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MODELLING OF PRODUCT-SERVICE SYSTEMS (PSS) BASED ON THE PDD APPROACH

C. Weber, M. Steinbach, C. Botta and T. Deubel

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1. Introduction

To achieve a sustainable competitive advantage, it is necessary to minimise the development time of new products. At the same time, any new product must be a rather optimal compromise between fulfilment of the customers' and/or users' requirements, economical efficiency and ecological awareness. To deal with these – partially conflicting – requirements, it seems to be necessary to allow a new perspective onto the product development process. On the one hand, a continuous methodology is necessary that guides the designer through the development process, beginning with (often fuzzy) requirements and supporting him/her right through to the final description of the solution. On the other hand such a methodology is closely linked to a suitable approach to modelling the product itself, and also in this respect extended or new concepts are required.

An integrated view on material and non-material components of products ("products" in the traditional meaning of the word and "services") seems to be very promising. Such a holistic perception has been made in an implicit way for a long time, but an explicit and systematic consideration is rather new. In recent publications, the term *Product-Service System* (PSS) has been established for this type of integrated business; where the traditional separation between material and service components is given up and both are considered as potential means to fulfil customers' needs [1, 3, 6, 10, 11].

Considering material components and services of a product ("product" in an extended sense) fully integrated and on equal terms, it can not be determined in advance which requirements will be fulfilled by services and which requirements will be fulfilled by material components. In some cases certain properties of a product can only be achieved by services that complement or even replace the material component.

Although the importance of PSSs in today's marketplace is undisputed, there is no clear approach to develop them in a systematic way.

The main problem of applying traditional design methodologies like VDI 2221 [9] to the development of PSSs is their strong orientation on functional, physical and building structures of a product. This orientation may match material products, but does not fit PSSs, the purpose and behaviour of which can hardly be displayed in the categories mentioned. A result-oriented approach seems to be necessary. In the field of business engineering, there do exist some models to describe services and some – still very conceptual – approaches to how to develop them.

The goal of a joint research project of the Institute of Engineering Design/CAD (LKT) and the Institute of Information Systems (IWi), both of Saarland University, is to develop a consistent methodology for developing PSSs. The initial point for this consideration is the concept of *Property-Driven Design/Development* (PDD), a new product development theory and methodology developed by LKT originally to describe material products and to lead through development processes for them.

The following paper will briefly introduce the basics of the PDD concept. Requirements for applying the PDD approach to PSSs will be covered, and a new approach to capturing integrated product models of PSSs will be shown. Furthermore, we want to give some outlooks, mainly with regard to the question how to describe (integrated) development processes of PSSs.

2. Property-Driven Development/Design (PDD)

The concept of Property-Driven Development (PDD) was developed a couple of years ago, originally for material products. Before applying it to Product-Service Systems, the PDD concept is briefly described. A more detailed explanation, especially on how to derive analytical views (product models) rsp. synthetical views (process models), is presented in [4, 5].
The core of the PDD-concept is the clear distinction between *characteristics* (in German: "*Merkmale*"), which describe the structure and constituents of a product, and *properties* ("*Eigenschaften*"), which describe the product's behaviour. This distinction is based upon the approach of Andreasen, among other things presented in [12].
For material products, the characteristics are very similar to what Hubka and Hubka/Eder call "internal properties" [16] and what Suh calls "design parameters" [17], i.e. parts' structure, geometry, material and surface characteristics of a product. The properties are related to Hubka's and Eder's "external properties" and to Suh's functional requirements. Typical properties of products are weight, safety and reliability, aesthetic properties, but also things like manufacturability", "assemblability", "testability", "environmental friendliness" and – last but not least – cost.
While the characteristics can be directly determined by the designer, the properties are a result of the chosen characteristics and can not be directly influenced.
To be able to handle characteristics and properties – literally thousands of them in complex products – and to keep track of them in the development process they have to be structured. Figure 1 shows on the left a fairly obvious proposition for the (hierarchical) structuring of characteristics of material products which follows the parts' tree of the product.

