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DEVELOPMENT OF PRODUCT-SERVICE-SYSTEMS – COMPARISON OF PRODUCT AND SERVICE DEVELOPMENT PROCESS MODELS

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ABSTRACT
The paper focuses on development processes in the context of industrial *product-service-systems* (PSS). The main influencing parameters for a comparison of different *development process models* and *methods* are brought together. The main purpose is to identify possibilities for the integration of product and service development processes into one process model. At the moment the development of technical artefacts is well defined in numerous development process models, but the development of service and its delivery is not very well defined:
The paper starts with a short description of product-service-systems, including as an example their potential for developing mobile machines, and the importance of development process models. Then a brief analysis of the influence of services on the *decision making* process of PSS designers is provided, which leads to some constraints for the development of new process models in the context of PSS. Tasks like *generating requirements* or *estimating system maturity at specific stage gates* are discussed. From this analysis research questions and a scheme for the comparison of different process models are derived. The comparison scheme is used as a starting point for the research project which will use the *Design Research Methodology* as a framework.
Finally the paper provides a first, coarse comparison of some models and methods for product and service development before it ends with conclusions and future prospects.

Keywords: Product-service-systems (PSS), development processes models, requirements definition, maturity states, delivery models, Design Research Methodology (DRM), empirical study

1 INTRODUCTION
Products have to be produced before they can be sold to the customer. They can be stored, transported or transformed, independent of being physical (hardware) or virtual (software). Services are "produced" during delivery. A service cannot be stored or transported, only the artefact or person, which is necessary to "generate" the service, can be stored, transported etc. In the case of service delivery the customer is the *receiver* of the service whereas in the case of a product sale the customer will be the *owner*.
Products and services are both intended to fulfil a need, by transforming an undesired initial state into a desired final state. In other words, they both fulfil certain functions in this transformation process. If used together in one system, products and services will influence each other and therefore they need to be developed together as part of one, integrated *system* for being utilized to their full extent. Such a system constituted by products and services is called a *product-service-system* (PSS). To develop the most efficient and effective integration and configuration between interacting products and services a specific PSS methodology has to be defined.

Based on the above the following concepts are used:

- *System*: Used instead of *product* to underline that this could be either a technical artefact or a service or a combination of both.
- *Product*: Used to denote technical artefacts (hardware) and software.
- *Service*: Immaterial parts of a system, but not software. Everything which has to be delivered just in time and which is not storable.

- *Delivery*: Phase of providing a system to the customer, including sale, support and the "execution" of services.
- *Provider*: Company which supports (sells) the product-service-system. In the delivery phase multiple providers and subproviders can participate. *Supplier* is used as synonym for *provider*.

1.1 Scope of product-service-systems

A product-service-system consists of product modules, e.g. a machine and software, and of service modules, e.g. remote administration. Existing PSS, such as car leasing or telecommunication contracts including mobile phones, are usually straightforward combinations of both which may lead to sub-optimal systems. The intention is to generate a development process description to address the requirements of the system as a whole and to develop optimal solutions to the customers' needs. The fulfilment of these requirements, derived from the life-cycle of the system as a whole, is to be achieved via a deliberate, purposeful, consistent interplay of the product modules and the service modules (cf. [1], [2]).

PSS are also referred to as "*hybride Leistungsbündel" [1] or functional sales* and *functional products* although each term has its particular background and focus. PSS is related to *sustainability* (reduce energy and resource consumption), *eco-efficiency*, *dematerialisation, innovation, opportunity parameters* (cf. [3] and [4]), *life-cycle* and the shift from the customer as product owner towards a customer as a member of the delivery chain. Often the necessity of a paradigm change to establish PSS is underlined (cf. [1] and [3]). In most cases, providing a more efficient solution for customer problems is emphasized as the main reason for the development of PSS.

In the area of high-tech systems, such as micro production systems, the integration of product and service modules can be beneficial. These complex systems can only be operated economically when their full functionality is being utilised. Therefore well-integrated service modules are indispensable for system success [1].

