Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 136 (2025) 189–194

www.elsevier.com/locate/procedia

35th CIRP Design 2025

Analysis on industrial framework conditions for a holistic system development process

"Veronika Spale, Uwe Kenntner*, Christian van Husen"

Furtwangen University, 78120 Furtwangen, Germany

* Corresponding author; *E-mail address:* veronika.spale@hs-furtwangen.de ; uwe.kenntner@hs-furtwangen.de

Abstract

This paper summarises the results of the project “Hyper” (Holistic System Development Process) and provides a foundation for future research. The project analyses the development process for product-service systems (PSS), taking into account boundary conditions and influencing factors. The aim of the project was to clarify the needs of a holistic approach, how it can support the innovation and development of PSS and which industries could benefit most from it. Data was collected through 14 expert interviews in the manufacturing industry and a consolidation and systematic workshop, in order to develop a framework that comprehensively defines boundary conditions for an ideal PSS development process.

Keywords: Product-Service System ; Holistic framework; PSS development process

1. Introduction

The development of product-service systems (PSS), which consist of a physical product and associated services, represents a complex and multifaceted field that poses numerous challenges [1]. In the industrial context, several critical questions arise: Which development models are most appropriate for PSS? Is there an ideal model, or should a tailored approach be developed? Additionally, decisions regarding the use of agile, hybrid, or traditional development methodologies must be made. Various constraints – such as regulatory, technological, and market-related factors – must be considered.

A key aspect of this process is the integration of services in the early stages of product development. Although services hold significant potential to enhance the value and adaptability of traditional products – paving the way for innovative business models – they are often considered only in later phases of development, as confirmed from the interviews. This delayed consideration limits the capacity of the service components to realize their full potential, as they are not fully embedded into the design and operational framework of the product from the beginning.

Moreover, product development is undergoing significant transformation. Globalised markets, rapid technological advancements and an increasing emphasis on sustainability are introducing new complexities for companies. In response to these challenges, the concept of a holistic product development process, one that integrates all stages of the product life cycle – from first idea to end-of-life management – is gaining increasing attention.

Accordingly, the aim of this study is to answer the following research question: **How should a framework be defined to represent the holistic complexity and all boundary conditions for product-service systems?**

For this, it is necessary to explore the specific requirements of a holistic approach in the context of PSS and to investigate

10.1016/j.procir.2025.08.034

how early integration of services can enhance innovation and development.

2. Methodology

The aim of the project was to specify the requirements for a holistic approach and to analyse how this can promote the innovation and development of an industry-oriented product-service system. Particular attention was paid to value creation through services and the early integration of business models. The following methodology as seen in Figure 1 was used to achieve the aim.

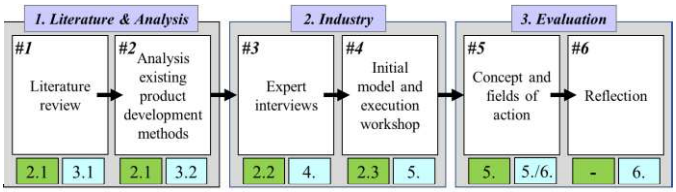

Figure 1 – Methodology

Each of the steps one to six in Figure 1 also contains a green and a blue field with a corresponding number. The green boxes show the section of this article in which the methods are described in more detail and the blue boxes show the sections with the corresponding results.

2.1. Literature review and analysis of existing product development methods

Firstly, a comprehensive literature review was conducted to create the theoretical basis for the research. More than 20 existing methods in product development processes were analysed. The literature review provided an overview of the current state of research and practice and served as a basis for a subsequent empirical study.

2.2. Expert interviews

Based on the literature research, guided interviews were conducted with experts from various sectors in the field of product development, such as the development department, product management, production management, homologation department, sales and others. The aim of the interviews was to gain deeper insights into current practices and challenges in product development processes. The interviews focussed on three main topics:

- How is the product development process currently carried out?
- What boundary condition and external factors need to be considered in the development process?
- How are the individual hardware, software and services value streams organised within the product development cycle?

The interviews were conducted on the basis of open questions in order to give the participants room for detailed answers and individual perspectives. The results of the interviews provided valuable qualitative data that served as the basis for the initial development of a conceptual model for a holistic product development process.

