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Towards a Methodological Framework for the Development and Operation of Smart Product-Service-Systems

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Abstract: Enterprises are increasingly adopting smart Product-Service Systems (smart PSS) to enhance their value propositions by integrating smart products with associated data-based services. However, transitioning to smart PSS presents unique challenges, necessitating suitable development approaches. This research aims to bridge this gap by proposing a framework for smart PSS development, synthesized from an analysis of various frameworks, methodologies, and industry insights. This framework supports the integration of hardware, software, and services within a unified business model.

Keywords: Product-Service-Systems (PSS), Systems Engineering (SE), Service Oriented Design, Integrated Product Development, Framework

1 Introduction and motivation

In the contemporary industrial landscape, producing enterprises are increasingly striving to enhance their value proposition by offering additional services. This trend marks a significant shift from traditional product-oriented business models towards Product-Service-Systems (PSS). PSS represents a business model where a product and its associated services are bundled together and sold as a package. In recent years, the emergence of smart products, characterized by embedded sensors, software, and electronic components, has further revolutionized this concept, giving rise to what is now known as smart PSS (Böhmann et al., 2018; Kuhlenkötter et al., 2017; Vogel-Heuser, 2014). These smart products are integral components of Industry 4.0, leveraging advances in Information and Communication Technologies (ICT) to generate data that can be utilized for extending existing PSS, thereby offering novel, data-based services. The degree of intelligence embedded within a product can range significantly - from basic components that merely supply data, such as simple sensors, to highly sophisticated edge devices equipped with AI capabilities. For products that initially lack advanced features, the integration of complex, data-driven functionalities can significantly enhance their smartness. This enhancement often involves implementing sophisticated services that utilize data to improve performance and user interaction. Conversely, even straightforward services, such as routine maintenance, can be transformed by leveraging a comprehensive dataset. Such data richness allows for exceptional precision in determining the optimal timing and extent of maintenance activities, thus improving efficiency and effectiveness.

The transition to smart PSS necessitates a clear distinction between traditional downstream product-oriented services and the integrated services of PSS. The system architecture of a smart PSS encompasses a diverse array of disciplines, perspectives, actors, and entities. These components must interact synergistically and coexist harmoniously to generate value. At the core of this system lies the smart product, serving as the primary source of data and the fundamental physical element. Surrounding it is a robust communication infrastructure, which facilitates the seamless exchange and preprocessing of data. This is complemented by a service platform that specializes in analytics and the provision of data-driven services. An orchestrator plays a crucial role in managing the interactions among all stakeholders, ensuring that each component's contributions are aligned and integrated effectively. Central to the entire system is the customer, who stands as the primary beneficiary of the value created. Services in smart PSS are not just add-ons but are integral to the complex business model, thus requiring different developmental approaches due to the varied value structures they possess (Schenkl, 2015; Zheng et al., 2021). This evolution towards smart PSS has brought about a higher complexity in design and development, significantly different from conventional product design. As a result, there is a pronounced need for methodologies that support systematic PSS development and manufacturing (Sarancic et al., 2023; Zheng et al, 2021; Alix and Zacharewicz, 2021). The systematic development process for smart PSS is not just beneficial but paramount for its success (Abramovici, 2018; Zheng et al., 2019).

Despite the growing importance of smart PSS in the industrial sector, literature addressing their development process is relatively scarce. Existing literature tends to address related issues only briefly, indicating a gap in comprehensive research in this area (Abramovici, 2018, Rizvi and Chew, 2018, Chowdhury et al., 2018). Furthermore, integrating 'smartness' into PSS is recognized as a significant challenge (Beverungen et al., 2017; Zheng et al., 2019; Paliyenko et al., 2022). Thus, to adequately support the development of smart PSS, a systematic design approach and valid assumptions are essential. It is also crucial to investigate ways of integrating an interdisciplinary development approach for smart PSS.

The integration of smartness into PSS goes beyond simply adding technological components to existing products or services. It involves a holistic rethinking of the business model, where the product, services, and smart technologies are seamlessly interwoven throughout the lifecycle stages of the PSS. This integration poses significant challenges, including the alignment of diverse value structures, the synthesis of multidisciplinary knowledge, and the management of increased system complexity (Kuhlenkötter et al., 2017). Therefore, a framework that can effectively guide the development of smart PSS, addressing these challenges, is of paramount importance.

