Chapter 2

Life-Cycle Perspectives of Product/Service- Systems: In Design Theory

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Abstract Manufacturers are moving more and more towards the business approach of Product/Service Systems (PSS) in order to achieve greater revenue. PSS have many benefits such as achieving closer customer connection and generating increased profit from manufactured products. However, in order to achieve a PSS which is adapted for this business approach, the products and services used need to consider a life-cycle perspective. The business approach of PSS allows for the provider to control the flows of physical products, both the forward flow to the user and the reverse flow of products back to the provider. This new logic of material/product flows allows for adaptations along the product life-cycle. For example, maintenance and end-of-life strategies such as remanufacturing can become more beneficial due to the new circumstances that PSS provide the manufacturer. The aim of this chapter is to elucidate how manufacturers can develop their PSS with a life-cycle perspective. It shows the many aspects that should be considered throughout the life-cycle of both physical products and services. In addition, several considerations and theories are presented for the different stages of the PSS life-cycle. Finally, this chapter presents theory on product/service design with a life-cycle perspective, which serves as a base for the practical design considerations presented in Chapter 3 of this book.

Keywords Life-cycle, PSS, Industrial Product/Service-Systems, DfX

2.1 Introduction

Manufacturing companies around the world are striving to increase their revenues and profitability through, for example, obtaining a larger share of the market and controlling a greater share of the product value chain. This can potentially be achieved, in concert with environmental benefits, through a change or at least a move towards a higher degree of integrated product/service offerings instead of just physical products. Furthermore, there are promising economic opportunities in the aftermarket of the products, as exemplified in the automobile industry. Because of this, many manufacturing companies are changing their production philosophy from a traditional focus on the manufacturing of the physical product towards a focus of the life-cycle of the physical product. As a result, more emphasis is now put on the use and end-of-life phases, including maintenance and remanufacturing. Given the above, the aim of this chapter is to elucidate how manufacturers can develop their product/service-systems with a life-cycle perspective.

2.2 What Are Product/Service-Systems?

The phenomenon of product/service-systems (PSS) has become more prevalent in current consumer patterns, and its emergence is primarily market-driven, although some companies also mention environmental issues as important for starting their PSS business models. The importance of services gets larger as the economy of our society matures. Service activities are provided as the source of core value in the tertiary industry. In addition, the secondary industry has recently become increasingly interested in services (Oliva and Kallenberg 2003). The importance of services is also recognized in the marketing field (Vargo and Lusch 2004). As a result, new concepts such as Product/Service-System (PSS) (Goedkoop *et al.* 1999, Morelli 2003, McAloone and Andreasen 2004, Mont 2004, Tukker and Tischner 2006, Aurich *et al.* 2006), Functional Sales (Sundin *et al.* 2000, Lindahl and Ölundh 2001, Sundin and Bras 2005), Functional Products (Alonso-Rasgado and Thompson 2006, Alonso-Rasgado *et al.* 2004), Integrated Product Service Engineering (IPSE) (Sundin *et al.* 2006), and Service/Product Engineering (SPE), formerly called Service Engineering (Sakao and Shimomura 2007), have been developed. What these concepts have in common is the incorporation of a service into the design space, a space which has been traditionally dominated by physical products in manufacturing industries. In PSS, a very strong focus is placed on how to fulfilll customer needs and create customer value (Lindahl and Ölundh 2001); thus, the main focus is not on producing new products. Furthermore, Sakao *et al.* (2009) provide a good overview of recent research direction in the PSS area.

Today, value is added to products in a variety of ways, including technological improvements and non-material aspects such as intellectual property, product image and brand names, aesthetic design and styling. These aspects help producers to differentiate and diversify their products to better respond to customers' demands. According to Mont (2004), this means a change from mass production to mass customization. The issues of combining the development of mass-customized products used in PSS are further described in Sundin *et al.* (2007). Kimura (1997) states that a paradigm shift is needed to change from traditional product selling to more service-oriented product sales. In addition, the traditional boundary between manufacturing and services is becoming increasingly blurred (Mont 2004). Within PSS, the function-providing company decides how to fulfill the function that the customer is buying, whereas in leasing the physical product used for the function is known by the customer. In the cases of renting, leasing and PSS offerings, the product is not sold, and a contract is written between user and provider; however, this contract is more advanced for the PSS offerings concept. Leasing is a contract form that often is used for financial reasons, as products are often sold to the customers who leased them when the contract has run out. Tischner *et al.* (2002) have studied the links between PSS and traditional products and services. The general image of a PSS can, as shown in Fig. 2.1, be broken down to three main categories: product-, use- and result-oriented PSS.

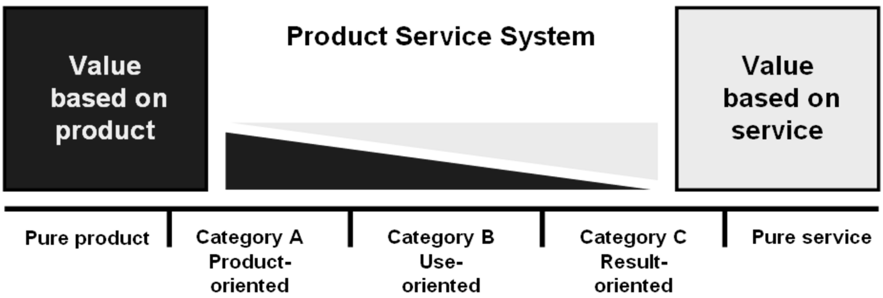

Fig. 2.1 Placing Product/Service Systems in a perspective to products and services (Tischner *et al.* 2002)

Category A Product-oriented Services: product is owned by the user/consumer.

