Engineering PSS (Product/Service Systems) Toward Sustainability: Review of Research

33

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Abstract

This chapter gives a review of research on PSS (product/service system) and its relation to environmental sustainability. The focus of this chapter is on engineering, especially design, of PSS. It first explains why PSS gains attention from the sustainability and business viewpoints and then moves on to what PSS is. One definition of PSS is "a marketable set of products and services capable of jointly fulfilling a user's needs." Importantly, from the engineering viewpoint, service is beginning to be increasingly incorporated into the design space, an area which has been traditionally dominated by physical products in manufacturing industries.

In relation to environmental sustainability, PSS is argued to have potential for decreasing environmental impacts in many cases. Among others, the "functional result" type is regarded as the most promising. However, PSS is not always environmentally superior to its reference offering based on product sales.

From the viewpoint of design, introduced are three dimensions of PSS design: the offering, the provider, and the customer/user dimensions. In principle, any PSS design is supposed to address at least part of all the three dimensions since service includes the activities of customers and providers. Then, this chapter will guide readers to the works on modeling, designing, and evaluating PSS with emphasis on the differences to traditional product design. In sum, PSS design is design toward value of stakeholders by utilizing various alternatives – either product or service. This means that PSS design provides designers with new degrees of freedom and covers an earlier phase of design that is not addressed in design of pure physical product. The latter further implies the importance of information to be available in design about product usage or service delivery.

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For modeling and design, some examples of methods for supporting PSS design are introduced.

In the end, the author's recognition of important industrial challenges and research issues about PSS are described based on the experiences of the author's group. They are from various areas such as business model development, marketing and sales, R&D and PSS development, (re)manufacturing, service delivery, supply chain management, organizational and managerial topic, and energy and material consumption.

1 Introduction

Environmental sustainability is a challenge for people on our planet. Soon, in 2012, the United Nations Conference on Sustainable Development, Rio+20, is going to be held. Since "Our Common Future," also known as the Brundtland report, was published, international organizations such as the United Nations have recognized the need to tackle this issue. As a result, the "Agenda 21" (United Nations General Assembly 1992) was developed at the Rio Earth Summit, with an objective "to promote patterns of consumption and production that reduce environmental stress and will meet the basic needs of humanity." In 1994, the Oslo Symposium (Norwegian Minister of Environment 1994) pointed out the necessity to link production to consumption with a working definition of sustainable consumption which is used by many researchers and organizations including OECD (OECD 1997, 2002). However, very few industrial activities are practiced in a form of sustainable production linked with sustainable consumption. One of the greatest barriers preventing producers and consumers (or customers, users) to go for it is obviously just that producers are business organizations pursuing profits and consumers demand based on their needs. Many of successful eco-efficient services are regarded driven not necessarily by environmental considerations. The problem cannot be solved unless commercial activities between the supply and demand sides are somehow changed.

Looking at manufacturing industries in pursuing environmental sustainability, they have traditionally in most of the cases focused on improving the performances of their physical products without addressing their commercial activities for the last two decades. A number of producers' activities can be actually seen as successful sustainable production if the supply side alone is focused. A number of methods and tools for Ecodesign (environmentally conscious design) of physical products have been developed. The Ecodesign manual by UNEP (UNEP 1997) is such a good example, and there are several other good textbooks (e.g., Fiksel 1996; Abele et al. 2005). In addition, a lot of Ecodesign products are released on the market. However, very few of those methods and tools have succeeded in addressing properly the commercial activities, the business aspect. Consequently, ecodesigned products are not necessarily accepted by consumers at present. The case where producers succeed in releasing eco-products that are well accepted by consumers, in contrast, often ends up with "more consumption of sustainable products." So-called "win

(producer) – win (consumer) – win (environment)" has not been realized. Namely, the present sustainable production in many cases does not accelerate sustainable consumption. Producers should be more careful of their business aspect if they pursue profitable activities through sustainable consumption.

To tackle this challenge, the concept of value is among the crucial pieces because value is the interface between consumers and producers. Value can be defined "what consumers (customers, users) get for what they give" according to classical marketing literature (Zeithaml 1988). Then, what do they get? Much literature has pointed out it is not a physical product per se but the result or performance of the product in many cases (see, e.g., Stahel 1994). Therefore, there should be support for companies to develop their offerings based on this idea. This type of support is, however, a point that conventional Ecodesign methods/tools lack. What is another weapon of manufacturers to create the result of a physical product than the product itself? – Service. Manufacturers especially in developed countries today regard service activities as increasingly important. Some manufacturing firms are even shifting strategically from a "product seller" toward a "service provider." Service in this chapter includes operation, maintenance, repair, upgrade, take back, and consultation. This combination of sustainability and business seems to be observed background for how the concept product/service system (PSS) has gained high attention for more than a decade. One definition of PSS is "a marketable set of products and services capable of jointly fulfilling a user's needs" (Goedkoop et al. 1999). In addition to this definition, Tukker and Tischner (Tukker and Tischner 2006) regard PSS as a value proposition, including its network and infrastructure.