2 Problem clarification and goal

A framework for the development of PSS should aim to integrate the business model, product, software, and services cohesively throughout the lifecycle stages, thereby creating additional value for the system (Vasantha et al., 2012; Verdugo et al., 2018; Broy et al., 2020). Over the past decades, various development methodologies and frameworks with different specializations and focuses have emerged. Some prioritize software development, emphasizing robust and scalable applications that efficiently utilize data. Others focus on hardware development, ensuring reliable functionality and seamless integration with digital components. Service-oriented approaches are aimed at creating service models that enhance a product's value proposition. In contrast, system-level frameworks offer a comprehensive perspective, prioritizing the coordination of various components - software, hardware, and services - to create a cohesive and functional whole (Cong et al., 2020; Vasantha et al., 2012). Given the complexities and interdisciplinary nature of smart PSS, a comprehensive, structured framework is required for successful development. This leads to the central research question: *Which characteristic elements does a framework for smart PSS design have to contain, and how do these elements need to be structured or related to each other to enable efficient and effective smart PSS development?*

Addressing this question is vital for several reasons. Firstly, the integration of smart technologies into PSS introduces new challenges and opportunities, which traditional product development methodologies may not adequately address. For instance, the inclusion of ICT and data analytics necessitates a different approach to design, development, and lifecycle management (Rizvi and Chew, 2018). Secondly, the interdisciplinary nature of smart PSS, which encompasses fields such as mechanical engineering, software development, and service design, requires a holistic framework that can integrate these diverse areas effectively (Paliyenko et al., 2023b; Zheng et al., 2021).

From an industrial perspective, professionals face complex obstacles when developing smart PSS, as highlighted by Paliyenko et al. (2022) and Abramovici (2018). The management of smart PSS lifecycles presents a challenge, integrating physical products, software updates, and service modifications. One key problem lies in the mismatch between rapid design of digital technologies and the slower pace of hardware and service models, leading to integration issues and less than optimal system performance (Martin et al., 2020; Chowdhury et al, 2018). This can lead to increased costs, longer time to market, and difficulties in predicting future needs and technologies, thus hindering the ability to provide scalable and sustainable solutions. Furthermore, the creation of smart PSS requires interdisciplinary cooperation across various domains, like mechanical engineering, software development, and service design (Zheng et al, 2019; Chowdhury et al., 2018). However, siloed departmental structures and differing terminologies and practices among these fields can impede effective communication and integration efforts. This lack of coherence can lead to misaligned objectives, inefficiencies in the development process, and a fragmented end-user experience. Thus, companies may struggle to deliver cohesive and high-value smart PSS offerings, potentially leading to lost revenue and reduced competitiveness.

The goal of this research is to develop and present a framework that supports the integrated development of smart PSS. This framework aims to provide guidelines and methods that can be applied to support the design and development of smart PSS, ensuring that all components – hardware, software, and service – are integrated and aligned with the overall business model and its underlying value proposition.

This paper is structured as follows: The third chapter introduces the methodology behind the research conducted and offers a comprehensive summary of the knowledge sources utilized, which include both academic literature and industrial insights. In the fourth chapter, the findings are presented in a dual aspect: initially conducting an in-depth examination of current methods and models that may be applicable for the development of smart PSS; subsequently, it introduces a newly designed framework for the development of smart PSS, along with its evaluation by industry professionals. The fifth chapter engages in a discussion about the newly proposed framework, comparing it against existing academic works and feedback from practitioners. It concludes with an outlook on future research directions.

3 Approach to research

The methodology of this research integrates a comprehensive literature analysis with valuable industry insights to develop a robust framework for smart PSS development. Thereby, this paper is not only grounded in academic rigor but also attuned to the practical realities of the industry. This approach is designed to provide a comprehensive understanding of the current state of smart PSS development and to identify gaps where a new framework can make a significant contribution. Figure 1 visualizes the applied approach to research.

