General Data Model for the IT Support for the Integrated Planning and Development of Industrial Product-Service Systems

Holger Bochnig, Eckart Uhlmann, Hoài Nam Nguyễn, and Rainer Stark

Institute for Machine Tools and Factory Management, Technische Universität Berlin, Pascalstr. 8-9, 10587 Berlin, Germany
{bochnig,uhlmann}@iwf.tu-berlin.de,
{h.nguyen,rainer.stark}@tu-berlin.de

Abstract. The approach of Industrial Product-Service Systems (IPS²) focuses on providing added value by integrating products and services. The complexity of their multi-disciplinary planning and development calls for methods and tools to support this integrated process. Therefore, the authoring tool "IPS² assistance system" has been developed, which represents an extensible framework and supports the entire IPS² planning and development process. For the implementation of this authoring tool, a general data model of IPS² is needed which helps with the management and exchange of phase-specific and discipline-specific data and results.

For the generation of this model, the phases of the planning and development of IPS² are examined based on a generic IPS² development process. The results of each phase (discipline-specific data) and their relations to each other are then defined and included in the data model.

Keywords: IPS² development, IPS² data model, IPS² authoring tool, Industrial Product-Service Systems, IT support.

1 Introduction

Industrial Product-Service Systems (IPS²) consist of integrated, interacting product and service elements and create an additional benefit throughout their lifecycle for customers and suppliers in the context of industrial applications [1-3].

Machine tool manufacturers often sell add-on services with the physical product, i.e. the machine tool. The influence of service aspects in the design and the use of the product are not considered, however, even though the revenue generated by industrial services is increasing. Thus, potentials are created by the integration of products and services over the entire lifecycle [4], [5].

IPS² represent customized solutions and allow a flexible adaptation to changing requirements of both customers and suppliers by the resulting solution space [6]. The extension of the solution space increases the organizational complexity, because the

H. Meier (Ed.): *Product-Service Integration for Sustainable Solutions*, LNPE, pp. 521–533.
DOI: 10.1007/978-3-642-30820-8_44

time dimension of the service elements contained in the Industrial Product-Service Systems sets special requirements for tools and methods of the IPS² provider [7].

IPS² product and service elements depend on and influence each other and, therefore, need to be developed together as an integrated system. This puts high demands in regard to technical knowledge from different domains (esp. in both fields of product design and service engineering) as well as to the process complexity and organizational complexity. Also, it is necessary to take the interdependencies between products and services into account with concurrent and iterative development (sub) processes until contradictions are eliminated and the best solution is reached.

Moreover, a holistic view on the lifecycle of the IPS² should be applied in order to obtain the best solution, because the use phase moves into focus of the IPS² provider. The responsibility of the provider and the business relation with the customer do not end after shipping the product. All of these facts show that IPS² development is more demanding in contrast to conventional product design or service engineering [7].

While IT support for product design has been available for decades, IT tools for service engineering still have a relatively young history, and the integrated development is just emerging in the research field. IPS² development requires many different partial models resulting from various domains and development phases. However, smooth collaboration requires access to the latest development data across the entire value chain. Also, homogeneous environments are a success factor for development projects. They enable efficient data exchange and synchronization of project members and between different disciplines.

In order to support IPS² developer during the entire planning and development process, the authoring tool "IPS² assistance system" has been developed [8]. For the implementation of this authoring tool, a general data model of IPS² is needed which helps with the management and exchange of phase-specific and discipline-specific data and results.

2 IT Support System for the Integrated IPS² Development as a Scope for the General Data Model

The IT-based authoring tool "IPS² assistance system", developed at the Institute for Machine Tools and Factory Management of TU Berlin, supports the integrated planning and development processes of Industrial Product-Service Systems. This software system guides and supports the developer along the integrated development processes of products and pertinent services while constantly considering their mutual interdependencies starting at the earliest development phase. In order to reduce the complexity of the development task, the developer is provided with product-service module (PSM) libraries and technology databases containing aggregated knowledge about products, services, processes and pre-developed module solutions.

