INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

A MODEL BASED APPROACH FOR CONCEPTUAL DEVELOPMENT OF INDUSTRIAL PRODUCT-SERVICE SYSTEMS

Tim Sadek, Ewald Georg Welp
Ruhr-University of Bochum, Germany

ABSTRACT
Industrial Product-Service Systems (IPS²) are characterised by the integration of investment goods (technical products) and industrial services along their entire lifecycle. Against the background of sustainable value creation, while providing a performance is set above the purchase of pure technical products, an IPS² constitutes a suitable solution. It can comprise any combination of product and service shares. Once such an offer has been planned, the IPS² concept development is responsible for generating principle solutions that meet customer-specific requirements. This paper presents a model-based approach to support an IPS² designer generating heterogeneous IPS² concept models in the early phase of IPS² development. The proposed modelling approach allows the combination of multidisciplinary solution elements on arbitrary levels of abstraction from different development perspectives. The heterogeneous IPS² concept modelling approach has been implemented as a software demonstrator and has been evaluated solving a typical IPS² issue.

Keywords: Industrial Product-Service System (IPS²), conceptual development, heterogeneous IPS² concept modelling approach

1 INTRODUCTION
The combination of globalisation effects and technological advances has led to long-term, cooperative customer-supplier relationships and to a decline in supplier's differentiation based on technical products solely. Today, industrial services have evolved from being a peripheral add-on for technology to become a complementary part of an integral solution.
As the importance of long-term customer-supplier relationships, especially in investment goods industry, grows, the sale of pure technical products has been replaced by new business models. The implementation of these business models does, however, require the integration of technical products and industrial services to form product service bundles [1]. In academia these types of solution are called "Industrial Product-Service Systems" (IPS²).
To meet customer requirements and to properly develop solution elements as well as relations between them, it is important to consider interdependencies between product and service at an early phase of development [2]. There are currently no integrated, model-based approaches available that support IPS² designers generating IPS² concepts. In order to satisfy this demand, we propose a methodology, which comprises a heterogeneous IPS² concept modelling approach.
Heterogeneous IPS² concept modelling aims at supporting a designer to develop IPS² concepts. To establish a common comprehension of the system to be developed, basics of Industrial Product-Service Systems are addressed in this contribution first. After that, basic aspects of the heterogeneous IPS² concept modelling approach are explained. Furthermore, the implementation of the proposed approach as a computer-aided tool is presented. The modelling approach has been evaluated with an IPS² specific issue of micro manufacturing industry. The paper concludes with a summary.

2 BASIC UNDERSTANDING OF IPS²
In academic discussions there is often a discrepancy in the basic definition of both Product-Service Systems (PSS) that target B2C-markets and IPS². Concerning IPS² this basically results from interdisciplinarity and complexity of the subject matter. To establish a consistent comprehension of

IPS² in general essential basics are discussed below. This also constitutes a necessary basis to propose the heterogeneous IPS² concept modelling approach.

2.1 Business models, business contracts, revenue models and property rights

The aspired change from selling pure technical products or industrial services to a performance-based sale of IPS² aims at increasing customer's and supplier's benefits alike. This leads to a change in business models as well as in the customer-supplier relationship.

Unlike the strategic focus of a company, which is defined by a business model [3], a commitment between customer and supplier is specified in a *business contract*. This explicitly affects the architecture of an IPS². Thus, business contracts are used to coordinate business relationships. Concerning IPS², contracts that coordinate long term cooperation between contractual parties are particularly important. Basically two aspects of such contracts need to be considered in IPS² concept development. On the one hand, an IPS² concept is explicitly determined by the assignment of *property rights*. On the other hand, the choice and design of the *revenue model* is crucial. As a purchaser of an IPS² is no longer necessarily the owner of its material components, a wide range of different possibilities to design revenue models is conceivable. A revenue model specifies measurable economic parameters for pricing as well as the value proposition of a business relationship. According to Burianek et al. [4] traditional and innovative revenue models can be distinguished from each other as presented in Figure 1.