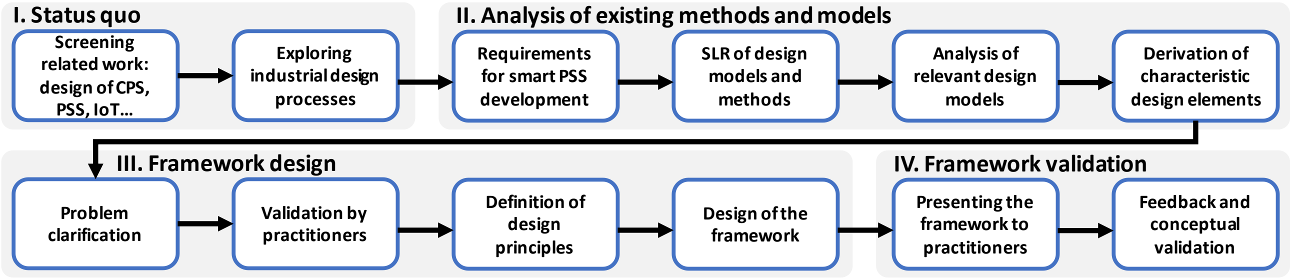

Figure 1. Approach to research and methodology

Both a broad and a systematic literature review form the bedrock of this research. The review process involved searching for methods and frameworks relevant to the development of smart PSS and in adjacent disciplines, such as PSS and Cyber-Physical Systems (CPS) Design. This extensive literature review helped in identifying a total of 17 methods and 13 frameworks that are common to Product-, Software-, Service-, CPS-, or PSS-development (see Table 1). To complement the literature analysis, insights from the industry were also considered. This involved examining case studies, industry reports, and expert opinions to understand practical challenges and industry standards in smart PSS development. An overview of experts that supported this research provides Table 3.

Table 1. Overview of the analyzed development models and methods

Method (reference)	Model (reference)
Conceptual framework for modeling and design of CPS (Dumitrache et al., 2017)	VDI 2221- Design of technical products and systems (VDI/VDE 2221, 2019)
QFD for smart PSS (Fargnoli and Haber, 2023)	IPEMM - Integrated Product Development Process Management Model (Albers, 2007)
Service innovation of smart PSS (Zheng et al., 2018)	Spiral Model (Boehm, 1986)
User-centric design of smart PSS (Bu et al., 2020)	DevOps (Erich, 2014)
ICT prototyping framework for smart service development (Tardo et al., 2022)	Development of mechatronic and CPS (VDI/VDE 2206, 2021)
DT for smart manufacturing (Damjanovic-Behrendt and Behrendt, 2019)	W-Modell: Systems engineering in the development of active systems (Nattermann and Anderl, 2010)
Integrated cyber-physical production system (CPPSS) development (Mennenga et al., 2020)	3-cycle model for product creation (Gausemeier, 2013)
Business model engineering for smart PSS (Boßlau, 2021)	Generic PSS development process model (Stark and Müller, 2010)
Support for the development process of CPS (Pokojski et al., 2022)	Designing sustainable PSS (Sarancic et al., 2023)
CyProF (Kolberg et al., 2016)	Development of data-based PSS (Aurich, 2019)
Engineering tool for CPPS (Kannengiesser et al., 2021)	Societal embedding of sustainable PSS (Ceshin, 2014)
Kano-FBS model for smart PSS development (Ying et al., 2022)	Configuring New Business Models for Circular Economy through PSS (Pieroni, 2019)
Framework for smart PSS ecosystems (Zheng et al. 2017)	Development of digital service systems (DIN SPEC 33454, 2019)
Risk-oriented smart PSS engineering framework (Coba et al., 2020)	
Method for modelling a smart PSS value network (Paliyenko et al., 2023a)	
Systematic design of CPPSS (Rizvi and Chew, 2018)	
Framework for value creation with digital twins (Barth et al., 2023)	

Central to the methodology is the analytical evaluation of the identified frameworks, focusing on those that hold particular relevance to smart PSS development. This evaluation was guided by the requirements for smart PSS development as defined by Keller and Binz (2009) and Paliyenko et al. (2023b) (see Table 2), ensuring a targeted analysis that directly addresses the research question. The aim here was to assess how existing frameworks align with the needs of smart PSS design and to identify key elements that could be beneficial in crafting a new, more effective framework.

