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A Technology-centered Framework for Product-Service Systems

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Abstract

Product-Service Systems (PSS) integrate product and service elements and thus are a basis for better differentiation from the competition, better fulfillment of customer demand and sustainability. Scientific approaches describing PSS often neglect the key resource technology; despite the fact that great potential for innovations can be achieved through disruptive technologies and an extended view on technologies. Extending the view means incorporating services and infrastructure in the technology management of PSS. To meet that research gap, we present a framework describing a layer model for PSS including goals on the upper level, PSS elements at medium level and technologies at the bottom. The layers are connected by means-end relations to highlight the correlations between goals and PSS elements as well as PSS elements and technology.

Keywords: PSS framework; technology; layer model for PSS

1. Introduction

Product-Service Systems (PSS) are an approach for companies to cope with several challenges such as raising customer expectations regarding cost and quality. This is enabled by integrating service and product components in one market offer [1]. Tukker [2] characterizes three different types of PSS: 1) Product-oriented PSS embrace product related services as well as advice and consultancy. 2) Use-oriented PSS incorporate product renting, leasing or pooling. 3) Result oriented PSS incorporate activity management, pay per service unit and functional result.

Developing and delivering PSS raises the complexity, for example due to the higher number of involved domains. For managing that complexity, integrated approaches supporting the development or delivery of PSS are necessary (cp. [3]).

Of particular interest for the development and innovation of PSS is the key resource "technology". "Technology" is defined as knowledge for solving technical problems [4]. Following the service-dominant logic of marketing (cp. [5]), "the application of specialized skill(s) and knowledge is the fundamental unit of exchange", the importance of technology becomes apparent.

This paper discusses a framework for PSS with the goal of an integrated system description by modeling the constituting elements of a PSS. Particularly the key-resource technology is analyzed. The scope of the term "technology" is widened from a purely product- towards a holistic PSS-perspective. Furthermore findings from innovation and technology management as the "technology-push" and "market-pull concept" are applied to PSS. On a methodical and practical level, the system description serves as an analysis and communication basis for PSS as well as to identify/define innovation potentials for PSS.

Based on a literature study, benefits and limitations of existing frameworks describing PSS were identified. A key finding is the underrepresented regard of the resource "technology" for PSS-innovation amongst scholars. The goal of the framework is to include the relevant action fields in PSS development and to establish a basis for a technology management of PSS. The model is applied exemplarily in a use case. Based on that, conclusions are drawn.

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2. State of the art

This section shows different PSS-frameworks with a particular allowance of "technology" as a basis for the development of the technology-centered framework for PSS framework. McAloone & Andreasen characterize PSS by three domains: artefact system domain, time domain and value domain [6]. Mont considers for product and service components as well as supporting networks and infrastructure in a PSS [7]. A Generic PSS Development Process Model consisting of the three layers value layer, functional layer and module and component layer is presented by Müller & Stark [8]. For application within the planning phase of PSS, Müller et al. discuss the IPS² Layer Method incorporating nine levels which address both the customer view and design layers (e. g. lifecycles activities, core products) [9]. The subsequent design phase is supported by the IPS² Concept Modeling by Sadek & Köster which provides several perspectives on PSS regarding functions, objects and processes [10]. Aurich et al. present a framework for the configuration of PSS integrating stepwise product and services in the context of their lifecycle [11].

Geum et al. [12] describe three different types of technologies within PSS: "enabler technologies" (1) enable the direct integration of product and services. The technology may be embedded into the product (e. g. actors or sensors) or be independent. "Mediator technologies" (2) are available already in a product or service and are used for servitization (or productization). "Facilitator technologies" (3) are applied additionally for servitization and facilitate the problem solving. A condition monitoring system may for example facilitate the operation of a maintenance contract. Sakao et al. [13] discuss how new technologies can be encapsulated within a PSS so that the transfer of knowledge to the user may be prevented.