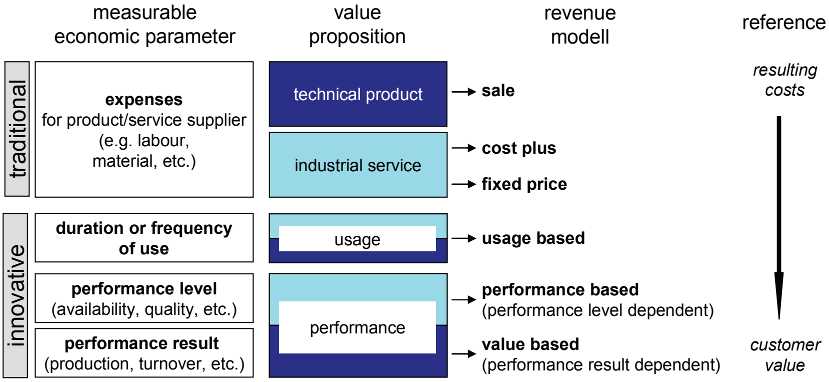

Figure 1. Distinguishing traditional and innovative revenue models (cf.[4])

Traditional revenue models that are based on the transactional sale of technical products or the offer of pure service (e.g. cost plus or fixed price) are cost-based and their price is measured by the expenses involved in manufacturing products or delivering service respectively.

Unlike traditional revenue models, innovative revenue models are no longer characterised by incurred costs. Instead, their basis for pricing is determined by realized customer benefit. According to Burianek et al. three different types of innovative revenue models can be distinguished: i) usage-based, ii) performance based and iii) value based. These revenue models are planed to provide a more efficient risk distribution between contractual parties. This leads to new incentives for suppliers and customers alike. Thus, all this needs to be considered in the development of an IPS² concept.

2.2 Definition: Industrial Product-Service System (IPS²)

The problem solution required to fulfil such innovative business contract equals an Industrial Product-Service System. Due to the diversity of similar terms, the general definition of an IPS² given below aims at clarifying basic IPS² characteristics [5]:

"An Industrial Product-Service System (IPS²) is a problem solution solving business-to-business market issues. An IPS² meets individual customer requirements by integrating multidisciplinary, technical product components and industrial services. Thus, an IPS² is a long-term, socio-technical, economic commodity. Due to partial substitution of component parts an IPS² is changeable during its delivery and use. Furthermore an IPS² is characterized by an integrated and mutually determined planning, development, delivery and use."

Thus, from supplier's point of view an IPS^2 is an economic commodity that targets generating added value. According to the IPS^2 definition mechatronic systems are immanent constituents of an IPS^2 [6]. They form not only the technical product needed for manufacturing processes, but are also the basis for automating industrial services. Furthermore customizing revenue models and assignments of property rights comprises the diversity of possibilities described in chapter 2.1. Partial substitution of constituents of an IPS^2 allows its adjustment to changing restrictions or influencing factors during its long-term delivery and use. This specific feature of an IPS^2 is considered as "changeability".

2.3 Component Parts: IPS² artefact

Based on the IPS^2 definition given above, it is necessary to specify elementary constituents of an IPS^2. Rather than a standard comparison of product and service that is often inconsistent due to fuzzy distinctions between both, a new construct is defined, called "**IPS^2 artefact**". Its systematical and detailed deduction is presented in [5, 6 and 7].

The introduction of the IPS^2 artefact aims at both dissolving fuzzy distinctions between product and service as well as consolidating multiple perspectives in IPS^2 concept development. All this leads to the definition of *five constitutive characteristics* that form the basis to characterize IPS^2 artefacts.

IPS^2 artefacts can be distinguished in terms of their **specificity**. Besides human or technical artefacts, artefacts with superordinate properties, for example controlling, logistics, do also exist. The definition of the second constitutive characteristic, called **dominant transformation**, is based on three types of transformations. According to [8], transformation of a material, energy or information flow can be distinguished. That is also true for IPS^2. Moreover, the interaction with the external factor that comprises all types of customer's resources is important, as it can play a vital role in IPS^2 delivery and use. Thus, IPS^2-artefacts are characterised by a gradual integration of the external factor into an IPS^2. This is called **scale of integration**. The dynamic adjustment of an IPS^2, enabled by partial substitution of its constituents, is another essential and unique feature of an IPS^2. The **capability for partial substitution** of an IPS^2 artefact, ranges from its particular exchange, which means that an IPS^2 artefacts can only be substituted with an alternative IPS^2 artefact of same specificity, to universal partial substitution. In terms of universal partial substitution a human can be replaced by a technical artefact, for instance. The fifth constitutive characteristic called **connectivity** complements the others. Characterising IPS^2 artefacts regarding their connection to other constituents (non-physical vs. physical) represents the cohesion of an IPS^2.