What kind of discipline do PSS providers call for? A much bigger framework is obviously needed than for Ecodesign because a business manner must be changed ultimately. It may be impossible to tackle this problem by only one of those disciplines such as engineering, marketing, and management. This is truly a multidisciplinary subject. Especially, PSS design lies in a domain differing from that of a product, and the research community has not yet established commonly agreed methodologies. This chapter aims at guiding you to learn about this relatively young but crucial concept of PSS in relation to sustainability from the engineering, especially design, viewpoint.

2 Why and What of PSS

This section gives you why PSS gains attention from the business viewpoint and then moves on to what it is. First, especially in the developed countries, the competition with hardware manufacturers in low-wage countries is severe, and companies find services as critical measure for value added. Another reason from the demand side is servicification of customers' activities, which in some cases means a shift from customers' owning physical products to getting access to the functionality of products.

According to a recent "white paper" on industrial PSS (Meier et al. 2010), "In 10 years the following statements will be relevant: Result oriented business

models evolve as an industry standard. Complex development processes are simplified by automatic [...] configuration by Plug and Play of product and service modules. Service will be provided globally by service supply chains based on modularized service processes." As implied by this future picture, a lot of research needs to be carried out in this subject.

PSS consists of "tangible products and services designed and combined to jointly fulfill specific customer needs" and is also a value proposition, which includes the network and infrastructure (Tukker and Tischner 2006). There are other closely related concepts such as industrial product-service system (IPS^2), integrated solutions, integrated product service offering (IPSO), and functional sales found in not only theoretical but also practical fields in industries. In common to those concepts, they comprise combinations of hardware and support services. Other concepts such as service engineering and life cycle design (LCD) referring to engineering activities on both products and services are also closely related to PSS.

Importantly from the engineering viewpoint, service activity is beginning to be increasingly incorporated into the design space, an area which has been traditionally dominated by physical products in manufacturing industries (see, e.g., a classic textbook for engineering design by Pahl and Beitz 1996). This has a great impact on the business in such companies. Fulfilling PSS design is a complex task and may force companies to change development process, organizational structure, and their mind-sets along with PSS design. PSS design addresses the customer value, while the functions of physical products and provider's activities are measures that create effects. The provider's activities, such as maintenance services, are included in the usage process, and customer evaluation is paramount. This issue is also relevant to service industries, as they often have power to influence on the characteristics of hardware utilized in their business offerings, and developing a good combination of hardware and services can be a key in those cases.

3 Contribution of PSS Toward Sustainability

Through PSS, companies could attempt holistic optimization from the environmental and economic perspectives in a better way throughout the life cycle. In addition, PSS would be more effective when products and services have been developed in parallel and are mutually adapted to operate well together. This contrasts with the traditional product sale, where the provider transfers control and responsibility to the customer at the point of sales. PSS often creates close contact between the supplier and customer, leading, for example, to offers being customized and improved to better suit the customer. In many cases, the PSS provider retains responsibility for the physical products in the PSS during the use phase. One example is when a client does not own the machines installed by the supplier, but only uses them and pays for the manufactured volumes; then, when the customer does not need them anymore, the supplier takes back the machines. Such cases increase the provider's interest to

PSS type	Impacts compared to reference situation (product)				
	Worse	Equal	Incremental reduction (<20%)	Considerable reduction (<50%)	Radical reduction (<90%)
1. Product-related service		←----------→			
2. Advice and consultancy		←----------→			
3. Product lease	←----------→				
4. Product renting and sharing		←----------→			
5. Product pooling		←----------→			
6. Activity management		←----------→			
7. Pay per unit use		←----------→			
8. Functional result		←----------→			

Notes:
- Renting, sharing: radically better if impact related to product production.
- Pooling: additional reductions compared with sharing/renting if impacts related to the use phase.
- Renting, sharing, pooling: even higher if the system leads to no-use behaviour.

Fig. 33.1 Tentative (environmental) sustainability characteristics of different PSS types (Original source: Business Strategy and the Environment, vol. 13, (Tukker 2004) © Wiley and ERP Environment)

ensure that the customer uses machines installed as long as possible and that any disturbances, such as the need for repairs, are reduced. The increased responsibility by the PSS supplier also potentially facilitates improvements identified and implemented in comparison to traditional sales. This could lead to a product lifetime extension.