There exist numerous models of PSS, but technology is hardly addressed explicitly. Sakao et al. [13] state that "research on PSS based on technological innovation is limited". In the next section a technology-centered framework for PSS is presented. It aggregates relevant aspects that have been identified within the literature study and beyond that focusses on "technology".

3. Technology-centered framework for Product-Service Systems

The goal of the framework is to deliver an abstract description of PSS on three levels: goal layer (1), solution layer (2) and technology layer (3) (see Fig. 1). The upper layer describes the goal of a PSS. The medium layer describes the product and service components to fulfill the goals. The bottom layer describes the technologies needed for realization of the PSS. The proximity to the customer rises with ascending layers. The technology layer incorporates the provider's know-how (cp. [4]), the solution layer the know-what and the goal layer the know-why. The layers are interconnected by means-goal relations.

The model illustrates two innovation paths: Top-Down (A) and Bottom-Up (B). Top-down (A), (market pull), a PSS-innovation is initiated by demands or requirements of the customer, the company or the market. On this basis, solutions are defined and suitable technologies are identified or respectively developed. In the bottom-up path (B), (technology-push), new technologies emerge and deliver new potentials on the solution layer. An optimization of a certain key performance indicator is achieved by the technology or entirely new functionalities are enabled. The layers (1-3) are described in detail below. The two innovation paths (A & B) are specified in section 4.

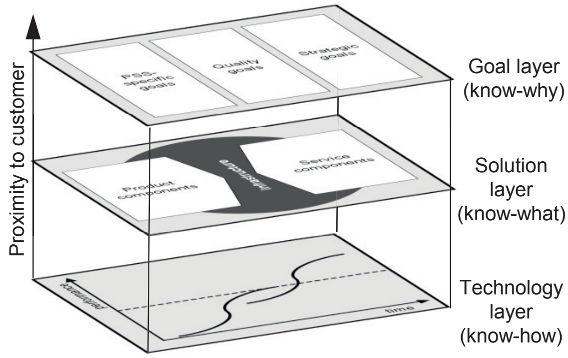

Fig. 1. PSS layer model

3.1. ***Goal layer***

The goal layer (1) consists of three pillars: PSS-specific goals, quality goals and strategic goals.

PSS-specific goals embrace all benefits that are promised by a PSS for both, providers and customers. These goals may consist in the achievement of a higher customer loyalty [2], customer lock-in [14], differentiation from the competition [15], stability of revenues [15], higher revenues [16], new market opportunities [17], higher customer value [16], allowing the customer to focus on core activities and competencies [2] or enhanced sustainability [18, 19].

Quality goals are exhaustively described in Garvin's eight dimension of quality: performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality. Strategic goals may consist in reaching constant revenue streams from PSS in comparison to mere product sales [20], one-face-to-the customer approaches or specific technology strategies.

3.2. Solution dimension

The solution dimension describes concrete components of the PSS (cp. Fig. 2). The model describing product components is based on the Munich Model of Product Concretization, that consists of three levels of abstraction: the function model, the model of working principles and the model of components [21]. A similar description for services on a similar level of abstraction is given by Bullinger et al. [22]. Services are modeled at three dimensions: a product model, a process model and a resource model. These two concepts were integrated into one comprehensive PSS solution model. Service and product components are modeled separately by function models, a model of working principles respectively processes and a model of components respectively resources. Product and service components are linked by the infrastructure which is the coupling element between product and service elements.