The authors also see great PSS potentials in road construction, agriculture and transport. Many machines in these fields are very expensive so that multiple owners often share a machine or these machines are hired in cases of demand. Sometimes the machine is driven by the customer (hirer), sometimes by a driver who is familiar with the special machine and who works for to the provider. Operating these complex machines based on a PSS strategy could increase the efficiency of their use substantially. Furthermore, there are some other interesting aspects apart from those of ownership, rental and cost reduction:

- Especially the analysis of process data which is recorded during harvest or road construction can usually be performed better by the provider. "Precision farming" in agriculture or "intelligent compaction control" in road construction are only two examples of the use of GPS-signals for recording and mapping process data with specific software tools. Those tools, however, are complex and many farmers and construction workers do not have the necessary time or knowledge to manage these tools and the additional demands on machine drivers could be too much. The increasing number of digital extensions in farming and road construction machines could be promising fields for PSS.
- In the transport sector, elaborate strategies of machine surveillance could deliver valuable information via telecommunication technologies to the supplier or to the hirer. For example information about state-oriented maintenance or necessary repair work may influence the route planning of a perishable goods cooling container, to avoid delays and to guarantee efficiency. Some recent examples have been identified in this market and will be investigated in detail in this research project.

Data analysis, machine surveillance and professional documentation may lead to better quality assurance and monitoring reliability in both above mentioned aspects.

1.2 Potentials of product-service-systems

PSS afford more degrees of freedom for the individualization, configuration and optimization of systems. PSS can be adapted more flexibly to changing needs for function fulfilment because the relationship between customer (receiver) and product or system is more than just product ownership.

- Product modules and service modules may be developed such that they can substitute each other for the generation of variants and for individualization or customization.
- Customer needs will change, even after the system has been introduced. Thus, the dynamics, i.e. the time-dependency of requirements related to the whole life-cycle, have to be considered in the early phases of the development process. Especially service modules can play an important role in addressing this issue.
- The delivery model of a PSS could be result-oriented or availability-oriented and not only function-oriented. For example, the customer does not necessarily want a new machine but a certain number of pieces to be produced within a given time. The provider has to guarantee the functionality of the machine until the result – i.e. the determined number of items – has been produced, whether with a product module, a service module or a combination of both. The provider could even substitute a product module with a service module within the life-cycle.
- In our context, the result- or availability-orientation is more relevant than the aspect of sustainability discussed by McAloone et al. However, both points of view have in common that "[…] we have the opportunity to rearrange (and sometimes redefine) the stakeholder gallery connected to the product. This redefinition of stakeholders' roles and responsibilities should be carried out in order to provide benefits to all stakeholders […]", [5]. This "stakeholder gallery" so far is one of the main factors influencing the PSS development. The integration of the customer as a so-called *external factor* into the service chain is one of the most important factors and is discussed by Meyer et al [2], Steinbach and Weber [6] or McAloone and Andreasen [3]. Also, the consistent integration of cooperating PSS providers into the delivery chain to use the individual core competences is relevant in this context.

1.3 The importance of development process models and methods

In many cases, engineering becomes nearly "chaotic" and poorly structured because of unexpected problems during the development processes [7]. The proper use and implementation of process models in a company is expected to support a better quality of the development results within the given time and budget, to enable the controlling of projects and to enhance the productivity of the engineers [8]. At least development time and costs can be monitored, controlled and reduced by applying well structured processes. Especially in locally distributed development activities or in projects with members of different disciplines – which is a typical situation in PSS development – this is very challenging.

2 OBJECTIVES

The main objectives of our research are to investigate existing processes and methods of product and service development to understand their nature and to define a process model for PSS development by integrating, adapting or extending existing models.

Currently, the development of products and services is performed separately, which hinders the proper integration of their results. Furthermore there is no adequate development process model for services [1], [9]. Given the advantages of product development models (section 1.3) and of the integration of products and services already during development, there is a demand for a methodology for PSS development which allows the concurrent design of interdependent product and service modules. Service modules then become more than just add-ons for products and the other way round. To reach the best configuration of a PSS, dedicated methods have to be developed, in particular for the early phases of the development process. Within the scope of a new PSS-methodology, these methods have to enable a *flexible and variable allocation of system functions* to product modules or service modules to ensure system success. This in turn requires the development of a solution-independent set of requirements (i.e. product- or service-independent) and a solution-neutral problem statement. (Currently known product development methodologies such as Pahl and Beitz already emphasize these aspects, although they do not refer to services, see [11] p. 130ff.)