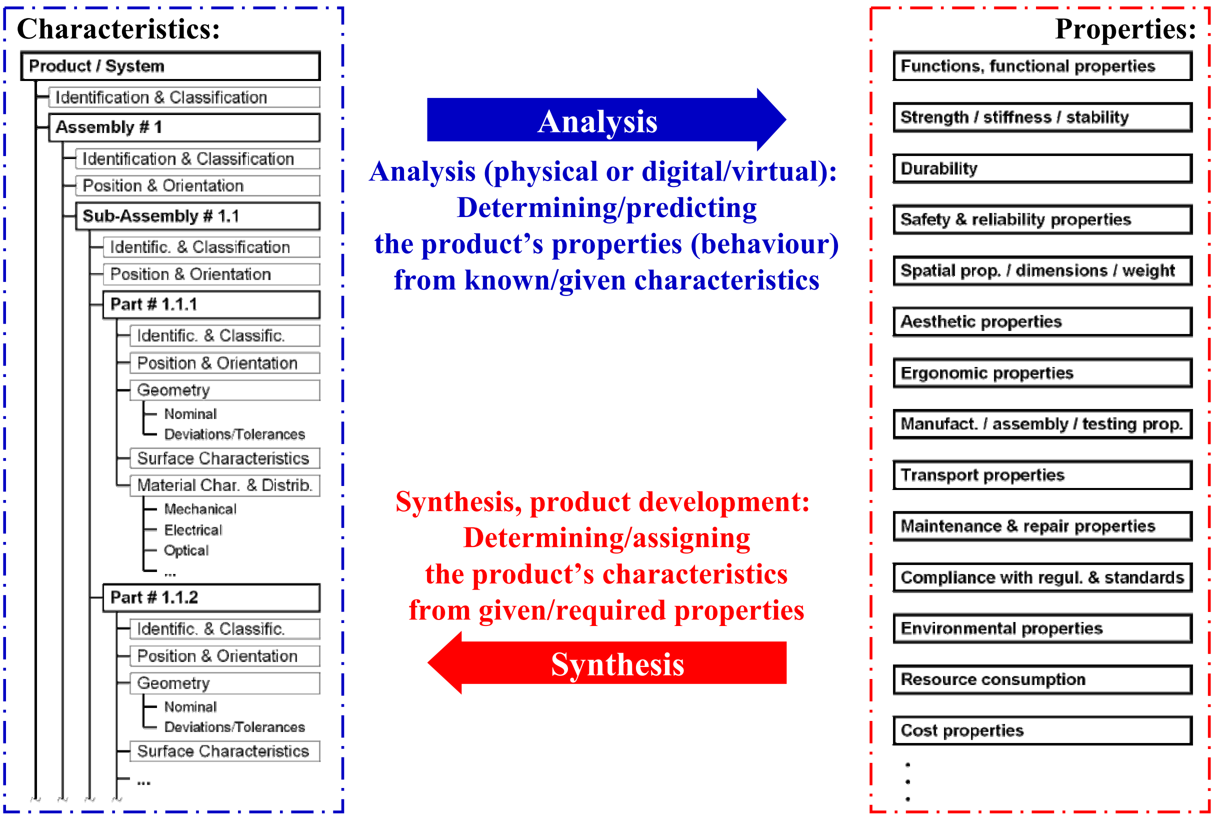

Figure 1. Characteristics and properties with the two main relations between the two

On the right of figure 1 the most important ("top-level") classes of properties for material products are given as a first entry into the structuring. Of course, these also should be structured more deeply by further expanding them. It is the authors' opinion, however, that such an expansion of properties is always specific to individual industries (product classes), often even specific to individual companies within the respective industry.

Figure 1 also shows the two main relations between characteristics and properties which correspond with the two main activities in the product development/design process:

Analysis: Based on known/given characteristics of a product, its properties are determined or – if the product does not yet exist in reality – predicted. Analyses can, in principle, be performed via experiments (e.g. using a prototype) or "virtually" (e.g. using digital simulation tools).

