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A GENERIC PSS DEVELOPMENT PROCESS MODEL BASED ON THEORY AND AN EMPIRICAL STUDY

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1. Introduction

Generic process models provide guidance in core, support, and management processes in product, service, and systems engineering. For the development of industrial Product-Service Systems (PSS, IPS^2) such models are hardly available or foremost conceptual. The definition of a generic IPS^2 development process model is one aim of our research on PSS and IPS^2. In this article, we elaborate on a generic process model for PSS and IPS^2 development, which is part of a PSS development methodology. The process model bases on theory and empirical findings. An empirical study has been undertaken to compare as-is processes in German industry in 2009 in order to compile the new, generic PSS development process model. Thirteen interviews have been conducted in companies of different size and domains. Product, service, and systems engineering companies and consultants participated. The next subsections introduce some major aspects of development process models and product-service systems. In section 2. we describe our research methodology, in section 3. the interview study and in section 4. the state of the art of generic development process models. In section 5. we compile and describe the new generic process model.

1.1 Development process models

Generic development process models help managers and designers to communicate tasks, work results, and process concerns in an engineering process:

- Generic (in the sense of general or common) development process models describe, in which sequences and iterations process phases and engineering activities follow up.
- Terms used in such models function as defined reference terms and are typically used to communicate process progression or reached stages.
- Shared process models are use to synchronize processes of multiple stakeholders. This can be within one company or cross-company. Foremost, generic process models a model are shared within one domain. Some as shared by several domains.
- Standardized models are used for documentation, visualization and finally process deployment in research and companies.
- Depending on the granularity of the model, for instance (milestone) deliverables or stage gates are defined on a generic level.
- Apart from such general functions of process models, they define a framework for task specific method application. Furthermore, they are part of development methodologies and incorporate systems views implicitly. Project planning and execution often base on generic processes models, which are instantiated and tailored for a specific, unique case.

1.2 Product-Service Systems / Industrial Product-Service Systems

The value provided by the concept of (industrial) Product-Service Systems (PSS, IPS^2) is a broad, holistic view on technical systems by taking into account technical artefacts, services, business models and drivers like sustainability and business advantages. The premise is to provide "added value" to satisfy customer needs along the whole lifecycle of a product-service system, cp. [Müller et al. 2010].

The basic idea is not to sell products and services separately, but to sell a defined result, a system's availability, or just functionality. Customer needs are not reduced to the single need for product ownership. Instead, business models [Tukker 2004] [Meier et al. 2005] define the value for the customer and couple customers and providers for longer periods. Maintenance, adoption to changing needs and boundary conditions, reconfiguration or upgrading can be part of a PSS, e.g. in form of services included in the business model. The integration of products and services finally can maintain or enhance functionality of a product or a service or implement new functions, which are not available without integration. In the area of high-cost machinery IPS^2 are sold instead of standalone products or services to exploit earlier unused economical and technical potentials or to enhance the value for the customer [Meier et al. 2005]. The contractors share responsibilities and risks.

1.2.1 Brief definitional summary

- *[Necessary]* Product-Service Systems (PSS) are customer, lifecycle, and foremost sustainability oriented systems, solutions, or offers, integrating products and services.
- *[Sufficient]* Business models framed by contracts align incentives of the customer and the provider, aim at assuring functionality throughout system lifetime and aim at implementing added value to satisfy customer needs.
- *[Remarks]* Industrial Product-Service Systems (IPS^2) represent PSS business-to-business applications. Explicit PSS and IPS^2 are characterized by an integrated planning, development, delivery, and use of products and services. Implicit PSS and IPS^2 are not explicitly planned, developed, delivered and used in "integrated" processes, but already existing in today's markets and (somehow) integrating products and services.

