INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED23
24-28 JULY 2023, BORDEAUX, FRANCE

REQUIREMENTS FOR A SMART PRODUCT-SERVICE SYSTEM DEVELOPMENT FRAMEWORK

Paliyenko, Yevgeni (1);
Heinz, Daniel (2);
Schiller, Christian (3);
Tüzün, Gregory-Jamie (1);
Roth, Daniel (1);
Kreimeyer, Matthias (1)

1: University of Stuttgart;
2: Karlsruhe Institute of Technology;
3: Fraunhofer Institute of Indsutrial Engineering

ABSTRACT

Nowadays, companies operate in increasingly competitive and dynamic markets with fast-changing customer needs. Simultaneously, major advances are being made in information and communication technologies, and the digitization of products is progressing. Based on these economic and technological trends, smart product-service systems (PSS) are emerging as a new form of business model. Recent studies show that the transition to developing smart PSS is a major challenge for companies and that they require methodological support, as their internal structures are undergoing significant changes.

In order to provide a sound basis for support, we have undertaken a comprehensive study to identify requirements for a smart PSS development framework. 24 interviews and 5 workshops with companies that have recently focused on the development of smart PSS provide a rich set of empirical data to explore the challenges faced by companies today. We systematically analyzed the data and evaluated the results with our respondents. To increase the robustness and generalizability of our findings, we performed a contextual literature review and analyzed additional cases. This led us to a set of 17 requirements for a smart PSS development framework.

Keywords: Product-Service Systems (PSS), Systems Engineering (SE), Requirements, Development Framework, Design Methods

Contact:
Paliyenko, Yevgeni
University of Stuttgart
Germany
Yevgeni.paliyenko@iktd.uni-stuttgart.de

Cite this article: Paliyenko, Y., Heinz, D., Schiller, C., Tüzün, G.-J., Roth, D., Kreimeyer, M. (2023) 'Requirements for a Smart Product-Service System Development Framework', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.309

1 INTRODUCTION

Today's companies are operating in ever more competitive markets. Due to fast-changing customer needs and increasing market dynamics, companies are struggling to differentiate themselves from their competitors (Verhoef et al., 2021). To counteract this trend, manufacturers have been integrating additional services into their portfolios for some time to enhance their value proposition (Lee and Kao, 2014). In this way, companies are transforming their product-oriented business models into system-oriented ones (Chowdhury et al., 2018; Rizvi and Chew, 2018). Besides increasing their competitiveness, companies are primarily concerned with increasing customer satisfaction and generating new opportunities for value creation. Recent studies show the growing efforts of small and medium-sized enterprises (SMEs) to manage the shift toward more service- and system-oriented product development (Schiller et al., 2022). The resulting product-service systems (PSS) can offer considerably higher value to customers and providers alike, especially when they interact as a system (Meier and Uhlmann, 2012; Spath et al., 2012). For example, customers can benefit from the increased availability and reliability of plants and machines while providers achieve higher sales from their service business (Meier and Uhlmann, 2012).

In addition to servitization, another trend exists in manufacturing: The digitalization of products and plants in pursuit of "Industry 4.0," which is driven by major advances in information and communications technology (ICT) (Legner et al., 2017). Embedded sensors, software, and electronic components are bringing a new level of intelligence to products (Kuhlenkötter et al., 2017; Böhmann et al., 2018). Such "smart products," which are also part of cyber-physical systems (CPS) (Rizvi and Chew, 2018), can generate data and communicate with external entities via the internet (Abramovici, 2018) to allow remote monitoring and control or even (semi-)autonomous operation (Gausemeier et al., 2013; Vogel-Heuser, 2014; Filho et al., 2017). Therefore, they offer the potential to provide data-based smart services and establish the basis for smart product-service systems (smart PSS) (Kuhlenkötter et al., 2017; Zheng et al., 2017). The value proposition of a smart PSS is characterized by the integration of smart tangible products and data-based intangible services.

Based on these parallel trends in technology (digitalization, here referred to as "smart") and the market environment (servitization, here referred to as "PSS"), new smart PSS business models are emerging. However, these trends extend the classic product design domain into new branches and introduce an increased number of dependencies, thus increasing the complexity of the product and software architecture. This gives rise to a wide range of reasons for studying the development of smart PSS. While companies often already follow defined and established development processes for designing traditional products, there is a lack of processes for systematically developing smart PSS. For this reason, many companies, especially small and medium-sized enterprises (SMEs), still face major challenges in this regard when dealing with these more complex systems (Heinz et al., 2022a).

