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Considerations towards Systematic Engineering of Product Service Systems

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Abstract
Product Service Systems (PSS) are being discussed among researchers in engineering design as sources for innovation in industrial production and consumption. Furthermore, their potential for achieving sustainability has been examined. This paper looks at features of the systematic engineering design of products and discusses in how far these may apply to PSS. To this end, integration between the functional structure of the product and the "service blueprinting" method is attempted. The method aims to facilitate the integration of product and service development and provide a basis for generating and evaluating design variants.

Keywords: PSS design, PSS functions, PSS properties.

1 Introduction

In systematic engineering design as formulated e.g. by Pahl and Beitz [1], the recommended working procedures go hand in hand with particular views of the object of design (i.e. the product as a technical artefact). These views are formalised in product models. In PSS design, both models and working procedures have been proposed.
The aim of this paper is to elaborate, in how far this correlation between design procedure and conceptual models can be found in or applied to Product Service Systems. To this end, the literature is examined with regard to particular features of both the concepts of systematic engineering design and functions and properties of Product Service Systems.
To this date, PSS literature offers a wealth of information and concepts on matters of PSS-related company strategy, success factors, actor networks, environmental performance, process models, and methods of PSS development, and industry case studies. Furthermore, PSS in their widest sense are commonplace in todays business environment (one would be hard pressed to find a product that is sold without any form of accompanying service, be it a warranty, a phone support hotline or even a website with product information/advertising). In contrast, a study conducted by Wong ([2], p.77) mentions, that only in four out of 16 reviewed cases of mostly business-to-consumer PSS, any solution alternatives have been considered.
One of the strengths of systematic engineering design methodologies is the support they provide for exploring "solution fields" for design tasks. Finding and evaluating different solution variants on a conceptual level and selecting the most promising ones for further concretisation is one of the recurring tasks in systematic engineering design.

It must be assumed, that the often cited benefits of PSS over traditional sales, particularly ecological ones, will not occur by themselves, but have to be designed into the PSS.
This raises the question: What are the prerequisites for treating a PSS as a “designable” object, and which benefits may be drawn from this?
This paper presents a modelling approach used to explore the theoretical basis for comparing product- and PSS design and transferring some of the procedures from the former to the latter.

2 Characteristics of systematic engineering design

Methodologies, procedural models of the design process and product models help structure and accomplish the many different tasks of developing a product. Methods of design are usually heuristic in nature, in the sense that they rely to some extent on the experience and intuition of the user in order to perform their tasks.
The methodology according to Pahl/Beitz is used as an example here. The design process is divided into the main phases “task clarification”, “conceptual design”, “embodiment design”, and “detail design”. For each phase, a number of general activities are given, such as e.g.: “find and select product ideas”, or “elaborate a requirements list” for the first phase. For these, methods and procedures are suggested, which are either generally applicable to similar tasks in different phases (e.g. abstraction, analysis) or specific to a phase in the process.
To clarify, what type of support is intended for PSS design, some features of procedural models and methodologies for systematic engineering design processes are collected here. The list refers mainly to Pahl/Beitz, but the features can also be found, to a greater or smaller extent, in most other procedural models and methodologies.

- Dividing the overall design task into sub-tasks (e.g. through functional decomposition or modularisation of the product in the concept phase)
- Prioritising tasks or product modules which are for various reasons regarded as crucial to the success of the design project (e.g. those modules likely to have the largest impact on the overall solution, or the most time consuming tasks)
- Alternating between abstracting the task in order to open up a wider range of possible solutions and then concretising different solution concepts
- Alternating between divergent and convergent progress means creating not just one solution to a design task but creating alternative solution variants for sub-tasks (diverge), comparing and evaluating them and selecting the most promising ones for further development (converge)
- Alternating between analytical tasks (gathering and evaluating information about the envisioned solution, e.g. by calculation, simulation, etc.) and synthesis (generating new information e.g. by deciding on product features)
- Problem-/Goal-oriented selection of methods and procedures and flexibility of method use – it is important to note that procedural models are not rigid prescriptive processes. Depending on the situation, the selection of the appropriate method and framing the subtasks in an appropriate way is at the discretion of the designer.

