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Function allocation in product-service systems
Are there analogies between PSS and mechatronics?

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Abstract

This article aims for a discussion on the allocation of required functions to elements in a product-service system. After a brief description of product-service systems (PSS) and their potential to fulfil customer needs some examples of PSS will be presented. A definition of the term function allocation in the context of PSS development processes introduces a discussion on how to collaborate between different engineering disciplines to setup solution variants for system concepts. An analogy between mechatronic and PSS design concerning the function allocation is emphasized and linked to an integration of PSS into the V-Model. The necessity of domain-embracing function modelling is detected as critical point for a successful application of the V-Model during mechatronic and maybe also PSS development. Guesses about a lack of a sustainable and traceable application of an overall domain-embracing function modelling and results form interviews with engineers from industry underline the importance of future research in this area. The article closes with a summary, conclusions and future prospects.

1. Introduction

The development of technical systems, mainly in mechanical engineering, leads from the collection of requirements over function structure design towards conceptual, embodiment and detailed design. Identified functions described in the function structure (boxes representing functions/subfunctions connected with arrows showing material, energy and information flows) have to be realized by working principles and finally by system elements [Pahl&Beitz 2007]. The task of *allocating* these functions to system elements is hardly methodically supported. In a product-service system this task becomes even more complex, because service is also a possibility to provide required functions in a system in addition to products which consist of mechanic and electronic components or software. The analysis of the function allocation task is the core part in this article and will be discussed in the context of the V-Model.

1.1 Product-service systems

Industrial product-service systems (IPSS) consist of technical artefacts (product modules, e.g. a computer) and of services (service modules, e.g. web-based services providing software updates) and they are characterized by an integrated planning, development, delivery and use, cf. [TR29 2007], [Meier et al]. The product and service modules are integrated in one system. Possibilities of exchanging product modules by service modules and the other way around are one of the major aims especially to implement flexibility to react quickly on fast changing customer needs during the delivery phase. The delivery phase encloses the operation and use of a product-service system and a delivery of products and services by a provider.

Existing product-service systems, such as car leasing or telecommunication contracts, including mobile phones, are usually straightforward combinations of both which can be a suboptimal solution. The interaction of the product and the service modules is not exploited by its full extent. Information from the use of a PSS is not fed back effectively into the development or the delivery providence. The customer integration is low and the combination of products and services does not support new, more or 'wider' functions in the system. According to our point of view of product-service systems we emphasize the importance of product and service integration. This integration aspect underlines the difference between integrated PSS and conventional straight forward combinations of products and services in one system.

1.2 Relevance of PSS

In today's markets there are many examples of product-service combinations which can be characterized as simple types of product-service systems, even when they were not explicitly planned and developed as PSS. Global players like Hewlett-Packard, Apple or IBM use modern information technologies, for instance web-based client-server architectures, to couple services to their products. Examples for typical services are technical support like providing software updates or the management of outsourced data. The providers of such product-related services (operation of servers, data management, data storing) offer next to their services also valuable know-how. New forms of offers, use and provider networking arise. In addition a tendency towards servicification [Tomiyama 2001] is visible, because especially services are important for the providers' sales revenue during the product lifecycle. Manufacturers of aircraft engines like Pratt & Whitney [Pratt&Whitney 2007] or Rolls-Royce [Ong et al] include services as an immanent element of their offers. Concepts like "Fleet Maintenance Programme (FMP)" [Pratt&Whitney 2007] or "Power-by-the-hour" [Ong et al] contract the manufacturers of the engines for maintenance and repair. In the context of networking customers and engine manufacturers, aspects like function availability, risk, and strategies to react on break-down should already be considered accordingly in an integrated development of products and services. In many cases the integration is not as adequate as necessary and the utilization of relations between product and service modules is unsatisfactory. Basic interactions between product and service modules, which are fixed in early development phases, often remain unconsidered. Cf. [Sadek et al].

2. Function allocation in development of product-service systems

To exploit the full potential within product-service systems a proper support of the development activities is necessary. At the moment there is a lack of PSS-specific development methodologies, process models and methods [Müller&Blessing 2007]. Research in this area, so far, is very important to fill this gap.

The development of products and services usually is done in separate development processes. This hinders the proper integration of product and service modules in one system. Due to that we aim to define an integrated development process model which covers the product and the service development tasks. In particular we focus on the methods for the early phases in the integrated development process.