2 PROBLEM CLARIFICATION AND GOAL

Recent developments show how the systematization of design processes is seeking to catch up with technological advances. For example, the guideline VDI 2206, which was used in the past as a guideline for the development of mechatronic products, now primarily deals with the development of CPS since its recent revision (VDI/VDE 2206, 2021). However, the guideline only mentions service development or service integration in passing, leaving the systematic procedure for integrating service and product development an open question. On the other hand, there are also specific guidelines for service development, such as the DIN SPEC 33453 (2019). This guideline, in turn, focuses exclusively on developing services and hence does not address integrated product and service development. Separate development processes can lead to improper conformity of product and service, which limits the value proposition, hinders the coordination of development efforts, and contradicts the systems engineering approach (Abramovici, 2018). Developing smart services, in particular, the integrated development of smart services and products is by no means trivial and therefore it requires adequate support.

In the context of systems engineering, it is necessary to distinguish classical downstream product-oriented services, like after-sales, from services in PSS, like condition monitoring, as they have different value structures and require different development approaches. Since traditional downstream services are mostly designed for products that have already been specified, they have little to no impact on the product architecture (Schenkl, 2015). In contrast, services in PSS are an integrated element of a business model. Such services must be given careful consideration as early as the product development stage

https://doi.org/10.1017/pds.2023.309 Published online by Cambridge University Press

because they influence and are influenced by the product architecture (Paliyenko et al., 2022). Adding "smartness" to the concept of PSS changes and expands the possible services that can be provided as part of the PSS: As smart products generate data, they enable data-based services that were not feasible before. According to current literature, moving from PSS development toward smart PSS development is a major challenge for companies (Beverungen et al., 2017; Zheng et al., 2019; Heinz et al., 2022a).

Currently, enterprises try to tackle the development of smart PSS on their own and are struggling because they often lack the resources and knowledge to manage the development of such systems (Schiller et al., 2022; Paliyenko et al., 2022). Due to the high complexity of smart PSS design, manufacturers need support by providing suitable methodologies, i.e., procedures, methods, and tools (Idrissi et al., 2017; Paliyenko et al., 2022). Meanwhile, literature addressing the integrated development of smart PSS is scarce, while the existing literature only briefly addresses related issues (Abramovici, 2018; Chowdhury et al., 2018; Rizvi and Chew, 2018).

According to research by Kuhlenkötter et al. (2015) and Böhmann et al. (2018), it is necessary to reconsider and adapt the classical approaches of product development to the development of smart PSS. Further research analyzes the applicability of classic methods of product engineering (Hagen et al., 2018) and service engineering (Marx et al., 2020) for the development of smart PSS. Their research shows that the methods and frameworks have to be adapted to the specific requirements of smart PSS, but the authors do not state what exactly those requirements are. In order to provide adequate support for the development of smart PSS, a systematic design approach embedded in practical application is essential for creating a smart PSS methodology – and valid assumptions play a key role as the basis of this creation process (Verdugo et al., 2018; Broy et al., 2020). Therefore, as a first step, it is vital to investigate the requirements for a smart PSS development framework (Spohrer and Demirkan, 2015).

Overall, the body of literature shows that the design of a smart PSS development framework has yet to be solved by research. Therefore, this paper aims to answer the following research question: *Which requirements does a methodological framework for the development of smart PSS need to fulfill?* With this empirical study, we explore and identify the (current) needs of enterprises and provide a sound overview of requirements for further research. In this way, we draw on insights from practitioners currently trying to adapt to the development of smart PSS as well as the existing literature.

This paper is structured as follows: Section 3 describes our research method, namely an extensive study, and depicts its key elements. Section 4 presents the results and provides a reflection of the findings in the context of the existing literature. Section 5 contains a detailed discussion of our findings, and section 6 concludes this paper with an outlook and potential areas for future research.

3 RESEARCH METHODOLOGY

As our primary data source, we examined five intentionally chosen sample cases of SMEs representing different industries, positions in their value chain, and company ages to obtain a broad picture. Each of the companies has built a successful business model around the provision of physical goods combined with non-digital downstream services (e.g., system design, after-sales purchases, maintenance, or troubleshooting). Driven by internal transformation processes and the potential of digitalization, the five cases have recently put a strategic focus on integrating their product and service offerings into product-service systems and using digital technologies to make their offerings "smart".

3.1 Data collection and research setting

The five cases offer insights for answering our research question, as their novel engagement with smart PSS development and their rather small company size allow us to gain a holistic view of their requirements for methodological support in this context. To gather empirical data that allowed us to derive requirements for a framework for smart PSS development, we interviewed decision-makers from each case who have a central role in the context of smart PSS development in their respective firms. We conducted 18 semi-structured, open-ended interviews with leading questions that focused on six areas:

1. Descriptions of currently offered products and services.
2. The organizational context of the recently launched smart PSS development project, including the interviewee's role in the project.
3. Identified strengths and weaknesses related to smart PSS development.
4. Development processes currently in use, including responsibilities, milestones, and methods used.

https://doi.org/10.1017/pds.2023.309 Published online by Cambridge University Press

5. Internal and external management of communications, data, and information.
6. Requirements for methodological support of smart PSS development.