2.1 Decision parameters of designing PSS

Designers are confronted with a new context given by the widened scope of PSS: They have more degrees of freedom in addressing the system's functionality than usual, because of the possibility to use services as system modules. 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 designer.
In particular the generation and comparison of system variants become more complex, because service and product modules do not have the same formalism for their descriptions. The generation of requirements and the estimation of a system's maturity at different stage gates [12] become more difficult and therefore also decisions about *continuation*, *abandonment* or *iteration* in the process. The question how to measure the maturity of requirement fulfilment is linked to this problem. Integrating customers into the phases of development and delivery, and not only during planning and testing complicates the processes, but is useful to more closely orient requirements generation and system evaluation to customer needs.

All together, this implies a wider range of responsibility but also a wider scope of opportunity. Designers, so far, have to consider more decision parameters. They have to take in account

- the company's and the providers' strategic planning of delivery capacities (see [13]),
- the providers' operational and strategic controlling (target costs) (see [14]),
- the possibility of being closer to the delivered system within the network of joint manufacturers, providers and customers (cf. section 1.1),
- product and service possibilities.

2.2 Research questions

The introduced set of PSS decision parameters leads to the following research questions:

1. Which kind of process model is able to define the integrated development of services and products to ensure the most effective and efficient combination of both?
2. What are the possibilities to describe requirements, variants and the maturity states of the system during a PSS development process?
    i. How to model/describe services?
    ii. What are the service analogues of concepts from the product development domain such as *function, function structures*, *concept*, *working principle*, *embodiment, detail design, preliminary layout* and *definitive layout* (cf. [15])?
    iii. Which interfaces exist and can exist between service and product modules depending on the systems architecture?
3. How to include strategies, capacities, interaction plans, delivery plans and costs into the designers' scope?

To answer these questions a comparison model has been developed. In Figure 1 an extract of this complex model is shown: This scheme briefly accumulates the parameters that influence the development of PSS according to above explanations.

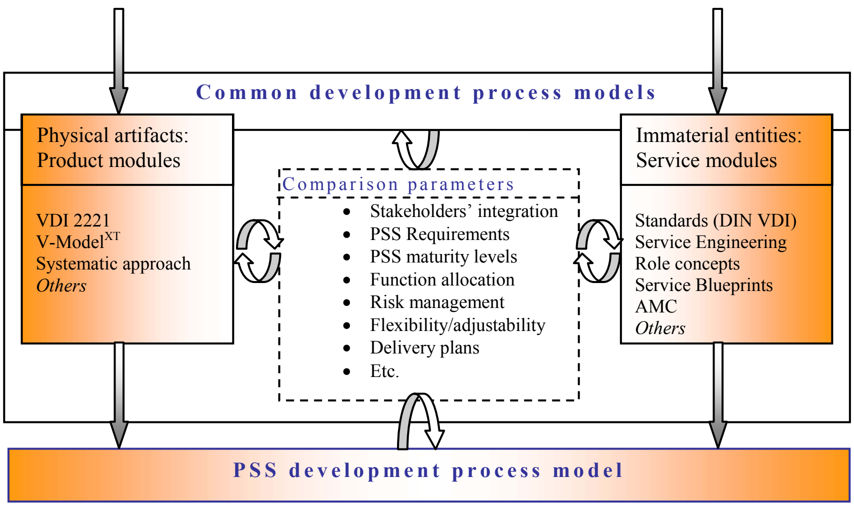

Figure 1. Comparison parameters, extract from the comparison model

2.3 Research approach

The research approach is based on the so-called *Design Research Methodology* [16], which is divided into three main parts. One prescriptive part (method/tool proposal) is surrounded by two descriptive ones (empirical studies, literature studies) (see Figure 2). This research methodology is used to investigate the actual state of the design processes and to consider how the preferred target state could be reached. The actual state is represented by the *reference model* and results from the Descriptive Study I stage. In the Prescriptive Study stage, the target state, represented by the *impact model,* has to be derived from careful logical consideration and based on the knowledge contained in the reference model. Comparing the impact model with the reference model provides suggestions for the methods needed to transform the actual state into the target state. In the third stage of the Design Research Methodology, the Descriptive Study II stage, the methods obtained from the prescriptive part have to be evaluated, to investigate whether the target state has been reached. The feedback of the use of the methods will result in iterations to modify the method or impact model, or to better understand the actual state. This first descriptive stage of the Design Research Methodology is already in progress. The initial results are presented in this paper.