To generate system concepts, required system functions (from a requirements list) have to be allocated to working principles and later on to system elements [Pahl&Beitz 2007] which are 'carrying' or realizing the function. In a product-service system these elements can be product or a service modules or a combination of both. The question at this point is, how to decide if a product or a service module or a combination is the best for the function realization. There are more degrees of freedom in addressing the system's functionality than usual. In contrast to products, services and their delivery can not be described by equations of physical values or geometric parameters. The type and structure of service delivery and the architecture of a system defined by product and service modules are issues to be considered by the system designers. This aspect has an impact on the allocation task. The assessment of different variants of function allocations within generated system concepts becomes more complex.

To understand the function allocation task the following questions could be asked:

- How does the allocation process take place? (Process steps, methods, experiences?)
- Which values, parameters or dimensions are useful to decide about a specific allocation and for assessing it?
- Which knowledge about problems, advantages and drawbacks of function realization via a product or a service module has to be fed back from the delivery phase?

3 Development of mechatronic systems – short excursion to the V-Model

The V-Model, as documented in the VDI guideline 2206 [VDI 2006], describes a development approach for an integrated development of systems which are developed by the domains mechanical engineering, electrical engineering and information technologies. It is parted into the system design, the domain-specific design, the system integration and the assurance of properties. The function allocation, as described above in our terms, takes place during the system design and it leads to the partitioning of the whole design task into domain-specific design tasks. The steps in the system design follow the approach for the early development phases as described by Pahl and Beitz [Pahl&Beitz 2007]. After the planning and clarifying of the task a requirements list is derived. Based on the requirements list the system design is executed to generate a solution concept. The system design (top-down) includes

- an abstraction for identifying the main problem,
- a setup of function structures,
- a search for operation principles and for solution elements for the subfunctions,
- a concretizing to form solution variants in principle,
- an assessment and selection of variants, and
- an establishment of the domain-embracing solution concept.

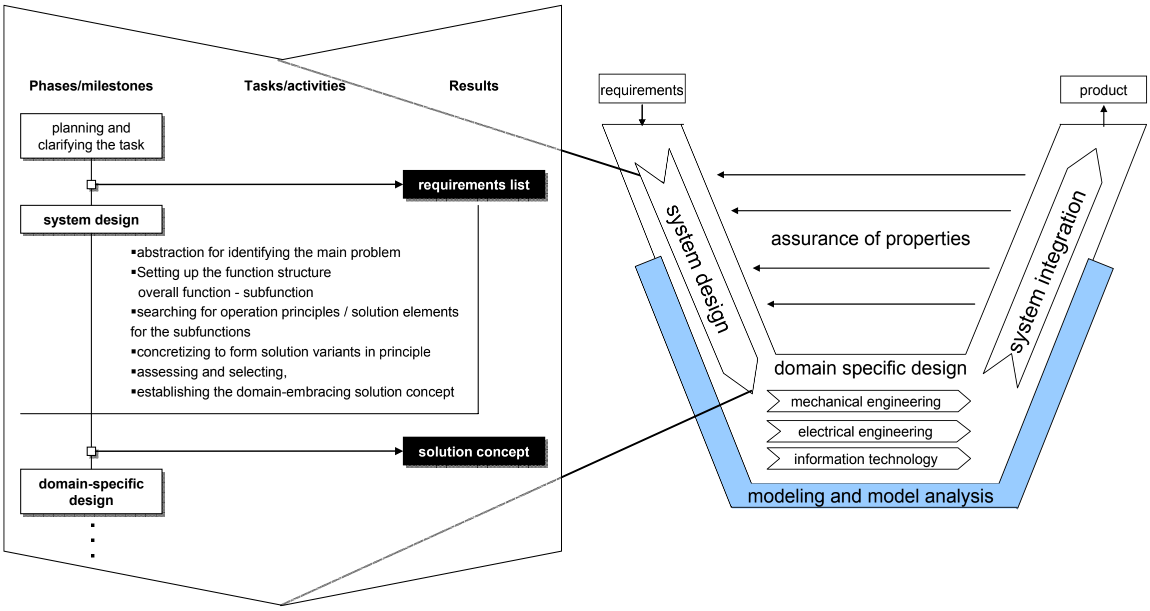

Figure 1. V-Model as a macro-cycle, according to [VDI 2006]

The setup of function structures ideally is used to allocate functions to system elements which have to be developed by the participating domains. After the partitioning ideally there is a simultaneous development of system components realizing system functions in the three domains. In this phase the domain-specific methods, models and processes of each domain are applied. Following the domain-specific development and modeling the components are integrated into the entire system (bottom-up). The full approach is shown in Figure 1.