The partial models (specific models used in the respective planning and development phases) have to be combined within a consistent user interface. Since IPS² development aims at customized solutions, the aspect of customer interaction has to be taken into account by providing interfaces to the customer. The software system also has to be designed to permit an iterative development process. Feedback of changed or extended requirements needs to be included in the following development cycle in order to approach or reach the best solution for the customer. Finally, the architecture of the IPS² assistance system needs to be extensible in order to include other partial models.

Figure 1 depicts the software architecture of the IPS² assistance system, which has a modular structure and serves as a framework for the integration of software modules and partial data models that correspond to the respective process steps. So far the following software modules have been implemented: identification of customer and provider needs and their transformation into requirements, the IPS² configuration module together with the product-service module library and compatibility information database. A top-down approach has been applied to the task, so that after examining the creation of IPS² from pre-developed product-service modules, the research is now focusing in more detail on the creation of the product-service modules, consisting of product and service elements, and the detailed interdependencies between these elements [9]. For this framework, the general data model of IPS² has been developed in order to manage and standardize the exchange of phase-specific and discipline-specific data and results in the established industry standard XML.

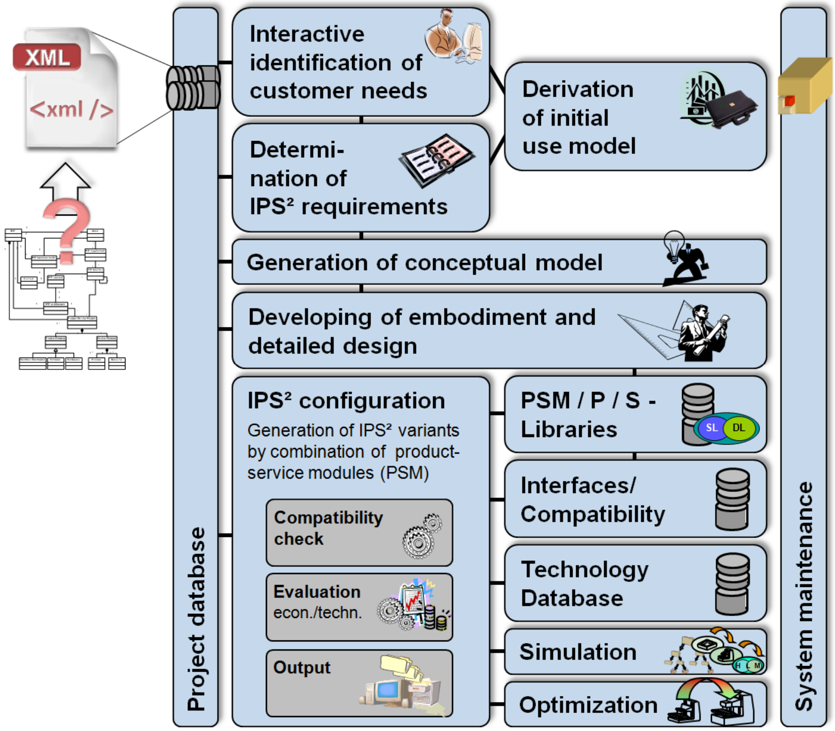

Fig. 1. Modular software architecture of the IPS² assistance system [9]

3 Process for the Planning and Development of Industrial Product-Service Systems

For the development of physical products as well as IT systems, a number of methodologies exist which define the development process from abstract to detailed levels. Widespread methodologies are the VDI guideline 2221, the methodology of Pahl/Beitz and for software the V-Model [10-12]. The development and delivery of services are not well specified. In [13] a very rough and abstract phase model for service development is introduced. Service classes in the engineering field are defined in [14] and service delivery described in [13]. A concept for service design with a lifecycle context is outlined in [15]. Detailed process models for service development are missing at present.

In the IPS² domain, many generic development concepts and approaches with different focuses have been proposed. For instance, among others, Sakao and Shimomura have proposed a generic method which has its focus on service design [16]. In the field of Eco-Design, a design process for PSS eco-innovation has been proposed [17].

In this paper, the generic IPS² development process proposed by Müller [18] will be used as a basis to derive an IPS² development process, which sets the scope for the generation of the general data model.