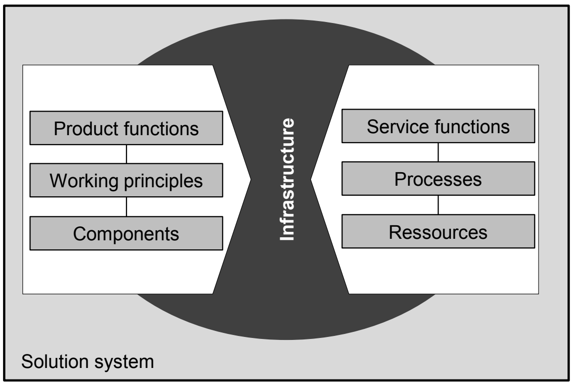

Fig. 2. Solution dimension

3.3. Technology dimension

New and more sustainable technologies are an important factor for PSS. Technical inventions allow for performance improvement and differentiation from the competition. But only by embedding technologies in a competitive PSS-concept, benefits and potentials of a technology can be exhausted and maxed out. A decisive role play bottleneck technologies, or respectively technologies which limit the performance of a PSS-function [23]. These technologies may be product- or service-related, as well as infrastructure-related. They are characterized by technological limits or competition-critical properties. Only by embedding technologies in a PSS, limiting factors may be cleared (cp. [24]): "The history of innovation is littered with companies that had a disruptive technology within their grasp but failed to commercialize it successfully because they did not couple it with a disruptive business model". PSS may both enhance or enable a technology. PSS enhancing a technology

3.3.1. PSS enhancing a technology

The case of enhancing a technology or a product component applying a specific set of technologies by servitization is depicted in Fig. 3.

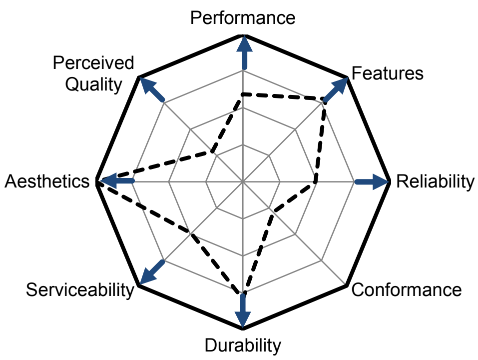

Fig. 3. PSS enhancing a technology

The dashed line depicts the characteristics of a pure technical product, by applying Garvin's eight dimensions of quality (cp. [25]). Delivering better specifications is limited by a mature bottleneck technology. Servitization of the product allows for rising the customer value of a product as stated by many authors, e. g. Baines et al. [15]. Performance may be risen by operating the machine by the specialist staff of a PSS provider (cp. [26]).

3.3.2. PSS enabling a technology

The maturity of technologies is often described by the S-Curve-Phenomenon (cp. [27]). Emerging or substituting technologies may have a lower performance than an established technology [27, 28]. That performance gap can be bridged by integrating the technology in a PSS (see Fig. 4).

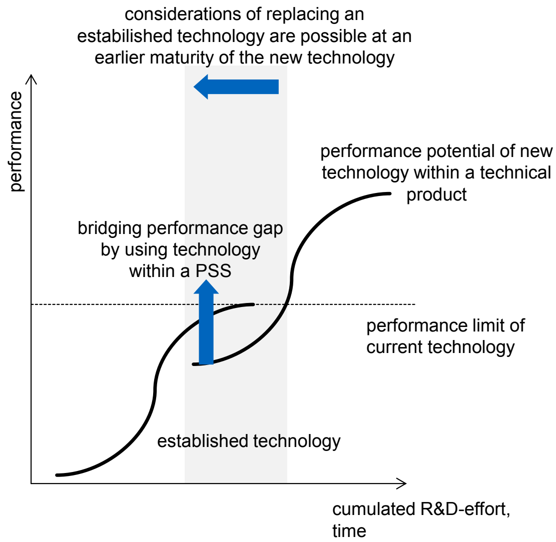

Fig. 4. PSS enabling a technology

Due to the limited capacity to store energy, battery electric vehicles allow for a significantly lower operation distance than fuel powered cars. The performance gap may be bridged by providing a PSS incorporating a battery electric vehicle and delivering a mobility service for long distance travels, for example by providing rental cars within the PSS offer.

4. Innovation paths in the layer model

The layer model introduces a bottom-up and top-down-innovation path to assign the known technology-push/market-pull concept for PSS. Top-down path (A) and Bottom-up (B) path (see Fig. 5) are described in this section.