You might think that PSS is automatically environmentally superior to its reference offering based on product sales – it is not true. According to Tukker (2004), PSS is in many types argued to have potential for decreasing environmental impacts (see Fig. 33.1). Among others, the "functional result" type is the most promising. On the other hand, the "product lease" type can be worse, because the fact that the user does not own a product could even lead to negative effects, such as a careless use, shortening its useful life span. Thus far, the relation between PSS types and their influence on environmental impact has not been analyzed thoroughly, though some works have been initiated (Lingegård et al. 2011).

4 Three Dimensions of PSS Design

Approaches to PSS design involve changes in the traditional design procedures, delivering processes, and engineer mind-sets. Therefore, it has a lot of influence on a provider. Introduced here are three dimensions of PSS design: the offering, the provider, and the customer/user dimensions based on (Sakao et al. 2009c) as depicted by Fig. 33.2. The first one refers to both "product" and "service" elements of PSS. In addition, the other two, that is, the provider and the receiver, are indispensable to address PSS.

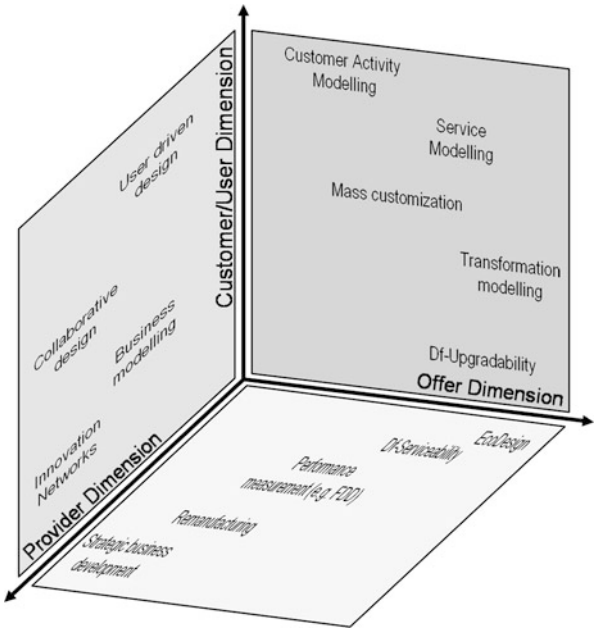

Fig. 33.2 The three dimensions of PSS design (Original source: J. Manufacturing Technology Management, Emerald, vol. 20, 2009 (Sakao et al. 2009c))

The offering dimension addresses the elements and activities in the life cycle. It includes the lives of physical products that are part of the PSS, as well as service activities. Successful design of PSS depends on a thorough understanding of the solution life cycle and active design of beneficial linkages with the heterogeneous systems involved.

The provider dimension addresses the evolution of product/service providers' organizations and operations. This covers such issues as the setup of development projects, organizational streamlining of the company for service delivery, and the identification of partnerships needed for successful operation of services.

The customer/user dimension addresses the evolving needs of service receivers. It is crucial for the provider of services and products to anticipate receivers' reaction to new offerings.

In principle, any PSS design is supposed to address at least part of all three dimensions, since service includes the activities of customers and providers, and because products are included. This characteristic of service is represented by the term "co-creation." As such, the three dimensions are fundamental to PSS design. In addition, anticipating and utilizing the dynamics along each dimension is crucial. This implies that the essence of PSS design, especially when compared to traditional engineering design, lies in the utilization of the dynamics of and between offer, provider, and customer. Figure 33.2 illustrates the links of some of the research topics to the three dimensions.

5 Designing PSS: What Is Different to Product Design?

Thus far, there has been relatively more work on PSS with the analytical approach (see mostly analytical and not synthetic approaches in, e.g., Mont and Tukker 2006). For instance, researchers in the EU-funded Suspronet project (Tukker and Tischner 2006) have contributed extensively to PSS research: They mainly take an analytical view, which is indicated by their result of analysis in Fig. 33.1 (Tukker 2004). On the other hand, the engineering approach on PSS is relatively new. The rest of this section will guide you to the works on modeling, designing, and evaluating PSS. Note that the first two, that is, modeling and designing, are basic targets of engineering activities.