The focus of the collecting and analysing data in Descriptive Study I is on the following points:

- Existing development processes of products and of services as well as of combined product-service-systems will be analysed by an empirical study (mail survey) in industry in order to build process models.
- Results of literature research will supplement the empirical data.

Some initial findings based on literature were presented above and will be discussed later on in this paper: The different available models for the development of products, services and PSS will be compared to understand their differences and communalities. The empirical study will show which process models and methods are currently used and which of those models from literature are relevant in industry. The combination of the results will be the foundation for the *reference model*.

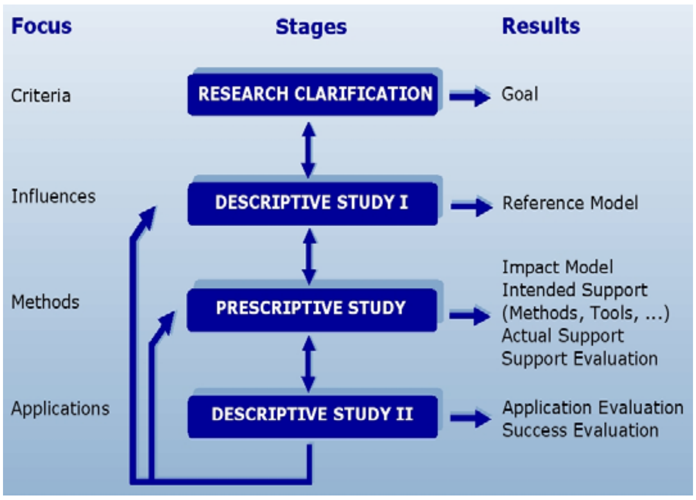

Figure 2. Design Research Methodology (cf. [1])

3 COMPARISON OF DEVELOPMENT APPROACHES

An initial analysis of some development models and methods has been undertaken to identify those properties that could be relevant in PSS development. These properties should be introduced into the comparison model (Figure 1) as a demand.

3.1 Product development

3.1.1 Scope of "product development"

The VDI guideline 2221 defines "product development" as follows: "Purposeful application of the results of research and experience, for example of a technical or economic nature. The total sequence of activities required to create a new product, including design, development, manufacture, assembly, installation and operation. The results can include new products and computer programs." [15]

This guideline already includes *operation* into the product development. The *operation* takes place as shown in Figure 3 as part of the delivery phase at the estimated end of the systems life-cycle. The delivery phase in particular plays an important role in the context of PSS development. In contrast to products, the PSS development requires a maximum of flexibility of participation of all stakeholders in the providing network to organize each participant's core competence most efficiently during the delivery phase. For example, the substitution of product modules by service modules in a kind of early test-phase during system introduction into the market may provide significant feedback into the development phase and to the stakeholders. Taking this fact into account, the PSS process model should at least integrate

- flows concerning the *design decision parameters* of section 2.1,
- detailed references for the conclusion of contracts between different stakeholders and
- detailed guidelines for the planning and evaluation of the delivery phase.

The model should be able to bring together the view of the provider, the subproviders and the customer(s) to close the PSS cycle.