2.4 Basic structure of an IPS²

Next to IPS^2 artefacts that define the primary content of an IPS^2, the **IPS^2 basic structure** [5] represents an overall view of an IPS^2. Furthermore, it serves as a constitutive basis for modelling and developing IPS^2 concepts. As shown in Figure 2, the basic structure of an IPS^2 contains three superordinate components: i) influencing factors / surrounding conditions ii) the IPS^2 itself and iii) a dynamic target system.

The IPS^2 takes centre stage. As a transformation system [9] it should meet a nominal reference given by the dynamic target system (w or w*). Influencing factors or surrounding conditions (z or z*) cause negative effects and need to be compensated by the transformation system. The IPS^2 is separated from its system environment by a system boundary. The IPS^2 transforms immaterial input, such as labour or financial resources, and material input, such as an unmachined part, into material output, such as a machined component. With that, an immaterial output, which equals performance in general, is also result of this transformation process and therefore represented in the IPS^2 basic structure. An assured level of availability of a manufacturing system or a maintained component are examples of immaterial outputs. Supplier and customer that interact with each other during the transformation process are relevant stakeholders of an IPS^2. The transformation process itself is controlled by the dynamic target system. It contains different aspects of the business contract, especially all nominal references. To ensure the changeability of an IPS^2, a portfolio of options (o_{ij}) that can be defined in the business contract is also specified in the dynamic target system. Options imply the right but not the obligation for the customer to decide in favour of future business decisions [10]. This implies discrete state changes of an IPS^2 as well.

The core of an IPS^2 is its robust IPS^2-basis, which can be compared to a controlled system in terms of cybernetics. Against the background of business-to-business market solutions, the robust IPS^2-basis equals a manufacturing system with its related human resource required to fulfil a certain task. The combination of IPS^2 artefacts, which constitute the robust IPS²-basis, can be adjusted but cannot be exchanged completely. The robust IPS^2-basis is regarded as a micro control loop, which reacts to disturbing effects (z) without external interference. It is also capable to stabilize or optimize an IPS² according to the nominal references (w). Taking economic restrictions into account, the range of control of the robust IPS^2-basis is, however, restricted, so that it is not capable to react to all kind of changes.