5.1 Modeling PSS

There are different approaches to modeling PSS. Two modeling methods are introduced here from suggestion by the International PSS Design Research Community (Web site). One of them especially allows designers to evaluate an intermediate solution mathematically during PSS design (Sakao et al. 2009d) based on the QFD (Quality Function Deployment (Akao 1990)) technique. This method models services as service receivers' transition of status, called the "receiver state parameter." Importantly, providing a product is also modeled as a service by this method and, therefore, so is providing PSS. Then, it further allows a designer to model why the state transition has value, concerned actors (provider and receiver), and how to provide the value as shown in Table 33.1. Here, a service is defined as an activity that a provider causes, usually with consideration (i.e., commercial transactions), in which a receiver changes from an existing state to a new state that the receiver desires in which contents and a channel are the means to realize the state change (based on Tomiyama 2001). Service contents are provided by a service provider and delivered through a service channel. Physical products and service activities are either the service contents or the service channel. This provides designers with a flexible modeling scheme by beginning with a receiver's state transition so that PSS can be modeled as well. Using this model, a computerized tool named Service Explorer is also developed.

The other approach is called PSS Layer Method (Müller et al. 2009). This aims at providing a framework to describe a PSS and is partly motivated by the need to establish a common set of terminologies for PSS. This motivation is linked to standardization on PSS design: For instance, the German DIN PAS 1094 (Public Available Specification) about hybrid value creation has been set up by German researchers and has been released (DIN working group 2009). PSS Layer Method assumes that nine dimensions can be defined that cover most of the important PSS aspects – (1) customer need, (2) customer value, (3) deliverables, (4) life cycle activities, (5) actors, (6) core products, (7) periphery, (8) contract, and (9) revenue. These dimensions have relations to each other:

Table 33.1 Information modeled by the method (Based on: Computer-Aided Design, Elsevier, vol. 41, 2009 (Sakao et al. 2009d))

Information		Modeling scheme
What	Provided value/cost	*Receiver state parameter*
Why	Reasons for value to be effective	*Scenario model* • State transition of a service receiver • Persona model of a service receiver
Who	Provider and receiver	*Flow/scope model*
How	Measures to provide value	*View model* • Functions of physical products and service activities • Physical products and service personnel as entities

Customer needs (dim. 1) are satisfied by customer value (dim. 2), which a customer perceives. Such value is generated by deliverables (dim. 3) for a customer. The deliverables are results of delivery processes, that is, life cycle activities (dim. 4). To implement a life cycle activity, chain resources are needed. Actors (dim. 5), core products (dim. 6), and periphery (like IT infrastructure or public transport systems) (dim. 7) are such resources. Contracts (dim. 8) frame the entire value creation process, including billing (dim. 9), offerings, and finally the entire business model. This is a simple manner especially for multidisciplinary team members, who have different focuses, to share the information of a PSS and discuss it during design.

5.2 Designing PSS

PSS designed is design toward value of stakeholders by utilizing various alternatives – either product or service. This means that PSS design provides designers with new degrees of freedom and covers an earlier phase of design that is not addressed in design of pure physical product. The latter further implies the importance of information to be available in design about product usage or service delivery. To design a PSS, a new method is required to support those who engineer a PSS effectively and efficiently. Note that a method to support physical product design is not suitable, because of the wider range of parameters to be designed and the multidiscipline of PSS design.

Figure 33.3 compares a present Ecodesign of service (i.e., PSS design) that is wished to be realized with a typical Ecodesign of product. A typical Ecodesign of products (a) targets the environmental burden while fulfilling a requested function of a physical product without changing the provider's process during the usage phase. The consumers' behaviors are not the main focus. On the contrary, a present Ecodesign of service (b) targets the "state changes" of a consumer (or customer, user) while the functions of physical products and provider's activities are media. For instance, consider a customer (or consumer) who wants to get meat for food.