Table 2. Guiding set of requirements for the analysis

Requirements for a smart PSS development framework	
General requirements (Keller and Binz, 2009)	R1: Revisability; R2: Scientific soundness; R3: Applicability; R4: Complexity reduction; R5: Flexibility; R6: Practical relevance; R7: Usefulness.
Smart PSS-specific requirements (Paliyenko et al., 2023b)	R8: Adaptivity; R9: Integrated system design; R10: interdisciplinary teamwork; R11: Interdisciplinary education; R12: ICT-driven; R13: Legal regulations; R14: User-centric; R15: User participation; R16: Information structures; R17: System extensibility.

Utilizing the insights gained from the analysis, a novel framework was drafted. This framework was designed by synthesizing the best manifestations of each element identified in the existing frameworks. The goal was to combine the strengths and mitigate the limitations of the existing frameworks, resulting in a more comprehensive and effective tool for smart PSS development.

The novel framework was presented to twelve practitioners from six Small and Medium-sized Enterprises (SMEs) and researchers from three different research fields (see Table 3). This diverse group of evaluators was chosen to ensure that the framework was assessed from various practical and theoretical perspectives. To gather feedback on the framework, both questionnaires and interviews were used. Questionnaires provided structured and quantifiable data, while interviews allowed for more in-depth exploration of the participants' views and suggestions. The evaluation focused on assessing the framework's applicability, comprehensiveness, usability and usefulness in supporting smart PSS development. Feedback was sought on how well the framework addressed the challenges identified in the literature and industry insights, as well as its practical applicability in different industry contexts.

Practitioners have contributed significantly to the refinement of the framework by providing feedback based on their real-world experiences. For instance, they have suggested simplifications to enhance the user-friendliness of the framework, making it more accessible to non-experts. They have identified and filled gaps in the initial framework design, ensuring a more comprehensive structure. Their insights have been crucial in adjusting the scalability of the model to function effectively across various organizational sizes and types. Practitioners have also assessed the technological feasibility of the framework's components, offering practical alternatives where needed. Furthermore, they have provided case studies and examples that demonstrate the framework's potential applications, enriching the illustrative content of the model. Their feedback has also emphasized the importance of a rigorous testing phase, highlighting specific areas that require thorough validation before the framework's full implementation. Based on the feedback received, refinements and adjustments were made to the framework. This iterative process ensured that the final framework was not only theoretically sound but also practical and user-friendly for stakeholders involved in smart PSS development.

Table 3. Overview of experts that evaluated the proposed framework

Description of enterprise (number of employees)	Expert roles
SME 1: Parts supplier of plastic seals for system solutions (< 250)	Product developer; Service manager
SME 2: Modular contract developer (< 50)	Project manager; Product developer
SME 3: Single-order producer of electric components (< 250)	Director of software development; Product manager; Project manager
SME 4: Product manufacturer of laser technology (< 250)	Product manager; Project manager
SME 5: Hardware start-up for battery systems (< 20)	CTO
SME 6: Software consultancy and developer (< 20)	CEO; Software developer

4 Results

To establish a robust foundation for the development of the new framework, all the development models listed in Table 2 were meticulously examined. The following text offers a concise description of three selected models and delineates their characteristic elements that can be derived for the development of smart PSS. Namely, we deliver the findings for the three most prevalent frameworks in current industry practice in German SMEs: VDI 2206:2021, DIN SPEC 33453:2019, and DevOps. The VDI framework lays ground for the models developed by Nattermann and Anderl, 2010, Stark and Müller (2010), and Aurich (2019). DevOps is increasingly being applied within the product domain, as evidenced by the work of Blüher et al. (2023), Macarthy and Bass (2020), and Erich (2014). Similarly, DIN SPEC 33453:2019 holds critical importance, offering a specialized approach to the development of smart services, thereby complementing the broader scope of product and software development models (Aurich et al., 2019).

4.1 Framework analysis: VDI/VDE 2206 (2021)

The VDI 2206 (2021) guideline represents a significant advancement in the systematic development of CPS, offering a comprehensive framework that facilitates the integration of mechanical, electrical, and information technology disciplines. However, when applying this guideline to the specific context of designing smart PSS, several points of critique emerge. These critiques are not necessarily limitations of the guideline itself but highlight areas where its application to smart PSS design might require further adaptation, refinement, or supplementation.