2.3. Development of initial model and execution of a workshop

An initial model was developed based on the findings from the literature research and the qualitative interviews. This model aimed to integrate the various phases of the product life cycle and to take the identified boundary conditions and value streams into account. Among other things, one of the basic ideas relates to the differentiation and coupling of the hardware and software value streams in the automotive industry [2].

A workshop session was held to validate and further refine the model. Key stakeholders from the manufacturing industry, including interview participants and other experts, were invited to this workshop to review and discuss the proposed model. During the workshop, the preliminary results were presented and participants had the opportunity to provide feedback and participate in collaborative discussions. The aim of the workshop was to explore the applicability of the model in greater depth and helped to identify areas for improvement. The feedback gathered was then incorporated into the further development of the concept.

3. Literature review and analysis of existing product development methods results

3.1. Development of Product-Service Systems

PSS essentially consist of a material product that is supplemented by various services products in a targeted manner over the various phases of its use, i.e. its life cycle [3]. In contrast to traditional business models, which usually only offer products or services in isolation, PSS enables both elements to be closely interlinked.

PSS can be divided into different types, depending on the focus on product or services: product-oriented systems offer services as a supplement to the product, benefit-oriented systems focus on the use of the product by the customer instead of ownership, such as leasing or pay-per-use models and result-oriented systems, in which actual services are in the foreground and the product is only a means of achieving the services objective [4]. These different PSS models allow flexible adaptation to different business strategies and market requirements.

The advantages of PSS lie in extended value creation [5] that spans the entire product life cycle, greater customer satisfaction and loyalty [6] and potentially more sustainable resource utilization. However, there are also long-term processes [7] whose complexity lies in the fact that the entire product life cycle must be considered in order to generate customer value. There are also challenges, particularly when integrating services elements into traditionally product-focused development processes, as traditional business models need to be modified [7, 8]. This requires both – changes in the corporate culture and organisational adjustments, such as the redefinition of responsibility for products, changes to pricing

models, risk structures, customer relationships and technological requirements [6, 7, 9].

Modern technologies are essential for the successful implementation of a PSS. Internet of Things (IOT) systems, for example, enable real-time monitoring of products in use, which improves services planning and can extend the life of services through predictive maintenance [7, 10].

3.2. Agile & traditional development methods

There are many different development models that can be used by the manufacturing industry. This paper will focus on agile and traditional development models.

To analyse the different product development methods, a total of 25 relevant sources were consulted, which describe different approaches and their application in product development. Based on this literature research, 20 development models were identified and subjected to a detailed analysis of their strengths and weaknesses. This analysis enabled a well-founded evaluation of the respective models with regard to their suitability for different development requirements and framework conditions.

Traditional development models, such as the stage-gate, waterfall or V-model, follow a sequential process with clearly defined phases and milestones [11]. These models offer a high degree of predictability and controllability [12-14], which makes them particularly suitable for the development of physical product elements in PSS. In interviews with experts, the stage-gate model was identified several times as a currently widespread methodology. However, the limitations of traditional models lie in their limited flexibility [13-16], which often makes adjustments during the development process more difficult.

Agile development approaches such as Scrum, Kanban or Lean, on the other hand, are based on iterative processes that enable continuous adaptation to changing requirements. Their flexible structure is considered particularly suitable for the dynamic development of software and service components in PSS, as they support a rapid response to market requirements [12, 13, 17] and customer feedback [12, 13]. The prioritisation of requirements in a backlog [13] also makes it possible to adjust the sequence and content, which increases agility. However, such models require a high level of personal responsibility and adaptability to the size of the teams and are potentially less suitable for highly regulated and structurally defined processes [13, 14, 16]. Table 1 shows a simplified overview of strengths and weaknesses of agile and traditional product development methods.

Table 1 – Simplified overview of strengths and weaknesses of agile and traditional product development methods

Characteristics of process / project	Agile develop-ment	Models and sources	Traditional develop-ment	Models and sources
Easy use / Implementation	Low	Scrum, Lean, Kanban [16]	High	Waterfall, V-Model, RUP [15, 16]
Predictability / clearly defined	Low	Scrum, Agile Waterfall [13-15]	High	Waterfall [12-14]
Project time	Short	Scrum, Test driven development [13, 16]	Long	Stage-Gate, Waterfall [11, 13]
Adaptation to changes	Quick	Agile Waterfall, Extreme programming, Evolutionary, Spiral, Scrum, Scrum at Scale, Nexus [11-13, 16, 17]	Slow	Waterfall, V-Modell, Stage-Gate [11, 13-16]
Project team size	Small	Extreme programming, Scrum, Scrum at scale [13, 15, 16]	Large	Waterfall [7, 13]
Customer relevance and feedback implementation	High / Early	Scrum, SAFe Framework, LeSS [13, 14, 16, 18, 19]	Low / Late	Waterfall, V-Modell [7, 13]