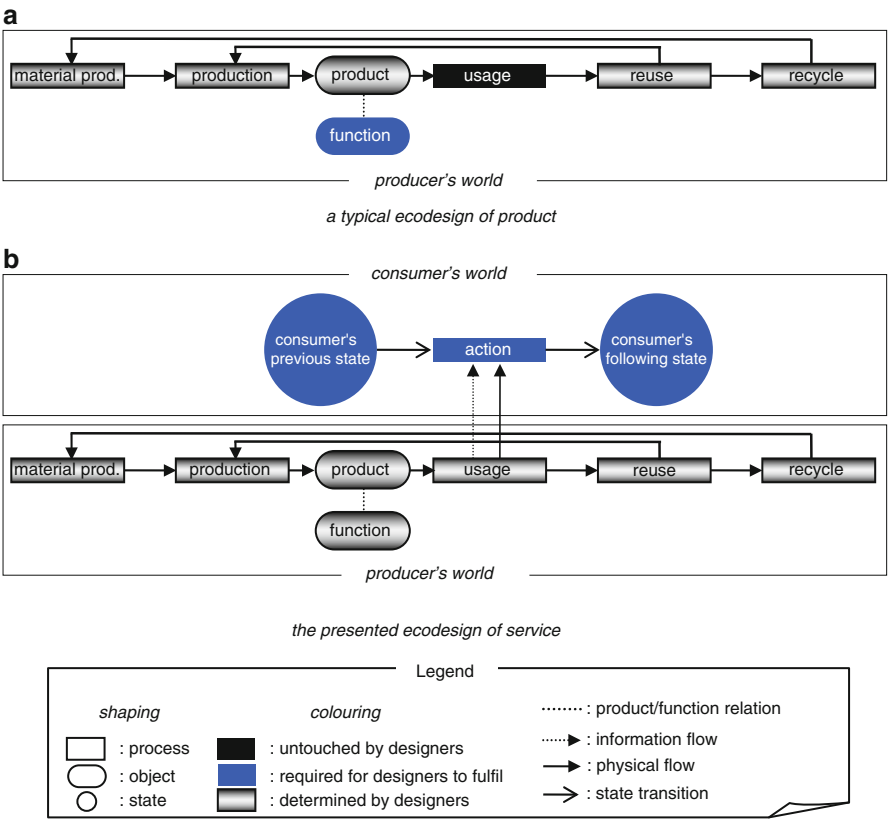

Fig. 33.3 Differences between a typical Ecodesign of product and of PSS. (**a**) A typical ecodesign of product. (**b**) The presented ecodesign of service (Original source: J. Cleaner Production, Elsevier, vol. 15, 2007 (Sakao and Shimomura 2007)). Note: "service" in this figure means PSS. The product function is realized during usage but is drawn on this figure with simplicity

This state change (from not having meat) can be realized by meat delivery service just on time or by keeping meat purchased from a supermarket in a freezer. A typical Ecodesign of products tends to focus on the function of a freezer (i.e., product) without exploring other possibilities of services such as delivery service.

Figure 33.4 compares the phases for PSS design supported by existing CAD for products and by CAD required for PSS, so as to show PSS design is different from traditional product design. The two steps in the last half of this design flow are relatively well covered by existing CAD. However, the first two steps, for analyzing customers and then identifying functions, are insufficient. Existing CAD systems can only cover a part of the second step (e.g., QFD (Quality Function Deployment)). Virtually no CAD system supports design with targeting value by means of functions of products or service activities. In addition, the first step for identifying value through customer analysis is not covered either.

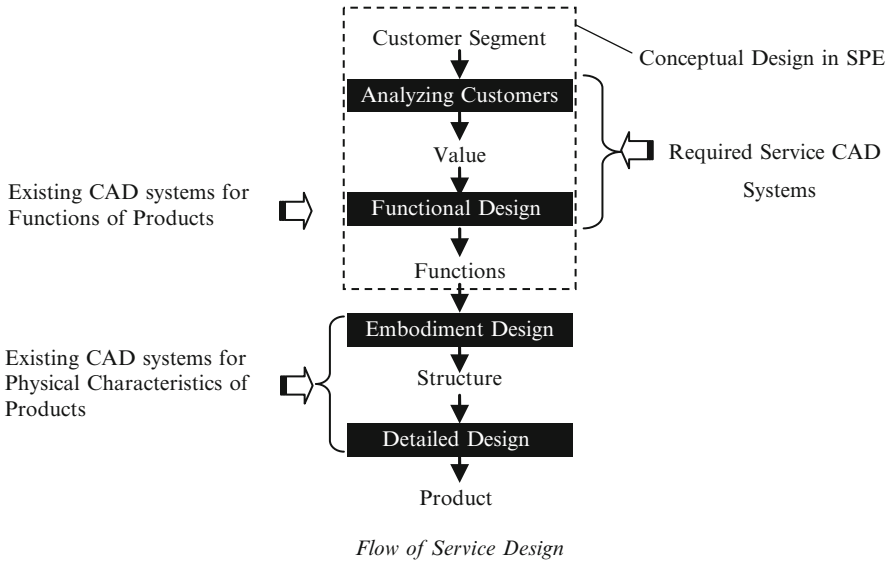

Fig. 33.4 Different stages for PSS design (Original source: Computer-Aided Design, Elsevier, vol. 41, 2009 (Sakao et al. 2009d)). Note: SPE stands for service/product engineering, meaning engineering of PSS. "Service" in this figure means PSS

5.3 Methods for Supporting Design of PSS

This part introduces some examples of methods for supporting PSS design. An example addressing development issues is a methodology for product-service systems (MEPSS) for companies to develop and implement a successful and sustainable PSS (van Halen et al. 2005). MEPSS is a procedure for analyzing the company systems, based on workshop sessions and supported by various tools. Thus, it represents a strong practical approach to PSS development.