Limited focus on service-oriented aspects: While VDI 2206 (2021) excels in providing a framework for the technical development of CPS, its focus on the hardware and software integration aspects may overshadow the service-oriented components of smart PSS (Exner et al., 2019; Stark and Müller, 2010). Smart PSS design not only involves the development of products but also the integration of these products with accompanying services to create value-added solutions. A more pronounced emphasis on service design, service engineering, and the management of service operations within the guideline could enhance its applicability to smart PSS.

Insufficient guidance on user involvement in the development process: User-centric design is crucial for the success of smart PSS (Paliyenko et al., 2023b; Zheng et al., 2019), as these systems often directly interact with users and are tailored to meet their specific needs and preferences. Although VDI 2206 (2021) emphasizes user-centric principles, it does not provide detailed methodologies or tools for effective user involvement throughout the design and development process. More explicit guidance on user research, co-design practices, and iterative user testing could be beneficial (Liu et al., 2018; Blüher et al., 2023).

Integration of business models and economic viability: Smart PSS design is inherently linked to innovative business models that leverage the combination of products and services to deliver value (Sarancic et al., 2023; Boßlau, 2021). The critique here is that VDI 2206 (2021) does not sufficiently cover aspects related to the design, economic viability, and scalability of business models associated with smart PSS. Guidance on business model innovation, cost-benefit analysis, and market analysis within the context of CPS development would be valuable additions.

Complexity management in multi-stakeholder environments: The development of smart PSS often involves multiple stakeholders, including manufacturers, service providers, end-users, and regulatory bodies. Managing the complexity and aligning the interests of these diverse stakeholders can be challenging. While VDI 2206 (2021) advocates for interdisciplinary collaboration, more specific strategies for stakeholder management, and collaborative innovation in complex ecosystems could enhance its utility for smart PSS development (Martin et al., 2020).

4.2 Framework analysis: DIN SPEC 33453 (2019)

DIN SPEC 33454 (2019) offers a structured framework for the development of smart services, emphasizing innovation, user-centricity, and the strategic use of digital technologies. However, when applying this specification within the specific context of smart PSS development, certain critiques emerge. These critiques highlight areas where DIN SPEC 33454 (2019) may require further adaptation or consideration to fully support the multifaceted nature of smart PSS.

Integration with physical product development: One significant critique is the potential gap in guidance regarding the seamless integration of smart services with physical products. While the DIN SPEC 33454 (2019) provides comprehensive insights into developing smart services, it does offer limited guidance on the intricacies of aligning these services with the lifecycle and design of physical products. Smart PSS inherently combines products and services into cohesive solutions (Zheng et al., 2017; Valencia et al., 2015). Hence, a more integrated approach that equally emphasizes product development processes and how they intertwine with service innovation could enhance the applicability of the guideline (Aurich, 2019; Stark and Müller, 2010).

Comprehensive stakeholder engagement strategies: While DIN SPEC 33454 (2019) emphasizes the importance of user-centric design, there could be a broader focus on comprehensive stakeholder engagement strategies. Smart PSS development often involves a complex ecosystem of stakeholders, including suppliers, partners, regulators, and end-users. A critique here is the need for more detailed methodologies for engaging with and balancing the interests of these diverse stakeholder groups throughout the service development process (Da Costa Fernandes, 2016).

Data privacy and security considerations: Given the critical role of data in smart services, DIN SPEC 33454 (2019) could enhance its focus on data privacy and security considerations. As smart PSS often rely on the collection, analysis, and exchange of data, ensuring the privacy and security of this data is paramount (Mennenga et al., 2020; Zheng et al., 2019). More explicit guidance on implementing robust data governance frameworks, compliance with regulatory requirements, and the adoption of state-of-the-art security measures would strengthen the standard's relevance in today's data-driven landscape (Ying et al., 2022; Dominik et al., 2020).

Business Model Innovation: Lastly, while DIN SPEC 33454 (2019) provides a foundation for developing smart services, it does underemphasize the importance of business model innovation. Smart PSS development is not only about creating technically viable services but also about ensuring these services are embedded within feasible and scalable business models (Yan et al., 2022). Insights into designing business models that capitalize on the unique value propositions of smart services, including considerations for monetization strategies, value networks, and partnership models, would be great enhancements.