Figure 1 illustrates a simplified architecture of IPS^2 core elements. Next to core products and services, stakeholders and contracts are important. IPS^2 are type of long-term commitments regulated by a contract. The contract provides tight linkages between stakeholders and defines how risks, responsibilities, and costs, concerning the integrated delivery and operation of product and service shares, are distributed among them. Simplified, the stakeholders are one provider, multiple suppliers, and one or more customer(s). They are typically organized in a locally distributed network with partly integrated business processes. An important aim is a value co-creation among the stakeholders during the integrated delivery. Supplemental systems and tools have to be taken into account to enable the delivery of products and services and the exchange of information.
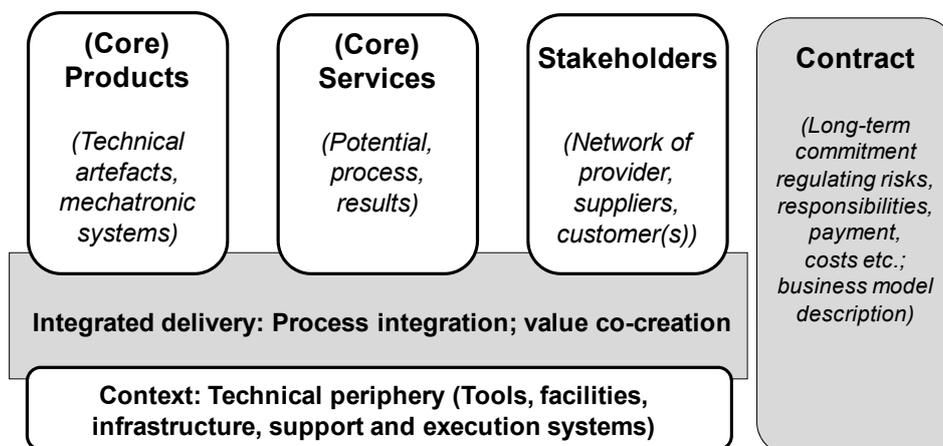

Figure 1. Simplified IPS2 / PSS architecture (own figure, cp. [Müller et al. 2009])

2. Research methodology

2.1 Research questions

To analyze the gap between industrial practice, the state of the art in literature and desired states in PSS development the research question have been partitioned in three major groups. The following three subsections summarize the major research questions, which are relevant for this paper.

Research questions for the empirical study

> **RQ1.1:** What is the fundamental difference of product and service development processes?
> **RQ1.2:** Which characteristics do product and service development processes have?
> **RQ1.3:** Which characteristics of such processes are relevant for (industrial) product-service systems?
> **RQ1.4:** Is there a need to integrate product and service development processes?

research questions for literature study

> **RQ2.1:** Which generic process models are state-of-the-art in product development, service engineering, systems and software engineering, and PSS literature?
> **RQ2.2:** Which characteristics do such models have?
> **RQ2.3:** Which characteristics are PSS relevant and which hamper a successful application?

research questions for model compilation

> **RQ3.1:** How can we integrate development processes of products and services?
> **RQ3.2:** How does an integrated, generic development process look like?
> **RQ3.3:** How is the requirements engineering for products and services realized?
> **RQ3.4:** How are the generation of ideas and concepts for products and services realized?

2.2 Research approaches

The entire study includes various methods of different bandwidth, deepness, and case numbers. Combined were a literature study, interviews with practitioners (n = 13, each approx. 2.5h), industrial workshops (n = 5, each approx. 2.5 days) and an inquiry with questionnaires (n approx. 22, some answers outstanding). The interviews build the basis to capture industrial as-is processes and reference cases and for the prescriptive compilation of the new, generic PSS development process model. Thus, we concentrate on the interview study in the following sections. As the literature study could fill another paper, we just mention some references, which are relevant within the context of this paper.

2.3 Limitations

The study has been undertaken from an engineering design perspective. The background of the authors is mechanical engineering, engineering design methodology, industrial information technology, and virtual product creation technologies. Impulses manly came from experiences in the branches automotive, software engineering, production technologies and renewable energy systems.

The generic IPS^2 / PSS development process model compiled in section 5.1 has been consolidated within the collaborative research project Transregio 29 [Transregio29]. The discussion in research communities and with practitioners has just started. The refinement of the model's phases is under construction. Thus, modifications of the model are expected on a long-term run.