4.1. Top-down innovation (A)

Firstly, product, service and infrastructure functions and requirements are defined and subsequently suitable technologies are identified. In that case, the solution layer is the driving force: new functions or non-functional requirements are defined – technologies take an enabler role, because they enable the function space. The PSS solution layer triggers a demand for new technologies. The technology dimension provides suitable technologies for delivering the demanded functionality within the PSS layer. This constellation can be found in evolutionary innovation projects.

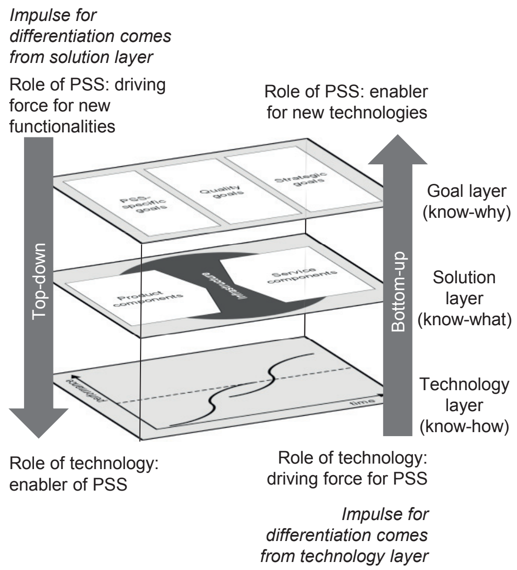

Fig. 5. Innovation paths of PSS

4.2. Bottom-up innovation

Vice versa, new technologies may emerge that deliver new potentials for solving problems and jobs to get done. The technology takes an enabling role because a suitable PSS concept allows for bringing a technology into the market.

Emerging technologies as those deployed in the field of electric mobility are at early stages of their technology-lifecycle (cp. S-Curve above) and often characterized as immature or even disruptive. Such technologies go along with new use potentials but a worse fulfillment in existing performance criteria [29]. The task of a PSS in the bottom-up-path is to wrap promising technologies into a competitive value proposition. On the basis of a technology characterization at the bottom of the PSS layer model, technological limitations, disadvantageous functions or use potentials especially regarding sustainability aspects can be deviated. According to such findings, the "performance dimension" is conceptualized in order to achieve high customer value in the goal dimension.

There is a huge potential for innovations in this constellation as new customer demands may be created or existing customer demands can be met substantially better. First movers define new standards and new types of usage.

The solution layer enables the technology by combining product components, service and infrastructure elements. At best, services contribute for a significantly higher performance or acceptance of the technology. A suitable infrastructure may even enable a faster diffusion of a technological innovation. This constellation is observable in radical innovations.

5. Use-case: BMW i3

To demonstrate a bottom-up innovation project using the layer-model, the battery electric vehicle (BEV) BMW i3 serves as a basis. In the following, benefits of BEVs at the example of the BMW i3 are presented and subsequently limiting factors that accompany the technology are described. In particular the bottleneck technology of Li-Ion batteries is analyzed. The following remarks also demonstrate how technology-related limitations can be overcome, balanced or avoided by a PSS, whereas a sustainable technology is introduced. The model is depicted in Fig. 6, on the basis of publically available information of the BMW i3, mainly from information from the BMW webpage.

In accordance with the PSS layer model, the technology of electromotive powertrains emerges as a generator of sustainability potentials. From a tank-to-wheel viewpoint, zero CO_2-emissions as well as lower noise and smell emissions are achieved in the goal dimension. To name a few examples beside sustainability factors, advantages such as more flexibility in package and design or the potential for new electric/electronic functions, due to the high voltage energy conversion system, can be realized in purpose designed BEVs.

