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Complexity in Product-Service Systems: Review and Framework

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Abstract

This study systematically reviews the existing research literature on product-service-systems (PSSs) to analyze the nature and characteristics of complexity in the PSS context. While mastering the PSS strategy can become a competitive advantage for manufacturing companies, moving to providing advanced services through PSSs increases the complexity of the offering and its implementation. How the manufacturing company can manage this complexity plays a critical role for the success of its PSS strategy. Although research in PSS strategies has grown significantly in recent years, and the existing literature recognizes that complexity is a common feature in PSS, the nature and content of complexity experienced by manufacturing companies remains largely unexplored. Based on a systematic literature review approach, this study develops a conceptual framework of complexity in PSSs. Following systematic search and screening procedure, 23 articles addressing complexity in the PSS context are identified and form the sample of the review. Using content analysis methods, four dimensions of complexity in PSS are identified in the articles: multiplicity, diversity, interdependence, and variability. The four dimensions are explained and elaborated. The review demonstrates that a major research gap exists in the field, and thus suggest several research avenues for further studies.

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Keywords: product-service systems; PSS; complexity; manufacturer; PSS implementation; service components; industrial services; servitization

1. Introduction

As a response to changing expectations from customers, tightening competition, and environmental pressures, an increasing number of manufacturers of complex system products are moving forward from a product-centric business orientation into product-service systems (PSSs) based business approach [1, 2]. PSS is a system including products, services, networks of actors and supporting infrastructure [3, 4]. PSSs are typically set up for extended contracting periods, enabling customers to outsource business functions including the technical infrastructure needed to run the operations.

Prior studies have pointed out that PSSs could reduce the consumption by closing material cycles [5]; increase overall resource productivity [5, 6]; decrease the creation of waste and the consumption of raw materials [7]; and extend the life-cycles of products [4, 8]. Therefore, successful PSS strategies can fulfill diversified customer demands and enhance resource efficiency, which eventually help manufactures to achieve revenue growth and environmental sustainability [3, 9]. Despite the potential benefits, manufacturers attached to PSS inevitably face complexities that make it difficult to design and implement successful service strategies [2]. Existing research agrees that complexity is a common feature in PSS organizations [10]. The literature recognizes complexity as a factor that influences both the rewards and the challenges associated with the adoption of a PSS strategy [10, 11]. However, the extant literature rarely defines complexity in the context of PSSs. In addition, what forms and characteristics complexity has, and how these could be classified, are not clear.

Defining and understanding complexity has received attention from researchers in a broad range of disciplines. Although the concept of complexity may refer to different things in different contexts, it has been studied by searching for common properties among diverse kinds of systems [12].

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PSS is an interdisciplinary research area, and conceptualizations of complexity and focus vary between academic disciplines. In social science, complexity has been defined as a large number of elements and the relationships between these elements [12, 13]. It has been found to cover three main aspects - hierarchy, relation and dynamics [12]. In the research context of PSS, some researchers have identified that complexity increases due to value being co-created jointly with the customer [14], and some have recognized that a higher number of stakeholders, also characterized by higher heterogeneity, involved in the process increase complexity in PSS [2, 15]. Others have found that unclear customer demands add complexity in the implementation of PSS, since when customer demands change in the lifecycle, service process and recourses need to be re-arranged to cope with these changes [16, 17]. All these descriptions tend to focus on specific aspects of complexity. However, very little research defines and summarizes what forms and characteristics complexity has in PSS, and how these could be classified. The emergence of complexity in PSS may be attributed to a large number of factors that constitute different dimensions of complexity. Better understanding of the characteristics of complexity facilitates manufacturing firms to manage complexity and to adopt PSS successfully. Yet, the literature that explicitly addresses complexity in PSS remains scant and its constitutive characteristics are not widely explored.

To address this research gap, this paper identifies the dimensions characterizing complexity in PSS. Using systematic literature review and thematic content analysis, the study develops a classification framework for complexity in PSS.

2. Methodology

2.1 Selection of research articles for review

The study adopts the systematic literature review methodology, which utilizes systematic search protocols to ensure breadth in coverage and prevent bias in selection of the literature included in the analysis, and then follows documented screening and analysis protocols to enable transparency and replicability of the study. Due to its coverage, Scopus was chosen as the database for the literature search [18]: in August 2017 the database had 1.4 billion references from 5000+ publishers 1970, with about 5500 new items added daily.