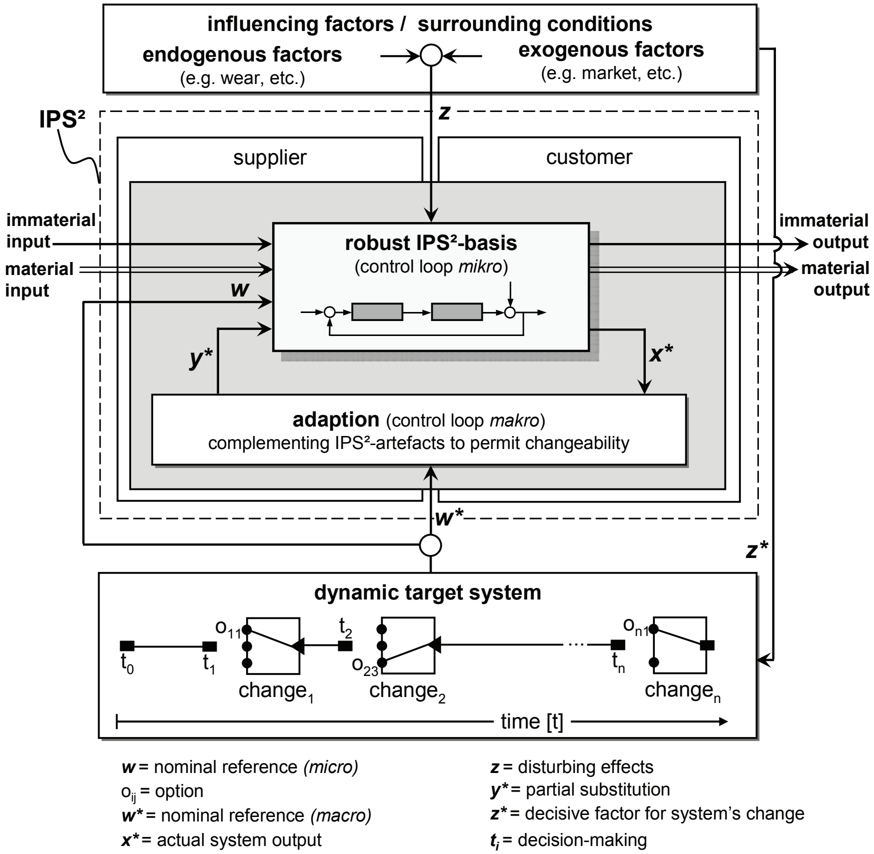

Figure 2. Basic structure of an IPS²

To adopt an IPS^2 to extensive changing market conditions or customer demands an additional macro control loop, called "adaption“, is included into the IPS^2. By partially substituting IPS^2 artefacts (y*) it is possible to implement alternative options. These need to be considered in IPS² concept development to adopt for uncertain future events. Exchanging IPS² artefacts basically depends on their capability for partial substitution and their connectivity to related elements.

3 ANALYSIS OF STATE OF THE ART OF MULTIDISCIPLINARY DEVELOPMENT METHODOLOGIES AND MODELLING APPROACHES

In a comprehensive study [5] existing approaches have been analyzed, which support the development and modelling of multidisciplinary systems in general and of Product-Service Systems in particular.
For the subject of multidisciplinary development methodologies different evaluation criteria have been defined. Amongst others the fulfilment degrees with regard to “integration of product and service development”, “systematic multidisciplinary concept deployment” or “determining product-service interdependencies in early phase of development” have been considered. Despite an existing multitude of methodologies, this study unfolds that designers are only insufficiently supported by computer

aided tools in the early phase of multidisciplinary systems develop. In terms of IPS² concept development, methods are missing for i) mutually determining IPS² artefacts, ii) integrating stakeholder's preferences iii) considering changeability of IPS².

Analysis of existing multidisciplinary modelling approaches has led to similar results. The state of the art has been examined according to specific criteria. Amongst others the fulfilment degrees with regard to "integrated product-service modelling" or "IPS²-appropriate modelling notation" have been assessed. The comparison of multidisciplinary modelling approaches has shown that there is also a lack of approaches that focus on integrated product and service modelling.

Nevertheless, some methodological and modelling approaches contain aspects that are significant for a model-based IPS² concept development approach. But currently no comprehensive integrated approach does exist.

4 HETEROGENEOUS IPS² CONCEPT MODELLING AS AN ESSENTIAL ELEMENT OF MODEL-BASED IPS² CONCEPT DEVELOPMENT

A new modelling principle has been created to support model-based IPS² concept development. This principle, called "heterogeneous IPS² concept modelling", is presented in the following paragraphs. It is particularly suitable for integrated product and service modelling, but is also transferable to other multidisciplinary development issues. Integration ranges from the combination of various types of IPS²-artefacts to linking model elements on arbitrary levels of detailing, abstraction and formalisation to form an IPS² concept model. A systematic and detailed deduction of this approach is described in [5].

4.1 Theoretical Framework

As already mentioned in [2, 6], the definition of a generally applicable modelling space that is defined by three modelling dimensions (detailing, formalisation and abstraction) aids to constitute a harmonized comprehension of IPS² modelling. It is also used as a fundamental basis to decompose the heterogeneous modelling approach of mechatronics [11, 12]. This is necessary to partially extend the existing approach and to combine it with a new paradigm for integrated product and service modelling. All this leads to the theoretical framework of heterogeneous IPS² concept modelling.

The **new paradigm** is based on the definition of the IPS² artefact. It aims at dissolving fuzzy distinctions between product and service (see section 2.3).