3.3. Business models

The selection and integration of suitable business models is a key challenge in the development of PSS. Traditional business models, based purely on the sale of physical products, are often not sufficient to realise the full potential of a PSS [20]. Complementary approaches such as pay-per-use, subscriptions and license models offer new opportunities to increase value creation and customer loyalty in the long term [21, 22]. Such models enable companies to generate recurring revenue while at the same time catering more closely to the needs and usage habits of customers.

In practice, however, it is often the case that companies only decide on the business model at later stages of the product development process, which can significantly limit the potential of a PSS [8]. In contrast, incorporating the choice of business models into the development process at an early stage could help to optimise the synergies between product, services and value creation [23]. An integrated business model not only supports the efficient utilisation of resources, but also promotes flexibility in responding to market requirements and technological developments.

4. Expert interviews results

The aim of the expert interviews was to answer the research question: How should a framework for representing the overall complexity and all boundary conditions for PSS be defined and designed? The interviews were conducted in order to gain a deeper understanding of the complex requirements of such a framework and to shed light on the specific challenges that arise in the context of PSS.

In order to take a holistic approach regarding the challenges and opportunities of PSS, the experts were carefully selected to cover a wide range of industries and positions. By including experts from different industries and positions, from product management to research and development and sales, it was possible to gain a variety of perspectives. In the end, a total of 14 professionals with extensive knowledge of the product development process were selected for the expert interviews, as seen in Table 2.

Table 2 - Overview sectors and departments of the interviewed experts

Interviewee	Sector	Department
I1	Sensor systems	Product development manager / process manager
I2	Gear and transmission technology	Innovation and technology manager
I3	Medical technology	Product manager
I4	Sensor systems	Head of development
I5	Mechanical engineering	Innovation manager
I6	Electronics industry	Innovation manager
I7	Rotary and linear drive technology	Business development
I8	Medical technology	Director business model design
I9	Hygiene and sanitary products	Production management
I10	Railway industry	Sales manager
I11	Railway industry	Sales manager
I12	Sensor systems	Product manager
I13	Sensor systems	Portfolio manager
I14	Railway industry	Regulatory Affairs Manager

The following section summarises the most important findings from the expert interviews:

4.1. Software vs. Hardware

In the majority of cases (8 out of 14 experts), a clear focus is placed on hardware development in the development process, as seen in Figure 2. However, five of the interviewed experts emphasised that the aim is to develop hardware and software in parallel, whereby the software is often developed further after the market launch in order to integrate additional functionalities or improvements. Two clearly separate value streams were identified for hardware and software, which is due to the different requirements and development cycles of the two components. In contrast, there is no separate, clearly defined value stream for the services component, which indicates a lower level of formal integration in the development process.

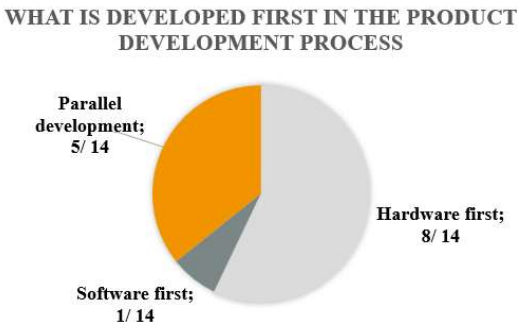

Figure 2 - Software vs. Hardware

4.2. New service vs. product development

The interviews make it clear that the services part of the development process is often neglected. 3 out of 14 experts stated that services are treated on an equal footing with new development. Almost half of those surveyed (6 out of 14) stated that giving services a higher priority in the development process is not a long-term goal. This emphasises the continued focus on physical product development, while services are often seen as a secondary consideration. The results are depicted in Figure 3.