4 Analogy between PSS and mechatronic development

4.1 Analogy in function allocation

In the area of mechatronics the designers or system architects have to take into account mechanics, electronics, and software for the complex function allocation. These three areas apply – as mentioned – particular development processes, methods and methodologies. Mechanical parts, electronics and software have different sets of (physical) parameters defining them (mechanical parts: weight, geometry, material properties, …; electronic parts: power, voltage, capacity, …; software: architectures, classes, performance, functions, …). In a product-service system products and services can be used to realize functions. The designers have to consider different parameters describing products (e.g. geometry, weight, color, stress, strains, etc.) and services (e.g. plans about capacity planning, time of delivery, interaction with customers, necessary tools, etc.).

The general problem of function allocation seems to be similar. Therefore the VDI 2206 [VDI 2006] has been taken to find out if the V-Model gives helpful insight for the PSS development and especially for the function allocation in a product-service system.

4.2 Proposal: Inclusion of service development into the V-Model

The use of service blueprints, for instance mentioned by Luczak and Reichenwald [Luczak et al 2004], shows, that services can be modelled as processes. The V-Model^{XT} (eXtreme Tailoring) [V-Model XT 2007], which is a further development of the V-Model can be applied to three different main aims. One of these is the implementation and maintenance process of the V-

Model XT or of other planned processes in a company. According to this the V-Model could be applicable to service development as well. Service engineering could be introduced as another discipline during the domain-specific development. Methods and models from this discipline could be used. As additional outcome service has to be included in the model as well. In addition to pure service engineering methods, those of PSS development maybe could also be included. How this can be done, has to be investigated in detail. Figure 2 summarizes all mentioned aspects.

Modern technologies are often based on mechatronic elements. Product-service systems for example have to implement a lot of information flows between PSS providers and their machines, service employees, or customers. Due to that there might be a big amount of mechatronic elements in product-service systems. One integrated development approach could be helpful to enable better collaboration between the participating designers. The integration of service engineering into the V-Model could finally be an advantage for a PSS development. This approach would be one step into the direction of one integrated development process model as described in section 2.