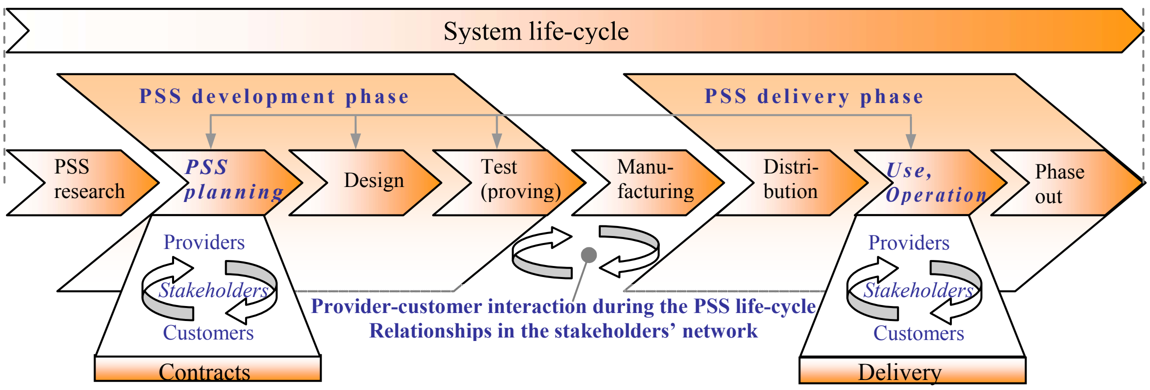

Figure 3. Phases of the systems life-cycle

3.1.2 VID 2221 – system approach model

VDI Guideline 2221 [15] describes the fundamentals of the *systematic approach*: "The process of solving problems represents a permanent relationship between goals, planning, execution and control, linked by decisions. *Systems engineering*, as an interdisciplinary methodology for solving problems associated with artificial systems, provides a general description of this process […]. The model of the systems approach […] divides the development of a system into *life phases*, progressing from the abstract to the concrete. The model also contains a strategy for solving problems which is, in principle, applicable to every life phase."

The approach is shown in Figure 4. It includes the *System operation* as a part of the systematic approach. As mentioned above, this is obligatory in the PSS context because the system operation is a central part in the delivery phase. Further work is needed to determine if this approach contains enough potential for PSS development. The tasks of *Problem definition*, *Evaluation* and *Decision* of *System operation* in particular have to be discussed bearing in mind the complexity of the stakeholder integration.

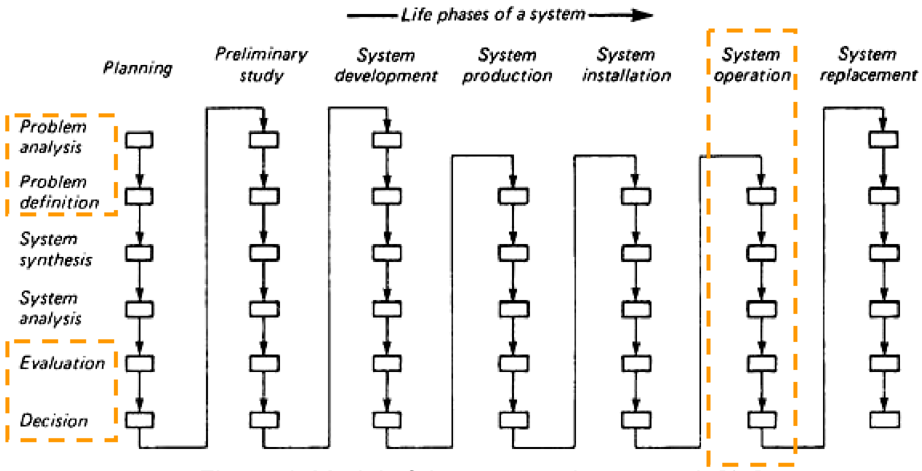

Figure 4. Model of the systematic approach [15]

3.1.3 VDI 2221 – general approach to design

A well known model of the development process is that in the VDI Guideline 2221 [15] shown in Figure 5, which is based on the systems approach discussed in the previous section. In consideration of its relevance and wide distribution in the discipline of mechanical engineering the transferability to the development of PSS has to be investigated in detail. Terms like *Function structure*, *Preliminary Layout* and *Definitive Layout* have to be translated to describe product and service modules in the same context.