3. The interview study

The target of the interviews was to attain deep insight in development processes executed in industrial practice. This includes:

- The collection of basic information on development processes in different application areas and domains, where (implicit) links to PSS and IPS^2 were expected.
- The detection of characteristic differences of the development of products and services

- To capture reference processes and issues, which are related to IPS[2] and PSS development
- To get a feeling for task specific method application during product and service development
- To understand industrial ways of thinking concerning product-service integration

The interviews were conducted in 2009 in German industry. Thirteen companies of different domains and competencies participated. Each interview had a length of approximately 2.5 hours (in some cases more). All interviews had an explorative character and were semi-structured in order to proceed aim-oriented but with enough space for exploration and "unexpected" answers. The shares of speaking time of the interviewer and the company representative were well balanced. Open lead questions, which were slightly tailored for each company and its product-service portfolio, were used to structure the interviews. Most interviews have been undertaken on site of the companies, so that we have gotten direct and clarifying impressions of the daily development within those companies. In all cases the participants had lead positions or sufficient experience within the company or domain.

In general, we used the following main question categories for all interviews:

- Questions on the interview participant (roles, responsibilities, education, experiences)
- Questions on the company and the portfolio (products, services, offerings)
- Questions on the development processes and product-service integration approaches
- Questions on methods applied during the development processes
- Questions on general ratings of PSS issues

Figure 2 illustrates all steps of the interview study. Those, which are marked with a tick box have been finished, all others are in progress or planned: Each participant received the generic set of questions before the interview to be informed and to prepare oneself. All interviews were carried out separately. The answers were written down in a structured protocol for each particular interview. All protocols were digitalized afterwards. The post-processing included the modelling of all investigated development processes in BPMN (Business Process Modelling Notation) and the textual documentation of all cases. A process example is shown in Figure 3. For the validation of our interpretation and analysis, all participants agreed to counter check our results. Due to the heterogeneous set of companies and because of the open questions asked, a straightforward comparison of the interviews is not commendable. Instead, the particular interviews can be used as reference cases. Table 1 summarizes the investigated cases. Service providers, product and system providers, and solution providers are included.
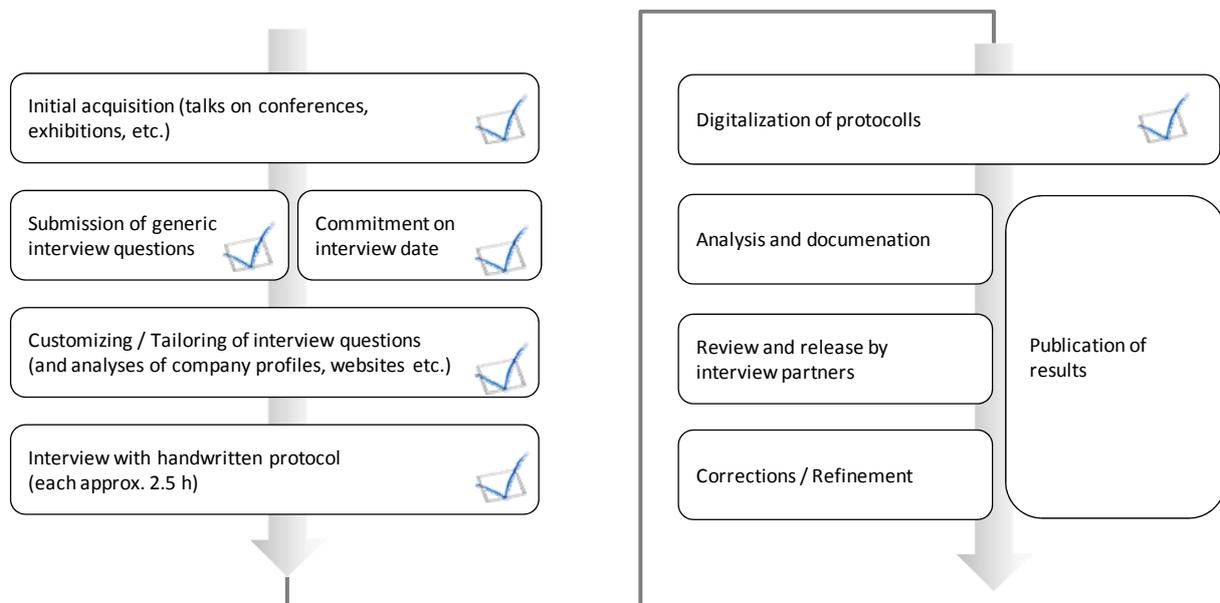