- **Service Integration** A new service is added to an existing product, often initiated through availability of new technology such as a modem for a computer.
- **Product Extension Service** The value of a product is increased through an additional service; examples include upgrades, repairs and guarantees.
- **Vertical Integration** Modified delivering strategies to supply products to customers, retailers, and/or customers, who become directly involved in the process of production; for example, production on demand.

Category B Use-oriented Services: product is owned by the service provider, who sells functions instead of products by means of modified distribution and payment systems; for example, sharing, pooling and leasing.
Category C Result-oriented Services: in a product-substituting service, products are substituted by new services, often driven by new technologies. Examples include virtual answering machines instead of a machine at home; pest control services instead of pesticides; and facility management. In all these cases, the supplier provides incentives for the customer to consume more efficiently and optimizes a system, for example, by using modified payment systems such as contracting.

An example of PSS is when a company provides the function of washing clothes instead of the actual washing machine performing the function. Here, customers pay for the laundry loads they require instead of buying the washing machine, as illustrated in Fig. 2.2. This example, called pay-per-wash, is further described in Sundin *et al.* (2000).

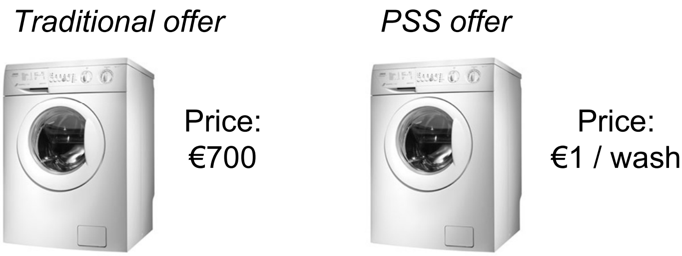

Fig. 2.2 Example of a washing function offered traditionally and as a PSS called pay-per-wash (modified from Sundin *et al.* 2000)

When providing a function instead of a product, a contract must be signed between the customer and the service provider. Here, the connection between the stakeholders becomes more formal, and the contracts that regulate what the offer includes are of importance (Lindahl and Ölundh 2001). Thus, if the manufacturing company provides the function, then it becomes increasingly knowledgable about how its products perform during use. This product control can be achieved through web monitoring, and thus can be facilitated by today's information technology. Monitoring the product for PSS allows the company to learn more about how it performs throughout its life-cycle. The whereabouts of *product life-cycle* is explored further in the next Sect..

2.3 What Is Life-Cycle Perspective?

The concept of the *product life-cycle* has been discussed widely in research (see the overview by Kotler (2003). In the theory, at least two conflicting definitions about the product life-cycle can be found. The first refers to the progress of a product from raw material, through production and use, to its final disposal as illustrated in Fig. 2.3. This is also the perspective of the *product life-cycle* considered in this chapter.

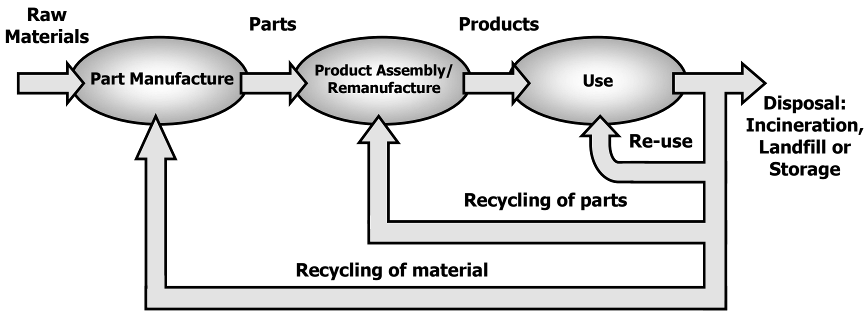

Fig. 2.3 The physical product life-cycle (Sundin 2004)

The second definition of the product life-cycle describes the evolution of a product, measured by its sales over time, as seen in Fig. 2.3. Every product passes through a series of phases in the course of its life, referred to as the product life-cycle. The phases that a product goes through during it life-cycle are the introduction, growth, maturity and decline stages (Cox 1967). The product life-cycle can be analyzed on different levels, from the main product type (product class) down to different product models, as illustrated in Fig. 2.4 (Tibben-Lembke 2002). The characteristics of the life-cycle and its effects on the reversed supply chain have been discussed by Tibben-Lembke (2002).

When the historical sales data (product distribution) is known, this data can be used as a basis for forecasting when these products are likely to be returned (product disposal distributions). Research about this economically related product life-cycle has also been conducted by Umeda *et al.* (2005) and Östlin *et al.* (2009). Umeda *et al.* (2005) present a model based on empirical data from return rates for remanufacturing of a single-use camera and the remanufacturing of a photocopier. In this model, a simple normal distribution function has shown sufficient results in predicting returns when using average life as an indicator for timing of returns. In the study performed by Östlin *et al.* (2009), life-cycle perspective influences on product remanufacturing have been further explored in detail.