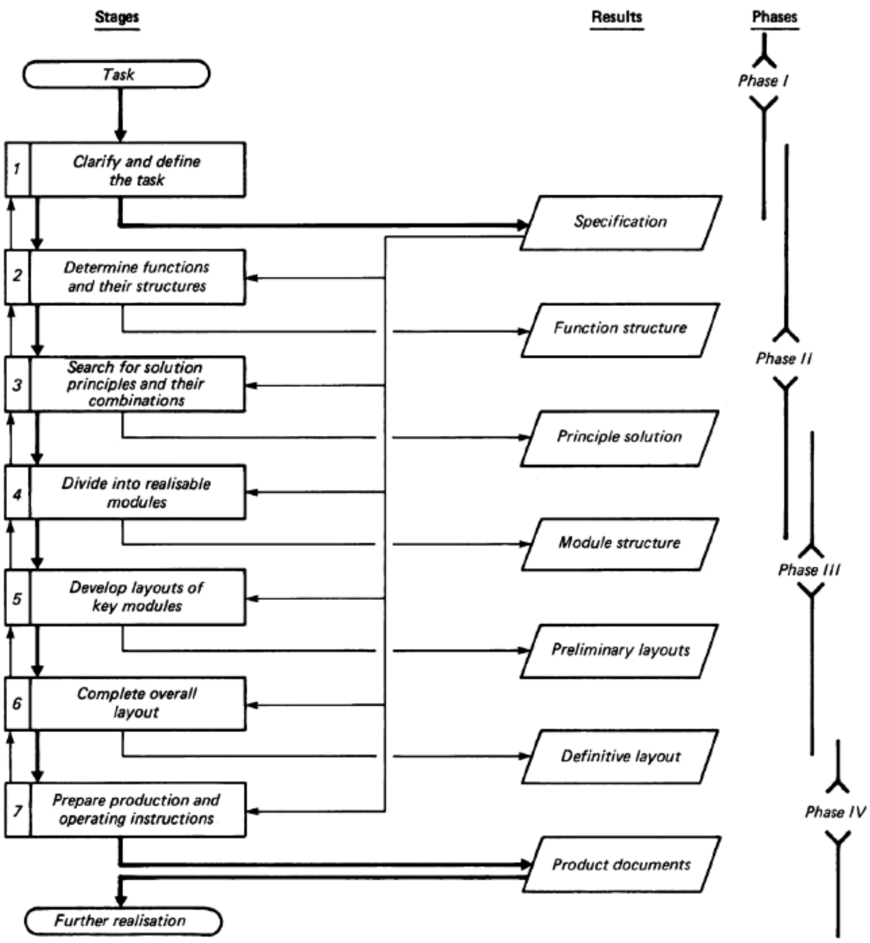

Figure 5. VDI 2221 – general approach to design [15]

An advantage of the VDI model is the clear structure showing the different abstraction levels of the system under development. This design process is "subdivided into general working stages, making the decision approach transparent, rational and independent of a specific branch of industry", [15]. Each stage is producing a specific result as a kind of stage gate. The first step is the *task clarification and definition* generating a system *specification* (requirements list). To avoid a too early fixation on a specific, possibly sub-optimal solution this specification has to be considered carefully in all following stages. In the scope of PSS this requirements list has to include customer attitude towards the delivery strategies of a provider and towards their own integration in the delivery phase.

3.1.4 V-Model XT

The *V-Model*^{XT} is an advancement of the *V-Model 97* for the development of hardware and software. The *V-Model*^{XT} *(eXtreme Tailoring)* [17] is a generic system development approach based on a consistent implementation of the V-model for evaluation steps, iterations, sub-projects etc. It guides the planning and realisation of development projects including project execution strategies, the allocation of responsibilities to project members, incl. the project leader, and the results which have to be achieved.

The dashed line in Figure 6 highlights the activities for developing a contract. The model's emphasis on this phase makes it interesting for PSS development (see section 3.1.1). This point is underlined by the support of three different project types that are based on the main project characteristics [18] and on the user of the model:

1. System development project of an acquirer.
2. System development project of a supplier.
3. Introduction and maintenance of an organization-specific process model.

Based on the project type the model allocates different *decision gates* to each project type. Different project types run concurrently. Figure 6 shows which project type is involved in which decision gates.