This is not to say that every design process following any one of the systematic approaches will necessarily display these qualities; many additional factors, such as e.g. individual experience and working styles, team composition, process management, etc. play a role ([1], p.125 ff.). One can assume that this should be no different in PSS design.

3 PSS Background

The identifier “Product Service System” is comprised of three parts. “Products” and “services” each have their own inventory and history of models and methodologies. Some of their features, which are relevant here, are discussed in this chapter. The third part is “system”.

According to Ropohl [3], there are three distinct views of technical systems:
- Functional – a system has inputs, internal states and outputs,
- Structural – a system is comprised of elements and the relations between them, and
- Hierarchical – a system can be divided into subsystems, each with their own functions and structure.

These views are implicit in product models. The theory of technical systems has been developed by Hubka [4], in particular the concept of the technical artefact as part of a "transformation system". A discussion of how these can be applied to PSS is given by Matzen et al. [5].

Product

Ehrlenspiel [6] presents a "product model pyramid", which can be seen as an illustration of the different levels of abstraction, on which a product may be considered. These levels are: "functions", "physical principles", "design and material solutions", and "manufacturing solutions".[1] Heidemann [7] presents a generic process model of product use as an even more abstract view, with the product represented as a black box and characterised solely by its outward relations. It is comparable to the transformation process model of Hubka and Eder [4] in emphasising the process as a state transition, but different in the types of factors considered.

The function structure provides a clear indication of how product models and design procedures are linked. A function is a "solution-neutral" ([1], p.170) description of a subset of the product structure. In essence, it describes the throughput of material, energy, and information through a (sub-)system of a product. A function structure can be prepared through the method of abstraction from a given implementation, leading, e.g. in the case of a lawn mower from the requirement "include a four-stroke engine and a tank" to: "provide a source of mechanical energy", thus opening up new possibilities in searching for solution ideas. A solution neutral function could be seen as a design task, to which the available physical effects and working principle are the potential solutions.

Functions can be represented verbally (general functions), or in various formalised and/or domain-specific sets (e.g. logical functions "AND", "OR", etc., cp. [1],p.31ff.). Corresponding to the hierarchical structure of the technical system, the general functions can also be viewed at different levels of aggregation. Thus, the division of the design task into subtasks is supported.

Also relevant in this context is the division of inner (designable) properties from outer (perceivable) properties, originating from the product property model of Hubka/Eder [4]. In newer research by Weber et al. [8], "characteristics" are used instead of inner properties. In products, characteristics are e.g. geometrical features and (outer) properties range from mechanical (stiffness, weight), to aesthetical- or recycling properties.

Service

Research on service design and marketing has its roots in the field of business administration. However, the convergence of service and product design is explored from this direction as well. Bullinger and Scheer [9] for example argue for establishing process models of service engineering in analogy to those of product or software design and present concepts, models and methods in that direction.

The distinguishing features of services as opposed to products have been discussed in connection with PSS [5] and are: intangibility, inseparability (production and consumption of

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[1] Translation by the author of this paper, likewise in the other quotes from german language sources (unless indicated otherwise)

the service take place at the same time), heterogeneity (due to an external factor – the customer or an item in his possession – being part of the delivery, the service can not be planned ahead in all details), and perishability (services can not be stored). According to Bullinger et al. [10] Service also has three dimensions:

- Structure – the resources needed for a service (the factors that constitute "the ability and willingness to deliver the service")
- Process
- Outcome – "the material and immaterial impacts for the external factors"

PSS functions and properties

Having found some of the features relevant to product and service design, the question now is, how they are represented in PSS design.

"Functional sales" is in large parts synonymous with "Product Service Systems" [11]. The focus is on selling a "function" to the customer, i.e. a means to reach a specific goal or fulfil a need. It is important to distinguish these functions from the "product functions" of Pahl/Beitz.

In literature, PSS functions are given as general functions in a verbal description. A classification scheme for sets of formalised functions was not found. One important difference between the functional structure of a product and the functional description of the PSS is the added factor of Who carries out the functions. Networks of actors (customer, provider, suppliers, etc.) are a prominent feature in PSS modelling, e.g. [12].