Figure 2. Steps of the interview study (own figure)

Table 1. Interview cases, 13 companies in German product and service industry

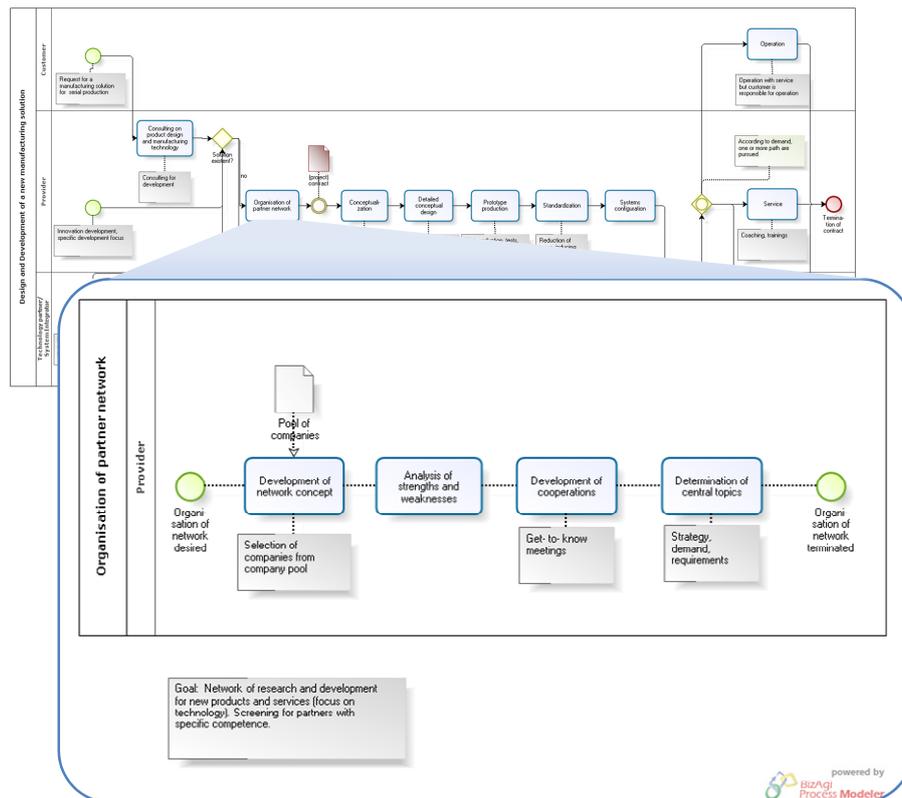| No	Case (brief description of company and offerings)	Turnover in €	Staff	Practitioner
#1	Consultant for product/system development and integration of virtual product creation software	8.5bn	83 000 (4500 in Germany)	Consultant, 2 years experience
#2	Service provider for small banks (controlling and risk management)	0.9m	13	CEO, several years experience
#3	Security service provider (security of people and buildings)	*<missing>*	330	Consultant and "service developer", 18 years experience
#4	Service provider for development and operation of call center solutions	55.9m	1650	Several members of 2nd level management
#5	IT solution provider (planning, development, implementation and operation) for sales systems	*<missing>*	25	Authorized representative, sound IT knowledge, several years experience
#6	Electrical engineering and services like maintenance, repair and overhaul (voltage transformers for wind turbines; prototypes and series)	115m	800	Sales and service engineer, several years experience
#7	System provider of medical equipment (planning, development, update, repair)	6m	50	CEO
#8	Service provider for maintenance, repair and overhaul (MRO) of manufacturing systems (MRO contracts)	100m (in 2005)	250	Chief of service division
#9	Provider of manufacturing system components (planning, development, manufacturing, maintenance, repair)	45m	360	2 practitioners: 1 process responsible, 1 component developer
#10	Provider of applied science, consultancy, planning, development, and test services to develop and configure customer specific micro manufacturing systems; application: especially micro milling and compound design for the manufacturing of medical or bioscience equipment.	2m	18 (+25 in charge)	CEO
#11	Industrial trucks (forklift trucks), high racks and solutions for manufacturing plants (consulting, planning, development, system configuration, implementation, maintenance contracts in different types of business models)	2.1bn	10000	Sales engineer, system consultant, many years experience
#12	Service provider for technical facility management (consulting, planning, development, operation)	100m	1000	Sales member, employed in two companies
#13	Provider of chemical plants and power plants (consulting, planning, development, implementation, operation, project management)	115m	800	Chief for the company's business in east Germany

Figure 3. Example of development process model derived from an interview (own figure)

The figure illustrates a simplified model in BPMN notation, which contains selected aspects of a business and development process. Iterations and decision processes have not been modelled in detail. (Interview case #10; confidential information has been deleted for this paper.)