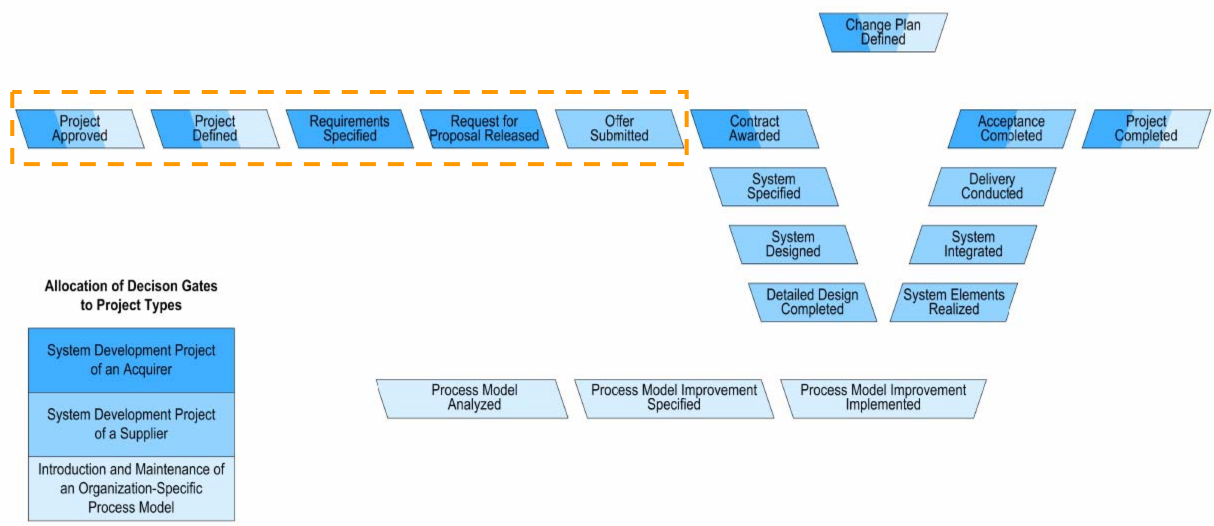

Figure 6. V-Model^{XT}, decision gates of the project types (execution strategies) [18]

An advantage is that the model explicitly synchronizes the processes of providers and subproviders using common decision gates. This is also reflected by the *tailoring* which constitutes one of the V-Models core characteristics: "The V-Model […] is intended to be applicable to a maximum variety of project constellations. Therefore, the V-Model must be adaptable to the actual project conditions. This adaptation, the so-called *Tailoring*, is one of the first and most critical activities to be executed by the V-Model user. In the V-Model, Tailoring is defined as specification of the project type, the applicable process modules and project execution strategies. The detailed adaptation of the V-Model to the level of the products to be developed and activities to be executed is conducted within the scope of project planning in accordance with the specifications of the generative product dependencies" [18]. Based on the project characterization, the model defines different obligatory and optional *process modules* to execute (not visible in Figure 6). The order of these activities is defined by the chosen execution strategy. Other models do refer to adapting the model to the specific project context, but do not provide support or suggestions as to how to adapt the model [19].

Tailoring using process modules seems helpful to adapt the process model to project characteristics. A transfer of this approach to PSS could be used to synchronize processes of all participants within the stakeholders' network. Tailoring could also be used to synchronize the development of product and service modules in the PSS development. In how far the specific advice on tailoring and contract preparation given in the V-Model^{XT} can be transferred to the development of PSS has not been analyzed yet.

3.2 Service development

3.2.1 Technical report DIN-Fachbericht 75

The technical report *DIN-Fachbericht 75* [10] (which has been withdrawn) defines the phase model for service development, shown in Figure 7. It is very simple and includes the delivery as a phase.

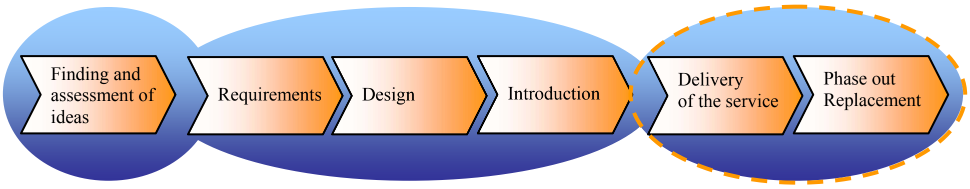

Figure 7. Phase model for service development, cf. [10]

The technical report allocates the delivery and the replacement to the area of service management. It describes the necessity to put in place structures and procedures to enable a permanent feedback from service management into service development. Documentation and continuous improvement of the quality of delivery are considered to be very important and life-cycle models are suggested as tools for a timely service replacement.

Structures supporting the feedback from the delivery into the development phase have already been discussed as very important for PSS development projects, PSS delivery strategies and for the development approach. The technical report therefore strengthens the claim for a consistent feedback management. Any explicit link with product development is not visualized in this model.

3.2.2 Guidelines – DIN, VDI

Some DIN and VDI guidelines refer to a proper integration of services into an offer. VDI guideline 4510 [20] e.g. defines classes of engineering services. These classes can be divided into the following two groups:

1. Engineering activities to adapt existing systems to customer needs (in the field), e.g. the development of new interfaces for integration of a machine into an existing production line. This category also includes engineering services such as *calculation* and *simulation*.
2. Engineering services that relate to ramp-up of production and operation, e.g. *installing*, *maintenance*, *repair* and *monitoring*.

These two types of service only describe conventional types of engineering and do not exploit the scope of PSS. The integration of customers into the phases of planning, development and delivery, however, is recognized in VDI guideline 4510 [20].