Although the generic IPS² development process fulfils its purpose as a communication basis by describing IPS² related issues, it is not suitable to serve as a basis to derive a general IPS² data model, because it does not contain any specific results of development phases. Therefore, an extended process for the planning and development of IPS² has been developed, which contains milestones and results of development phases (Figure 2). The process has been divided into four phases (planning, concept modeling, specification and modularization, embodiment and detailed design) with detailed description and results of its execution. This increases the understanding for a flow of this specific development process. Between the phases, milestones have been defined. They serve as orientation points, at which results of phases are reviewed and decisions are made whether or not to start the next phase. Iterative feedback loops are not shown in the figure for simplicity reasons.

3.1 Planning of Industrial Product-Service Systems

The planning of IPS² starts with an acquisition of customer needs and values in the planning phase. The integration of the customer in the planning and development is a key point for providing IPS², which in most cases is a customized solution. Apart from customer specific factors (e.g. competences, business strategies, production processes) also external factors like legislation, infrastructure, market, competitors, etc. have to be considered at this stage.

As a next step, IPS² requirements are derived from the customer needs. While needs, expressed explicitly or implicitly, describe the problem of the customer, requirements are solution-neutral descriptions of the behavior of an IPS² both from a customer and provider view [19].

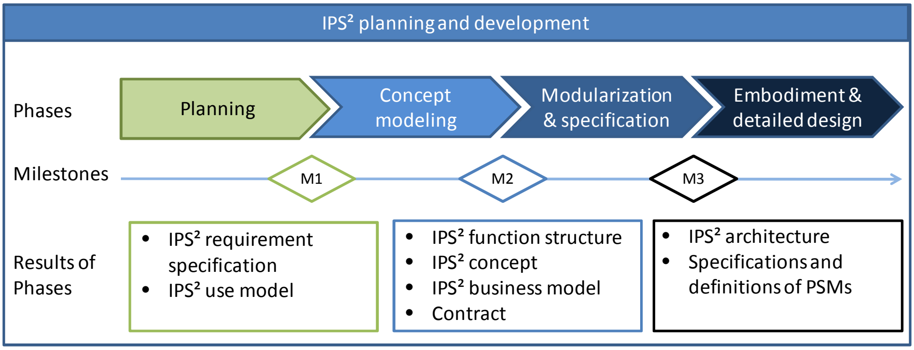

Fig. 2. Simplified IPS² planning and development process derived from [18]

Simultaneously, a use model is determined that benefits both the customer and the IPS² provider. A use model describes the usage of the IPS² and the resulting requirements in a specific business case.

3.2 Concept Modeling of Industrial Product-Service Systems

From the inputs, the IPS² requirement specification and the IPS² use model, a function structure and a concept model are generated in the concept modeling phase. The function structure is a representation of the intended behavior (the functions) of an IPS² and its modules without specifying an IPS² module (product or service), which should fulfill the function. For example, a function "temperature monitoring" describes a functional behavior of an IPS², which provides the exact temperature of a product element that is needed for maintenance.

A concept model includes a function model and principle solutions of an IPS². It describes the structural interaction between them and their logical functionality [20]. A principle solution for the function described above could be a temperature sensor together with an analysis tool.

At the same time a customer specific business model is developed based on the IPS² use model. A business model is defined as a business relationship between provider and customer as well as any third parties over the lifecycle of an IPS². It describes benefits, yield mechanisms, risk allocation, and an ownership of all parties in the IPS² network and the organizational implementation [21]. For example, an availability oriented business model resulting from an availability oriented use model, determines a maintenance contract in order to ensure the functional availability of a machine tool over an agreed period of time [22]. Additionally, responsibilities are defined for machine tool failure.

3.3 Modularization and Specification of Industrial Product-Service Systems

Based on the concept model, product-service modules can be defined and specified for an IPS². The concept of subdividing an IPS² into PSMs is borrowed from systems engineering, which defines a system as a composition of various subsystems for better handling. This means IPS^2 is a system, a PSM is a subsystem. A PSM consists of product and service elements in variable proportions and fulfils one or more functions. Thus, a PSM can take three forms: PSM composed of both product and service elements; PSM with product elements only, and PSM with service elements [8].