If the product is returned to the manufacturer for remanufacturing, it is possible to evaluate how the product has performed throughout its life-cycle and what needs to be improved. This knowledge allows the manufacturer to improve its products accordingly; it could, for example, be used to help reduce the need for service throughout the use phase, or to discover latent design errors more quickly and thus obtain better knowledge of how the product is used. Having an ownership-based relation to the customer, i.e. the provider owning the product during use, has been found to be one of the most preferable relationships in achieving a successful remanufacturing business (Östlin *et al.* 2008).

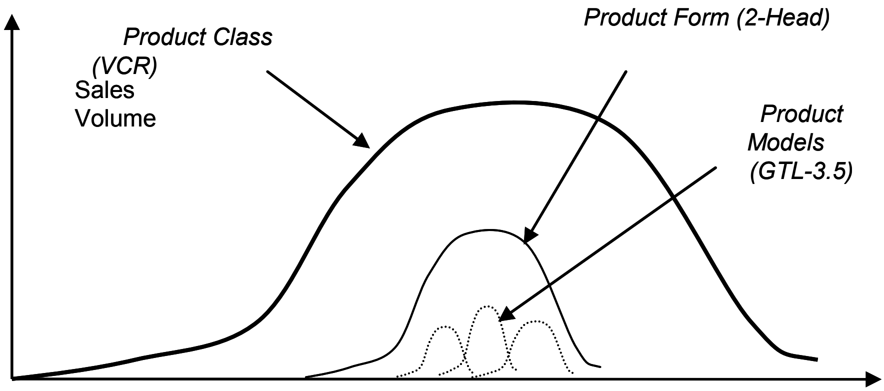

Fig. 2.4 The product life-cycle of a VCR (Tibben-Lembke 2002)

2.3.1 Environmental Concerns of Product/Service Systems

According to Kimura (1997), a paradigm shift is needed to move from traditional product selling to more service-oriented products sales, as illustrated in Fig. 2.5. People often buy things not because they want the things themselves, but rather for what they can do, as Magretta (1997) states in her paper *"nobody wants his or her own carpet just to walk on it."* What would happen if the carpet manufacturer owned the carpet and promised to come in and remove it when it required replacing? It might be that if we got the carpet back, we could afford to put more cost into it in the first place in ways that would make it easier for us to recycle. Substituting services for products is one solution. Selling a carpet service instead of a carpet could be more sustainable (Magretta 1997). The PSS-providing company may satisfy customer needs by providing hardware in the form of physical products. This generally means that the physical product that performs the service is owned by the PSS-providing company, and not by the customer. By doing this, customers only pay for the actual function that the physical product provides.

However, when asking PSS providers, they answer that most ownership is still transferred to the customers (Lindahl *et al.* 2009).

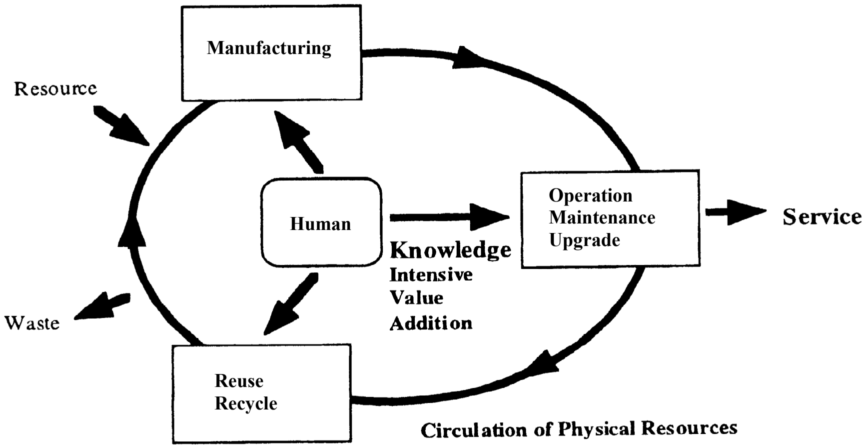

Fig. 2.5 Paradigm shift: from products to services (Kimura 1997)

PSS have the potential to be environmentally benign because they address current levels of material consumption, seeking options that may provide function/service to consumers without lowering their level of welfare (Mont 2000). Prevailing environmental advantages for PSS are (Agri *et al.* 1999):

- Decreased use of virgin materials in production
- Increased lifetime of each part of a product
- Minimised number of times materials pass through the production cycle

The absence of ownership transfer would also facilitate implementation of new, more advanced and resource-efficient technologies, which in turn can reduce the environmental impact (Agri *et al.* 1999). Kimura (1997) states that it is obvious that the concept of PSS based on remanufacturing (inverse manufacturing) will be a definite solution for our environmental problems caused by manufacturing. PSS could in some cases, depending on the solution for fulfillling customer need, be a way to move towards a more sustainable society, but this is not always the case. Some goods do not change in design although they are intended for leasing (Lifset 2000), and/or when being a part of a PSS (Sundin & Bras 2005, Lindahl *et al.* 2009).

2.4 Life-Cycle Perspective of Product/Service Systems

Having a life-cycle perspective on combined services and goods means that life-cycle considerations must be considered for both physical products used in the PSS and the services used during and between the contract times. The physical products can be adapted in various ways for the product life-cycle according to DfX (Design-for-X) methodologies. For this, there exist many engineering methods that would result in adaptation for manufacturing, delivery, usage, service, disassembly, reassembly, testing, recycling and/or remanufacturing. The following paragraphs describe what issues to consider for products and services during the life-cycle phases of:

- Manufacturing;
- Usage;
- Delivery;
- Maintenance;
- Recycling; and
- Remanufacturing.