3.2.3 Methods of service modelling

Modelling tools such as *service blueprints*, *role concepts* or *Petri nets* (cf. [10]) can be used to map the delivery of a service, the information flows and the interaction between providers and receivers (customers). Especially the *Activity Modelling Cycle* (AMC) defined by Matzen et al [21] which is a further development of the *Customer Activity Cycle* (CAC) by Vandermerwe seems relevant because it is a special tool for conceptualising PSS. The model shows the cycle of activities of the stakeholders to map the actual state or future scenarios of systems in order to model the interaction between the main provider, the customer and other supporting providers. The cycle is divided into the three phases *pre-delivery*, *during delivery* and *post-delivery*.

However, these methods only describe the delivery of the service and not its development process. Nevertheless, they might – in their current form or after adaptation – be useful for inclusion into the PSS methodology to be developed.

4 CONCLUSIONS

PSS are capable to deliver more value to the customer, they afford more opportunities to the designer but they complicate the design process. The need for a new PSS development process model has been detected. PSS-relevant properties of existing development process models have been identified and a detailed investigation of the adjustability of these properties to PSS development is currently being undertaken. More development process models have to be included into the discussion, especially for the development of services. (Approaches from the area of software development have to be investigated also. For instance, investigations of the *Rational Unified Process* or *Service Oriented Architecture* have been made, but the results are not yet mature enough to be presented here.)

Finally it has to be figured out if the advantages of the diverse process models can be brought together into one development process model matching the requirements of integrated product and service development. The following paragraphs provide some suggestions for a possible approach for PSS development, aimed at including the advantages of the various process models and approaches.

4.1 Reference process

Although many models and approaches have features that are relevant for the development of PSS, no one model covers all the requirements. The aim is to develop a methodology and a process model that covers all life phases, including the contract phase and parts of the delivery phase (cf. Figure 3). Our process model would function as a *reference process* which has to be tailored for types of projects, for particular enterprise structures or for the particular stakeholder (e.g. providers and subproviders) like it is possible in the V-Modell^{XT}. The success of a concurrent or integrated development can be assured by the use of common stage gates / decision gates. The strong links between the phases of *planning*, *development*, *delivery* and *use* of product and service modules can be mapped with such a model.

4.1.1 Adaptation via detailing

Detailing the *reference process* using *process entities* that act as combinable "primitives" would make adaptations to individual properties of a company's process or a specific project easier. This approach is related to *process elements* discussed by Freisleben and Vajna [7] or *process modules* described by Meißner [19] or the V-Modell^{XT}.

Properties of the process entities could be the following:

- Standard combinations of entities can be used to build process modules.
- Entities can be combined to form user-defined process modules.
- Predefined interfaces make entities substitutable.
- New entities can be defined.
- Entities can be individualized.
- Entities can be updated.

These properties will be beneficial especially in the development of modular systems where contracting companies have to work together closely. Tailoring as in the V-Model^{XT} is supported by the use of reference processes in combination with process entities.

4.1.2 Layers of adaptation

The adaptation of a reference process could be carried out in different (horizontal) layers of detailing. A rough model of the provider management process e.g. could be broken down into a more detailed layer for the designer or a group leader (cf. [19]). Stage gates would act as a kind of (vertical) intersections synchronizing the development activities on the different layers.

4.2 Implementation of process models

The integration of new process models and development methods into EDM/PDM-systems is important and has to be analysed carefully: A proper implementation of new process models will only be successful if they can be linked to the available data and knowledge management, planning and engineering tools. Furthermore the models have to be adaptable, so that they can be configured to fit the complexity of the developed systems and the related development processes. This is achievable using process entities.

5 FUTURE RESEARCH

In the near future, an empirical study is undertaken to collect data about product development, service development and combined product-service development processes in industry, including the relevance of particular models and methods. This data in combination with the models and methods proposed in literature will be used to compare product and service development. The results are the input for the Prescriptive Study phase of the Design Research Methodology (see Figure 2) in which a new PSS methodology will be proposed.

After the initial development of the new PSS-methodology, the applicability and adaptability of this approach for different types of systems will be investigated. To that end, the study covers two types of systems: micro production systems and mobile machines such as used in agriculture and for road construction (see section 1.1). The extremely different requirements and context of use, will underline the strength, weaknesses and problems of the new methodology.

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