The search targeted articles and review papers on PSS and complexity (in English). Since using full text search produced results low in relevance, the following search was limited to *titles*, *abstracts* and *keywords* : "product service system*" OR “integrated service product offering” OR “functional product*” OR “serviti*” OR “integrated solution*” AND “manufact*” AND “complex*”. Because the inductive, theory-building research strategy requires a focused set of literature, only PSS articles that explicitly address complexity were included.

This search identified 94 articles. The abstracts were read to ensure the presence of the search terms, and that the academic discipline was relevant. For instance, the search term “integrated solution*” was also used in chemistry without a link to PSS. 35 articles passed this screening. Full-text was screened next, and 18 articles remained. During the thematic analysis, further five articles indicated by the studied core articles were added to the final data set, resulting in a total of 23 articles.

2.2 Content analysis of the articles

First, a review of the basic characteristics of the selected articles was performed, collecting descriptive information such as year of publication, journal, and the research methods used. This analysis results are provided in the following section.

Due to the search strings and criteria used for selecting articles, each article explicitly expresses manifestations of complexity in PSS. This content was reviewed and thematically analyzed in depth to develop a clearly defined and conceptualized construct of complexity in PSS.

3. Literature review findings

The 23 articles represent a wide range of journals, with quality ranging from level 1 to level 4 using in the CABS ranking system (Chartered Association of Business Schools, UK). Four journals are technical and not ranked in CABS. The studies are scattered in 16 different journals, indicating no clustering in a particular outlet or sub-discipline (cf. Table 1).

The publication year ranges from 2006 to 2017, with publications increasing from 2015 onwards, as the topic has received increasing attention from researchers recently. 20 articles were based on case study approaches, two articles on qualitative approaches, and one study was conceptual. The absence of hypothetic-deductive survey studies, in addition to the obvious low total number of articles identified, perhaps signals the immaturity of the research area.

Table 1. Journals in which the articles were published

Journal of publication (Subj. area)	CABS 2015	No. of articles
CIRP Annals - Manufacturing Technology	-	3
Industrial Marketing Management (MKT)	3	2
International Journal of Operations and Production Management (OPS&TECH)	4	2
International Journal of Operations and Production Research	-	2
Journal of Manufacturing Technology Management (OPS&TECH)	1	2
Journal of Cleaner Production	-	2
Human Resource Management Journal (HRM&EMP)	4	1
International Journal of Advanced Manufacturing Technology	-	1
Journal of Business Research (ETHICS-SCR-MAN)	3	1
European Management Journal (ETHICS-SCR-MAN)	2	1
Journal of Decision Systems (INFO)	1	1
Production Planning and Control (OPS&TECH)	3	1
Journal of Relationship Marketing (MKT)	1	1
Service Industries Journal (SECTOR)	2	1
Requirements Engineering (INFO)	2	1
Sustainability (Switzerland)	-	1

Table 2 connects the observations to the dimensions that resulted from the thematic content analysis investigating

manifestations of complexity. The four conceptually distinct main dimensions of complexity in PSS are explored next: *multiplicity*, *interdependence*, *diversity* and *variability*.

3.1 Multiplicity

Multiplicity refers to the *growing number* of involved units, sub-systems, activities and actors. The PSSs provider must be able to orchestrate these into a reliably working socio-technical system. In manufacturing firms, PSS implementation typically raises the number of service components, stakeholders and interactions included in the PSSs provision process [16, 19, 20]. Multiple stakeholders are involved in the different stages of the PSSs provision process; the focal company, its suppliers, and other organizations or individuals, end users that affect the adoption of PSS [21]. This manifestation contributes to complexity in the implementation of PSS. Stakeholders may have their own value perspectives, expectations and priorities, challenging the alignment of the value propositions and performing consistently in the provision of PSS [22].

Combining services to support the tangibles increases the number of service components provided by the PSS firm. Service components consist of mixed resources, including human resources (service specialists, technicians, support staff), information (service content, product use history) and service tools (hard and soft tools, technologies supporting the delivery of services) [16]. These required components add to complexity in PSS adoption.

PSS manufacturers also manage numerous interactions between service components and involved parties for PSS requirement identification, design and delivery [2]. For most services, interactions are a prerequisite. Interactions between individuals within the provider firm and between involved parties facilitate information transfer, enable coordination and reduce conflicts in the alignment of value propositions [17, 23]. However, the increasing numbers of involved parties and their high degree of differentiation adds to complexity of interactions, certainly contributing to complexity in PSSs.