2.4.1 Manufacturing

For the manufacturing phase there are many guidelines for "Design for Manufacturing" (DfM), which includes, e.g., the adaption of products at levels of company, product family, product structure, and components (Eureka 1999). Manufacturers have saved much in production lead time and overall manufacturing costs by performing DfM, as well as through Design for Assembly (DfA) efforts. Examples of DfA design guidelines from Boothroyd and Dewhurst (1986) are:

- Reduce parts and part numbers;
- Eliminate adjustments;
- Make components self-guided and secured;
- Facilitate access and visibility during insertion;
- Minimize the need for reorientation;
- Eliminate assembly faults;
- Maximize component symmetry or maximize asymmetry; and
- Minimize the importance of component tolerances.

DfA can be seen as a part of DfM, but with a focus on assembly in the manufacturing process. For the service part of the PSS, this would include the finalization of service books and user guides. Also, this phase could include the finalization of the contract writing between the product/service provider and the customer. Most focus is traditionally put on the manufacturing of products.

2.4.2 Delivery

The delivery phase includes the delivery of the products and installation. This phase has extensive inclusion of services, which should be conducted accurately, with good quality, and fast so that the customer can start using the product/service paid for. This phase could be supported by Design for Delivery, meaning that the products are easy to pack, stack and install. Regarding services, the providing company could include technicians for installation of the products and/or good support through staff available online or by phone for those installing the products.

2.4.3 Usage

During usage, it is important for the products to be monitored for uptime and performance. Here, it could be beneficial to have warning systems installed to avoid breakdowns. As a service to the customer, instructions on how to use the products should be clear. Also, it could include how to fill up necessary consumables such as toner cartridges in printers or motor oil in cars. Furthermore, different ways of using the products could be declared, from low performance (with inexpensive usage and lower environmental impact) to high performance (with more expensive usage and higher environmental impact). Some car manufacturers have adopted this example and refer to it for their customers as “eco-driving.” Furthermore, this phase could include changes in capacity for the customer by increasing or decreasing the number of products used in the PSS, all according to the contract setup. This is, for example, included in the flexible fleet rental programs provided by Toyota Material Handling Group (TMHG) (Sundin *et al.* 2005).

2.4.4 Maintenance

This phase refers to the moments of the use-phase when technical service is needed. This could include for example preventive and unplanned maintenance. The products could be adapted for easy maintenance by having maintenance points easily found and accessed. Adaptation such as this is also called Design for Service (DfS). This phase also includes guidance on how the provider should react to malfunctions – depending on what is written in the contract. For instance, sometimes the downtime could be paid for by the provider.

Usually, manufacturers have a time horizon that considers their physical products’ performance until the time of warranty. However, the PSS approach requires a larger scope, including the entire product life-cycle and encompassing the phases after the first warranty/use phase. For this reason, end-of-life options “recycling of materials” and especially “recycling of parts,” e.g., remanufacturing in Fig. 2.3 will be explored in greater detail in this chapter than the previous life-cycle phases.

2.4.5 Recycling

According to Furuhjelm (2000), much research effort has been put into developing design guidelines and manuals for Design for Recycling (DfR). Many of these guidelines are linked to Design for Disassembly (DfD), and these cases are also valid from a Design for Remanufacturing perspective. A big difference here is that in recycling it is important to achieve material chunks that are compatible with one another. In addition, for the remanufacturing alternative, it is important that the components and joint can withstand being assembled at least once again.

Some guidelines that Furuhjelm (2000) has collected from research in the 1990s are shown in the following list:

- Product Structure
  - Integrate functions and make the design modular
  - Minimize overall number of parts
  - Allow a linear and unified disassembly direction
  - Make valuable/hazardous parts/materials easily accessible
  - Cluster parts that have to be removed
  - Avoid metal inserts and reinforcements molded into plastic parts
- Materials
  - Minimize the number of different types of materials
  - Make inseparably connected parts of compatible materials
  - Mark all plastic parts with identification markings
  - Eliminate incompatible labels on plastic parts
  - Mark hazardous parts
- Fasteners and connectors
  - Minimize the number of fasteners
  - Minimize the number of fastener removal tools needed
  - Ensure that fasteners are easy to access
  - Use fasteners of materials compatible with the parts connected
  - Eliminate adhesives unless compatible with both parts joined

2.4.6 Remanufacturing

There are different definitions for the term "remanufacturing." The US Automotive Parts Rebuilders Association (APRA) states "*Remanufacturing is the process of restoring worn and discarded durable products to like-new condition.*" In this chapter, remanufacturing is defined as "*the process of rebuilding a product, during which: the product is cleaned, inspected and disassembled; defective components are replaced; and the product is reassembled, tested and inspected again to ensure it meets or exceeds newly manufactured product standards*" (Sundin and Bras 2005).

If the remanufacture of the product is not extensive, i.e. few parts are replaced, either of the terms "reconditioning" or "refurbishing" are more suitable. Reconditioning typically refers to the restoration of parts to a functional and/or satisfactory condition by surfacing, painting, sleeving, etc. (Amezquita *et al.* 1995). In addition, some researchers use the term reconditioning/refurbishing when the product is only remanufactured to its original specification without exceeding it (Ijomah *et al.* 1999).