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- **Synthesis**: Based on given, i.e. required, properties the product's characteristics are to be determined. Synthesis is the main activity in product development: For the customer or user of a product mainly (only?) properties are relevant, thus the development/design process begins with a list of required properties. The designer's task is to find appropriate solution patterns and determine/ assign their respective characteristics in a such way that the required properties are met to satisfaction.

To apply this concept to PSSs, it is at first necessary to examine whether the same or a similar distinction between characteristics and properties is also possible and useful for service components of PSSs.

The first problem encountered is that the terms "characteristics" and "properties" are used in greatly varying meanings and that this problem becomes even bigger if we look into service engineering, which by tradition is a part of business administration, not of engineering. In some publications in the field of business engineering, the term "characteristic" doesn't match with the definition of this term in engineering science respectively the PDD concept.

Because of this, it is necessary to define characteristics, to classify properties of services and to synchronise these with the classifications of characteristics and properties of material products in a such way, that an extension and application of the PDD concept can be made possible. A consistent approach to classifying characteristics and properties of PSSs based on several attempts from business administration and engineering sciences will be shown. Their integration into the PDD concept and a framework for the systematic development of PSSs will subsequently be discussed.

3. The role of characteristics and properties in Service Engineering

In the field of service engineering, a large number of approaches exists to describe the term "service" and to define it in a proper way. In this context, the main problem is the border between services and material products, which is given by the integration of an *External Factor* and the *Immateriality* of the service. These terms define "services" in a very conceptual stage, but are not suitable to support a development/design process. This chapter will show which classes of characteristics and properties seem to be useful for the development of PSSs. Approaches both from the field of business administration and engineering sciences will be described.

Our opinion is that the characteristics and the classes of characteristics differ depending on whether material or the service components of a PSSs are considered. For the properties it is necessary to find a common classification, because the requirements of a PSS are associated with the properties, and the requirements are usually the required properties. Because material and non-material components should be considered equal, there has to be a common classification for the (required) properties.

Although the terms "characteristics" and "properties" of services are not defined clearly in service engineering, it seems to be very useful to keep on using them in the sense of PDD. The properties refer to the evaluation and the perception of the PSS by the customer, so are of obvious importance. The

characteristics describe the structure and constituents of the PSS and are of lesser relevance to the customer (alone they have no meaning at all for the customer). Starting from this concept, certain classes of characteristics and properties of PSSs were identified, based on the examination in the work of Corsten [2], DIN-Fachbericht 75 [8] and various quality models of services presented in the work of Konieczny [7] – here mainly the approach of Parasuraman, Zeithaml and Berry.
The results of this examination are shown in Table 1. No claim of completeness is made, as it is an open structure that could be extended if and when it seems useful or necessary.
On the side of the characteristics, a fairly clear distinction between structures and elements relevant for the material components of PSSs and others relevant for non-material components can be made. Apart from that no general classes of characteristics could be identified.
A connection between material and non-material components of the PSS is possible, e.g. a material component could be a prerequisite for the fulfilment of a service component, and also a service could be a prerequisite for certain material characteristics (condition of existence). An example is the application of a particular material that needs specific maintenance. This is, among other things, part of the characteristics class "degree of interaction with material components".
On the side of the properties, a distinction between three main-classes and subsequently some sub-classes seems promising – all of them described in literature on service engineering, but fitted here into the PDD concept. Following the qualitity approach of Zeithaml, shown in Corsten [2], these are the three main classes of properties:

- *Search properties* are such properties that are obvious in advance (before buying or using the PSS), therefore the costumer might utilize them to search for a product/PSS. Most properties of material products are search properties.
- *Experience properties* are properties, that cannot be judged a priori, but only by or after using the PSS.
- *Credence properties* cannot be evaluated by the customer at all, because he/she has not the knowledge and means to judge them, or because they could only be evaluated in the indefinite future. With regard to credence properties the customer has to trust the fact that the PSS has them (e.g. because the provider of the PSS has gained credibility in the past).