According to [5], an IPS² is basically composed of a combination of IPS² artefacts that fulfil required functions. Thus, the existential origin of an IPS² artefact is a function. According to [8] such a function is defined by a combination of "noun" and "verb". In this context a noun represents the *operand* of a solution element, which is functionally described. According to the prevalent comprehension of this term in mathematics an operand represents the structural point of reference of a function. In turn an operand can either be influenced or be transformed by an operator. Hence, an operand is characterized by its states. Represented on a high level of abstraction by a certain noun the component parts of an electric engine constitute the operant of a function, for example. Contrary to this a function's verb can be compared to an *operator* that causes a change in state of the operand. The distinction between operand and operator is generally applicable to all types of functions. To use this as a generic principle for integrating different types of elements on a medium and lower level of abstraction rather than just as a functional description, the terms "noun" and "verb" are extended by the terms "IPS² object" and "IPS² process". Whereas "noun" and "verb" constitute a function, the combination of "IPS² object" and "IPS² process" constitute an IPS² artefact. Thus, a functional, a object-related and a process-related development perspective can be distinguished.

Thereby, an **IPS² object** equals the material or immaterial operand of an IPS² artefact that possesses definable states. **IPS² processes** complement IPS² objects. On the one hand, they can be regarded as operators that effect IPS² objects and their respective states (intra). On the other hand, IPS² processes are regarded as operators able to coordinate and to control the interaction of IPS² objects (inter). But, only the combination of IPS² objects and IPS² processes can generate functional behaviour!

Based on this, a functional, an object-oriented and a process-oriented development perspective can be distinguished in order to fully grasp the complexity of heterogeneous IPS² concept modelling. This leads to the definition of three system-coherent modelling planes.

The transfer from planning an IPS² to its systematic conceptual development is carried out on the so-called **IPS² function plane**. Depending on the development task an IPS² problem solution can be

modelled abstractly and solution-neutral by defining and linking IPS^2 functions. The deliberately omitted concretization of an IPS² problem solution on that plane is transferred to adjoining modelling planes. The **IPS^2 object plane** is intended for modelling a material or immaterial operand of an IPS^2 artefact. In contrast, the **IPS^2 process plane** has been defined to model intra- and inter-operations that effect IPS² objects.
The definition of these modelling planes enables an IPS² designer to develop IPS² concepts in a successive way. Step-by-step IPS² functions, IPS^2 objects and complementing IPS^2 processes can be developed. In doing so, interdependencies between IPS^2 artefacts can be determined in an early phase of development. The combination of all three modelling planes constitutes a heterogeneous IPS² concept model. Heterogeneous IPS^2 concept modelling aims at supporting IPS^2 designers to represent different states of knowledge during IPS^2 concept development effectively. A further description of all modelling planes, model elements and relations is presented in following paragraphs.

4.2 System coherent modelling planes

A graphical, 2D representation is used to support intuitive modelling on the **IPS^2 function plane** (see section 4.4). Apart from modelling IPS² function structures this plane is used to specify and model the distribution of risk that needs to be shared between customer and supplier [13] according to a business contract. Therefore, the IPS² function plane is divided into the supplier and customer modelling zone (see figure 5). By placing an IPS^2 function in one of these zones, the associated risk can be clearly assigned to supplier or customer. Both modelling zones are logically connected via a supplier-customer relationship. Content of the underlying business contracts with relevance for IPS² concept development is defined in this meta-relation. This includes the distribution of property rights, the definition of the underlying revenue model as well as a certain portfolio of options, for instance.
The design of the **IPS^2 object plane** and its subdivision into three modelling zones is primarily based on the specificity of IPS^2 artefacts. According to this, technical, human and superordinate IPS^2 objects are defined and modelled in logically and spatially separated modelling zones (see Figure 5). IPS² object structures consist of such IPS² objects that are connected via specific relations (see chapter 4.4). To model IPS² object structures effectively the IPS² object plane is represented by a three-dimensional modelling space (see figure 5). 3D modelling mainly results from modelling technical IPS^2 objects. Visualizing IPS² objects by 3D elements improves the comprehension of IPS^2 object structures especially for interdisciplinary design teams. Furthermore, the model transfer from heterogeneous IPS^2 concept modelling to 3D-CAD design has been taken into account.
The syntactical structure of the **IPS^2 process plane** is comparable to the IPS^2 function plane. IPS^2 processes are mainly graphically modelled using an IPS^2 specific activity diagram. The IPS^2 process plane is also used to model interactions between supplier and external factor (customer). Therefore, two modelling zones are defined and separated by a "line of interaction" (see figure 5). In this case the line of interaction is equivalent to the correspondent line in ServiceBlueprints, according to [14]. The interaction between supplier's and customer's resources is modelled via placing IPS^2 processes in modelling zones. IPS^2 processes that are located in the modelling zone "external factor" imply a respective interaction with customer's resources. This enables a designer to take essential interdependencies between stakeholders into account already in the conceptual development phase.
By defining and attributing system-coherent modelling planes restrictions of an IPS^2 development task can be aggregated and specifically assigned to several steps of a conceptual development process. Moreover, a system boundary of an IPS² can be defined by specifying attributes of the aforementioned modelling planes.