The average duration of the 18 interviews was approx. 80 minutes. All interviews were recorded and transcribed, while the workshops were recorded and documented in written form. Following the semi-structured interviews, we conducted individual workshops with each company to bring together employee-specific perceptions of the development processes and related issues, thus reaching a common understanding. In these sessions, we aimed to investigate the enterprise's practices and understand the existing development processes. The insights and results from the interactive workshops were used for the following case analysis.

Finally, we triangulated our data by first interviewing decision-makers of six additional SMEs representing different levels of smart PSS adoption (applying the same interview guideline with less granularity) and - in parallel - thoroughly reviewing the existing body of knowledge on suggested development processes in the context of servitization and digitalization. These secondary materials helped us to generalize and validate our empirical findings throughout the data analysis and link the findings to the existing academic debate. Table 1 provides an overview of the examined material.

Table 1. Case description and collected primary and secondary material

Primary Data	
Description	**Collected Data**
5 purposefully sampled cases of SMEs (< 250 employees)	Interviews were conducted until theoretical saturation was reached; workshops were attended by interviewees and additional experts
Alpha: Parts suppliers of plastic seals for system solutions (< 250)	4 interviews, 1 workshop: Director of digital transformation*; Director of technology and innovation*, **; Product developer*, **; IoT developer*; Service manager*
Beta: Modular contract development (< 50)	3 interviews, 1 workshop: CEO*; Project manager*; Project manager*; PR manager*
Gamma: Single-order producer of electric components (< 250)	5 interviews, 1 workshop: Director of R&D*; Director of software development*; Software developer*; IoT developer*; Product manager*
Delta: Product manufacturer of laser technology (< 250)	2 interviews, 1 workshop: After-sales manager*; Product manager*, **; Product manager*, ** Service manager*
Epsilon: Hardware start-up for battery systems (< 20)	2 interviews, 1 workshop: CEO*; Product manager*; Product developer*
[Acronym: Firm Description (Employees)]	** Participated in the workshop* *** Joint interview*
Secondary Data	
6 expert interviews with representatives of SMEs other than the primary cases (I1 – I6)	I1: Hydraulic valve systems (Director R&D, < 100) I2: Plastic and sealing components (CEO, < 100) I3: Mechanical engineering (CEO, < 20) I4: Filter systems for the process industry (CEO, < 50) I5: Optics for laser machining (Lean Manager, < 250) I6: Industrial data, AI, and IoT solutions (CEO, < 50) *[Acronym: Enterprise Description (Role, Employees)]*
Analysis of research articles	A contextual literature review was performed in order to derive requirements from smart PSS characteristics and existing development frameworks for products, services, or PSS

3.2 Data analysis

As shown in Figure 1, the analysis of the collected data was structured into a divergent phase (Phase I) and a convergent phase (Phase II), in each of which proven methods of qualitative content analysis (Mayring, 2004; Meuser and Nagel, 2009) were applied. After immersing ourselves in the collected primary data, we first derived codes for each case's (a) initial situation, e.g., the engineering processes and methods used, established roles, or critical tasks, (b) existing weaknesses in dealing with challenges related to the development of smart PSS, and (c) case-specific objectives motivating the

https://doi.org/10.1017/pds.2023.309 Published online by Cambridge University Press

interviewees to adopt tailored processes and methods (I.1). Second, a cross-case analysis was conducted to compare the cases and to identify case-specific and cross-case requirements for the design of a smart PSS methodology, resulting in a set of 49 requirements (I.2). In a third step, our interviewees were asked to evaluate the generated list of requirements. In doing so, the practitioners were asked to prioritize the requirements for their company and to justify this prioritization. They were also able to suggest revisions, ask questions for clarification, and voice their comments (I.3).
In the first step of the converging phase, we used the semi-structured feedback provided to revise the requirements catalog (II.1). In a subsequent aggregating step, we relied on a contextual literature review and six interviews with additional cases ("secondary material" in Table 1) to triangulate and generalize our findings (II.2). This step led us to a set of 17 requirements for a smart PSS development framework, which has been divided into two categories (general requirements and smart PSS-specific requirements) and is presented in Section 4. Finally, we reflected on our research process in several research discussions among the authors and synthesized our findings by deriving three tensions arising from the particular nature of smart PSS development, which we present in Section 5 (II.3).