In addition to the specification and definition of PSMs, it is necessary to develop important aspects of integration of PSMs into IPS^2 like ICT infrastructure as well as synchronization processes. Together, they build an IPS^2 architecture.

3.4 Embodiment and Detailed Design of Industrial Product-Service Systems

In this phase variants and possible solutions are generated and evaluated. Existing PSMs from a PSM library are assessed in the IPS^2 configuration step with respect to their suitability for the new IPS^2. PSMs not yet included in the PSM library, must be developed in parallel development processes. The methodology resembles the development of the IPS^2 on a higher level. Each PSM requires planning (derivation of requirements for PSM), concept modeling (generation of concepts for PSM), specification and modularization (second level). Finally, product and service elements of the PSMs are drafted and designed. Typically, the embodiment and detailed design of PSMs is discipline-specific, for which the market offers many software tools (e.g. CAD for technical systems, IDE for software development, process modeling for service descriptions). For integrated development, however, the interdependencies between the IPS^2 elements must be considered.

4 Requirements to the IPS^2 Data Model

The partial models of the planning and development phases, and thus also the software modules of the IPS^2 assistance system that support the respective phases, differ substantially. They form a very heterogeneous system with diverse data formats. In order to enable efficient data exchange and improve communication between development phases, a general data model of IPS^2 for the authoring tool IPS^2 assistance system is needed. A data model defines the structure and intended meaning of data [23]. The general IPS^2 data model should

- support the entire planning and development process across all process phases,
- allow for development of a concrete IPS^2 instance for a particular customer,
- allow the management of data for IPS^2 authoring,
- represent all the different elements of IPS^2,
- allow the modeling of the interdependencies between the IPS^2 elements (essential due to the focus on an integrated development),
- allow for combining IPS^2 elements to modules and thus a modularization of IPS^2,
- carry along results across phase borders,
- be generic, not domain specific,
- allow traceability of results from preceding phases and process steps,

- preferably be simple, not too complex,
- be flexible and extensible,
- contain different views on the model and
- allow links between partial models.

5 General Data Model for Industrial Product-Service Systems

5.1 Data Structure of the General IPS² Data Model

Based on the requirements defined in section 4, the general data model is being developed (Figure 3). The first step is to identify the model elements. Primarily, the elements will be intermediate results of the entire planning and development process, which are generated during the aforementioned phases. In particular such results are of interest which are necessary inputs for subsequent phases, because of the focus on supporting the planning and development and allowing the traceability of results across all phases.

The root element is the particular IPS² instance that needs to be developed. It is derived from a specific inquiry or order of a customer. The IPS² model element serves as a container for the following elements, which are associated directly or indirectly with this IPS² instance.

The needs and the IPS² requirements specification from the planning phase form the direct basis for all development steps. The results of the development phases must at any time meet the needs of the customer and provider, which should constantly be checked. The IPS² use model is another result of the planning phase. It is included in the IPS² business model, which is further developed in the concept modeling phase.

Business model, contract, IPS² function structure and IPS² concept are essential elements from the concept modeling phase. A revenue model is added to the IPS² use model. Together with the value configuration they form the IPS² business model [22]. The contract creates an institutional framework, which regulates the rights, duties and responsibilities and establishes the business relation between the IPS² provider and the customer [21]. The contract model element is gradually completed from a basic structure to the final contract. The IPS² function structure has a hierarchical composition with higher-level and lower-level functions. This is modeled by the self-referring relationship.

During the modularization and specification phase at system level, an IPS² architecture is derived from the concept, and principle solutions are merged into product-service modules. The IPS² architecture describes how the PSMs integrate with each other and form the IPS² as a whole.