If a PSS is to be an object of design, it should have properties which result from the relations of product- and service components in addition to those resulting from the properties of the individual elements (corresponding to the structural view of the system according to Ropohl).

In order to approach the topic of properties, the specific features of PSS which are setting it apart from product or service should be looked at. There is some discussion about the merits of PSS compared to "traditional" sales. In the literature, topics are variously "potentials", "benefits", "opportunities", "characteristics", "drivers and barriers", etc. (cp. e.g. [1],[13],[14],[15]). The following list is by no means exhaustive, but it reiterates some of the general properties of PSS or subsets thereof, which may serve as points of reference in PSS design, either as goals, requirements, functions, or evaluation criteria:

- Responsibility for results of use processes – this category combines product characteristics (e.g. which particular outputs occur) with service characteristics (who has, by arrangement, responsibility for the product at the time?). Reallocating responsibility can lead to changes in user behaviour.
- Control over processes – not necessarily identical to the above point. In a very abstract view, "control" is derived from the opportunities available to conduct a process (which may be, at least in part, based on product characteristics, e.g. which power settings are available in a vacuum cleaner) and the outer limitations on the control over the process in the PSS setting (e.g. who gets to decide, which setting should be used).
- Cost – similar to "responsibility". In the widest sense, cost includes every kind of effort that has to be put into conducting a process, including opportunity costs. Who bears the costs (e.g. energy or consumable, in part or in total) for a transaction also influences user behaviour, frequency of use and intensity of use.
- Value – some definitions make value a cost/benefit ratio, thus encapsulating the previous point, but since both cost for and benefit from a transaction can be allocated independently, it is convenient to separate them. Moreover, the term "value" seems more appropriate, since the scope of PSS in general may include intangible factors,

which generate no immediate benefit, but still represent a certain value (e.g. warranty for a product)

Steinbach [16] presents an approach to PSS development based on the "property driven development" by Weber [8] and including a classification of PSS properties and characteristics. Characteristics of product and service are treated separately; product characteristics are equivalent to "elementary design properties" of [4], i.e. geometry and material of product assemblies, parts and features. Service characteristics are defined as those features of the service in the structure and process dimension, under the premise that they can be planned ahead of the service execution. Properties of product and service are seen as inseparable in the perception of the customer and are equated with the "quality" of the PSS. They are classified into "search-", "experience-", and "credence qualities". The products "external properties" and influencing factors on service quality (following [17]), e.g. reliability, and communication, are classified accordingly.

4 Applying systematic engineering design principles to PSS - Example

In order to apply the findings of the literature research in practical PSS design, a modelling scheme is presented here. It is based partly on the method of "service blueprinting" by Shostack [18] and rearranges some of the elements of the original method, in particular by including the function structure of the product. The aim of this ongoing research is to contribute to building a theoretical basis for introducing systematic variation of solution concepts into PSS design. It should be noted, that the application examples presented here are anecdotal accounts taken from student projects. The procedure in these projects was to confront students (with a background in systematic engineering design theory) with a hypothetical PSS design project. They were instructed to research and generate solution variants for major functions in the PSS. The applicability and usefulness of systematic engineering design concepts was tested and discussed. In these projects, the case of a mobile phone (in combination with a contract) has been considered as an example. This example has the benefits of product and service being integrated (a phone without access to a service providers network is as useless as access without a phone), of offering a variety of different service options and of being immediately recognisable for almost everyone, at least from the customers perspective. The downside is that the variety of the physical realisation of product functions is, from the mechanical engineering standpoint, quite low. Still, on a conceptual level one may find variations of product functions, which can be used in PSS solution variants.

Aim and general approach

The goal for this modelling scheme is to complement the more analytical approaches to PSS design with a way to systematically elaborate on solution ideas. To this end, the information about the object of design is structured in analogy to product models, and similarities and points of contact are sought. The following is a "wish list" for the properties of the modelling scheme:

- It should facilitate task- or problem-oriented work such as taking advantage of specific opportunity parameters in PSS.
- It should put intuitively found solutions or solution components into context and complement them with structured consideration of possible alternatives.
- The modelling scheme should provide a visual representation of the key components of a solution and aid in the prioritising significant subsystems or features and determining further steps in the design process.