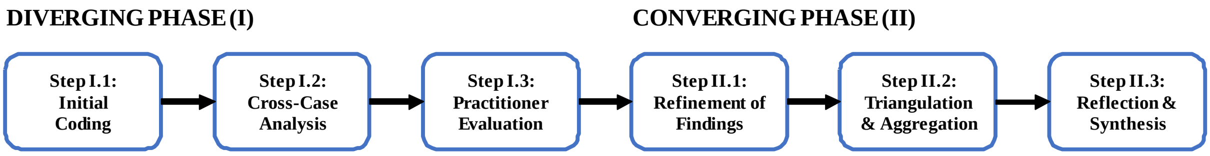

Figure 1. Data analysis procedure

4 REQUIREMENTS FOR A SMART PSS DEVELOPMENT FRAMEWORK

Overall, our research yields 17 requirements for a smart PSS development framework, which are split into a set of "general requirements" that apply to any engineering design methodology (Table 2) and a set of "functional requirements" that are specific to smart PSS development (Table 3). Both tables contain brief descriptions with key statements about each requirement.

Table 2. General requirements for a smart PSS development framework (following Keller and Binz (2009))

Requirement	Description
Revisability (R1)	The validation and verification of the framework within the associated community must be possible.
Scientific soundness (R2)	The framework must be objective, reliable, and valid. Thus, consider and reduce the creators' and users' biases.
Applicability (R3)	The framework must be applicable to a non-trivial problem. Therefore, it needs to be comprehensible, learnable, and repeatable.
Complexity reduction (R4)	The framework must reduce the complexity of the problem by structuring it and breaking it down into simpler tasks.
Flexibility (R5)	The framework must allow for alternative combinations and sequences of tasks and methods within the framework.
Practical relevance (R6)	Demand for the specific framework must exist, and it needs to perform at least as well as existing methodologies.
Usefulness (R7)	The framework must be both effective and efficient, providing the desired result and reducing the required effort.

The first set of *general requirements* (revisability, scientific soundness, applicability, complexity reduction, flexibility, practical relevance, and usefulness) corresponds to the requirements defined by Keller and Binz (2009). The authors performed a meta-analysis on engineering design research, engineering design methodologies, and their development, which allowed them to extract general requirements on engineering design methodologies. A framework for smart PSS development must consider those requirements as well.
Additionally, the framework must take functional requirements into account. Overall, our research yields ten smart PSS-specific requirements, which are presented in Table 3.

https://doi.org/10.1017/pds.2023.309 Published online by Cambridge University Press

Table 3. Smart PSS-specific requirements for a development framework

Requirement	Description
Legal regulations (R8)	The framework must consider the legal requirements, regulations, and customer agreements.
Adaptivity (R9)	The framework must allow for the adaptation of individual conditions of the development project.
Integrated system design (R10)	The framework must integrate relevant domains (product development, service development, smart systems engineering), consider the relationships between actors, and account for their needs.
Interdisciplinary teamwork (R11)	The framework must consider interrelations between experts from different domains (product development, service development, smart systems engineering) and allow them to simultaneously perform different tasks.
Interdisciplinary education (R12)	The framework must provide the required methodological understanding and knowledge for the performance of tasks and their purpose.
ICT-driven (R13)	The framework must support the development of technologically advanced systems that generate data and provide data services via remote access.
User-centric (R14)	The framework must have a strong user focus with an emphasis on problem-solving.
User participation (R15)	The framework must allow the integration of the user as an active participant in development.
Information structures (R16)	The framework must consider information regarding the service process flow, the required structures, relationships between service and product elements, substitution relationships, and service variants.
System extensibility (R17)	The framework must consider the peculiar lifecycle of smart PSS and use the generated knowledge to foster value creation and systemic growth.

Legal regulations (R8): The first smart PSS-specific requirement is the explicit consideration of legal regulations. Due to the nature of smart PSS, a lot of intellectual property, such as usage data, machine data, process data, expertise, etc., needs to be shared between the actors interacting through a smart PSS. Most of the time, the exchange happens via the internet using inter-organizational information systems. The transferred data are considered to be sensitive and therefore require regulatory contracts. Particularly in territories with strict data privacy regulations, such as the European Union, the framework must consider the legal requirements, regulations, and customer agreements.

Adaptivity (R9): Our research shows that “flexibility” as defined by Keller and Binz (2009) is by itself insufficient for addressing smart PSS development, as smart PSS development combines multiple detached disciplines and the enterprises are often specialized in one specific domain such as manufacturing or service provision. Therefore, the framework must allow a certain degree of adaptation to the given organizational background and existing developing processes. In addition, the tasks themselves need to be simple enough that they can be expanded and adapted by their user.

Integrated system design (R10): One of the biggest challenges of smart PSS development is the integrated development of smart products and data-based services (Paliyenko et al., 2022). Thus, a smart PSS development framework must integrate all three domains (product development, service development, and smart systems engineering) to realize joint development (Künzel et al., 2016; Kuhlenkötter et al., 2017). Additionally, the framework must account for the relationships between and the needs of the different stakeholders in the ecosystem surrounding the company’s PSS. In order to maximize the value created by the ecosystem, a clear distribution of responsibilities and roles is necessary, and all entities must actively participate in the development of the smart PSS.