The BMW i3 uses the Li-Ion battery-technology to store energy, which accounts for significant performance shortages compared to internal combustion engines (ICEs). Three limiting factors that correlate negatively with existing performance goals of ICEs are presented in the following. Concurrently the potential of PSS to overcome such performance limitations by service and infrastructure offers is demonstrated. Furthermore limiting factors may be used as a way to create new and more sustainable value propositions as the examples show:

(1) The capacity for storing energy per weight in Li-Ion-batteries equates to one percent of the capacity of gasoline in ICEs [30]. This technological bottleneck limits primarily the driving range and flexibility of use, whereas the commuting behavior in large cities is in most cases not affected. For longer ranges, the offer of a replacement vehicle (e. g. holiday, long distance business trip) can clear this performance limitation (BMW Add-On Mobility). Furthermore the integration of intermodal routing in the navigation system optimizes the mobility behavior by considering alternative and efficient routing options (e. g. use of public transportation, long distance and motor-rail trains, bicycles and scooters, car-sharing).

(2) Given that the chemical reaction of the charging process of Li-Ion batteries cannot arbitrarily be accelerated, another limiting factor are long charging cycles. Although, higher charging amperages enable a shorter charging time for Li-Ion batteries, the life expectancy of the battery will most probably decline. Compared to ICEs, goal criteria such as usability, operational readiness and flexibility in everyday life are therefore limited. To generate an equally comfortable use concept or to rather balance this drawback, the intermediation and installation of home charging stations is offered. Moreover this service/infrastructure measure allows widening the sustainability concept of the BMW i3-PSS. Advisory and

intermediation services in terms of green power supply contracts or solar panels for residential charging stations may be offered to reduce the overall "well-to-wheel" emissions (BMW iWallBox Pure).

(3) Technology-related issues are for instance the costs of required raw materials for which traditional cost saving potentials as economies of scale are not possible [30]. Li-Ion batteries are for instance linked with high raw material costs for copper, manganese or cobalt amongst others. The technology-related disadvantage of a high purchase price can partly be bypassed with the offering of a separate battery leasing (or entire vehicle leasing). High initial costs can be spread and payments submitted on a permanent basis to lower the barrier of a purchase. In addition, the BMW i3 is offered in a car-sharing program to avoid a high purchase price. The use of the electrical vehicle is charged time- or distance-dependent; costs and ownership are therefore fractionalized. The use-based business model may even lead to a more sustainable use of a BMW i3, as the degree of capacity utilization is higher.

Technology layer	*Solution layer*		*Goal layer*
	Service Offers	Required Infrastructure	
limited capacity for storing energy per w eight	provision of replacement vehicle	e.g. vehicle fleet management, processing platform (e.g. booking and payment system, internet portal), service and customer support facilities, mobile devices provided by the user including applications	range, flexibility
	integration of intermodal routing	e.g. server and ICT infrastructure, mobile devices including applications, navigation system, provision of interface to adjacent systems (data of public transportation)	range, flexibility, operational readiness
limited speed of charging process	distribution, installation and allocation services regarding home charging	e.g. w allbox, processing platform: accounting and payment system for electricity	flexibility, operational readiness, usability - long charging
high raw material cost	car-sharing, (Leasing)	e.g. vehicle fleet management, processing platform: booking and payment system, mobile device provided by user w ith application	one-off payment
lacking system require-ments of technology	information and processing services regarding use of public and semi-public charging infrastructure	e.g. processing platform: booking and payment system, smartphone provided by customer including application, provision of rapid charge stations including parking ground and other	flexibility, operational readiness, range
probability of default especially in early phases of the technology-lifecycle	e.g. w aranties, support services, mobility assitance services, tele-services, on- and offboard diagnostic	e.g. mobile service vehicle fleet, callcenter, online status monitoring system	risk of misuse or failure, reliability