Two more methods are introduced here also from the International PSS Design Research Community (Web site). One method is a structured and comprehensive PSS design method now called SPIPS (toward solution provider – through integrated product and service development) (Sakao et al. 2009a). The method addresses both service activities and physical products as measures creating value for different stakeholders and adopts a design-object model which represents critical concepts such as value, costs (sacrifice), functions either of products or of service activities, and entities introduced above (Sakao et al. 2009d). SPIPS realizes the idea mentioned above, new degrees of freedom for designers and an earlier phase of design addressed. SPIPS has been validated with some empirical results obtained from designing a PSS with companies – from both manufacturing industry and service industry. It is at present being implemented at a large manufacturer of investment machines.

As depicted in Fig. 33.5, SPIPS consists of seven steps (from 0 to 6), so that they fit well with the information assets of a given company. If customers' requirements

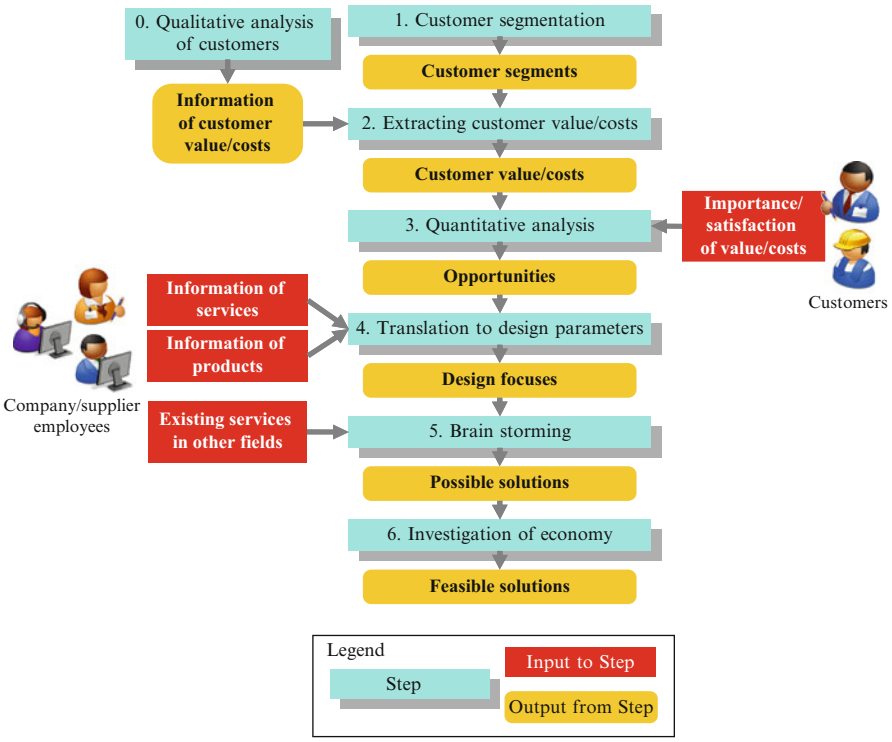

Fig. 33.5 Procedure of SPIPS (Original source: Int. J. Internet Manufacturing and Services, vol. 2, 2009. dx.doi.org/10.1504/IJSTM.2009.022379 © Inderscience Enterprises Ltd. (Sakao et al. 2009a))

on their value and costs already exist, Step 0 will be omitted. Step 3 adopts the method to identify opportunities by Ulwick (2002), while Step 4 utilizes a method to evaluate intermediate solutions by Arai and Shimomura (2005) as is explained below. Step 4, named "translation to design parameters," is among the core steps. It uses the information from customers and specialists from the provider's side. The former information is represented by quantitative importance/satisfaction on the given customer value/cost and can be collected by a simple questionnaire. The latter is either about services or products provided by the company and can be gathered using matrices similar to those used in QFD.

Once the design focuses are obtained from Step 4, brainstorming with employees with specific knowledge and responsibility will be held as Step 5. This is followed by Step 6, which is investigation of economic feasibility of possible solutions generated from Step 5. Finally, feasible solutions are produced. Since some steps, especially Steps 1, 5, and 6, are quite familiar to companies in general, the new essence of these working steps exists in Steps 2, 3, and, particularly, 4. Thus, these steps have proper contrivance; while they are familiar to widespread ways of working in companies in general, they are adapted to addressing PSS.