Certain properties can be arranged in several sub-classes, depending on the customer's priorities (or the customer's "profile"). For some customers the environmental properties of a PSS are of prevailing importance – for these customers they are search properties. Another example is the resource consumption: The resource consumption claimed by the manufacturer/provider plays the role of a search property, the resource consumption experienced when using the PSS is an experience property (and might not have the same value).
It should be mentioned that the classification of properties, shown in table 1 is seen from a developer's point of view. From the customer's point of view, his perception in form of certain qualities of the PSS is important. The fact, that there is a certain relation between the quality perception and the properties (in this particular paper only for material products, but this concept could be extended to PSSs) is shown in [15]. The qualities that have to be fulfilled with specifications of the actual properties of the PSS are, according to [15] divided in 3 classes: obligatory qualities, expectation qualities and positioning qualities.
Depending on the focus or branch of the company that wants to develop the PSS or the (demanded) type of PSS, it is favourable to use a more service-oriented or a more material-oriented view to work out the properties of a PSS. Some sub-classes of properties refer more to material oriented solutions, like dimensional properties, some refer more to a service solution, for example know-how transfer. Important is, that all qualities of the PSS required by the customer and all actual properties are considered adequately. Further on, it seems that, depending on the phase of the PSS's life-cycle, different classes of properties are of different importance resp. different quality perception. For example, maintenance cost of a PSS may differ with the age of the material components of the PSS. With this classification it is possible to consider these facts and to integrate them into the product model. Thus, it is possible to capture knowledge about the behaviour of the PSS in all phases of its life-cycle.

Table 1. Characteristics and Properties of PSSs

Characteristics		**Properties**		
Material components	Non-material components	Search-properties	Experience-properties	Credence-properties
Position Orientation Geometry: - Nominal - Deviation Surface: - Roughness - Waviness Material: - Mechanical - Electrical - Optical	Qualification of the service provider Duration (service provider's point of view) Cycle Personal expenses of the service provider Degree of customer integration Degree of interaction with material components (of the PSS) Degree of division of work	Functional properties Stability, stiffness Ergonomic properties Aesthetic properties Dimensional properties Manufacturing/ assembly properties Maintenance properties Repair properties Cost properties (claimed) Resource consumption (claimed) Environmental properties …	Reliability properties Environmental properties Resource consumption (experienced) Cost properties (experienced) Know-How transfer (from the service provider to the customer) Duration/ communication/ integration (customer's point of view) Customer understanding (understanding of the customer's needs by the service provider) Functional properties (experienced) …	Safety properties …

The classification of characteristics and properties of PSSs presented in table 1 offers the possibility of analysing possible marketing effects of certain defined characteristics. In a very early phase of the development of a PSS marketing experts and designers are able to concentrate on the fulfilment of a certain class of properties which is thought to be the most important. This fact is especially important because the technical similarity of material products is increasing and customers' decisions are often influenced by the service components of a PSS. As mentioned before, in later phases of the PSS's life-cycle other classes of properties may gain importance.

This approach must be seen as a first step towards a consistent methodology for modelling PSSs. Although it has been worked out of well established literature both from engineering science and business administration, its suitability for describing the properties and characteristics of PSS from a developing point of view has to be evaluated more deeply. A framework for this kind of modelling is shown in the next chapter.

4. Systematic Development of PSS – Product-Service Systems Engineering

As aforesaid, the systematic and integrated development of PSSs is a very promising field, which is, however, very sparsely covered indeed in literature; obviously the very sharp separation between engineering and business administration departments' efforts to deal with material products and services, respectively, has prevented research efforts in this direction. For the activity of developing PSSs systematically, in an integrated way and with customer integration (as is usual in service engineering), the authors have coined the term “Product-Service Systems Engineering” (PSSE). As a framework for PSSE we propose the shell model shown in **Figure 2**.