The model includes three distinct levels of abstraction or aggregation:

- The overall PSS is represented as a purely verbal description of the intended function(s) and participants (e.g. “the recipient of the service needs a means to move about, so we offer him a car-sharing or rental service”). While this is perfectly valid as a starting point for establishing a collection of solution variants, it offers little in the way of handholds for a systematic variation or deliberation about individual functions and properties.
- The principle solution concepts are arranged in a modified process model, leaving the actual solution still in a black box with only a verbal description of what it is supposed to achieve, but structuring high-level properties according to some of the categories discussed above. The suggested working procedure is the decomposition of the PSS into a small number of use “Episodes”, each encompassing one of the main functions, collecting a number of alternatives to fulfil them (intuitively, from experience or inspired by existing case studies), and the iterative addition of properties to the solution variants and estimating their relative importance, until one is satisfied that the crucial parameters have been found.
- The third level is a structural model of “Activities” and product functions within each Episode, in essence an adapted variant of the method of “service blueprinting. This view can be used to compare solution variants with regard to some of the PSS properties discussed above and provides the link to product functions.

Task clarification and first ideas

At the start of the project, the task and boundary conditions are elaborated. In the student projects in the absence of “real” boundary conditions, this amounted to a group discussion about likely and realistic ones. Gathering of ideas begins at a very early stage. There is no strict separation between the phases of task clarification and conceptual design. Model building starts with a verbal description of the main “top-level” functions to be implemented.

In the mobile phone case: The customer enters into a contract with the provider for a length of time. The contract specifies a monthly subscription fee, rates for connections, etc. and the customer also gets a mobile phone as part of the agreement. The customer takes this offer, because he expects a number of functions to be fulfilled, e.g. to make phone calls, to send and receive text messages, etc.

In order to avoid the excessive use of the word “process” and the resulting misunderstandings, the PSS is divided into a number of “Episodes”. A PSS Episode is loosely defined here as encompassing a sequence of events in the use phase of the PSS, which together fulfil a main function for the recipient (e.g. making a phone call). In the course of defining the episodes, it is important to estimate the frequency, with which the episode is likely to occur. This is a necessary prerequisite for evaluating and comparing solution ideas later on.

This stage is important for the subsequent production of solution variants in that it starts the functional consideration of the design goal. During the project, functional descriptions were usually found by abstracting from known solutions, asking: what is the purpose of a given episode? Alternative solution ideas are governed by the question of how else the purpose could be fulfilled. Naturally, the properties and characteristics of solutions were discussed on a very general level. It is possible to introduce specific opportunity parameters or design goals, which are then treated as characteristics (e.g. “try to come up with a solution idea, in which the provider and not the customer is in control of process X”). However, a structured consideration of the implications for the overall solution could not be performed. For this, the model was taken to the next stage.

Principle solution concepts

The process model related to that of Heidemann [7] is used as the basis for the structured representation of the solution concepts for an episode.