4.3 Framework analysis: DevOps

The DevOps framework represents a transformative approach to the development and operation of software, emphasizing continuous integration, continuous delivery (CI/CD), automation, and close collaboration between development and operations teams. It aims to shorten the software development life cycle, enhance deployment frequency, and achieve a high degree of system reliability and security. While DevOps has proven to be highly effective in software development environments, applying it within the context of smart PSS development brings forth unique challenges and considerations.

Integration with hardware and physical product development: One of the critical critiques of DevOps in the context of smart PSS is its primary focus on software development and operations, potentially overlooking the integration with hardware and physical product development. Smart PSS often involves complex interactions between software, hardware, and service components. The traditional DevOps model may not adequately address the slower pace and different nature of hardware development cycles, leading to challenges in synchronizing software and hardware development processes (Blüher et al., 2023; Macarthy and Bass, 2020).

Service evolution and lifecycle management: DevOps encourages rapid iteration and continuous improvement, primarily focusing on software. However, in the smart PSS context, this approach needs to be balanced with the lifecycle management of the service and product components (Leite et al., 2020). The critique here revolves around the need for a framework that not only supports fast-paced software updates but also considers the longer lifecycle of physical products and the evolution of services over time. Guidelines for managing the entire lifecycle of smart PSS, incorporating principles of adaptability and evolution, would be a valuable addition to the DevOps framework (Spohrer and Demirkan, 2015).

Broad stakeholder collaboration beyond development and operations: While DevOps promotes collaboration between development and operations teams, smart PSS development requires a broader scope of stakeholder engagement, including product designers, service engineers, customers, and even regulatory bodies. The framework could be critiqued for its limited focus on the internal aspects of software development and operations, without providing sufficient mechanisms for integrating external stakeholder inputs into the continuous development and deployment cycles. Expanding the collaborative principles of DevOps to include these additional stakeholders may enhance its effectiveness in smart PSS development.

Business model alignment and value creation: Lastly, DevOps focuses on improving efficiency, reliability, and speed in software delivery, which is undoubtedly beneficial for smart PSS (Erich, 2014). However, the framework might not directly address how these improvements translate into business model innovation and value creation for smart PSS (Blüher et al., 2023). The critique suggests a need for clearer guidance on aligning DevOps practices with business strategies that capitalize on the combined value of products and services, including models for monetization, customer engagement, and competitive differentiation.

4.4 Proposing a novel framework for smart PSS development

Our research bridges the gap between academic rigor and practical application. At the core of our methodology is the integration of academic frameworks with the practical insights derived from a collaborative venture with six German SMEs (see Table 3). This partnership not only enriched our understanding but also ensured that the model was tailored to meet the needs of industry practitioners. The collaboration with SMEs was crucial, providing a practical foundation upon which our framework was constructed. The initial conceptualization of our framework was thus a product of both academic inquiry and practical feedback, embodying the principles established through our rigorous review of existing literature and the real-world experiences of our industry partners. Building upon the comprehensive analysis of various frameworks and methodologies, we propose a novel, structured process model tailored for the development of smart PSS (see Figure 3).

This framework is the result of synthesizing the most effective attributes identified across existing frameworks, aiming to merge their strengths and overcome their limitations to forge a more inclusive and potent tool for smart PSS development. Our study follows a standardized modeling sequence to outline our framework (Figure 2). Initially, we establish the phases, followed by the delineation of steps and tasks, including the assignment of roles accountable for these tasks, along with the identification of methods and tools. This structured approach not only facilitates a thorough understanding of each phase of development but also ensures that the necessary tools and methodologies are employed to their full potential.

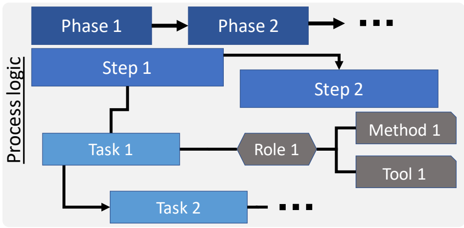

Figure 2. Process modelling logic

The model is methodically segmented into three interconnected phases, each foundational yet iterative, allowing for flexibility and adaptability throughout the development process. It incorporates a dual-cycle approach, juxtaposing the development and operation cycles to ensure a seamless transition from design to market. The model initiates with a pronounced focus on system analysis, emphasizing customer integration and stakeholder involvement from the outset.