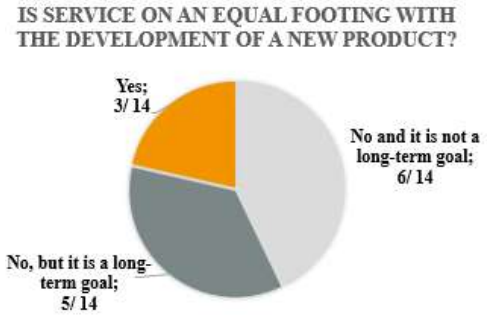

Figure 3 - New Service vs. product development

4.3. Current business models and implications for the PSS framework

The expert interviews clearly show that the traditional business model of product sales continues to dominate, as seen in Figure 4. All of the experts interviewed (14 out of 14) confirmed that their focus is on traditional sales concepts. Although there are initial attempts to implement alternative models such as pay-per-use, licence models or subscription-based models, these are often still in the introductory phase and are not widespread. Another key problem is that the choice of business model is not made consistently at the beginning of the product development process. Rather, this decision is made at different points, often late in the development process, which makes it difficult to implement a holistic framework for PSS.

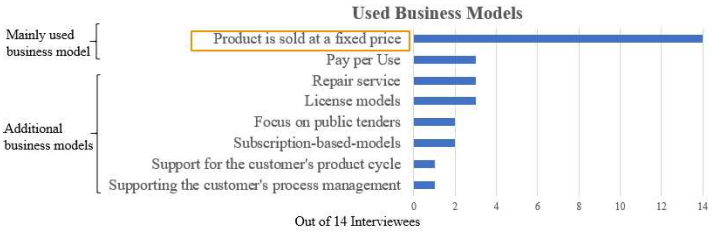

Figure 4 – Currently used business models

The expert interviews showed that a large number of boundary conditions influence the product development process. These can be divided into two main categories: external and internal factors, as shown in Table 3. External factors, such as market requirements, customer needs and industry-specific specifications, cannot be directly influenced by companies. Internal factors, on the other hand, such as the size of the project, the choice of development methods and internal resources, are under the control of companies and can be specifically managed.

Table 3 - Overview over external and internal factors of the product development process

External factors	Internal factors
Customer requirements	Methods (traditional vs. agile)
Regulatory conditions	Organisational framework (Area of expertise / resources, qualified employees, team size...)
Megatrends	
Security requirements (security of supply, cyber security)	Corporate goals (e.g., market coverage, cost savings, sustainability goals, etc.)
Framework conditions of the business areas	Corporate culture
Ecosystem	Digitalisation
Dependence on public funds	

5. Workshop results and current concept

In this section, the results of the workshop and the first concept of a holistic PSS are presented. After the results from the interviews were analysed, a workshop was held in which an initial model concept was presented and further developed. Five participants – mostly consisting of the experts already interviewed in the expert interviews – were invited to evaluate an initial concept of a planned framework. The concept shown in Figure 5 emphasises the importance of defining a comprehensive overall idea at the beginning of the product development process that integrates hardware, software and services components of the PSS. A central element of this overall idea is the early selection of one or more business models that are to be pursued throughout the entire development process. By simultaneously defining the business models and the central product and services components, the PSS should be clearly structured and strategically aligned as a holistic system from the outset.

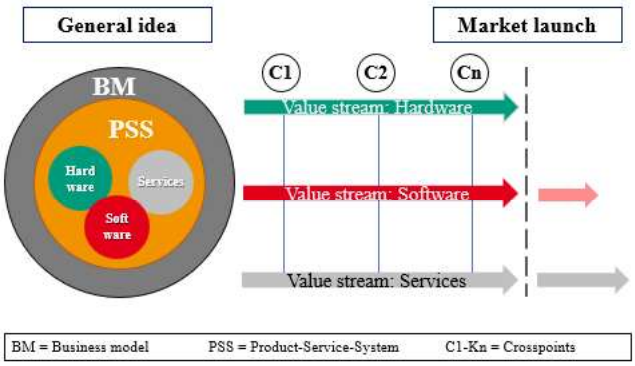

Figure 5 - First concept of a holistic model

Another key component of the concept is the early definition of three separate, but flexibly linked value streams for hardware, software and services. This clear structuring is intended to ensure that the services potential of the product-service system is utilised as fully as possible. The targeted coupling and decoupling (C1, C2, Cn) of these value streams throughout the entire product development process enables flexible coordination, which allows the necessary connections to be established in a timely manner and enables a rapid response to short-term changes. This approach promotes a dynamic development environment that can respond adequately to both internal requirements and external influences.

