, we applied dissociation and association as two basic mechanisms of recombinant innovation. In a final step, we identified two possible solutions for the resulting predictive maintenance service. On the one hand, the predictive maintenance service might be offered independently to

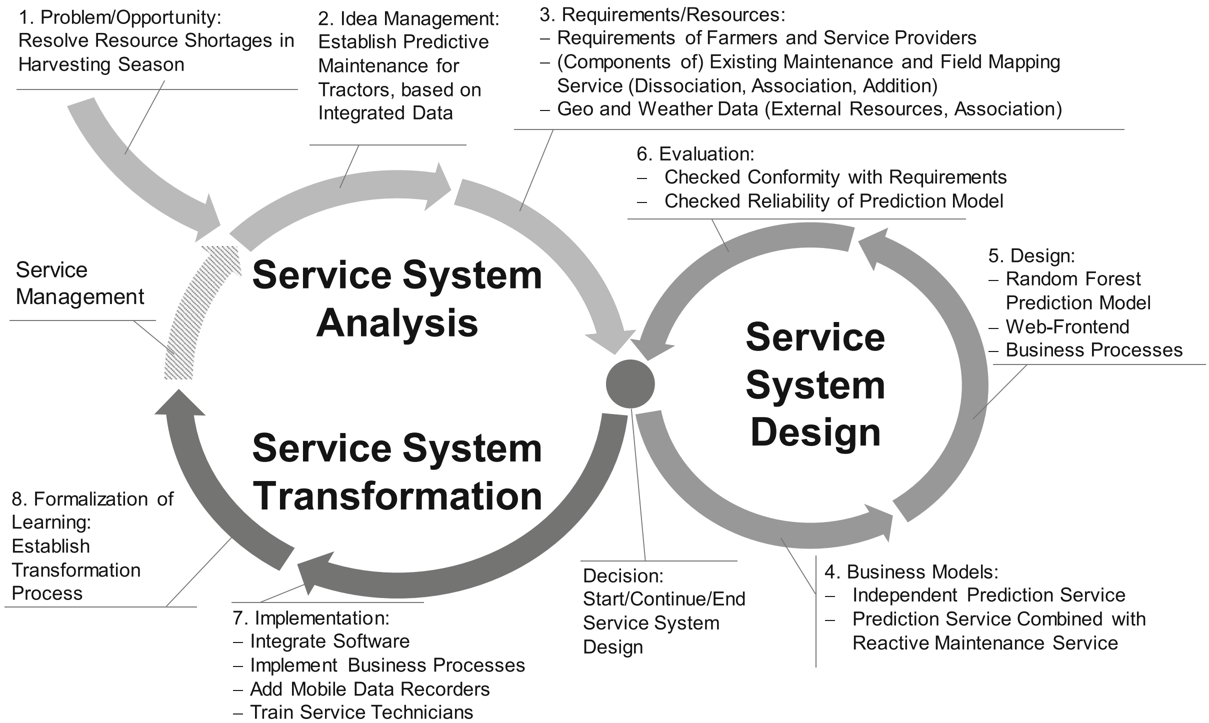

Fig. 3 Demonstration of the method for recombinant service systems engineering

attract new customers. On the other hand, a holistic solution can be designed, which combines the current (reactive) maintenance service and the predictive maintenance service by applying addition as a basic mechanism of recombinant innovation. Therefore, we considered all three mechanisms of recombinant innovation in the Service System Analysis (Fig. 3). Reaching the Decision Point, we presented the preliminary service concept to the company, which decided to proceed with Service System Design.

Service System Design is an agile cyclic process that results in a prototype at the end of each cycle. In Business Model Design, we detailed the preliminary service concept with the Business Model Canvas (Osterwalder and Pigneur 2010), considering amongst others costs and revenues, activities, resources, value propositions, and channels.

In Service Concept Design, we designed integrated business processes and information systems for the new service system. Information systems mainly comprised two IT artifacts. First, we designed and implemented a data-driven prediction model that predicts maintenance events based on a machine's master data, usage data, position data, and context data. For this, we implemented a Random Forest approach for two-class classification problems using the open source software tool KNIME (Breiman 1984; KNIME.com AG 2017). Second, we designed and implemented a web interface for a maintenance management system, which farmers and service technicians can use to display the status and maintenance events of their machines. This interface was implemented in the open-source framework.NET Core (Microsoft Corporation 2017b) and developed based on the ASP.NET MVC Pattern (Microsoft Corporation 2017a). In order to build on the new technology, we designed new business processes for the predictive maintenance of the tractors. A comparison with the old business processes showed that three out of five sub-processes were automated by 95%, while the two remaining sub-processes (Handover Machine, Maintain Machine) remain mostly executed manually in the new service and become augmented with additional data.

As Service Concept Evaluation, we evaluated the business process and information systems with the requirements identified in Service System Analysis. Additionally, the reliability of the data driven prediction model was assessed by calculating a confusion matrix and analyzing a receiver operating characteristics (ROC) graph, which are both common measures in the machine learning community (Fawcett 2006).

At the decision point after completing the first Service System Design cycle, the service concept and the implemented software were presented to the management of the company. A decision was made to continue with an additional design cycle for detailing the concepts for marketing, sales, and pricing and enhancing the implemented IT artifacts.

Since the design of the service system is not yet finished today, the third sub-process – Service System

Transformation – was not reached yet. Before starting the transformation, the new value proposition will be tested and piloted with selected customers. The transformation will include – amongst others – integrating the software with the company's ERP system, embedding the new business processes for predictive maintenance into the organization, supplying the tractors with mobile data recorders, and train service technicians. After the transformation, the innovation process will be concluded with Formalization of Learning.

6 Conclusion

Our paper offers three contributions to research and practice. First, we provide an up-to-date review on available methods for service engineering. We show that the identified methods differ conceptually since they originated from different sub-disciplines involved in Service Science. Second, in a conceptual review we identify shortcomings of these methods with respect to (1) applying a socio-technical service systems perspective, (2) taking into account the mechanisms of recombinant innovation that constitute innovation in the Second Machine Age (Brynjolfsson and McAfee 2014), (3) considering both transfer of ownership and access to external resources as sources of value co-creation, and (4) implementing service engineering as an agile process. Third, we conceptualize, instantiate, and demonstrate a new class of methods that enable recombinant service systems engineering.

Limitations of our literature review and analysis refer to the lack of generalizability that is inherent to conceptual and qualitative research. While we took precautions to objectify the coding process and attain inter-coder reliability, we cannot exclude that other researchers might come to different assessments of the reviewed service engineering methods.

The application scenario of designing a predictive maintenance service for agricultural machines convinced us that recombinant service systems engineering is useful and applicable; however, the proposed method needs to be subjected to more extensive evaluation. Beyond the focus of this paper, longitudinal studies need to provide rich qualitative accounts on multiple cycles of service system design and service system transformation. To stimulate these studies, we present design principles that other researchers can use to instantiate their own methods for recombinant service systems engineering and evaluate them in naturalistic settings. In particular, we are eager to see further examples of how other researchers use and concatenate the three basic mechanisms of recombinant innovation to implement service innovations. Second, naturalistic evaluations could also shed light on how intensively or loosely product engineering and service systems engineering methods can be intertwined. While a close integration seems favorable to design service systems consistently, loose coupling could keep the design of service systems more agile, by decoupling them from more inflexible product development processes. Third, subsequent research could investigate how efficiently organizations can conduct the proposed approach, therefore highlighting its applicability and utility compared to non-recombinant approaches.

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