2.4.6.1 Levels of Remanufacturing

In the remanufacturing environment, the life-cycle of a product and the disposal rate for both products and components has great impact on the possibility to perform profitable remanufacturing. Previous research has shown that issues such as the age of the generation of the product, the expected life (reliability), the rate of technological development and the willingness to return products for remanufacturing will influence these distributions (Guide & Jayaraman 2000). This Sect. will focus on shedding light on these issues, as well proposing strategies that have the potential to make the overall remanufacturing system more efficient. In the following Sect., the stages of the life-cycle will be addressed according to three different remanufacturing scenarios (adapted from Umeda *et al.* (2005)):

- **Product remanufacturing** Used products are remanufactured to "as-new" or upgraded status; an example of this category is the remanufacturing and upgrading of Tetra Pak filling machines.
- **Component remanufacturing** Used components are remanufactured to "as-new" or upgraded status; an example of this category is the remanufacturing of automotive components and toner cartridges.
- **Component cannibalization** Used products are cannibalized for components, and the components are then remanufactured to an "as-new" or upgraded status. An example of this category is the cannibalization of components from heavy trucks and forklift trucks; in these cases, the component cannibalization option is mainly a supporting activity for the product and component remanufacturing scenarios.

Moreover, designers may lack remanufacturing knowledge because there is a paucity of remanufacturing knowledge and research (Guide 1999, Ferrer 2001, Ijomah 2002). Research indicates that Design for Recycling has received more attention among design and manufacturing engineers than Design for Remanufacturing (DfRem) (Ishii 1998a), even though remanufacturing may provide greater environmental and financial benefits than recycling. For example, many designers are reluctant to use recycled materials because of uncertain quality or supply standards (Chick and Micklethwaite 2002). Furthermore, additional energy is required to reform recycled materials into manufactured products because the energy embodied in the materials and purchased parts assembled in the initial manufacture of the product is lost during the recycling process (Jacobs 1991). Research by Lund (1984) has shown that when the total energy used in initially producing a product is summed up and compared to the energy required to remanufacture the product, the ratios are in the order of 4:1 and 5:1. This is because energy is used in every stage of manufacture, from ore smelting, assembly, and refining, through testing.

As Shu and Flowers (1988) also contend, the reliability of the part is very important since it must go through at least one life-cycle, including all remanufacturing steps, and still work satisfactorily. Sundin (2004) has studied which product properties are important to facilitate remanufacturing. By looking at what properties are suitable for the different remanufacturing steps (inspection, cleaning, disassembly, storage, reprocessing, reassembly and testing), a matrix called RemPro, shown in Fig. 2.6, was created. In case studies performed at remanufacturing companies in Sweden, Canada and Japan, it was shown that the remanufacturing process steps of inspection, cleaning, and reprocessing were the most crucial (Sundin 2004).

To facilitate these steps, the RemPro-matrix presented below shows that designers of new products should focus on giving the products the properties of ease-of-access and wear resistance, since these are important for both the cleaning and reprocessing steps. Following this, the designer should prioritize the properties of ease-of-identification, ease-of-verification, ease-of-handling and ease-of-separation, since these properties are also included as preferable for the crucial steps, but not to the same extent.

The remanufacturing company should first investigate which steps are crucial for its specific remanufacturing business area, and thereafter try to facilitate this according to the RemPro-matrix, as well as place effort on making the crucial steps in the remanufacturing process as efficient as possible. By doing so, many obstacles could be reduced, and the remanufacturer would have an advantage over its competitors (Sundin 2004). In efforts to use remanufacturing to assist PSS, in addition to decisions on how to conduct DfRem, consideration should also be given to the need to design the product for remanufacture. Only products satisfying environmental legislation can be introduced into the market. Thus, DfRem guidelines must help to ensure that products can meet current environmental legislative requirements and have at least good potential to satisfy future ones, either in their original design or because of their ease of redesign after first life. Since products may have different types and levels of environmental impacts at different stages, DfRem guidelines must consider the whole life-cycle to target key environmental impacts and therefore reduce potential penalties. However, research by Ijomah *et al.* (2007) indicates that there appears to be a lack of DfRem guidelines based on life-cycle thinking.

From a service perspective it is important to have supporting systems to support the reverse logistics. The remanufacturing of products is often a more complex operation than ordinary manufacturing, since the timing and condition of the used products is seldom known. Therefore, it is important to have systems in place that could inform the remanufacturers beforehand about the products' conditions and expected arrival to the remanufacturing facilities. Having this information can shorten the lead times and improve the quality of the remanufactured products, which in turn can be used in new PSSs, see Sundin *et al.* (2005).

Remanufacturing Step / Product Property	Inspection	Cleaning	Disassembly	Storage	Reprocess	Reassembly	Testing
Ease of Identification	×		×	×			×
Ease of Verification	×						
Ease of Access	×	×	×		×		×
Ease of Handling			×	×	×	×	
Ease of Separation			×		×		
Ease of Securing						×	
Ease of Alignment						×	
Ease of Stacking				×			
Wear Resistance		×	×		×	×	

Fig. 2.6 The RemPro-matrix showing the relationship between the preferable product properties and the generic remanufacturing process steps (Sundin and Bras 2005)

2.5 Discussion

Manufacturers using the business approach of PSS face many challenges. In order to achieve good PSS performance, they need to take a life-cycle perspective on their physical products and services.

There are several ways to identify design improvements for PSS. In this study, focus was put on manufacturing, usage, delivery, maintenance, recycling and, especially, remanufacturing.