Interdisciplinary teamwork (R11): In accordance with the interdisciplinary system design, the framework must consider the interrelations between experts from different domains (Künzel et al., 2016; Song, 2017). Those experts often have non-matching qualifications and areas of focus. Nevertheless, the framework must allow for the simultaneous and coordinated development and execution of different tasks by these experts. Therefore, it must provide structures for interaction between those experts. Given the different nature and practices of, e.g., hardware and software development, the framework must also structure the development to accommodate different development speeds and cycles.

https://doi.org/10.1017/pds.2023.309 Published online by Cambridge University Press

Interdisciplinary education (R12): The purpose of interdisciplinary education is manifold. The framework must provide the methodological understanding and knowledge required for performing the tasks and understanding their purpose. To be specific, this involves providing comprehensive expertise from relevant domains such as product development, service development, or smart systems engineering. Only by overcoming a silo mentality is it possible to handle the emerging complexity of integrated smart PSS development as well as the organizational challenges.

ICT-driven (R13): The framework aims to support the development of technologically advanced products that allow data generation and remote access. Those products are part of an embedded system that is the basis for mostly internet-based digital services. In addition to providing the services that are an inherent part of the developed PSS, the data can be an essential part of a smart service ecosystem – meaning that other stakeholders can use the data to further data-driven value creation. Conversely, providing smart services often requires the usage of additional external data sources. A smart PSS methodology must therefore support the development of such technologically advanced systems. In particular, it should address ICT-related issues such as coordinating the standardization of data and communication protocols, promoting the modular reuse of software building blocks, and defining a solution architecture (Broy et al., 2020), all of which typically require cross-functional input and coordination.

User-centric (R14): The actual purpose of adopting PSS-oriented development is to turn a product-based value creation focus into a solution-based one by focusing on a holistic view of value co-creation with the help of the solution on the customer site. A key factor for the successful development of a smart PSS is, therefore, a strong user orientation (Kuhlenkötter et al., 2017; Abramovici, 2018). The more the development team understands the underlying issues and demands of the PSS users, the better the PSS can work towards solving these problems and fulfilling the users' demands. In addition, this approach can simplify communication with the customer by highlighting the solution's added value without having to translate the technical features first.

User participation (R15): One of the key elements that differentiates a smart PSS from regular product sales is the user's involvement in the ecosystem (Valencia et al., 2015). During product usage, user-generated and product-sensed data are generated in the smart ecosystem, which should be used for providing data-based services and double-checking and validating the system design. The real product usage may show deviations from the initial assumptions; therefore, the framework must allow for the integration of such insights and enable a system redesign. As a result, the framework should support the design of adaptable systems. Since the smart PSS aims to provide user-centric solutions to given problems, it is key to involve the user in the development of the smart PSS (Zheng et al., 2019).

Information structures (R16): A common added value of smart PSS is to allow the absence of employees at the operation site. Service provision in such systems relies heavily on remote data and information availability. Hence, a central concern of the methodology must be to consider information about the flow of the service process, the required structures, relationships between service and product elements, substitution relationships, and service variants (McKay and Kundu, 2014). Other information requirements correspond to the research of Bochnig et al. (2013), which defines multiple requirements for the information structures of information systems in industrial PSS. The underlying data model and information structure must support the entire planning process across all phases. Additionally, it must allow for the modeling of interdependencies between the PSS-related actors and thus support integrated, interdisciplinary development of smart PSS.

System extensibility (R17): A smart PSS is composed of a tangible product and data-based, intangible services that jointly create value for the participants throughout the lifecycle of the solution (Song, 2017). The peculiar nature of smart technologies allows the technical and business ecosystems to grow and develop over time (Heinz et al., 2022b), making it crucial to consider all lifecycle phases during its development. The development framework must therefore foster development approaches that enable innovative transformation and extension beyond the product's point of sale, for example, by ensuring updateability as well as the compatibility of individual CPS components.

5 DISCUSSION

By combining empirical insights with existing literature, our study identifies a broad variety of requirements for a smart PSS development framework. On the one hand, we can translate some identified requirements into known denotations, such as the general requirements by Keller and Binz (2009). That

https://doi.org/10.1017/pds.2023.309 Published online by Cambridge University Press

allows this study to build on (and thus verify) literature from adjacent domains while expanding the body of knowledge into a novel context. On the other hand, in addition to the known requirements for most development frameworks, five cases are used to identify new functional requirements specific to the development of smart PSS, contributing to the interdisciplinary study of this highly relevant phenomenon.

As the interviews show, the successful development of smart PSS depends mainly on the orchestration (cf. Hurmelinna-Laukkanen et al., 2012) of three practical areas: product development, service development, and smart systems engineering. Therefore, in order to maximize the impact of a smart PSS in the market and, thus, the success of its development, it is crucial to bridge the gap between these domains and provide common ground for effective collaboration. However, if we reflect on the challenges mentioned by the respondents and the identified requirements, it becomes apparent that areas of tension arise at various levels and should be addressed by a smart PSS methodology.