The PSMs are subsequently designed and detailed in the drafting and design phase and consist of product and service elements. Components of product elements can have a mechanic, electric/electronic or a software based nature. The discipline-specific development results like 3D-CAD models, EDA (Electronic Design Automation) models, simulation models and source code as well as platform-specific executable programs are stored here as product elements. The service elements

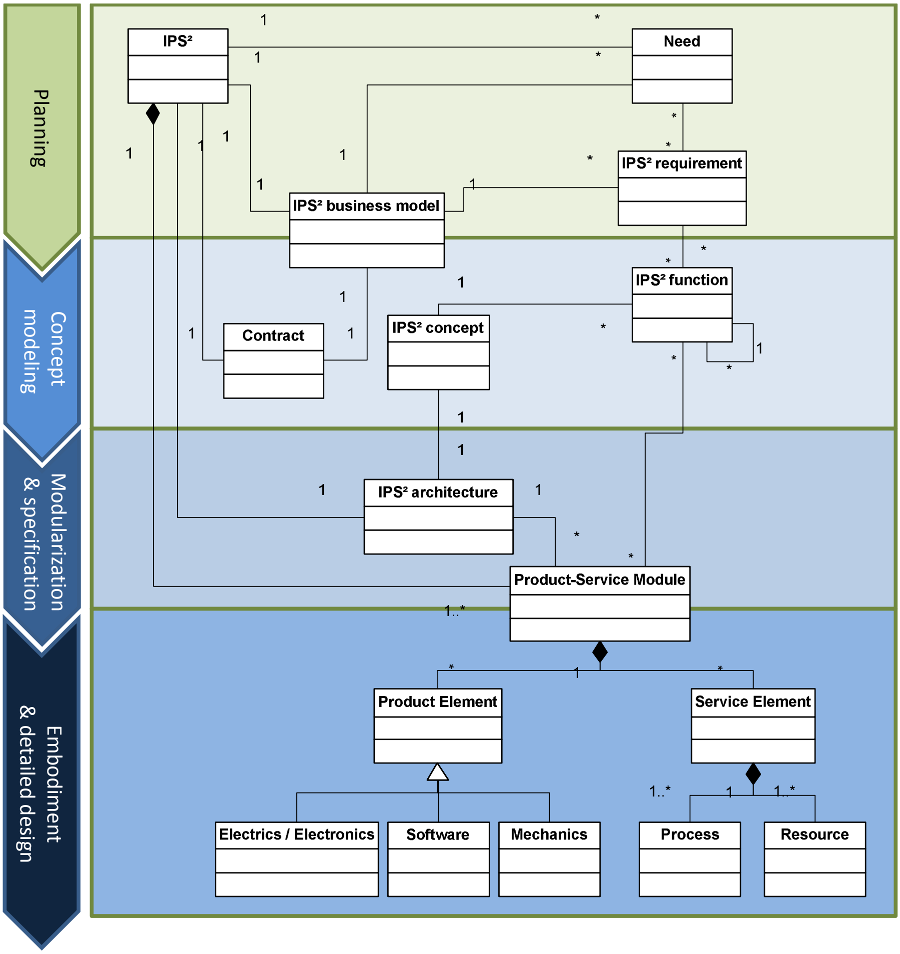

Fig. 3. The general IPS² data model

consist of processes (which include process steps and their sequence) and resources (which can be personnel, tools, consumables or auxiliary equipment).

The model elements are connected by relationships, which add semantics to the UML model. The following types of relationships have been used in the general IPS² data model: association, composition and generalization.

An association relationship is a structural relationship between two model elements, which shows that objects of one element connect objects and can navigate to objects of another element. A composition relationship is a type of aggregation and represents a relationship between an element that is a part of or subordinate to another element. A generalization relationship indicates that a specialized child element is based on a general parent element [24].