"Design-for-X" is an umbrella term for the many design philosophies and methodologies developed to address designers' lack of knowledge in important product life-cycle areas. The 'X' in 'DfX' may stand for one of the aims of the methodology, for example, assemblability or manufacturability (Boothroyd and Dewhurst 1986, Kuo *et al.* 2001). DfX practices aimed at integrating environmental considerations into product and process design, as well as design-for-environment (DfE), can be particularly applicable to remanufacturing, as seen through developments including the reverse fishbone diagram (Ishii and Lee 1996), the application of modularity and clumping to the recylability issue (Ishii 1998b) and the End-of-Life Adviser (ELDA) by Rose and Ishii (1999). Other tools developed to assist DfRem include Repro2, by Gehin *et al.* (2005), for assessing the remanufacturability of proposed designs via their comparison to current remanufacturable products. Amezquita *et al.* (1995) developed guidelines based on design features that assist remanufacturing, and use these to identify design changes to improve automobile door remanufacturability. Bras and Hammond (1996) used the Boothroyd and Dewhurst design-for-assembly metrics as a foundation for remanufacturability assessment metrics based on product design features. Mangun and Thurston (2002) presented a decision tool to help decide when products should be taken back as well as the most appropriate component end-of-life options. The tool includes a model to help introduce redesign issues in product design. Ijomah *et al.* (2007) provide information obtained via industrial case studies and workshops of the features and characteristics that assist and hinder remanufacturing, while Ijomah (2008) provides high-level guidelines to assist DfRem. The high-level guidelines are being used to educate Masters-level design students, and have formed the basis of lower-level guidelines which in turn are being used as the basis for robust design for remanufacturing software tools. Another source of information about product design and remanufacturing is a report written by Gray and Charter (2007).

DfRem requires products to be designed for ease-of-disassembly, with no damage to the product affecting functional performance for parts hidden from the customer, and no damage affecting performance or aesthetic appearance for parts visible to the customer (or providing good mechanisms to rectify damage). Various DfRem guidelines have been proposed, the most useful being those that are not general guidelines and that also simultaneously consider product features and remanufacturing process activities. Furthermore, research by Ijomah *et al.* (2007)

indicates that there is opportunity to build on previous work by introducing new parameters to enable the development of enhanced DfRem guidelines, for example, based on life-cycle thinking. In fact, the World Summit for Sustainable Development (WSSD) identified product life-cycle-based tools, policies and assessment tools as key sustainable production requirements (United Nations General Assembly 2002).

Analyzing the products and having a good knowledge of the product use was also a focus of this study. To have these issues in mind when developing new products, designers can use the RemPro matrix (Sundin and Bras 2005), design guidelines, etc. Products' potential for remanufacture can be enhanced using remanufacturability-specific design guidelines and by applying, individually or in combination, other DfX practices, provided that remanufacturing priorities are considered. Thus, application of design-for-disassembly to remanufacturing is for a special case requiring that parts are not damaged during separation to preserve their "fitness for reuse". Shu and Flowers (1995) exemplify this sentiment by showing that joints designed for ease-of-assembly and recycling may not facilitate remanufacturing because methods assisting assembly do not always support disassembly without component damage. This is not an issue for recycling, but is vital in remanufacturing as components must be "fit for reuse" following disassembly.

When adapting products for any of these life-cycle phases, for example, remanufacturing, all of the operational steps should be considered. For instance, if one step such as reassembly is very difficult to perform on a product, it does not matter, in respect to remanufacturing, how much effort has been put into adapting the product for disassembly. One should remember that the essential goal in remanufacturing is part reuse. Thus, if a part cannot be reused as is or after refurbishment, the ease of cleaning or reassembly will be of no consequence in the case of remanufacturing (Shu and Flowers 1988). This means that much effort can be made in product design without obtaining any expected benefits.

Looking at the different DfX guidelines, one can see that there are conflicting goals that need to be considered. If a product and service is to be included in a PSS, it is important to have the full life-cycle perspective to avoid the suboptimization of any specific life-cycle phase. Considering the categories of PSS shown in Fig. 2.1, according to Weissenberger-Eibl and Biege (2009), most design guidelines and principles are developed for product-oriented PSS rather than use-oriented and result-oriented PSS, which would require more attention in industry and research.

2.6 Recommendations

To the industrial practitioners I would like to recommend the following:

- Go through the product life-cycle of the physical product and services used in the PSS and identify any challenges and pitfalls that require attention.
- At the same time, seek opportunities for new services that traditionally do not exist for a manufacturer.
- Try to keep the life-cycle perspective when developing new PSS, and thus avoid sub-optimizing any specific life-cycle phase.

2.7 Conclusions

To conclude, this chapter has presented issues for a product/service system provider to consider from a life-cycle perspective. This includes both considerations regarding the product and the services used during the life-cycle phases. Chapter 3 will continue this discussion from a more practical perspective, showing how the life-cycle perspective could be performed in practice.

References

Agri, J., Andersson, E., Ashkin, A., Söderström, J. (1999) Selling Services: A study of environmental and economic effects of selling functions. CPM report No.6.

Alonso-Rasgado, T., Thompson, G., Elfström, B.-O. (2004) The design of functional (total care) products. J. Eng. Des., 15(6), 515-540.

Alonso-Rasgado, T., Thompson, G. (2006) A rapid design process for Total Care Product creation. J. of Eng. Des., 17(6): 509-531.

Amezquita, T., Hammond, R., Bras, B. (1995) Characterizing the remanufacturability of engineering systems. In: ASME Advances in Design Automation Conference, DE-vol. 82. ASME, Boston, Massachusetts. p. 271-278.