The development phases are intricately designed to ensure a thorough understanding of consumer needs, beginning with extensive market analysis and consumer research. This foundational stage is pivotal for identifying market gaps and opportunities for innovative smart PSS introductions. Subsequent stages involve meticulous planning, design, testing, and implementation, each geared towards realizing a product or service that aligns with strategic business goals and fulfills consumer expectations. Notably, the process incorporates a learning stage aimed at continuous improvement, leveraging user feedback and operational insights to refine and enhance the smart PSS post-deployment.

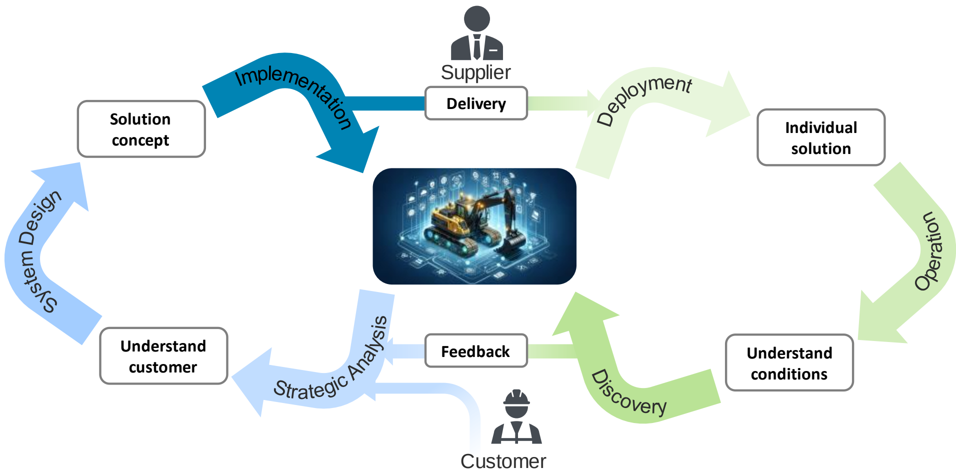

Figure 3. Framework for smart PSS development

P1 - Strategic Analysis: The journey of smart PSS development begins with the Strategic Analysis phase. This foundational stage involves a meticulous exploration of market dynamics, technological capabilities, and customer requirements to identify novel opportunities for smart PSS innovation. Key activities during this phase include stakeholder and market analysis, technological assessments, and the identification of customer needs through innovation workshops and roadmapping. The primary goal is to develop a deep understanding of customer needs, ensuring that the resulting smart PSS not only leverages cutting-edge technology but also delivers tangible customer benefits and is economically viable.

P2 - System Design: Progressing from strategic analysis, the model moves into the System Design phase. This phase is centered on transforming the insights and business ideas evaluated in the previous phase into detailed solution concepts. It encompasses the design of subsystems and components, underpinned by a rigorous development of the business case. This involves exploring customer willingness to pay, estimating cost structures, defining yield mechanics, and determining the value network. A critical element of this phase is the analysis and definition of data needs and availability, crucial for value creation across the value network. The objective is to formulate a comprehensive business case and a well-defined solution concept, ready for development and operationalization.

P3 - Implementation: The implementation phase represents the final phase of the development cycle, focusing on bringing the developed smart PSS to life within an organizational context. It involves laying down both the technical and organizational foundations required for a successful market launch. This phase entails a broad range of activities, including requirements management, system decomposition into modular components, system architecture development, prototyping, and service demonstration. Additionally, it covers production planning, application system development, and preparation for delivery. The ultimate goal of this phase is to deliver a functional Minimum Viable Product (MVP) or smart PSS prototype, ready for real-world application.

The operations cycle of the smart Product Service Systems (PSS) plays a crucial role in transitioning from theoretical design frameworks to their practical, real-world utility, focusing significantly on sustained value generation. This cycle commences with the smart PSS being delivered to the customer by the supplier, marking the initiation of the deployment phase.