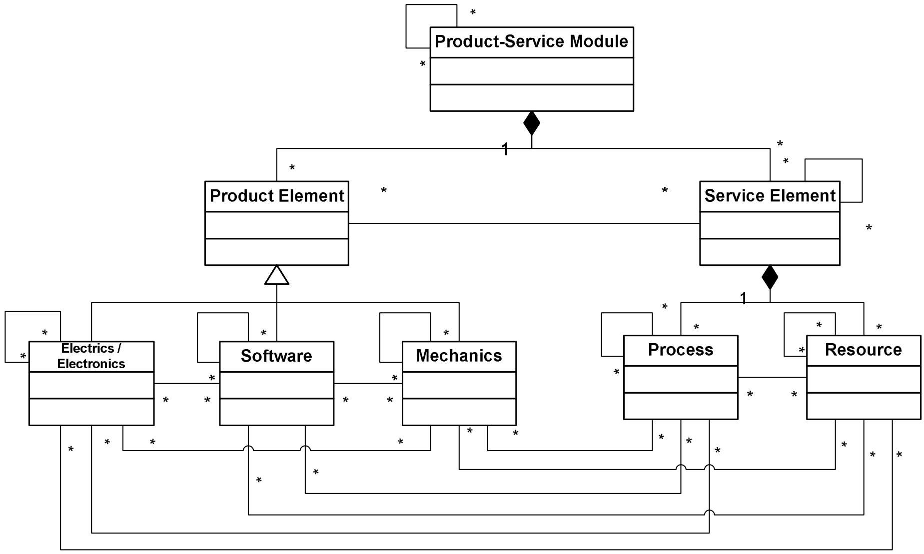

Fig. 4. Interdependencies in the general IPS² data model

In general the associations used in the model result directly from the order of the planning and development steps. Additionally, crosslinks have been inserted to incorporate multiple partial models or results from one phase and from parallel process steps.

The composition at the IPS² model element denotes the modularization concept of IPS². IPS² consist of one or more product-service modules, which in turn are composed of product and service elements. The latter are formed by the set of process and resource. The composition relationship has been used in this case because the development of a particular IPS² instance is concerned. Therefore, the model elements represent concrete instances of results of each phase and are valid only for this particular IPS² instance.

The product element is the generalization of the disciplines mechanics, electrics/electronics and software. Thus, a PSM can consist of and fulfill its function by components from the three disciplines and/or processes that are executed by or with the help of resources. This reflects the substitutability between solution variants for one function, which can be product-centric or service-centric or even consist of only one element type.

5.2 Interdependencies between IPS² Elements

The integrated development of IPS² makes it necessary to describe the interdependencies between IPS² elements. These interdependencies can be found at different levels within an IPS². The highest level is that of product-service modules. The next level is represented by the product and service elements. The third level consists of the discipline-specific components as well as the processes and resources. The attributes of these components, processes and resources are on the last and most detailed level. In this context attributes are characteristics or properties of the components, processes and resources like object mass, duration of a process step and qualification of a technician.

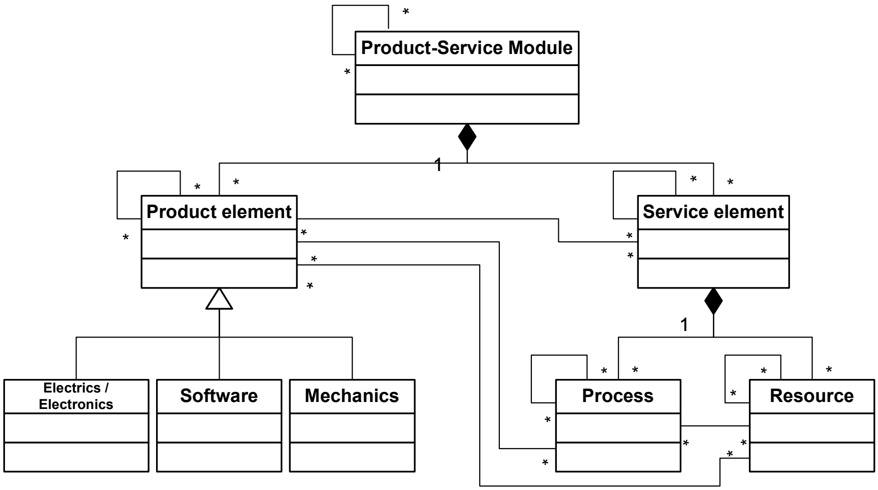

Fig. 5. Simplified model of interdependencies in general IPS² data model

Interdependencies can exist either within each of these levels or across these levels. In figure 4 the association relationships represent the identified interdependencies within the levels. The inter-dependencies across levels have been omitted in favor of better clarity. The composition relationship in the model also implies interdependencies across levels. If the components or parts of the elements belong to a whole, they need to be compatible with each other, and there exists a dependency between the whole and the part.