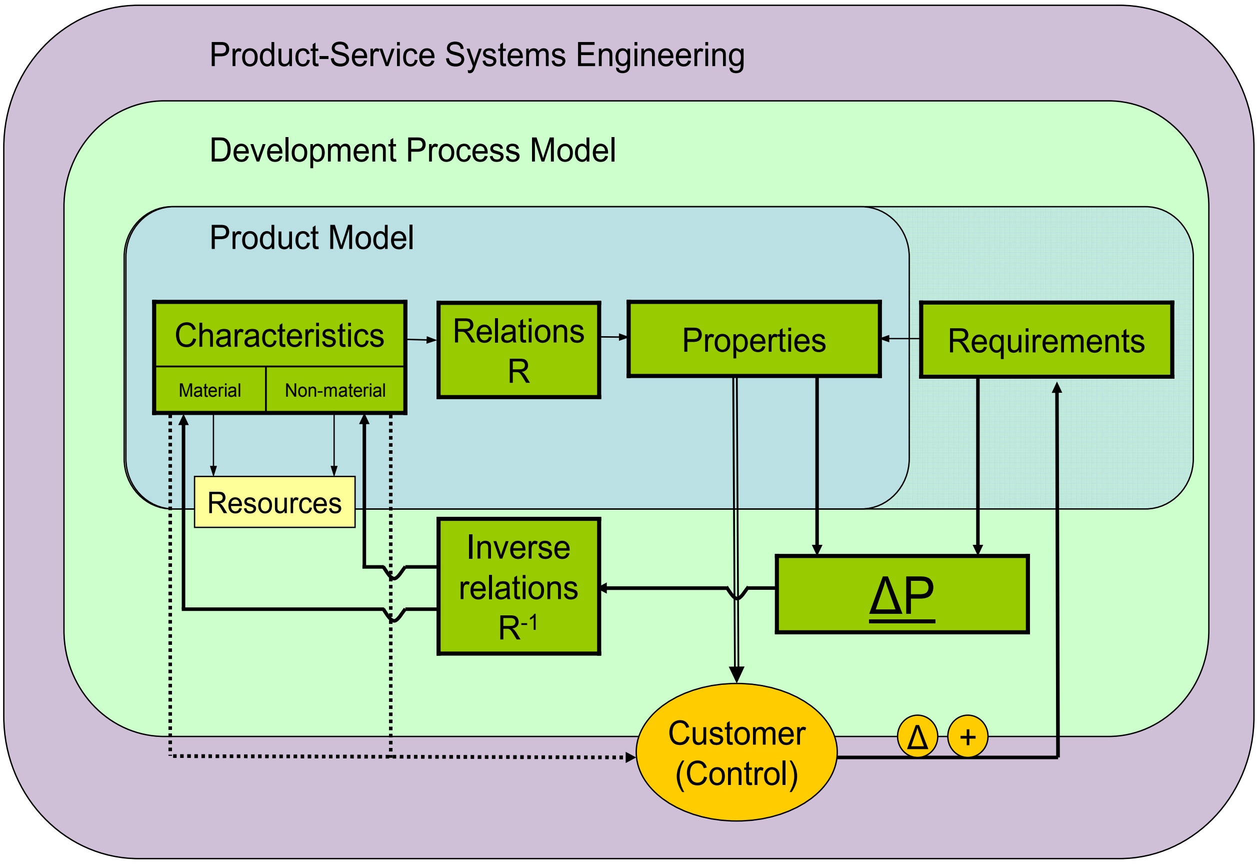

Figure 2. Shell Model of Product-Service Systems Engineering

Beginning with the customer’s need for certain values or desired qualities (the way the customer experiences the product [15]) of a PSS, technical requirements of the intended PSS will be identified. These requirements are mainly the properties which the PSS should have, the characteristics usually not being very interesting for the customer. It should be kept in mind that the user experienced qualities of a product resp. a PSS are the result of certain manifestations of one or more properties [15]. Also the bidirectional connections between society, customer and company [14] have to be regarded in a holistic view while setting up the required properties. Because of this it should always be mentioned, that the requirements could change during the design process because it is not completely predictable, in which way the customer notices the actual properties as qualities[15]. The advantage of PSS is, that it is possible to react to these conditions and to modify the PSS after shipping to the customer by modifying the non-material components of the PSS.

The important role of the costumer resp. the wishes of the costumer is undisputed. The QFD approach underlines this importance, shown in [13]. Unfortunately, this approach is still too vague and not structured enough to support the whole development process of a PSS, the structure of which is not known at the beginning of the process. The classes of properties, presented in chapter 4 seem to be more suitable to collect the costumer’s wishes in a structured way in order to work out the required properties.