Aurich, J. C., Fuchs, C., Wagenknecht, C. (2006) Life-cycle oriented design of technical Product-Service Systems, J. of Clean. Prod., 14(17): 1480-1494.

Bras, B., Hammond, R.. Towards Design for remanufacturing–metrics for assessing remanufacturability. In: Proceedings of the 1st International Workshop on Reuse, Eindhoven, The Netherlands, 11–13 November, 1996, pp. 5–22.

Boothroyd, G., Dewhurst, P. (1986) Product Design for Assembly. Boothroyd Dewhurst Inc., Wakefield, RI.

Chick, A., Micklethwaite, P.(2002) Obstacles to UK architects and designers specifying recycled products and materials. In: Design History Society Conference, Aberystwyth, Wales.

Cox Jr., W. E. (1967) Product life-cycles as marketing models. J. Bus. 40: 4.

EUREKA (1994) Design for Manufacture DFM, Guide for improving the manufacturability of industrial products. Institute for Product Development (IPU), Lyngby, Denmark.

Gehin, A., Zwolinski, P., Brissaud, D. Imaging a tool to implement sustainable end-of-life strategies in the product development phase. In: Proceedings of the 10th ESCP Conference, Antwerp, Belgium, 5–7 October, 2005.
Goedkoop, M. J., Van Halen, C. J. G., te Riele, H. R. M., Rommens, P. J. M.. (1999) Product Service Systems, Ecological and Economic Basics. Hague, the Netherlands, VROM.
Gray, C., Charter, M. (2007) Remanufacturing and Product Design: Designing for the 7th Generation. The Centre for Sustainable Design, University College for Creative Arts, Farnham, UK.
Guide, V.D. (1999) Remanufacturing production planning and control: U.S industry best practice and research issues. Second International Working Paper on Re-use, Eindhoven, The Netherlands, p. 115–128.
Guide Jr., V.D.R., Jayaraman, V. (2000) Product acquisition management: current industry practice and a proposed framework. Int. J. Prod. Res. 38(16): 3779-3800.
Ferrer, G. (2001) Theory and methodology on the widget remanufacturing operation. Eur. J. Oper. Res. 135, 373–393.
Furuhjelm, J. (2000) Incorporating the end-of-life aspect into product development: Analysis and a systematic approach. Linköping studies in Science and Technology, dissertation No. 642, Department of Mechanical Engineering, Linköping University, Linköping, Sweden.
Ishii, K. Design for environment and recycling: overview of research in the United States. Invited paper in CIRP 5th Life-cycle Engineering Seminar, Stockholm, Sweden, September, 1998a.
Ishii, K. Modularity: A key concept in product life-cycle engineering. In Handbook of Life-Cycle Enterprise:Molina, A., Kusiak, A. (eds.) Kluwer 1998b.
Ishii, K., Lee, B. Reverse fishbone diagram: a tool in aid of design for product retirement, in 1996 ASME Design Technical Conference: Design for Manufacturability Irvine, CA, September, 1996.
Ijomah, W. L., Bennet, J. P., Pearce, J. Remanufacturing: evidence of environmentally conscious business practice in the UK. In: Proceedings to International Symposium on Electronics and the Environment (IEEE), p. 192-196. Danvers, USA; 11-13 May 1999.
Ijomah, W. A model-based definition of the generic remanufacturing business process, PhD Dissertation, The University of Plymouth, UK, 2002.
Ijomah, W.L., McMahon, C.A., Hammond, G.P., Newman, S.T. (2007) Development of robust design-for-remanufacturing guidelines to further the aims of sustainable development. Int. J. Prod. Res., 45 p. 4513-4536.
Ijomah, W.L. Enhancing decision making in remanufacturing. The 17th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM), Skövde, Sweden, June 29-July 2, 2008.
Jacobs, M. (1991) The Green Economy: Environment, Sustainable Development and the Politics of the Future. p. 110–116, Pluto Press: London, UK.
Kimura, F. Inverse Manufacturing: from product to services, The First International Conference on Managing Enterprises - Stakeholder, Engineering, Logistics and Achievements (ME-SELA-97) (1997). Loughborough University, United Kingdom.
Kotler, P. (2003) Marketing Management, 11th edn., Prentice Hall, USA.
Kuo, T., Huang, S., Zhang, H.(2001) Design for manufacture and design for ‘X’: concepts, applications, and perspectives. Comput. Indus. Engin., 41, 241–260.
Lifset, R. (2000) Moving from product to Services. J. Ind. Ecol., 4, p. 1-2.
Lindahl, M., Ölundh, G., The Meaning of Functional Sales, in Proceedings of Life-cycle Engineering: Challenges and Opportunities: 8th International Seminar on Life-cycle Engineering, Varna, Bulgaria, 2001.
Lindahl, M., Sakao, T., Sundin, E., Shimomura, Y. (2009) Product/Service Systems Experiences – an International Survey of Swedish, Japanese, Italian and German Manufacturing Companies. Proceedings of CIRP Industrial Product/Service Systems (IPS2), 1-2 April, Cranfield, The United Kingdom, p. 74-81.