3.1 Findings and generalization (addressing RQ 1.1 to 1.4)

In all investigated cases, there was a gap between industrial practice and service development process models available in literature like [Jaschinski 1998], [Schwarz 1997], or [Ramaswamy 1996]. The most dominating findings are summarized in the following list *(all findings are limited to our cases)*:

- Companies developing products / systems and manufacturing industry have no explicit service development process. The implicit service development corresponds a consulting and offering work out process. Technical sales staff develops offerings like maintenance contracts, availability warranties or project plans for the implementation of complex systems or plants implicitly. Often there is no separate billing of such consulting and engineering services.

- Typical service providers have less formalized processes, compared to mechanical engineering. Reference processes for service development published in literature seem to lack implementation in industry, so far.

- PSS specific activities today happen foremost in early development phases and during system configuration, i.e. on a level were customer value is relevant. They happen just partly on a system and hardly on a function or component level. Concept, embodiment and detailed design in a sense after [Pahl et al. 2007] today have few PSS specific characteristics because the relation between product and service attributes is hardly considered in product (and service) modeling. (Nevertheless, the consideration of serviceability requirements becomes more important.)

- Consultancy and engineering service are important activities to provide customer oriented solutions in mechanical and plant engineering. After design and prototyping (pilot runs in

case of services) standardization, reduction of variants and configuration are of major importance.

- There is a need for a more explicit execution of activities of "service engineering" and for integration of product and service development processes. This is, because the development of services is often implicit and thus difficult to control / manage.
- Project oriented development goes beyond generic processes and plays a leading role for an efficient implementation of (customer and lifecycle oriented) solutions. This was valid in all investigated cases.
- If there was an explicit service development (cases #2 and #4), the participants spoke about a "service concept", which was close to the meaning after [Edvardsson and Olsson 1996], even if the service was implemented after this concept. "Embodiment design" and "detailed design" were not used in such cases.
- The typical maintenance, repair and overhaul services have "historically grown". Additional services were used to fill the gap between product features and customer needs and expectations. A systematic innovation management for services has not been found in any production oriented case in our study.
- A systematic feedback of information retained in the field (during operation and service) is not state of the art. Just in case #8 design reviews including service staff and component designers were established and executed chronologically.
- In general we found a low degree of process standardization.
- Many engineering services are offered as a means to an end to sell complex systems.
- Interesting was a comment of a system provider on services like consultancy, implementation and maintenance: "You have to offer those services if you provide nonstandard or niche solutions." *(This comment was given in a workshop and not in an interview.)*

3.2 Deficits of product-service integration and need for enhancement – intermediate summary

On the one hand, our study has shown that there is an insufficient degree of frontloading of "service issues" in product development and vice versa. Experiences made in the field are not systematically analysed and fed back to design. Mechanisms to do this are rare. On the other hand product designers find themselves more and more under pressure to satisfy requirements on serviceability in order to design maintenance friendly products. Finally, service engineering is hardly implemented although especially engineering services are a means to an end to offer customer oriented solutions.

4. State of the art in literature (addressing RQ 2.1 to 2.3)

Generic development processes are published in various domains. A short comparison of some models shows which advantages and drawbacks exist from an IPS^2 and PSS design perspective. We apologize that a comprehensive discussion of many valuable models is not possible within this paper.