Fig. 6. Description of BMW i3 in the layer model

According to the PSS layer-model, the integration of product and service elements must be carried out by a supporting infrastructure. The infrastructure describes the necessity for the PSS provider to prepare internal performance factors that ensure the disposability of PSS-offers. It represents the (physical/tangible) potential that supports the process of a PSS delivery. Regarding the use case, several infrastructural elements (physical assets) must be held available to assure the PSS delivery, as presented in Fig. 6. These can be assigned to categories such as information and communications technology (ICT) infrastructure, mobile devices provided by the user, facilities and the management of physical assets (e. g. vehicle fleet) amongst many others. The separate consideration of infrastructure elements serves as a basis to identify new innovation potentials regarding supporting and service technologies. There is an amount of other technological limitations from which services must be deviated in order to ensure competitive performance. (e. g. specifications for recycling, environmental circumstances and conditions especially regarding operating temperatures of Li-Ion batteries, stability in function, contingency risk etc.) – Two further examples are given in Fig. 6.

The use case demonstrated the possibility of leading service/infrastructure measures back to technological characteristics or even restrictions. A PSS has the potential to clear performance limitations and establish goal-oriented solutions with lesser environmental impact by enabling sustainable technologies. Moreover, the depicted use case implies the opportunity to generate innovative user-concepts despite or rather on the basis of technological bottlenecks. PSS are a chance to achieve early technology adoption for disruptive and more sustainable technologies. Success factors of a First Mover-strategy may consist in raising the learning curve, getting privileged access to limited resources, increasing switching costs for users and increasing the reputation as a sustainable PSS-provider at the customer amongst other factors [4].

6. Conclusions

The paper presents a layer model, depicting central aspects of PSSs. By specifying the layers, a framework that allows an integrated system description is established. The key resource "technology" is placed on the bottom of the framework, to point out the integral role of technical know-how and technologies in PSS innovations. The layer model adapts the technology-push/market-pull concept by introducing two innovation paths for PSS. On the one hand technologies may take the role of a driver for new functionalities (bottom-up). On the other hand, technologies may enable a PSS (top-down). An infrastructure supports and integrates the several PSS-elements on the solution layer.

In the following the major contributions of this paper are summarized and discussed on the basis of the case study.

- Technology as a key resource for product-service systems: By taking a technology perspective, potentials for innovation and performance bottlenecks may be identified. The framework clarifies the role of the key resource technology and allows to introduce a technology management for PSS
- Consideration for infrastructure in addition to product and service components of a PSS: An explicit consideration of the infrastructure enables a more holistic view on PSS. The case study showed, that the infrastructure discloses additional technologies that are required for the integration of product and service components. For example the ever increasing importance of ICT in PSS may be addressed properly in comparison to existing frameworks. Thereby, the analysis of the infrastructure is basis to identify systematically additional innovation potentials
- Analysis of the value optimization of PSS: The goal layer is the basis for an integrated depiction of the goals of a PSS.

The paper describes two innovation paths for PSS: the bottom-up approach which is a technology push innovation and the top-down approach which is market pull. However there remains the question of customer acceptance of servitization. Do the customers accept the higher dependency of the provider in a PSS contract?