At the system level, there is a tension between *information transparency* and *ecosystem strategy*. This is because the development of smart PSS is a multi-actor problem and requires an ecosystem-centric perspective. Accordingly, the goal and purpose of a smart PSS should be to create value for all actors involved. However, this seems to contradict most companies' usual business model approach, which focuses on maximizing individual profit and keeping their data, information, and knowledge – i.e., their intellectual property – secret. An ecosystem strategy, in contrast, aims at user-centric system design and involves the active participation of users and partners in developing and operating a smart PSS, which requires a closer connection between all actors and the sharing of their intellectual property.

Second, at the organizational level, there is a tension between an *integrated system approach* and *complexity reduction*. To connect the people involved in development, points of interaction must be identified and integrated into the development processes, which in the cases studied were established partly by processes and partly by human interaction. However, particularly due to the frequent double occupation of roles in the SME cases, it also became clear that the additional effort thus generated must be in proportion to the productivity thereby gained. Therefore, explicit task descriptions and appropriate methods and processes as part of the methodology may guide the interdisciplinary team in different phases of development. In addition, a coordinating role should be created in the company and filled with an expert with diverse skills and interdisciplinary expertise. This way, the expert can mediate between the different disciplines and ensure unambiguous communication within the development team.

Finally, on the application level, the third tension arises between *adaptivity* and *ease of use* of the proposed methodology. On the one hand, the framework must be sufficiently configurable to account for smart PSS development being highly context-dependent. Smart PSS, for example, are developed by both SMEs and market-dominant global companies, which may be product manufacturers or service providers with very different starting positions. But, on the other hand, as the SMEs we interviewed pointed out, configuring and customizing the methodology should not take so much effort that it creates new barriers to entry into smart PSS development. Therefore, on the one hand, the framework must offer possibilities for adaptation to situational factors, but on the other hand, it must be particularly concrete and clearly defined.

6 CONCLUSION AND OUTLOOK

With this study, we set out to identify requirements that a methodological framework for the development of smart PSS needs to fulfill. By conducting 18 interviews and 5 workshops to study five cases that have recently placed a strategic focus on the development of smart PSS, we collected a rich set of empirical data for exploring the challenges faced by today's organizations. We systematically analyzed the data using qualitative content analysis methods. To increase the robustness of our findings, we evaluated the preliminary results with our respondents. In a subsequent step, we relied on a contextual literature review and six interviews with additional cases to triangulate and generalize our findings. This led us to a set of 17 requirements for a smart PSS development framework, which we divided into general and smart PSS-specific requirements. In addition, we derived three tensions that emerge from the interdisciplinary nature of smart PSS development, which need to be addressed by a development framework to provide methodological support for organizations.

This research offers a sound basis for future research that could provide methodological support for the development of smart PSS. Future work may apply the discovered requirements to existing development frameworks for product, service, or PSS development in order to analyze their suitability for smart PSS development. In addition to examining the possibility of recombining existing elements, this will allow the need for adjustment to be identified and the existing frameworks to be extended. Additionally, the identified areas of tension require further investigation. In a multi-domain development environment, tensions and opposing objectives are unavoidable. However, academia should strive to discover concepts and methods which simultaneously minimize the undesirable effects and maximize the desired ones. For both of these research avenues, a close collaboration with and validation by practitioners is crucial for the successful design of a methodological framework, as empirical findings help guide research efforts to understand and manage the new phenomenon of smart PSS development.

ACKNOWLEDGMENTS

This work has been supported by the German Federal Ministry of Education and Research through the research project "bi.smart" (grant no. 02J19B041).

REFERENCES

Abramovici, M. (2018), Engineering smarter Produkte und Services Plattform Industrie 4.0 STUDIE, acatech – Deutsche Akademie der Technikwissenschaften, Munich, Germany.

Beverungen, D., Müller, O., Matzner, M., Mendling, J. and vom Brocke, J. (2017), "Conceptualizing smart servicesystems", Electron Markets, Vol. 29 No. 1. http://doi.org/10.1007/s12525-017-0270-5

Bochnig, H., Uhlmann, E., Nguyễn, H. N., Stark, R., "General Data Model for the IT Support for the IntegratedPlanning and Development of Industrial Product-Service Systems", Product-Service Integration for Sustainable Solutions, Meier, H. (Ed.), Springer, 2013, pp. 521–533. https://doi.org/10.1007/978-3-642-30820-8_44

Böhmann, T., Leimeister, J. M., and Möslein, K. (2018), "The New Frontiers of Service Systems Engineering", Business & Information Systems Engineering, Vol. 60 No. 5, pp. 373–375. http://doi.org/10.1007/s12599-018-0553-1