4.3 Model elements

Heterogeneous modelling of an IPS² concept to be developed is carried out by the help of model elements. Therefore, three different types of model elements are defined: i) system elements, ii) disturbance elements and iii) context elements. The combination of all types of model elements and their respective relations constitutes a heterogeneous IPS² concept modell. Representing the structure of all model elements a system element, particularly an IPS^2 function, is shown in Figure 3. In addition to four different *"content blocks"* (meta, description, attributes and methods), a system element has got *interfaces* (system, disturbance and context relation as well as system association) to link it to other model elements.

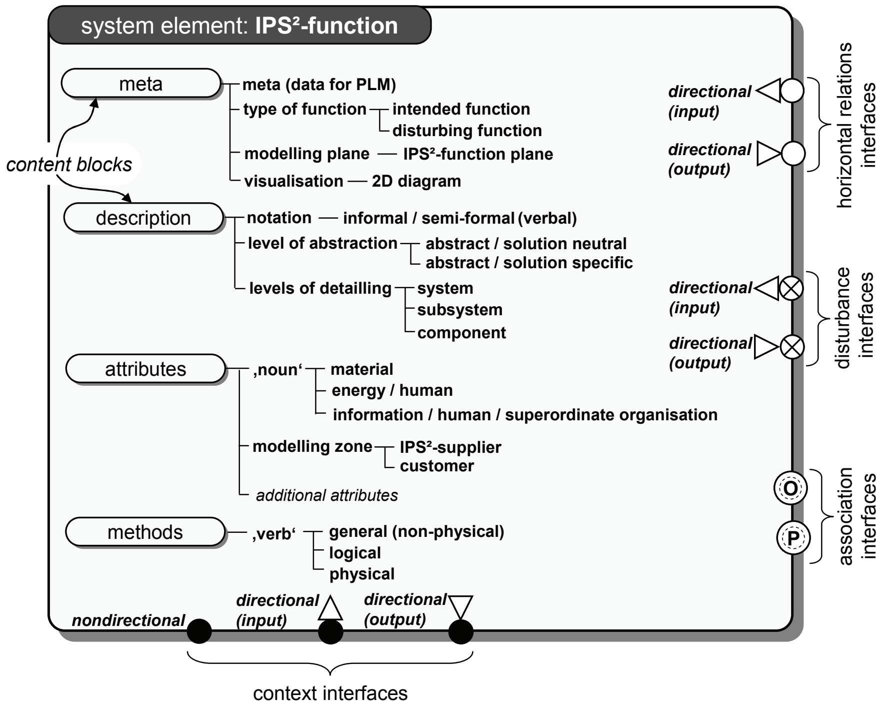

Figure 3. Structure of system elements

To model an IPS² concept three coequal **system elements**, namely i) IPS² functions, ii) IPS² objects and iii) IPS² processes, are defined. Each of these elements represents a constituent part of an IPS² taking into account a certain level of abstraction as well as an object- or process-dominated development perspective.
In heterogeneous IPS² concept modelling **IPS² functions** are used to model constituent parts of the system to be developed on a high level of abstraction. In general IPS² functions are solution-neutral which means that a problem solving solution principle is not defined explicitly. Besides the content block "meta", which is used to define general attributes of a model element, an IPS² function possesses three additional content blocks (see Figure 3). Whereas the block "description" characterises an IPS² function in terms of its modelling properties, "attributes" and "methods" are used to specify its intended purpose. The operand of an IPS² function is represented by its attributes. According to chapter 4.1 this can be a "noun" in a broader sense. Attributes are complemented by methods, represented by "verbs", which are modelled to change states of operands. Distinguishing attributes and methods corresponds to the basic idea of the object-oriented paradigm [15].
Beside the functional description, **IPS² objects** are needed to model operands of an IPS² on a medium level of abstraction. Based on the characterisation of the IPS² artefact, three different types of IPS² objects have been defined. While technical IPS² objects are artificially generated by the combination of mechanical, electronic and information technology elements, human IPS² objects represent human individuals. These can be connected with technical IPS² objects to form socio-technical systems. In contrast, superordinate IPS² objects are defined to control and to affect technical and human IPS² objects. Contrary to human and technical IPS² objects these system elements possess properties of a "organizing collective" (e.g. logistics, controlling, planning). Depending on the level of knowledge, IPS² objects are modelled as abstract solution principles as well as concretized designed components due to the scope of heterogeneous modelling. In general content blocks of IPS² objects are similar to content blocks that are defined to constitute IPS² functions.
IPS² processes are discrete operations that influence IPS² objects. IPS² processes are capable to either change IPS² object's states (intra) or to control the interaction of IPS² objects (inter). Beside content blocks that are needed to define general properties of an IPS² process, this system element also