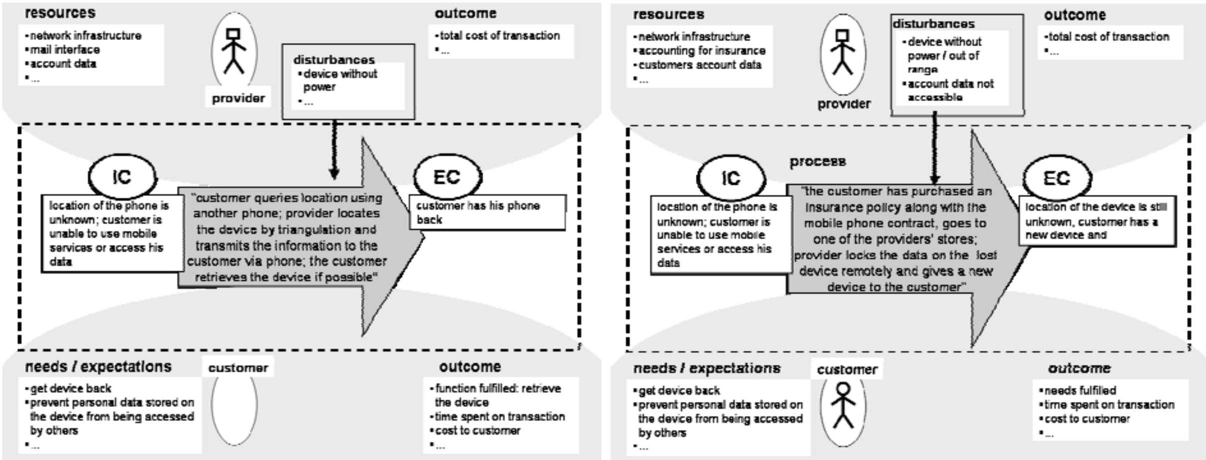

Figure 1. Two variants for the episode "what to do in case the phone is lost or stolen"

The results of the preceding stage are: the list of episodes, their functional description, and possibly also ideas for solutions. The functional description is transformed into initial condition ("IC") and end condition ("EC"). All solution alternatives for a given episode need to provide some way to transform IC into EC. The solution ideas (if any) are sorted, assigned to the respective episodes (an idea may concern a number of episodes) and described verbally on the level of individual episodes. Further solution ideas may be generated through intuition, referring to literature (best-practice examples, documentation of existing offers, etc.) or other means. Detail is then added, also verbally, in form of general properties of the solution idea. Properties, which are visible at this stage, are:

- Resource properties – Which resources would in principle be needed to conduct the episode using this solution idea? (e.g. in the case of making a call on the mobile phone: the providers infrastructure)
- Cost (estimated)
- Outcome properties – what is the likely outcome of the episode? Here, any considerations specific to the solution idea are added.

These considerations are necessarily vague. Only very rough estimations can be expected at this point. However, this improves the systematic formulation and evaluation of solution concepts in two respects: Firstly, new solution ideas may be found by negation of individual properties. An example from the mobile phone scenario is: "find a PSS concept that transmits text messages without the need for the resource property: provider's infrastructure". This resulted in the idea of a peer-to-peer network for transmitting SMS. This variant may not make a lot of sense at first glance, and many obstacles were cited in the resulting discussion. Nevertheless, in many cases new solution ideas could be found.

The second benefit of this collection of properties is that it could allow for a first prioritisation of crucial episodes or promising solution ideas (although this has not been tested yet). For the purpose of comparison, a detailed knowledge e.g. about costs is not necessary (as it would be, if a solution were to be evaluated by itself). Rather, a qualitative comparison of the solution ideas, e.g. by subjecting them to a pair-wise comparison with the collected properties as criteria, may be sufficient to indicate clear favourites. In the same manner, if an episode is judged to be critical with respect to a number of important properties (resources needed, costs estimated, etc.) it could also be made a priority in the design process.

“PSS blueprinting”

The first functional decomposition of a PSS into episodes and the collection of the properties provide the preconditions for conducting a variation of solution concepts. They are, however, not sufficient for the type of problem oriented development that was envisioned, since some important properties are not included. These are added in this next stage.

The basic components of “service blueprinting” are activities of customer and service provider, the latter being divided into those activities that are visible for the customer and those that take place behind the scenes. It should be noted, that blueprinting has been applied to PSS before [19], although with a different aim and scope.

The procedure here is to add to the description of the process model a sequence of activities and necessary product functions. An “Activity” is defined here as a process that is initiated by one actor and uses one set of product functions and continues until the initiative goes to another actor, or different product functions are used.