Broy, M., Böhm, W. and Rumpe, B. (2020), Advanced Systems Engineering - Die Systeme der Zukunft, fortiss GmbH, München, Germany

Chowdhury, S., Haftor, D. and Pashkevich, N. (2018), "Smart Product-Service Systems (Smart PSS) in Industrial Firms: A Literature Review", Procedia CIPR, Special Issue: 11th CIRP Conference on Industrial Product- Service Systems, Vol. 73, pp. 26-31. http://doi.org/10.1016/j.procir.2018.03.333

Deutsches Institut für Normung e. V., (2019), DIN SPEC 33453: Development of digital service systems

Filho, M.F., Liao, Y., Loures, E.R. and Junior, O.C. (2017), "Self-Aware Smart Products: Systematic Literature Review, Conceptual Design and Prototype Implementation", Procedia Manufacturing, Vol. 11 Special Issue: 27th International Conference on Flexible Automation and Intelligent Manufacturing, pp. 1471-1480. http://doi.org/10.1016/j.promfg.2017.07.278

Gausemeier, J., Dumitrescu, R., Steffen, D., Czaja, A., Wiederkehr, O. and Tschirner, C. (2013), Systems Engineering in der industriellen Praxis, Heinz Nixdorf Institut, Universität Paderborn, Lehrstuhl für Produktentwicklung, Paderborn, Germany

Hagen, S., Kammler, F. and Thomas, O. (2018), "Adapting Product-Service System Methods for the Digital Era: Requirements for Smart PSS Engineering", Customization 4.0, Springer Proceedings in Business and Economics, Springer International Publishing AG, pp. 87-99. http://doi.org/10.1007/978-3-319-77556-2_6

Heinz, D., Park, H.-R., Benz, C. and Satzger, G. (2022a), "Innovating Smart Product-Service Systems in Manufacturing SMEs: Current Practices, Affordances, and Constraints", 24th IEEE Conference on Business Informatics, IEEE, Amsterdam, Netherlands. http://doi.org/10.1109/CBI54897.2022.10046

Heinz, D., Breidbach, C. F., Benz, C. and Satzger, G. (2022b), "Towards Explaining Smart Service Innovation Events and Trajectories", 43rd International Conference on Information Systems (ICIS 2022), Association for Information Systems. http://doi.org/10.5445/IR/1000151310

Hurmelinna-Laukkanen, P., Olander, H., Blomqvist, K. and Panfilii, V. (2012), "Orchestrating R&D networks: Absorptive capacity, network stability, and innovation appropriability", European Management Journal, Vol. 30, No. 6, pp. 552-563. http://doi.org/10.1016/j.emj.2012.03.002

Idrissi, N. A., Boucher, X. and Medini, K (2017), "Generic conceptual model to support PSS design processes", The 9th CIRP IPSS Conference: Circular Perspectives on Product/Service-Systems, Elsevier B. V., pp. 235-240. http://doi.org/10.1016/j.procir.2017.03.055

Keller, A. and Binz, H. (2009), "Requirements on engineering design methodologies", International Conference on Engineering Design - ICED 09, Stanford University, Stanford, CA, USA, pp. 2203-2214.

Kuhlenkötter, B., Bender, B., Wilkens, U., Abramovici, M. and Göbel, J.C. et al. (2017), "Coping with the challenges of engineering smart product service systems - Demands for research infrastructure",