Product, software and systems engineering

The generic process model defined by VDI 2221 [VDI 1987] is widely known in mechanical engineering. The planning phase is especially in IPS^2 development relevant, because many consulting and implicit engineering activities are performed as services in this phase. In contrast to VDI 2221, we state that this phase should be emphasised in IPS^2 engineering. In the V-Model after VDI 2206 [VDI 2004], the development starts with requirements as input for a mechatronic system development project. We argue that the clarification of customer needs and preferences should be the starting point for PSS and IPS^2 development. Thus, an extension of the V-Model would be necessary. Within the Harmony Process [Hoffmann 2006], which is a process model supporting model driven development, there is a requirements repository, which is accessible at all development phases. We support the idea that the requirements list is not a "frozen" document after the planning phase in this model. The Rational Unified Process [Kruchten 2006] starts with the inception phase. The set up of (i) a project scope, (ii) the business cases, (iii) a candidate system architecture, and (iv) the basic system

requirements, is performed in this phase. Even if this process model is related to IT systems development, those activities seem to be analogue to the early phases in customer oriented product and service development projects. The V-Model[XT]® [http://www.v-modell.iabg.de/] provides tailoring approaches for different stakeholders. This is a valuable property in order to support planning processes shared by customers and providers.

Service and PSS engineering

Ramaswamy presented in 1996 [Ramaswamy 1996] a cyclic model for design and management of service processes. In general, this model comes up with development activities which are equally relevant for PSS and IPS^2. For instance the phase "implementing the design" is part of the management process in his model. This phase includes the development of a pilot and test plan. Nevertheless, the terminology used by Ramaswamy is very service specific and thus the model is not directly applicable for IPS^2 planning and development. Jaschinski defined a process model which has many phases and deliverables like "infrastructure plans" or "interaction plans" at each phases end, see [Jaschinski 1998]. We assume that this model is too sequential, although iterations are allowed, and that the definition of specific milestone deliverables is more a task for IPS^2 development project planning and execution. Schwarz adapted systematic product development after Pahl and Beitz [Pahl et al. 2007] and VDI 2221 [VDI 2221] to service development [Schwarz 1997]. His model includes many service relevant design activities, but those in a sequence which did not cover most of our findings made in our interview study. Sakao and Shimomura explain a service engineering process which is specific for Japanese service engineering [Sakao and Shimomura 2006], but which is closely related to the application of the service engineering software "Service Explorer". Aurich et al. presented a process model for IPS^2 development, which synchronizes a product and a service development process [Aurich et al. 2006] for the design of technical services. Nevertheless, there is no real integrated planning of products and services and a low degree of customer integration in their model. Lindahl et al. presented in 2006 a PSS deign method, which is not a typical process model [Lindahl et al. 2006]. However, they underline the importance of contracts in their PSS design model, which is an important issue especially in IPS^2 planning and configuration.

5. Generic PSS and IPS^2 development process model (addressing RQ 3.1 to 3.4)

The generic development process model provides three main functions:

1. Setting a framework to include the PSS related findings retrieved in our study (descriptive)
2. Setting a framework for new PSS planning and development methods (prescriptive)
3. Defining a communication basis for future PSS development processes (prescriptive)

5.1 Compilation of new process model

The generic development process model in Figure 4 bases on our findings made in the interviews (and workshops), on calibration with our research partners (within project TR29), and many valuable impulses from literature. From the V-Model we "borrowed" the shape, the validation and verification iterations and the breakdown form a system level to domain specific design. From the V-Model XT ® we adapted the idea to extend the models shape horizontally on the left and right branch, to capture activities which are not pure engineering activities. Characteristic for the new model is the strong emphasis on the planning and project definition at the left branch and the fade out from development into delivery on the right branch. Both phases are iterative and have high PSS relevance as discussed earlier. The upper levels "customer / market / environment" and "value" address customer needs and customer values, which are essential PSS and IPS^2 design dimensions, cp. [Müller et al. 2009] [Müller and Sakao 2010]. Additionally, the model highlights the simultaneous activities (i) brief conceptualization, architecture and business model design, (ii) specification on system level, and (iii) development project definition. Together all three activities lead to the offering of a provider towards a customer. The phase "integrated concept and embodiment design" is addressing new PSS design approaches for an integrated design of products and services on a sub-systems level. The breakdown of system-level requirements to product and service level requirements is a straightforward orientation at product and service quality issues and supporting the application of domain specific design methods