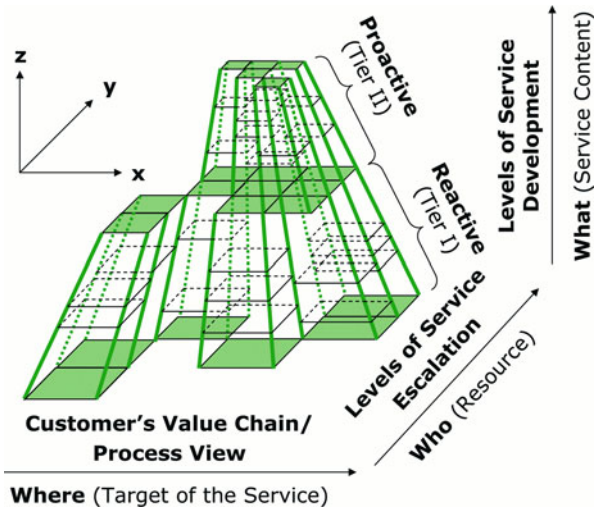

Fig. 33.6 Illustration of potential areas for providing services (Original source: Int. J. Services Technology and Management, vol. 11, 2009. dx.doi.org/10.1504/IJSTM.2009.022379 © Inderscience Enterprises Ltd. (Panshef et al. 2009))

Other methods are available to support PSS design (see, e.g., Sakao and Lindahl 2009b; it provides methods from different disciplines such as engineering, marketing, and innovation), one of which aims at identifying user activities and reveals business opportunities for new services (Panshef et al. 2009). This method has been applied to PSS design with companies successfully. Figure 33.6 depicts the adopted profile, representing a structured view of the targets (x-axis: where), resources (y-axis: who), and contents (z-axis: what) of the service activities.

As a way of using this profile, a 2D profile named taxonomy table is derived, as shown Fig. 33.7 in a case for print production processes: prepress, press, post-press, and logistics. The 2D profile allows designers to explore the consequences resulting from uncertainty during the user process and enables the improvement of existing service content (even removing the current service content and provider) by recognizing and understanding the less significant service capability. On the y-axis, all the possible levels of service escalation are derived. In this example, three escalation fields have been defined: the user's own resources; secondly, the resources of the device manufacturer or the local service provider; and thirdly, the resources of other service providers. In this case, a high concentration of the reactive services was observed for the areas of press and post-press, and thus a new business opportunity can be identified by the design of new service contents with focus on the prepress area. For instance, in order to improve the reactive service contents in the area of prepress, new service contents for "data handling" can be created and provided by the "Central Service Network of the Manufacturer."