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References

[1] Schenkl SA, Behncke FGH, Hepperle C, Langer S, Lindemann U. Managing Cycles of Innovation Processes of Product-Service Systems 2013 IEEE International Conference on Systems, Man, and Cybernetis. Manchester: IEEE Computer Society; 2013. p. 918-23.
[2] Tukker A. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Business strategy and the environment. 2004;13:246-60.
[3] Omann I. Product Service Systems and their Impacts on Sustainable Development. Frontiers 2 conference “European Applications in Ecological Economics”. Tenerife (Spain) 2003.
[4] Bullinger H-J. Einführung in das Technologiemanagement - Modell, Methoden, Praxisbeispiele [Introduction to technology management - models, methods, examples from practice]. Stuttgart: Teubner; 1994.
[5] Vargo SL, Lusch RF. Evolving to a new dominant logic for marketing. Journal of marketing. 2004;68:1-17.
[6] McAloone TC, Andreasen MM. Defining Product Service Systems. In: Meerkamm H, editor. 13 Symposium Design for X. Neukirchen (Germany); 2002. p. 51-60.
[7] Mont O. Clarifying the concept of product–service system. Journal of cleaner production. 2002;10:237-45.
[8] Müller P, Stark R. A Generic PSS Development Process Model based on Theory and Empiry. 11th International Design Conference - Design. Dubrovnik (Croatia); 2010.
[9] Müller P, Kebir N, Stark R, Blessing L. PSS Layer Method - Application to Microenergy Systems. In: Sakao T, Lindahl M, editors. Introduction to Product/Service-System Design. London: Springer; 2009. p. 3-30.
[10] Sadek T, Köster M. Sach- und dienstleistungsintegierte Konzeptentwicklung [Product and service integrating concept development]. In: Meier H, Uhlmann E, editors. Integrierte industrielle Sach- und Dienstleistungen. Berlin: Springer; 2012.
[11] Aurich JC, Wolf N, Siener M, Schweitzer E. Configuration of product-service systems. Journal of Manufacturing Technology Management. 2009;20:591-605.
[12] Geum Y, Lee S, Kang D, Park Y. Technology roadmapping for technology-based product - service integration: A case study. Journal of Engineering and Technology Management. 2011;28:128-46.
[13] Sakao T, Öhrwall Rönnbäck A, Ölundh Sandström G. Uncovering benefits and risks of integrated product service offerings - using a case of technology encapsulation. Journal of Systems Science and Systems Engineering. 2013;22:421-39.
[14] Vasantha GVA, Roy R, Lelah A, Brissaud D. A review of product-service systems design methodologies. Journal of Engineering Design. 2012;23:635-59.
[15] Baines T, Lightfoot HW, Evans S, Neely A, Greenough R, Peppard J, et al. State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 2007;221:1543-52.
[16] Meier H, Roy R, Seliger G. Industrial Product-Service Systems—IPS2. CIRP Annals - Manufacturing Technology. 2010;59:607-27.
[17] Aurich JC, Mannweiler C, Schweitzer E. How to design and offer services successfully. CIRP Journal of Manufacturing Science and Technology. 2010;2:136-43.
[18] Tukker A, Tischner U. Product-services as a research field: past, present and future. Reflections from a decade of research. Journal of Cleaner Production. 2006;14:1552-6.
[19] Velamuri VK, Neyer A-K, Möslein KM. Hybrid value creation: a systematic review of an evolving research area. J Betriebswirtsch. 2011;61:3-35.
[20] Cavalieri S, Pezzotta G. Product–Service Systems Engineering: State of the art and research challenges. Computers in Industry. 2012;63:278-88.
[21] Ponn J, Lindemann U. Konzeptentwicklung und Gestaltung technischer Produkte [Concept development and design of technical products]. 2nd ed. Berlin: Springer; 2011.
[22] Bullinger H-J, Fähnrich K-P, Meiren T. Service engineering - methodical development of new service products. International Journal of Production Economics. 2003;85:275 - 87.
[23] Löffler K, Boutellier R. Managing technological limits. International Journal of Technoentrepreneurship. 2009;2:134-55.
[24] Christensen CM, Grossmann JH, Hwang MD. The Innovator's Prescription: A Disruptive Solution for Health Care. New York: McGraw-Hill; 2009.
[25] Garvin DA. Competing on the eight dimensions of quality. Harvard Business Review. 1987;65:101-9.
[26] Mont O. Drivers and barriers for shifting towards more service-oriented businesses: Analysis of the PSS field and contributions from Sweden. The Journal of Sustainable Product Design. 2002;2:89-103.
[27] Christensen CM. Exploring the limits of the technology S-curve. Part I: component technologies. Production and Operations Management. 1992;1:334-57.
[28] Sood A, Tellis GJ. Technological evolution and radical innovation. Journal of Marketing. 2005:152-68.
[29] Christensen CM. The Innovator’s Dilemma. Munich: Vahlen; 1997.
[30] The Boston Consulting Group. Batteries for Electric Cars - Challenges, Opportunities, and the Outlook to 2020. Boston; 2010.