in the later phase. The pilot run integrating external factors (customer, environment) highlights the influence of services and is type of prototyping. The configuration on the value level underlines the customer orientation even in late development phases. The requirements management is modeled as an accompanying process in order to satisfy today's approaches of requirements management cp. [Hoffmann 2006] and [Kruchten 2006]. The possibility to feed back knowledge from the delivery and use phase is illustrated by arrows in the right part of the model. The separator line between the value and the system level annotated with "contracts" (development project contract; service level agreements (SLA)) considers the influences of customer specific PSS development projects, the appointment on a business model or operation model and e.g. maintenance contracts.
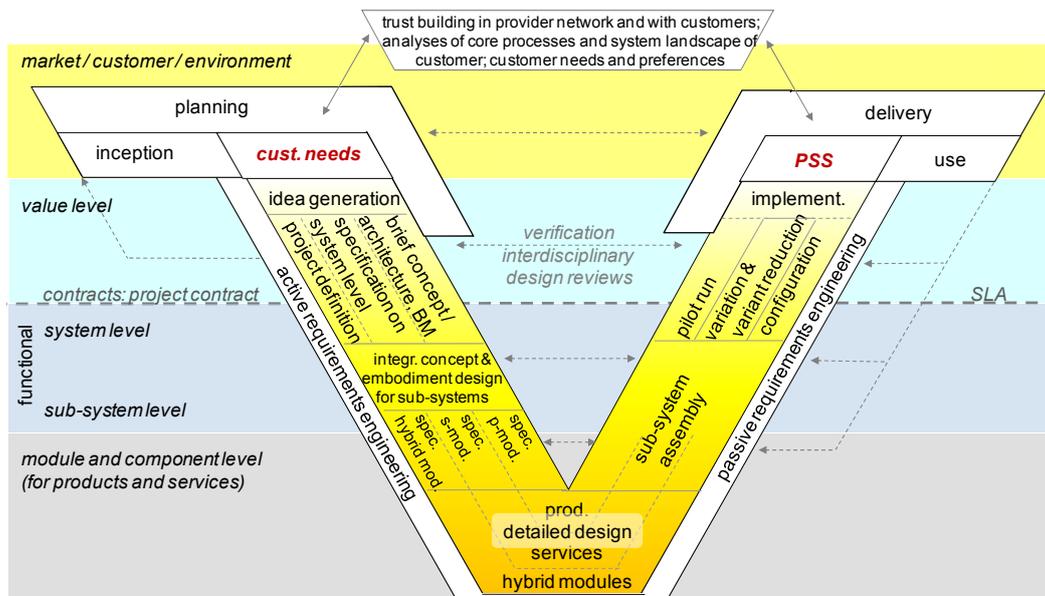

Figure 4. Generic IPS^2 / PSS development process model (own figure)

6. Summary

Thirteen interviews, each approximately 2.5 hours long, have been carried out among different types of companies in German industry in 2009. Each interview has been considered as a reference case. For each case, the development process has been transferred into a particular process model. Findings from all cases were used to compile a new generic PSS development process model, which also adapts some elements form models in literature. The generic PSS development process model has been consolidated within the collaborative research project Transregio 29 [Transregio29].

7. Conclusions

Services are provided in most areas. Customer orientation is being cited as major driver and mindset, lifecycle orientation is vital in case of business and operation models. Nevertheless, service engineering as discipline has not yet reached a high penetration in German mechanical engineering and plant engineering. Thus, many cases can be classified as implicit IPS^2 (see section 1.2.1). Service activities happen implicitly to large extent. There is a huge potential to implement systematic approaches to service design in mechanical engineering. Generic process models making service development explicit, synchronizing product and service development, and methods for an integrated development are lacking awareness and implementation, so far.

8. Outlook

The particular process models of all interview cases will be counter checked by the interview partners to make sure that our models represent the particular case adequately. The generic process model provided in Figure 4 is now being transformed in a formal process model that is extended by

documentation. A web based process guide is used as deployment platform, which includes the process models and text documentation. The next step is a validation and refinement of the generic model. Deployment and tailoring approaches and an integration in a commercial software for project, requirements and quality management is planned. To enable the breakdown of the model's generic phases, we refine the model's phases with planning and design tasks and links to IPS^2 and PSS design methods, which are available in literature. The discussion in research communities and with practitioners has just started. Thus, modifications of the model are expected on a long-term run.

Acknowledgement

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