Different types of interdependency relationships can be assigned. At the higher levels the interdependencies can be described by the relationships "requires" and inversely "enables". For example, condition monitoring (PSM level) may be a requirement for preventive maintenance (PSM level). In turn, sensors have to be integrated into the mechanical product (element or component level) for this purpose. Another example is that an inspection service (element level) together with its process and resources (component level) is needed for wear testing a roller bearing (component level). Also, a technician (resource/component level) needs a certain qualification (attribute level) for a maintenance process, which he can obtain by training (element level).

The interdependency relationships on detail level can be described as interdependencies between the attributes of the components, processes and resources. For this, the relationship types "identical", "not less than" and "not more than" have been identified. For instance, a wrench needs to have the same size like the hexagon screw to be removed. The lifting of a heavy object during the manual execution of a process is another example. The maximum permitted weight of the product varies and depends on the use of a lifting device. Finally, the minimum qualification of service technician depends on the specific type of a product.

The interdependency relationships in figure 4 have been modeled extensively. In order to reduce the complexity of the model, a simplified model has been derived. In figure 5 the generalization relationship has been used to save the detailed relationships between process and resource on one side and the discipline-specific components on the other side as well as their self-references. Due to the generalization concept, one relationship each from the process and resource elements, and one self-reference at the product element, suffice to describe the same relationships.

6 Conclusion and Outlook

For the integrated development of complex systems, such as IPS², new methods and tools are needed. However, IT support for the integrated development of IPS² is hard to find and no standards exist for the exchange of IPS² data within an IPS² authoring tool during the entire planning and development phases.

To overcome these difficulties, a general data model has been developed and implemented in the authoring tool "IPS² assistance system", which supports the entire IPS² planning and development. The data model includes partial models from all the phases of IPS² planning and development. Furthermore, it describes possible interdependencies between product and service elements in detailed as well as in simplified form.

As a next step the general IPS² data model shall be customized and detailed for specific industry cases and tested with various information standards, documents and models in the respective industry sector. It can be extended to integrate existing IT systems into the IPS² assistance system. For this purpose interfaces for data exchange need to be implemented.

Acknowledgments. We express our sincere thanks to the Deutsche Forschungsgemeinschaft (DFG) for funding this research within the Collaborative Research Project SFB/TR 29 on Industrial Product-Service Systems – Dynamic Interdependency of Products and Services in the Production Area.

References

1. Meier, H., Uhlmann, E., Kortmann, D.: Hybride Leistungsbündel: Nutzenorientiertes Produktverständnis durch interferierende Sach- und Dienstleistungen. wt Werkstattstechnik Online 95(7/2005), 528–532 (2005)
2. Tan, A.R., McAloone, T.C.: Characteristics of strategies in Product/Service-System Development. In: Andreasen, M.M. (ed.) 9th International Design Conference - Design 2006, Dubrovnik, Croatia, pp. 1435–1442 (2006)