In a first step from these required properties a bundle of characteristics (basic structures and constituents of the PSS) will be derived. According to Figure 2 this is the initial synthesis step. The actual properties resulting from this first set of characteristics will be examined in the second step of the development process (analysis). The – partly complex – relations (R) between characteristics and proper-

ties necessary to conduct this analysis step are represented, for example, by mathematical models, formulae, simulations, but could also be rather fuzzy judgements arising from experiences of the people involved or from customer interrogation. The opposite connections – the one between properties and characteristics, necessary for synthesis steps – are represented by the box denoted "inverse relations" (R^{-1}). This does not imply a mathematical inversion, only a formal inversion. The actual creativity in developing a PSS is represented by performing these inverse relations, i.e. "transforming" required properties into the PSS's structure and elements.
After a first step of synthesis/analysis, a rough draft of the PSS is obtained (containing characteristics *and* properties). The actual properties ("Ist-properties") of this draft are compared with the required properties ("Soll-properties"), the difference (vector) between the two being represented by $\underline{\Delta P}$. This difference is the starting point of the next synthesis step, where existing characteristics will be modified and/or additional characteristics will be introduced in order to close the gap between required and already achieved properties. An important feature of the scheme presented here is that $\underline{\Delta P}$ is the actual driver of the development process. The cycles of synthesis (modifying characteristics), analysis (determining "Ist"-properties) and evaluation (comparing "Ist"- with the required "Soll"-properties) will be repeated until the difference between actual und required properties ($\underline{\Delta P}$) reaches a tolerable small value (The determination of these values is not considered in this paper. It is the main subject of further research in the field of evaluation).
When considering PSSs, there is no question that the customer should be integrated into the development, at least as a kind of "control device" in back loops of the development process. When developing purely material products, the customer is considered responsible only for stating his or her required properties at the start of the process (which even here might be a wrong assumption!). To realise the service components of a PSS, however, it is necessary to integrate the customer, because the accomplishment of the service implies – at least partly – his/her involvement. The customer is shown the current state of properties of the still unfinished PSS as well as its characteristics during the process and is asked for feedback. This view provides quite a new perspective compared to existing concepts of development processes as they are known in the world of purely material products.
Another interesting feature of PSSs compared to purely material products should be mentioned: While the material characteristics of any product must be fixed at a certain point of the development process (at latest when delivering the product to the customer), the non-material characteristics of a PSS (or a purely non-material service) can, in principle, be modified later in the life-cycle. Consequently, it is possible to adapt the properties of the PSS even during its use phase, e.g. to adapt the product to changing needs and expectations. An example would be the short message service (SMS) of telecommunication providers. Today, you can receive news, stock prices and all kinds of other information and services with mobile phones which were built and shipped before such services were even invented.
Therefore, a change from material products to product-service systems (in research as well as in practice) can also be seen as a strategy to the a posteriori adaptation of products to modifications of requirements and to react quickly to changing markets, which subsequently can create a competitive advantage.

5. Conclusion

The potential of product-service systems (PSSs) is undisputed. Today, products like mobile phones are only working because of the integration of services and (material) products. In the future, PSSs will enable solutions which are more flexible and adaptable to individual demands and needs. In this paper, the authors outlined a first step towards a systematic description and integrated development of PSSs.
A next step is the detailed examination of the relations between properties and non-material characteristics of PSSs. While the synthesis of material characteristics out of required properties is, in principle, is a well known topic in engineering (design) research and practice, methodologies to synthesize services systematically only exist in a very preliminary stage.
Furthermore, the whole life-cycle of PSSs seems to be a very interesting field for future consideration. Especially in later phases of the life-cycle the differences between services and material components of PSSs should be examined more deeply.

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Dipl.-Ing. Michael Steinbach
Saarland University, Engineering Design/CAD
PO Box 15 11 50
D – 66041 Saarbrücken, Germany
Telephone: +49 / (0)681 / 302 – 6112; Telefax: +49 / (0)681 / 302 – 6111
E-mail: steinbac@cad.uni-saarland.de