P4 – Deployment: This phase is vital for the rollout of the system, ensuring its connectivity and functionality are up to par, providing essential support during the setup and the system's go-live. The deployment is meticulously designed to implement an individualized solution that caters specifically to the customer's needs, ensuring a smooth transition to operational status.

Conducting comprehensive tests to confirm that all features and functionalities of the smart PSS operate according to specifications. Ensuring that all components of the smart PSS are correctly integrated and communicating as intended, both internally and with external systems.

P5 – Operation: Following deployment, the smart PSS transitions into the regular operation phase, where the primary focus shifts towards creating value and maintaining operational capability. This stage is characterized by the continuous monitoring and management of the system to ensure optimal performance under varying conditions. It's during this phase that the smart PSS begins to generate real-life data from field operations, offering invaluable insights into usage patterns, system performance, and identifying potential areas for improvement. The aim here is to leverage the full capabilities of the smart PSS to create tangible value for the customer, such as improving efficiency, reducing costs, or enhancing the quality of service.

P6 – Discovery: An integral component of the operations cycle is the feedback loop. Insights derived from the regular operation phase are meticulously channeled back into the development cycle, facilitating an iterative process that ensures continuous improvements and technical advancements to the smart PSS. This feedback mechanism allows for systematic adjustments and optimizations to refine the system, addressing evolving customer needs and operational challenges. Moreover, it serves as a catalyst for innovation, enabling the identification of new opportunities for further enhancements and the development of next-generation smart PSS solutions that promise even greater value and performance.

By emphasizing data generation, analysis, and the integration of feedback into ongoing development efforts, the operations cycle transforms the smart PSS from a static offering into a dynamic ecosystem capable of evolving over time. This approach ensures that the smart PSS not only meets the current demands of customers but is also well-positioned to adapt to future challenges and opportunities, securing its relevance and efficacy in the fast-paced technological landscape. Through this continuous cycle of deployment, operation, and feedback, the smart PSS framework fosters a culture of perpetual improvement and innovation, laying the groundwork for the sustained success of smart PSS in the market.

5 Reflective conclusion and outlook

The proposed framework is synthesized from a thorough analysis of existing methodologies and specifically tailored for the unique needs of smart PSS, is designed to serve as a holistic guide for developers delving into the realm of smart PSS design. At its core, our approach advocates for a comprehensive strategy that effectively integrates various existing models, maximizing their strengths while meticulously addressing the distinct challenges they present. Feedback from industry practitioners, focusing on the framework's applicability, ability to reduce complexity, flexibility, practical relevance, and overall usefulness, has been invaluable for refining our methodology. Their positive reception of the framework's broad applicability and its effectiveness in simplifying complex processes has shown avenues for further enhancement, particularly in terms of customization and flexibility. The call for incorporating agile methodologies and real-life case studies has emphasized the importance of a framework that is not only theoretically robust but also practically agile, capable of adapting to the evolving demands of projects. The suggestion to enrich the framework with more methods, tools, roles, and practical templates, drawing from best practices, underscores the necessity for a dynamic and evolving toolkit.

The next phase, involving the application of the framework within an industrial setting, promises to be a test for its effectiveness and usability. This real-world application is expected to provide critical insights, enabling the iterative refinement of the framework and bolstering its utility in facilitating smart PSS development. Incorporating feedback from practitioners into the next iteration of the framework – with an emphasis on improving customization options, further simplifying its structure, and integrating agile elements and practical examples – reflects a methodical approach to advancing intelligent product service systems. This blend of empirical insights and theoretical foundation aims to deliver a tool that is both academically solid and pragmatically useful.

In summary, the framework we propose establishes a strong foundation for addressing the intricate challenges of smart PSS development. However, its success will ultimately be measured by its ability to adapt to the diverse needs of different industries. The forthcoming phase of deployment and testing within an industry use-case is critical for assessing the framework's practical applicability and for refining its guidelines to more effectively support the development of innovative and sustainable smart PSS solutions. This step is not only vital for enhancing the framework but also for advancing the discourse on smart PSS development, significantly contributing to the field's body of knowledge and setting the stage for future research and practical applications in this dynamic and evolving domain.

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