Lund, R.T. Remanufacturing: The Experience of the U.S.A. and Implications for the Developing Countries, World Bank Technical Paper No. 3, 1984.
Mangun, D., Thurston, D. (2002) Incorporating component reuse, remanufacturing and recycle into product portfolio design, IEEE Trans. Engin. Manage., 49, 479–490.
Magretta J. (1997) Growth trough global sustainability: an interview with Monsanto's CEO, Robert B. Shapiro. Harvard Bus. Rev. 75, No. 1, p. 78-88.
McAloone, T. C., Andreasen, M. M., Design for utility, sustainability and social virtues, developing product service systems. In: Proceedings of International Design Conference – (Design-04), Dubrovnik, Croatia, 2004.
Mont, O. Product-Service Systems: Final Report International Institute of Industrial Environmental Economics, Lund University, February 2000, AFR-REPORT 288, Swedish EPA, 106 48 Stockholm, Sweden, ISSN 1102-6944.
Mont, O. Product-service systems: Panacea or myth? PhD thesis, The International Institute for Industrial Environmental Economics (IIIEE). Lund, Sweden, Lund University: 233, 2004.
Morelli, N. (2003) Product-service systems, a perspective shift for designers: A case study: the design of a telecentre. Design Studies. 24 (No. 1) p. 73-99.
Oliva, R., Kallenberg, R. (2003) Managing the transition from products to services. Int. J. Serv. Ind. Manag., 14(No. 2) p. 160-172.
Rose, C. M., Ishii, K. (1999) Product end-of-life strategy categorization design tool, J. Electr. Manuf., 9, 41–51, Special Issue on electronic product reuse, remanufacturing, disassembly and recycling strategies.
Sakao, T., Shimomura, Y. (2007) Service Engineering: a novel engineering discipline for producers to increase value combing service and product, J. Clean. Prod., 15, p. 590-604.
Sakao, T., Matzen, D., Ölundh Sandström, G., Framing design research for service orientation through PSS approaches. Submitted to JMTM, special issue on Product/Service Systems, 2009.
Shu, L. H., Flowers, W. C. Reliability modeling in design for remanufacture. ASME, (1988) 120: 620-627.
Shu, L., Flowers, W. Considering remanufacture and other end-of-life options in selection of fastening and joining methods, in Proceedings of the IEEE International Symposium on Electronics and the Environment, p. 75–80, Orlando, FL, USA, 1–3 May, 1995.
Sundin, E. (2004) Product and Process Design for Successful Remanufacturing, Linköping Studies in Science and Technology, Dissertation No. 906, Department of Mechanical Engineering, Linköping University, SE-581 83 Linköping, Sweden.
Sundin, E., Bras, B., (2005) Making functional sales environmentally and economically beneficial through product remanufacturing. J. Clean. Prod. 13 (Issue. 9) 913-925.
Sundin, E., Jacobsson, N., Björkman, M. Analysis of Service Selling and Design for Remanufacturing, Proceedings of IEEE International Symposium on Electronics and the Environment (IEEE-00), p. 272-277, San Francisco, CA, USA, 8-10 May, 2000.
Sundin, E., Larsson, M., Nielsen, A. Design for functional sales – a case study of forklift trucks at BT Sweden. Proceedings of EcoDesign-05, Tokyo, Japan, 12-14 December 2005.
Sundin, E., Lindahl, M., Comstock, M., Shimomura, Y., Sakao, T. Integrated product and service engineering enabling mass customization. In: Proceedings of International Conference on Production Research (ICPR-07), Valparaiso, Chile, 2007.
Sundin, E., Lindahl, M., Öhrwall Rönnbäck, A., Ölundh Sandström, G., Östlin, J. Integrated product and service engineering methodology. In: Proceedings of 11th International Conference of Sustainable Innovation, Chicago, USA, 2006.
Tibben-Lembke, R. S. (2002) Life after death: reverse logistics and the product life cycle. Int. J. Phys. Distrib. Log. Manag. 32(3).
Tischner, U., Verkuijl, M., Tukker, A. First Draft PSS Review, SusProNet Report, draft 15 December. Available from Econcept, Cologne, Germany; TNO-STB. Delft, the Netherlands, or www.suspronet.org, 2002.

Tukker, A., Tischner, U. New Business for Old Europe, Sheffield, United Kingdom, Greenleaf Publishing, 2006.
Umeda, Y., Kondoh, S., Takashi, S. Proposal of "Marginal Reuse Rate" for Evaluating Reusability of Products. In: International Conference on Engineering Design, Melbourne, August 15-18, 2005.
United Nations General Assembly: World Summit on Sustainable Development: Plan for Implementation, UN Division for Sustainable Development: Johannesburg, 2002.
Vargo, S. L., Lusch, R. F.(2002) Evolving to a new dominant logic for marketing. J. Mark. 68(No. 1) 1-17.
Weissenberger-Eibl, M., Biege, S. Design for Product-Service Systems – A Literature Review. In: proceedings of QUIS 11 Moving Forward with Service Quality, p. 724-733, June 11-14, 2009. Wolfsburg, Germany.
Östlin, J., Sundin, E., Björkman, M. (2008) Importance of closed-loop supply chain relationships. Int. J. Prod. Econ.115: 336-348.
Östlin, J., Sundin, E., Björkman, M. (2009) Product Life-cycle Implications for Remanufacturing Strategies. J. Clean. Prod. 17: 999-1009.

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http://www.springer.com/978-1-84882-908-4

Introduction to Product/Service-System Design
(Eds.)T. Sakao; M. Lindahl
2010, XXII, 279 p. 80 illus., Hardcover
ISBN: 978-1-84882-908-4