During the workshop, the concept presented was, together with the participants, further developed and specific adjustments were made, using the analysis tool in Figure 6.

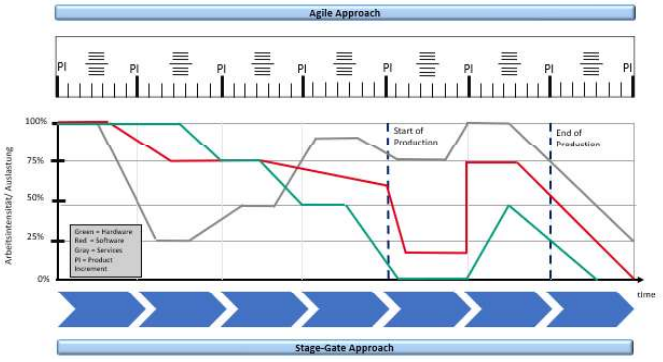

Figure 6 – Analysis tool for the manufacturing industry

The participants confirmed the design of the model, although they pointed out additional topics that have to be looked at with further consideration:

Fundamental confirmation of the model – The participants confirmed the basic structure and approach of the concept, but recognised that its applicability depends heavily on industry-specific terms and definitions.
Consideration of agile and traditional timelines – The need to integrate agile and traditional development approaches was

emphasised:

- Agile phases: The ‘backlog principle’ was emphasised as central here. Milestones are defined, while requirements can be flexibly prioritised and adapted. Tasks are prioritised between the phases, which can be changed as required.
- Traditional methods: The predominant model cited was the classic stage-gate model, which was identified in the expert interviews by 6 of the 14 interviewees as the product development model currently in use.

Coupling and decoupling points of the value streams – The participants noted that the respective labour intensities must be considered when defining coupling and decoupling points between the value streams (hardware, software, services). This allows effective synchronisation to be achieved and variable development requirements to be addressed flexibly.

6. Conclusion, discussion and further research opportunities

The primary research question "How should a framework be defined to represent the holistic complexity and all boundary conditions for product-service systems?" has been addressed in this study. Key boundary conditions were identified, and an initial model was developed to capture the multifaceted nature of PSS. This model lays the groundwork for an integrative approach to PSS development, enabling companies to better navigate the inherent complexities of combining product and services elements.

The study underscores the importance of clearly defined terms and frameworks, as many definitions were found to vary significantly across industries. For the successful adoption and implementation of a comprehensive PSS framework, it is crucial that future research efforts address these definitional nuances and standardise terms where possible. Furthermore, the framework’s applicability is affected by specific factors such as business models (e.g., B2B vs. B2C) and supply chain levels (e.g., Tier-X suppliers). These distinctions should be considered in subsequent iterations to ensure that the model’s flexibility and relevance extend across diverse industrial applications.

To further validate and refine this concept, it is essential to include up to ten additional companies in further research opportunities, allowing for a broader practise-based evaluation and the incorporation of industry-specific adjustments. The insights gained through these collaborations will contribute to refining the model, enhancing its applicability and relevance across various sectors.

References

[1] T. S. Baines *u. a.*, „State-of-the-art in product-service systems“, *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, Bd. 221, Nr. 10, S. 1543–1552, Okt. 2007, doi: 10.1243/09544054JEM858.

[2] D. Slama, A. Nonnenmacher, und T. Irawan, *The Software-Defined Vehicle - A digital-First Approach to Creating Next-Generation Experiences*. Zugegriffen: 24. April 2024. [Online]. Verfügbar unter: https://www.bosch-mobility.com/media/global/mobility-topics/mobility-topics/software-defined-vehicle/download/231019_sdv_ebook.pdf

[3] J. C. Aurich, Hrsg., *Produkt-Service Systeme: Gestaltung und Realisierung*. Berlin Heidelberg: Springer, 2010.

[4] A. Tukker, „Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet“, *Bus. Strategy Environ.*, Bd. 13, Nr. 4, S. 246–260, Juli 2004, doi: 10.1002/bse.414.

[5] T. Sakao und M. Lindahl, *Introduction to product/service-system design*. London: Springer, 2009.

[6] C. Schnürmacher, „Providing Product-Service-Systems - The Long Way from a Product OEM towards an Original Solution Provider (OSP)“, *Procedia CIRP*, 2015.