Based on the above illustration, multiplicity is defined as a dimension of complexity in PSSs. This definition is consistent with systems theory that considers systems to consist of a certain number of elements and their interrelationships [13]. This conceptualization is strongly grounded, 13 articles, out of 23, associate multiplicity with complexity in PSSs. *Multiplicity refers to the number of stakeholders, service components and interactions involved in the process of PSS adoption.* Therefore, the more stakeholders, service components and interactions in the process, the more complexity the manufacturing firm faces in the implementation of the PSS.

3.2 Diversity

Diversity refers to the *growing variety* of units, sub-systems, activities and actors involved. The general aim of PSS adoption is to fulfill diversified customer needs and wants by the means of creating a customized offering [2, 16]. A broad variety of customer requirements implies increasing diversity to be addressed by the PSS offering, involving differing stakeholders, service components and interactions in the service process [10, 24]. Heterogeneous stakeholders have different attitudes and preferences towards collaboration and therefore their behavior varies. This increases the challenge of predicting and controlling their performance in the service process [15]. The multitude of contexts that different stakeholders bring imply that providers must be flexible to resolve the large number of different demands and obtain the desired outcomes [17]. All these increase complexity in PSSs.

As mentioned, service components involve human resources, information and service tools. Therefore, the diversity of service components is reflected in the qualifications needed, information transferred and service tools implemented [15]. For instance, a manufacturer designing an advanced integrated offering receives information from market researchers, marketing specialists, customers and end users. All the information must be exchanged among the stakeholders to set up the phases for PSS implementation [25]. All this adds complexity to designing and managing the PSS process.

A challenge in PSS adoption noted by researchers and practitioners is the different expectations and understandings of heterogeneous stakeholders with regard to customer requirements [26]. Customers may articulate their requirements and needs ambiguously, increasing the manufacturers' difficulty of translating customer requirements into design requirements with definite specifications [27], and diversified interactions between different parties to design a solution are needed. Yet, heterogeneous actors have different preferences and attitudes towards cooperation in the service process. The outcome of interactions becomes unpredictable, increasing complexity in managing the service provision process [15, 28].

Also in line with systems theory, diversity represents the second dimension of complexity in PSSs. According to systems theory, elements and their interrelationships in a system differentiate in kind, design and intensity [24]. In the data set, 19 articles describe diversity. *Diversity is defined as heterogeneity of elements in a PSS, consisting of different stakeholders, service components and interactions involved in the service process.* In other words, the more variety of stakeholders, service components and interactions in the PSS process, the higher its level of complexity.

3.3. Interdependence

Interdependence refers to the interrelationships between units, sub-systems and actors involved in PSSs. Value of PSS offerings is realized during the use phase [29], which requires closer relationships among the stakeholders. Relationships allow parties to access the resources of each other and set grounds to managing the information and materials flows in the supply chain [22]. Thus, relationships among the involved parties are essential in determining the benefits of integration [1]. Strong relationships imply higher interdependence, facilitating mutual understanding and the designing of PSS.

When manufacturers develop new services, the interdependence between the involved stakeholders emerges [30]. In the PSS provision process, interdependence can be found in all relationships [24]. Because heterogeneity of the service components adds to the complexity of value proposition [2], manufacturers establishing strong relationships with customers can better understand their needs and align their