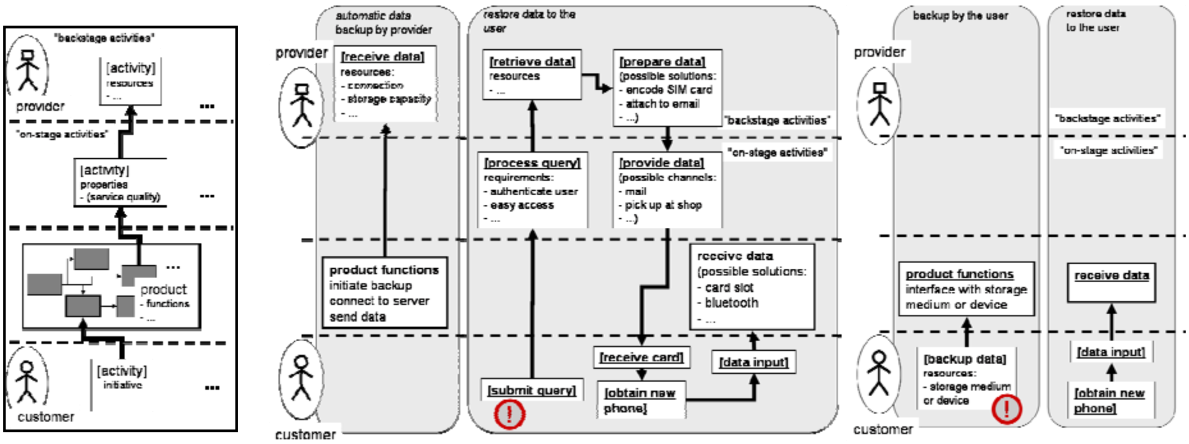

Figure 2. Basic blueprint (left) and variants (center and right)

Figure 2 shows the general layout of the blueprint on the left. It is comprised of four areas: the field of the provider’s “on-stage” activities (those, the customer can see and experience), his “back-stage” activities (which the customer can’t perceive), the product functions, and the customer’s activities.

In the center and right of figure 2, two variants of an episode for restoring data from a lost or stolen phone are given. The activities are formulated in a solution neutral way, although in some cases possible solutions have been put in, in order to illustrate the range of alternatives. Some properties relevant for evaluating the solution alternatives are also put in. However, a full depiction of the variants with all the information on the activities would take more space, so many of the applicable properties have been left out here. The PSS-specific properties of “control of” and, to some degree “responsibility for the processes” during the episode become visible in this model, by the simple indication of who’s part of the “playing field” the activity is located in. Furthermore, the exclamation mark is used to mark who initiates the transaction.

The PSS blueprint can be used:

- in creating variants by transferring individual activities from one area of influence to another, exploring the changes this would demand in the product functions or other elements of the episode
- in evaluating solution variants as to the (estimated or experienced) customer acceptance with regard to the visible properties – in some cases, customers may be unwilling to leave control over certain processes to a service provider; in other cases, an episode that is initiated by the provider may be regarded as bothersome by the customer

- in finding crucial activities or properties and prioritising them for further treatment in the design process.

5 Results and further work

Experimenting with the modelling scheme in this hypothetical application scenario has shown that some specific PSS properties and characteristics can be visualized. Among them are some which are judged to be crucial for achieving benefits over “traditional” modes of sales in the literature, both from an ecological and economic perspective. It has further been found, that components can be varied, and the expected results of these variations can also be seen in the models.

However, the findings do not amount to a final judgement about whether the described factors are functionally equivalent to those used in product design. Particularly the question, of whether some “high-level” features (=highly aggregated and abstract factors, which potentially depend on a large number of elements and relations) should be treated as (inner) characteristics or (outer) properties demands some further research. It is certainly possible to take an activity in a PSS blueprint and push it from one area of influence to another or perhaps even conceiving a product function that would achieve the same. This qualifies the factor of responsibility as a characteristic, since it is directly manipulated. Still, this action leads to a certain amount of re-wiring in the model until the episode with the newly allocated responsibility becomes viable and the change takes effect and the property becomes visible.

In the experiments, considerations on overall PSS quality could not be reconstructed. While the quality criteria of e.g. accessibility, friendliness, reliability, etc. certainly apply to individual episodes, the properties could not be scaled up to the PSS as a whole, since it was felt, that the overall property is not just the cumulative effect of the properties of it’s parts. One conclusion that may be drawn from this is to favour the approach of dividing the PSS into episodes and prioritise these properties in the episodes, where they are most influential. Similar considerations have led to factoring out the whole topic of overall PSS value.

The presented modelling scheme is not, at this time, a method for developing new product service systems. Still, further development of the model is intended to be performed on actual design tasks. Thereby, the inventory of high-level properties will be enlarged and the usefulness will be tested. A major question is, whether the PSS blueprints can be formulated with a manageable level of complexity while retaining enough information to allow for a meaningful comparison of solution variants that would satisfy practitioners of PSS design in a “serious” design situation.

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