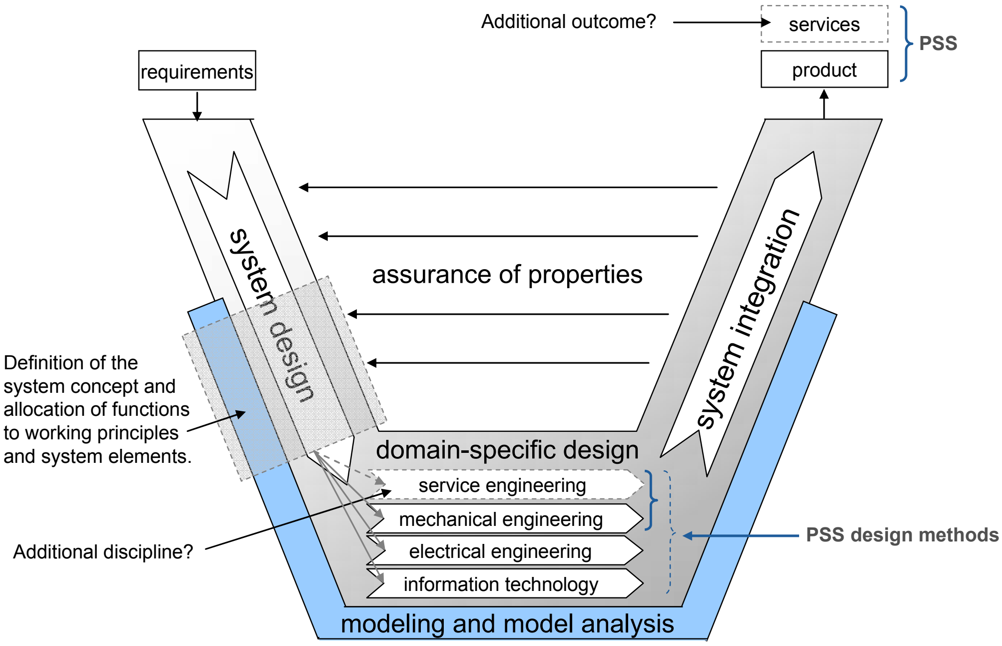

Figure 2. V-Model from [VDI 2006] modified

5 First findings

5.1 Results form literature study

Partitioning is mentioned often in mechatronic literature. How to do this is hardly described (cf. [VDI 2006], [Möhringer 2004], [Huang 2002]). Only few discussions, for instance on the systems reliability [DVM 2006], are related to the partitioning and therefore also to function allocation.
We suggest that the task of allocating functions to parts of heterogeneous systems – which can be mechatronic systems or PSS – is not methodologically supported. Due to that, we want to point out a need for a methodic guidance of this very important development step.

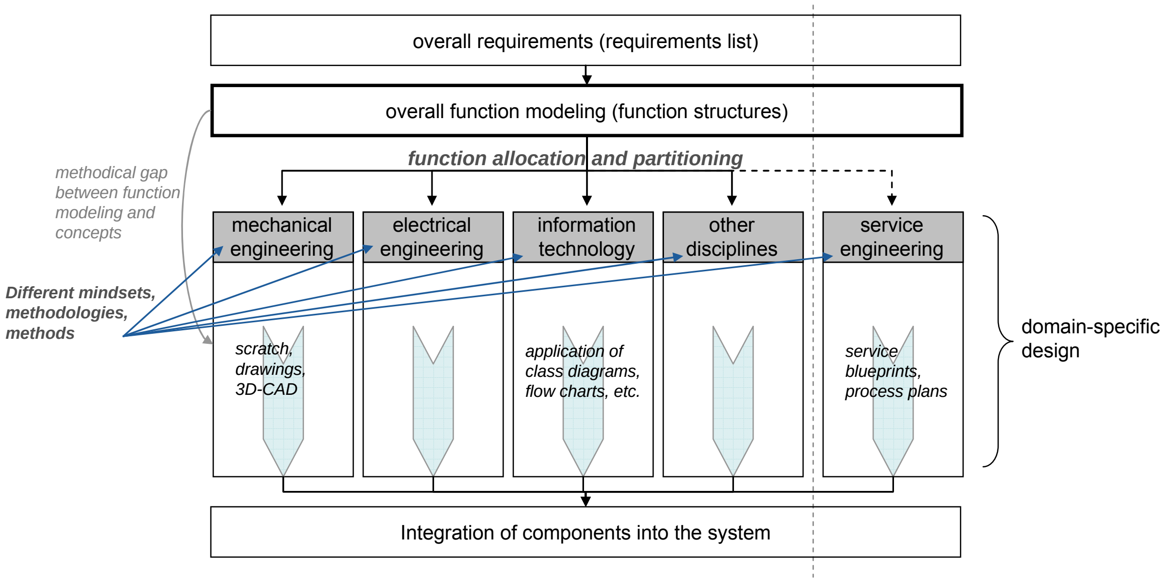

Figure 3. Gaps in the methodical support between different domains/disciplines

Corresponding to the V-Model guideline 2206 an overall function structure helps to partition the system design into domain-specific development tasks. This requires one common understanding of the function structure method to implement the V-Model successfully. We assume instead that different mindsets, terminologies, methodologies and methods are competing when designer of different disciplines have to collaborate. This also influences their understanding of functions. In addition the three processes in the domain-specific design normally are not proceeding simultaneously and there are system boundaries in the models of each discipline, compare Figure 3. Finally this hampers a proper communication. Another aspect is that the V-Model originates from software development and it is not well accepted in mechanical engineering. Also, there are methods to model complex systems which cover multiple domains as for instance the Systems Modelling Language (SysML), which is used in the domain systems engineering, but we guess that theory and practice do not accord.

5.2 Experiences from industry

According to own experiences from design activities the allocation of functions to parts or assemblies in a mechatronic system was not methodical supported. Most decisions in this process were based on the engineers' experiences. Decisions of function allocation are sometimes not traceable later on or mislead by wrong expectations. For instance, software modules have been chosen to implement a required function because of the assumption that it will be very easy to make changes in later development steps. The real implementation has shown later on that an enormous effort was necessary to fulfil the requirements to this system module.

A set of questions was composed to interview experienced designers from industry to gain more information about function allocation and the collaboration/communication between different domains/disciplines. The aim was to find out if function structures or equivalent methods are used in industry. The set can be compressed to the following questions:

1) Which kind of function modeling embraces mechanical engineering, electronic engineering and software development in your company?