Table 2 Outcomes of literature review on PSS complexity

Literature	Manifestations of complexity identified in the literature source	Dimensions of complexity associated with the observations
Brax & Visintin 2017 [19]	Involvement of multiple suppliers; amount of different stages in the process; amount of steps in a process; variety of service offering; involvement of different parties in each value stage.	Multiplicity; diversity
Huo & Neely 2017 [21]	Involvement of multiple stakeholders; diversified and unclear customer needs; variability of customer needs and environment.	Multiplicity; diversity; variability
Rondini et al. 2017 [15]	Uncertainty about customer's behavior; high level of interaction between customer and company; diverse resources' skills and qualification; operation of provider's resources at customer's premises.	Diversity; interdependence; variability
Sakao et al. 2017 [16]	Variety of customer needs and wants; dynamics of customer requirements; amount of service components.	Multiplicity; diversity
Song & Sakao 2017 [2]	High level of customization; amount of interactions between components in PSS; high interdependencies; multiple configuration objectives; customer requirements change in product use phase.	Multiplicity; diversity; interdependence; variability
Braun & Hadwich 2016 [24]	Multiple internal service components, internal suppliers, and interactions; variety of different service components and suppliers; the interrelationship between service elements and involved internal parties; changes occurring in service elements and internal relationships.	Multiplicity; diversity; interdependence; variability
Dahmani et al. 2016 [31]	Dynamics of decision-making process; difficulty of evaluating the relevance of the outputs from the decision processes.	Variability
Eloranta & Turunen 2016 [20]	Networks of relationships; difficulty of managing inter-firm configurations; dynamics of environment; multiplicity and variety of suppliers;	Multiplicity; diversity; interdependence; variability
Alfian et al. 2015 [28]	Lack of prediction; difficulty of evaluation.	Diversity; variability
Chalal et al. 2015 [30]	Involvement of multiple actors, stakeholders and interactions; distinct steps and processes; management of customer-provider relationships.	Multiplicity; diversity; interdependence
Kreye et al. 2015 [1]	High numbers of components, process steps and interactions; interrelationships within the service provision.	Multiplicity; interdependence
Widera & Seliger 2015 [32]	Size; diversity; dynamics; uncertainty	Diversity; variability
Berkovich et al. 2014 [26]	Different expectations and understanding of stakeholders regarding product requirements.	Diversity
Smith et al. 2014 [23]	High numbers of service components; variety of knowledge and skills required, as well as contextual use; closer collaboration between suppliers and customers.	Multiplicity; diversity; interdependence
Mills et al. 2013 [33]	High involvement of multiple individual stakeholders; diversity of involved parties; high interdependencies; complication of service tasks; high coordination of front and back offices.	Multiplicity; diversity; interdependence
Nordin et al. 2013 [34]	Number of parts; degree of interaction; level of variety; degree of order.	Multiplicity; diversity; interdependence; variability
Angelis et al. 2012 [17]	Variety of customer demands; high degree of flexibility and interactions; involvement of multiple stakeholders; multitude of different contexts that parties bring.	Multiplicity; diversity;
Geng et al. 2012 [27]	Difficulty of translating different customer requirements into design requirements and module characteristics with definite specifications; dynamicity of updating technology;	Diversity; variability
Lockett et al. 2011 [22]	Involvement of many organizational functions and actors in the process; high degree of risk transfer; networks of relationships; alignment of diversified stakeholders' incentives; changes occurring in the network relationships.	Multiplicity; diversity; variability
Meier et al. 2010 [35]	Unpredictability; risks and uncertainties involved in the process.	Variability
Raja et al. 2010 [36]	Dynamics of service offering; relationships between equipment, service and the context of the equipment use; heterogeneous customer needs.	Diversity; variability; interdependence
Johnstone et al. 2008 [37]	Management of customer relationships; development of service culture; complication of the organizational structures and priorities; cooperation and coordination within organizational structures; diversity of technologies, products and client demands; dynamics of environment.	Diversity; variability; interdependence
Krucken & Meroni 2006 [25]	Networks of relationships; different levels of interactions and information exchange.	Diversity; interdependence

PSS value propositions. However, strong relationships between different elements in a system add complexity in PSSs [13, 34]. Thus, addressed by 13 out of the 23 articles, interdependence emerges as the third dimension of complexity in PSSs. From systems theoretical the point of view, the influence of the systems' elements in each other over time generates complexity [24, 38]. Interdependence arises from interrelationships between different service *components, and*

between different stakeholders during the PSS implementation. The literature reviewed emphasizes the socio-technical aspects over purely technical kind of interdependence. Thus, the higher the interdependence perceived between components and stakeholders, the more complexity present in the PSS.

3.4. Variability

Variability here refers to the changes of involved units, sub-systems, activities and actors during the lifecycle of the PSS. Generally, customer demands change during the lifecycle of the PSS because the dynamics in the business environment change [2, 20]. To respond effectively, manufacturing firms modify their PSS offerings, which reflected in the service processes [24, 34]. When a customer demands change in the product use phase, service components are re-arranged, or even the whole PSS process might need to be redesigned, and in both cases the changes are reflected on the stakeholders [2].