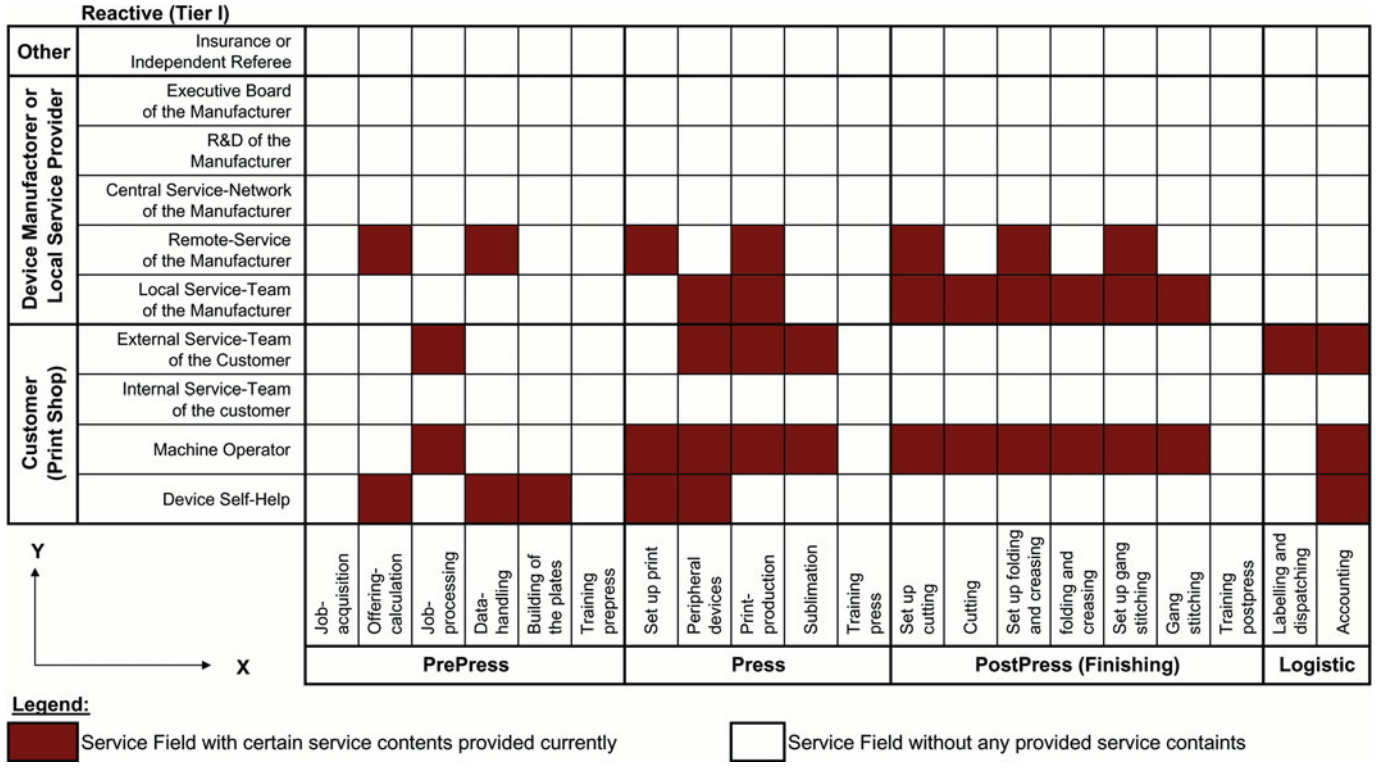

Fig. 33.7 "Taxonomy table for value-chain-oriented service development" of the sub-model for print production, "reactive (Tier I)" (Original source: Int. J. Services Technology and Management, vol. 11, 2009. dx.doi.org/10.1504/IJSTM.2009.022379 © Inderscience Enterprises Ltd. (Panshef et al. 2009))

6 Evaluating PSS

Thus far, more research addresses PSS modeling and PSS design, while very little addresses evaluation of PSS potential or consequences. This implies that there exist research opportunities for this topic. In PSS research in general, the environmental potential of PSS has been among the largest concerns. Furthermore, the potential of not only environmental but also economic aspects is still a hot research issue. Social effects of PSS are not researched intensively, so far.

7 Other Issues

Other than design which has been overviewed in this chapter, two issues related to engineering are organizational structure and mindset (Sakao et al. 2009c).

7.1 Organizational Structure

The organizational structure also needs to change in a company. More specifically, how to organize the company according to the services offered is one area where more research can be performed. Part of this is the competence profile of the company, which needs to shift when moving into services (for example, more service technicians or more business and service developers would likely be needed). A logistic system and a remanufacturing system may also need to be developed.

7.2 Mind-set

Companies need to undergo major changes in their mind-set. Companies that have a strong culture and pride in their products also have to build trust, and their employees need to believe in their services. Services also need to have a high status and be incorporated into the company. The importance of mindset and how it can be built up in line with new company values will be an interesting research area.

8 Summary

As an ending, this section describes the recognition of important industrial challenges and research issues about PSS by the author's group: Linköping University's Center for Service Research in Manufacturing Industry (ManuServ) based on its own experiences (Sakao et al. 2011). ManuServ's goal is advancing service knowledge acquisition and exploitation, thereby increasing the competitiveness of

manufacturing firms. Integration of services with products is among the most crucial issues in ManuServ, where PSS is naturally a central topic.

The following is a list of topics and challenges:

1. Business model development: Identification and implementation of service-based business model, structuring development process, building relationships with customers, adapting to changing customer needs, and new mindset
2. Marketing and sales: Pricing of PSS, value visualization, top management commitment, appropriate incentive system, and appropriate KPI used
3. R&D and PSS development: Service development, integrated development of PSS, integration of PSS development and customer value management, and evaluating R&D projects toward customer value
4. (Re)manufacturing: Adapting to return items with various types of uncertainty, setting up remanufacturing, and setting up fleet management
5. Service delivery: Building service delivery organization with new competencies, handling profit/cost center, building up service network, and lack of internal data management
6. Supply chain management: Establishing reverse logistics to use return items (return network, connection to forward network, and sorting) and balancing returns and demands for them
7. Organizational and managerial topic: Understanding organizational changes needed, increasing cooperation between service and product organizations, reframing of the firm's purpose, what to outsource, and working in an internal/external network
8. Energy and material consumption: How to integrate/promote energy services and product need modification for material efficiency

These challenges and research issues highlight the importance of the holistic view to avoid local optimization within a firm or a group of companies within the same value chain. In order to deal with one challenge, several other interdependent ones frequently need to be coped with. For example, organizational and managerial challenges often need to be overcome in order to succeed with new marketing and sales practices, supply chain management, PSS and business model development, etc. Likewise, PSS development and design processes and routines, marketing and sales metrics, etc. may need to be revised in order to successfully implement organizational changes. In other words, changes in one will affect the other, and it ought to be possible to balance different parameters from different areas between them. A PSS company cannot simply focus on one area to be successful – they need to balance and modify parameters from all the described areas. The author's group believes that PSS research would be more successful with a more integrated and holistic approach.

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