3. Matzen, D., Tan, A.R., Andreasen, M.M.: Product / Service-Systems: Defining a coherent terminology. In: Meerkamm, H. (ed.) Design for X. Beiträge zum 16. Symposium, Neukirchen, pp. 27–38. Erlangen (2005)
4. Nyhuis, P., Fronia, P., Pachow-Frauenhofer, J., Wulf, S.: Wandlungsfähige Produktionssysteme. wt Werkstattstechnik Online 99(4), 205–210 (2009)
5. Fleischer, J., Meier, H., Kaiser, U., Krings, R., Niggeschmidt, S.: Verfügbarkeitsoptimale Dienstleistungskonfiguration. wt Werkstattstechnik Online 98(7/8), 601–606 (2008)
6. Uhlmann, E., Bochnig, H.: IT-gestützte Anforderungsgenerierung für hybride Leistungsbündel. wt Werkstattstechnik Online Jahrgang 100(Heft 7/8), 578–583 (2010)
7. Uhlmann, E., Bochnig, H.: Computer Aided IPS^2 Development. In: Meier, H. (ed.) Industrial Product-Service Systems. Dynamic Interdependency of Products and Services in the Production Area. 2nd Int. Seminar on IPS^2, pp. 31–36. Shaker, Aachen (2009)
8. Uhlmann, E., Bochnig, H.: Assistenzsystem zur Ausgestaltung hybrider Leistungsbündel. In: Meier, H., Uhlmann, E. (eds.) Integrierte Industrielle Sach- und Dienstleistungen. Vermarktung, Entwicklung und Erbringung hybrider Leistungsbündel, pp. 89–111. Springer, Heidelberg (2012)
9. Uhlmann, E., Bochnig, H.: PSS-CAD: An Approach to the Integrated Product and Service Development. In: Shimomura, Y. (ed.) Proceedings of 4th CIRP International Conference on Industrial Product-Service Systems, Tokyo (in press)
10. Verein Deutscher Ingenieure: Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte: Systematic approach to the development and design of technical systems and products. VDI 2221. Verein Deutscher Ingenieure, Düsseldorf (1993)
11. Pahl, G., Beitz, W., Feldhusen, J., Grote, K.-H.: Engineering Design: A Systematic Approach, 3rd edn. Springer, London (2007)
12. Industrieanlagen-Betriebsgesellschaft mbH: Das V-Modell, `http://v-modell.iabg.de/`
13. Deutsches Institut für Normung e.V. (ed.): DIN-Fachbericht 75 - Service Engineering: Entwicklungsbegleitende Normung (EBN) für Dienstleistungen. Beuth, Berlin (1998)
14. Verein Deutscher Ingenieure: Ingenieur-Dienstleistungen und Anforderungen an Ingenieur-Dienstleister: Engineering services and requirements for an engineering service provider: VDI 4510. Beuth, Berlin (2004)
15. Aurich, J.C., Fuchs, C., DeVries, M.F.: An Approach to Life Cycle Oriented Technical Service Design. CIRP Annals - Manufacturing Technology 53(1), 151–154 (2004)
16. Sakao, T., Birkhofer, H., Panshef, V., Dörsam, E.: An effective and efficient method to design services: empirical study for services by an investment-machine manufacturer. International Journal of Internet Manufacturing and Services 2(1), 95–110 (2009)
17. Chen, J.L., Huang, S.-C.: Eco-Innovative Design of Product Service Systems by using the Substance-Field Analysis Method. In: Hesselbach, J., Herrmann, C. (eds.) Functional Thinking for Value Creation. Proceedings of the 3rd CIRP International Conference on Industrial Product Service Systems, pp. 63–68. Springer, Berlin (2011)
18. Müller, P., Stark, R.: A generic PSS development process model based on theory and an empirical study. In: Andreasen, M.M. (ed.) 11th International Design Conference - Design 2010, Dubrovnik, Croatia, May 17-20, vol. 1, pp. 361–370. Zagreb (2010)
19. Uhlmann, E., Bochnig, H., Stelzer, C.: Characterization of Customer Requirements in IPS^2 creation. In: Sakao, T. (ed.) Proceedings of the 2nd CIRP IPS^2 Conference on Industrial Product-Service Systems (IPS^2), Linköping, pp. 399–405 (2010)
20. Sadek Hassanein, T.: Ein modellorientierter Ansatz zur Konzeptentwicklung industrieller Produkt-Service Systeme. Shaker, Aachen (2009)

21. Rese, M., Meier, H., Gesing, J., Boßlau, M.: HLB-Geschäftsmodelle: Partialmodellierung zur Systematisierung von Geschäftsmodellen "Hybrider Leistungsbündel" (HLB). wt Werkstattstechnik Online Jahrgang 101(7/8), 498–504 (2011)
22. Tukker, A., Tischner, U. (eds.): New Business for Old Europe: Product-service development, competitiveness and sustainability. Greenleaf, Sheffield (2006)
23. West, M.: Developing High Quality Data Models. Elsevier Science & Technology (2010)
24. Olivé, A.: Conceptual Modeling of Information Systems. Springer, Berlin (2007)