The changes in customer requirements introduce changes in stakeholders involved in a PSS, including their demands, priorities, and incentives of alignment. These imply higher uncertainly about how they act in the PSS provision process. Moreover, the changes also influence service components, resulting in the changes of required employee skills, qualifications, and resources. This further indicates difficulties in addressing the changes. Also, the changes in stakeholders and service components come with changes in interactions and relationships. As a result, the growing number of changes in stakeholders, service components, interactions and relationships increases complexity in the PSS adoption.

Therefore, variability is the fourth dimension that characterizes complexity in PSSs. This aligns with the idea in systems theory that exchange processes in systems change over time [24, 38]. While 15 articles in the data set mention changing customer requirements as driving changes in PSS organizations, only 2 articles explicitly address complexity emerging from variability in PSS organizations. Although the research on complexity considers change as an attribute of complexity [24], variability as a term is not widely used. Here, *variability is defined as the number of changes in stakeholders, service components and/or interrelationships during the lifecycle of the PSS*. The more changes occurring in stakeholders, service components, interactions and relationships, the higher is the complexity in the PSS process for the manufacturers.

4. Discussion and conclusions

This study theorizes on the dimensions and constitutive characteristics of complexity in PSSs. Despite the increasing interest and a shared implicit view on the growth of complexity introduced by PSS, the literature explicitly addressing complexity in the context of PSS remains scant. This study identified the 23 research articles that have explicitly addressed complexity and its characteristics in the PSS context so far and systematically analyzed how complexity is manifested in the existing body of research literature. The analysis identifies four conceptually separate dimensions of complexity in PSSs, which are consistent with basic tenets of systems theory [38].

The conceptualization of complexity through the four dimensions – multiplicity, diversity, interdependence and variability – provides a basis for manufacturing companies to understand the detailed complexities and to analyze the main sources of complexity in their particular PSS context. This should help manufacturers to design effective ways to address complexities pertaining to PSSs. A potential threat for the successful implementation of the PSS strategy is that manufacturing organizations could become unnecessarily complex when shifting from product-based organizations to providing PSSs [30].

The theorizing points towards several pragmatic considerations for manufacturers adopting PSS strategies. As discussed, relationships can have both increasing and decreasing influence on complexity, and need careful consideration. The complexity in PSSs could be reflected on organizational cultures, since prior studies have found that organizational structures and cultures need to be changed during PSS adoption [37, 39]. Efficient information and communication systems should be designed to reduce complexity through connecting service components as well as different stakeholders of the PSS organization effectively, eventually facilitating the exchange of knowledge and experience. This would support better alignment of the value propositions and improve coordination between stakeholders. Service content and information could also be better shared with individuals and organizations. Manufacturers should invest in service employees and tools when organizations adopt a PSS strategy, because this could help to manage complexity and support the delivery of services. Furthermore, because complexity increases costs, it should be present where it adds value or is unavoidable. Knowing the sources of complexity allows providers to consider ways to reduce unnecessary complexity in their PSS offerings.

The study has two limitations that also point toward future research needs. First, this study only focuses on the PSS research that explicitly addresses complexity. While this focused approach is useful for the current theory building mode, it is not comprehensive in the coverage of PSS literature, abundant with studies that implicitly address dimensions complexity. On the other hand, while more dimensions of complexity might exist, all four identified dimensions are well grounded and exhaustively accommodate all observations of complexity in the set of studied articles and that present a comprehensive portfolio of diverse PSS contexts, as 20 articles are based on case studies and 2 are qualitative surveys. Second, the study does not consider the way that other research fields beyond PSSs characterize complexity or its dimensions.

The current findings and limitations open up several new avenues in researching complexity in PSSs. Future studies could investigate how different disciplines and research areas define complexity. The larger body of PSS literature that implicitly addresses complexity should be analyzed. Also, based on the results, the extant studies on PSS complexity remain highly fragmented both thematically and across the publication outlets and academic sub-disciplines. These observations suggest a promising field for researchers to explore further. As the research on the subject matures, studies should look at strategies by which firms may manage

complexity and reduce its costs. The results show that researchers are most familiar with the dimension of diversity, since 19 out of 23 articles consider diversity-related manifestations as attributes of complexity. However, only 2 articles explicitly conceptualize variability as the feature of complexity in PSSs, which points to an underexplored theme. Finally, this study provides a conceptual foundation for further research to develop the operationalization of complexity in PSS research, since existing research lacks a reliable and valid instrument to measure complexity in empirical PSS studies. The four dimensions identified in this study provides a basis to develop the scales to operationalize complexity in further research of PSSs.

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