Proceedings of the 21st International Conference on Engineering Design (ICED 17), Vol. 3: Product, Services and Systems Design, Vancouver, Canada, 21-25.08.2017, The Design Society, Glasgow, Scotland.
Künzel, M., Schulz, J. and Gabriel, P. (2016), Engineering 4.0 - Grundzüge eines Zukunftsmodells, Begleitforschung AUTONOMIK für Industrie 4.0, Berlin, Germany
Lee, J. and Kao, H.A. (2014), “Dominant Innovation Design for Smart Products-Service Systems (PSS): Strategies and Case Studies”, 2014 Annual SRII Global Conference (SRII), San Jose, CA, USA, 23-25 April 2014, IEEE, Piscataway, NJ, USA. http://doi.org/10.1109/SRII.2014.25
Legner, C., Eymann, T., Hess, T., Matt, C., Böhmann, T., Drews, P. et al., (2017), “Digitalization: opportunity and challenge for the business and information systems engineering community”, Business & information systems engineering, Vol. 59 No. 4, pp. 301-308. http://doi.org/10.1007/s12599-017-0484-2
Marx, E., Pauli, T., Fielt, E. and Matzner, M. (2020), “From Services to Smart Services: Can Service Engineering Methods get Smarter as well?”, 15th International Conference on Wirtschaftsinformatik, Potsdam, Germany, pp. 1-15. http://doi.org/10.30844/wi_2020_j9-marx
Mayring, P., (2004), “Qualitative content analysis”, A companion to qualitative research, Sage Publications, London, United Kingdom.
McKay, A. and Kundu, S. (2014), “A representation scheme for digital product service system definitions”, Advanced Engineering Informatics, Vol. 28 No. 4, pp. 479-498. http://doi.org/10.1016/j.aei.2014.07.0042012
Meier, H. and Uhlmann, E. (2012), Integrierte Industrielle Sach- und Dienstleistungen, Springer-Verlag Berlin, Heidelberg. http://doi.org/10.1007/978-3-642-25269-3
Meuser, M. and Nagel, U. (2009), “Das Experteninterview - konzeptionelle Grundlagen und methodische Anlage”, VS Verlag für Sozialwissenschaften, pp. 465-479. http://doi.org/10.1007/978-3-531-91826-6_23
Paliyenko, Y., Tüzün, G.-J., Roth, D. and Kreimeyer, M. (2022), “Inquiry and Analysis of Challenges in the Development of Smart Product-Service Systems”, Proceedings of the Design Society, Volume 2: DESIGN2022, Cambridge University Press, pp. 1935-1944. http://doi.org/10.1017/pds.2022.196
Rizvi, M. A. K. and Chew, E. (2018), “Towards systematic design of cyber-physical product-service systems”, Proceedings of the DESIGN 2018 15th International Design Conference, pp. 2961-2974. http://doi.org/10.21278/idc.2018.0248
Schenkl, S. A. (2015), Wissensorientierte Entwicklung von Produkt-Service-Systemen, Lehrstuhl für Produktentwicklung, Technische Universität München, Garching, Germany
Schiller, C., Friedrich, M. and Buchart, S. (2022), “Dissemination of Smart Product-Service Systems in the Corporate World”, The Human Side of Service Engineering, AHFE Open Access, pp. 279-285. http://doi.org/10.54941/ahfe1002568
Song, W., (2017), “Requirement management for product-service systems: Status review and future trends”, Computers in Industry, Vol. 85, pp. 11-27. http://doi.org/10.1016/j.compind.2016.11.005
Spath, D., Meiren, T. and Münster, M (2012), “F&E-Management für Lösungsanbieter”, Fachverl. Verl.-Gruppe Handelslatt, Düsseldorf, Germany. https://doi.org/10.1007/BF03373007
Spohrer, J. C. and Demirkan, H. (2015), “Introduction to the Smart Service Systems: Analytics, Cognition and Innovation Minitrack”, 48th Hawaii International Conference on System Sciences, IEEE Computer Society, p. 1442. http://doi.org/10.1109/HICSS.2015.175
Valencia, A., Mugge, R., Schoormans, J. P. L. and Schifferstein, H. N. J. (2015), “The Design of Smart Product-Service Systems (PSSs): An Exploration of Design Characteristics”, International Journal of Design, Vol. 9 No. 1, pp. 13-28.
Verein Deutscher Ingenieure (2021), VDI/VDE 2206: Development of mechatronic and cyber-physical systems.
Verdugo C., J. M., Papinniemi, J., Hannola, L. and Donoghue, I. D. M. (2018), “Developing Smart Services by Internet of Things in Manufacturing Business" 24th International Conference on Production Research (ICPR 2017), pp. 615-621. http://doi.org/10.12783/dtetr/icpr2017/17680
Verhoef, P.C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J. et al. (2021), “Digital transformation: A multidisciplinary reflection and research agenda”, Journal of Business Research, Vol. 122, pp. 889-901. http://doi.org/10.1016/j.jbusres.2019.09.022
Vogel-Heuser, B. (2014), Herausforderungen und Anforderungen aus Sicht der IT und der Automatisierungstechnik, Springer Vieweg, Wiesbaden, Germany, pp. 37-48. http://doi.org/10.1007/978-3-658-04682-8_2
Zheng, P., Wang, Z., Chen, C.H. and Khoo, L.P. (2019a), “A Survey of Smart Product-Service Systems: Key Aspects, Challenges and Future Perspectives”, Advanced Engineering Informatics, Vol. 42. http://doi.org/10.1016/j.aei.2019.100973
Zheng, P., Wang, Z. and Chen, C.-H. (2019b), “Smart Product-Service Systems: A novel Transdisciplinary Sociotechnical Paradigm”, Transdisciplinary Engineering for Complex Socio-technical Systems, IOS Press, http://doi.org/10.3233/ATDE19012
Zheng, M., Ming, X., Wang, L., Yin, D. and Zhang, X. (2017), “Status review and future perspectives on the framework of Smart Product Service Ecosystem”, The 9th CIRP IPSS Conference: Circular Perspectives on Product/Service-Systems, Elsevier B. V., pp. 181-186. http://doi.org/10.1016/j.procir.2017.03.037