2) Are function models/structures used in mechanical engineering in your company?
3) Which formulation is used for the collaboration between the disciplines in your company?
4) Which formulation is used for the collaboration between your company and others (suppliers)?
5) Which random influences are effecting the allocation of functions to elements/parts?
6) How is service considered in the allocation of functions and the system design?

5.3 Results from interviews

Two first interviews with well experienced engineers were executed. The aims were to get information about function allocation and to prove or reject the authors' guesses about a lack of common viewpoints and models of different disciplines/domains. The results are briefly summarized with the bullet points in the next paragraphs.

Experiences from a component developer/supplier in the aerospace business, developing rockets and aircraft engines (Engineer: project manager, 21 years engineering experience, employed in different aerospace companies. Company: > 3000 employees):

- The component developers (suppliers) get preliminary requirements lists for discussions on the final aim. Very simple images or drawings, showing the architecture of the whole system and the components which have to be developed, are used for the communication between by the acquirer (system integrators) and the suppliers. There is no specific formalism or language which is applied to these architecture models. Sometimes there are simple 2D- or 3D-CAD-drawings sometimes other images used. The refinement of the requirements list during the development is most important.
- In discussions the domain-specific models (CAD, FEM, thermodynamic models, models from production engineers, etc.) are used to improve the product and to plan next development steps in the participating disciplines. One common function modeling scheme is not applied to bridge the domains. Hard facts from the domain-specific models, for instance cost, performance, stress, strains or maximum temperature in one component, are discussed "verbally" in groups. The synthesis of concepts/design results bases on these hard facts and not on an integrated modeling.
- There are some random influences on the function allocation, depending on the individuals who are involved in the concepts groups (ca. 7 persons). Individuals dominating a discussion about system concepts, the function allocation (partitioning) can have a big influence on the final results, which sometimes are not clearly traceable later on.
- An "integrated tool might be helpful" for the generation of conceptual solutions but "maybe problematic" because this might hamper creativity, influence a designers intuition and the proper use of a designers knowledge negatively.

Experiences from a system integrator and developer of heavy mobile machines for construction works (development leader, many years in different departments (testing, development, etc.). Company/group: medium-sized):

- There is no direct use of function structures as described by Pahl and Beitz. Instead the group (consisting of three companies) is using an internal standard of 20 'virtual' functional assemblies, which are used to split up the machines into function groups (for instance machine frame, engine station, hydraulics, electronics, software, etc.). For each of the function groups in a machine a group of ca. 7 persons of different domains (different background knowledge and development focus) is composed to discuss about interfaces, planned and reached development states.
- Function structures are not even used for mechanical engineering design tasks in this company/group.
- The collaboration with suppliers is based on requirements lists and discussion protocols enriched with images, for instance. There is no superior modeling language like function

structures, which is applied to formulate the required functions of system components for a further development.

- Decisions during the function allocation are often based on general attitudes of the participating designers. General aspects like cost and the amount of, for example, other electronic parts, which are necessarily included into the machine caused by other reasons, dominate the decision about function allocation and partitioning. After the decision if a function should be realized by a mechanical, an electrical or a software-based solution it is “easy” to implement it. It is not the question “how” to solve it, because technical realization possibilities are often known from experiences. Due to that, detailed function structures are not necessary.
- A structured way of modeling functions covering multiple disciplines was considered also as possibly helpful, if the engineers were well trained and if creativity would not be decreased by too much formalism.

6. Summary, conclusions and future prospects

This paper started with an introduction of product-service systems, PSS development and the task of function allocation. Analogies in function allocation of PSS and mechatronics were detected and a possible inclusion of service or even PSS engineering into the V-Model was proposed. The V-Models dependency on function structures was mentioned as critical in case of unsatisfactory use of these. Own experiences about different mindsets of dissimilar disciplines led to guesses that especially this dependency might be problematic in practice for mechatronic and also for PSS-development. First interviews were made to study the theoretical findings and guesses. These interviews have shown that the implementation of function structures and the V-Model is not as ideal as theoretically proposed. Future investigations with more precise targets have to make clear, if function allocation really is a critical task, how it can be supported, and if the analogies between mechatronic and PSS development are strong enough to include service or PSS engineering into a general mechatronic development approach. This article hopefully helps to collect some experiences, estimations and advices, also during the AEDS workshop, to explore this challenging topic.

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