[7] T. Blüher, D. C. Amaral, K. Lindow, J. M. H. Costa, und R. Stark, „Research opportunities in PSS design focusing on the potentials of agile approaches“, *Procedia CIRP*, Bd. 84, S. 832–837, 2019, doi: 10.1016/j.procir.2019.04.275.

[8] H. Meier, R. Roy, und G. Seliger, „Industrial Product-Service Systems—IPS 2“, *CIRP Ann.*, Bd. 59, Nr. 2, S. 607–627, 2010, doi: 10.1016/j.cirp.2010.05.004.

[9] R. Oliva und R. Kallenberg, „Managing the transition from products to services“, Nr. International Journal of Service Industry Management, Apr. 2024.

[10] S. R. Moro, P. A. Cauchick-Miguel, und G. H. S. Mendes, „Product-service systems benefits and barriers: an overview of literature review papers“, Bd. 11, Nr. 1, 2020.

[11] A. Bhatia, J. Cheng, S. Salek, V. Chokshi, und A. Jetter, „Improving the Effectiveness of Fuzzy Front End Management: Expanding Stage-Gate Methodologies through Agile“, in *2017 Portland International Conference on Management of Engineering and Technology (PICMET)*, Portland, OR: IEEE, Juli 2017, S. 1–8. doi: 10.23919/PICMET.2017.8125390.

[12] M. Malikov, F. A. Aloraini, H. Kavak, und W. G. Kennedy, „DEVELOPING A LARGE-SCALE AGENT-BASED MODEL USING THE SPIRAL SOFTWARE DEVELOPMENT PROCESS“.

[13] W. V. Casteren, „The Waterfall Model and the Agile Methodologies : A comparison by project characteristics“, 2017, doi: 10.13140/RG.2.2.36825.72805.

[14] H. J. M. Ruël, T. Bondarouk, und S. Smink, „The Waterfall Approach and Requirement Uncertainty: An In-Depth Case Study of an Enterprise Systems Implementation at a Major Airline Company“, *Int. J. Inf. Technol. Proj. Manag.*, Bd. 1, Nr. 2, S. 43–60, Apr. 2010, doi: 10.4018/jitpm.2010040103.

[15] N. M. A. Munassar und A. Govardhan, „A Comparison Between Five Models Of Software Engineering“, Bd. 7, Nr. 5, 2010.

[16] University of Houston-Clear Lake,Houston, Texas, USA., M. Sameen Mirza, und S. Datta, „Strengths and Weakness of Traditional and Agile Processes - A Systematic Review“, *J. Softw.*, Bd. 14, Nr. 5, S. 209–219, Mai 2019, doi: 10.17706/jsw.14.5.209-219.

[17] F. Almeida und E. Espinheira, „Large-Scale Agile Frameworks: A Comparative Review“, *J. Appl. Sci. Manag. Eng. Technol.*, Bd. 2, Nr. 1, S. 16–29, März 2021, doi: 10.31284/j.jasmet.2021.v2i1.1832.

[18] J. Verlinden, F. van Duijnen, und I. Horvath, „Validating the strengths and w eaknesses of I nteractive Augm ented Prototyping in I ndustry“, 2010.

[19] A. Putta, „Benefits and Challenges of Adopting the Scaled Agile Framework (SAFe): Preliminary Results from a Multivocal Literature Review“.

[20] O. K. Mont, „Clarifying the concept of product–service system“, *J. Clean. Prod.*, Bd. 10, Nr. 3, S. 237–245, Juni 2002, doi: 10.1016/S0959-6526(01)00039-7.

[21] S. Balasubramanian, S. Bhattacharya, und V. V. Krishnan, „Pricing Information Goods: A Strategic Analysis of the Selling and Pay-per-Use Mechanisms“, *Mark. Sci.*, Bd. 34, Nr. 2, S. 218–234, März 2015, doi: 10.1287/mksc.2014.0894.

[22] C. W. J. Lindström, B. Maleki Vishkaei, und P. De Giovanni, „Subscription-based business models in the context of tech firms: theory and applications“, *Int. J. Ind. Eng. Oper. Manag.*, Bd. 6, Nr. 3, S. 256–274, Juli 2024, doi: 10.1108/IJIEOM-06-2023-0054.

[23] T. Baines *u. a.*, „Towards an operations strategy for product-centric servitization“, *Int. J. Oper. Prod. Manag.*, Bd. 29, Nr. 5, S. 494–519, Apr. 2009, doi: 10.1108/01443570910953603.