possesses "attributes" and "methods" to model its intended purpose. On the one hand, time-related or operation-related properties of an IPS^2 process (e.g. process duration, target values or input information for IPS^2 objects) can be specified in attributes. On the other hand, element content that initiates state changes of IPS^2 objects or affects their interaction is defined in "methods" of IPS^2 processes. Contrary to discrete operations, continuous processes, such as the transformation of electrical energy into mechanical energy for instance, are not modelled using IPS^2 processes. Continuous processes are part of IPS^2 objects and are modelled by means of their methods. Furthermore, IPS^2 process can be modelled on arbitrary levels of abstraction depending on the present state of knowledge.

To model disturbing effects on or within an IPS^2, system elements of all modelling planes can be linked to **disturbance elements** via their directional interfaces. In general it is possible to distinguish between disturbance effects with a physical or a non-physical origin. While wear and tear in mechanical components or noise in electronic circuits have a physical origin, disturbance effects such as opportunistic human behaviour cannot be modelled using physical equations. Nevertheless, both types of effects cause disturbance in an IPS^2 that needs to be considered already in the early phase of development. Therefore, a disturbance element possesses additional content blocks to specify disturbance cause, its primary influencing factors and propagation of noise within the system.

Furthermore, system elements of all modelling planes can be coupled with **context elements** via a specific interface. This permits to connect system elements to related relevant aspects of the development context, such as requirements, restrictions or IPS^2-engieering knowhow. Thus, context elements are not part of the system itself and they do not show any functional or physical behaviour. Nevertheless, they are important due to the organizational and administrative information which they represent.

4.4 Relations between model elements

Relations are used to link the aforementioned model elements to each other in order to combine them to heterogeneous IPS^2 function structures, IPS^2 object structures and/or IPS^2 process structures. To interconnect model elements within a certain modelling plane, the IPS^2 function plane for instance, three different types of relation are defined. Beside that, so-called “associations” are used to combine IPS^2 functions, IPS^2 objects and IPS^2 processes across their respective planes.

Model elements on a certain level of detailing can be linked to each other using **horizontal relations**. A horizontal relation is defined by a combination of a generally applicable "header" and an element-specific "class". The header of a relation contains information on the model elements to be linked, such as the element type or the element ID, as well as information on the representation to be used. A header is also used to specify "directional" and "non-directional" horizontal relations. This enables a designer to model the direction of an effect or its feedback. Moreover, the content of a horizontal relation is defined by the choice and specification of an element-specific class. Basically there are five different types of classes to define horizontal relations.

One plane-specific *system relation* is used on each of the three modelling planes to link IPS^2 functions, IPS^2 objects or IPS^2 processes. Contrary to common methodologies, as for example [8], the proposed modelling approach does not link IPS^2 functions by material-, energy- or information-flows. Instead, IPS^2 functions are combined to IPS^2 function structures on a certain level of detailing depending on their causal interdependencies using horizontal relation [5]. Furthermore, modelling physical, non-physical and logical relations is carried out on the IPS^2 object plane as well as the IPS^2 process plane. On a certain level of detailing disturbance or context elements can be linked to system elements using *disturbance or context relations* respectively.

In contrast, hierarchical relations between system elements are modelled using **vertical relations**. On the one hand, this allows to aggregate system elements to super-systems. On the other hand, super-systems can be detailed into sub-systems or single components. The structure of a vertical relation is comparable to the structure of a horizontal relation as it also defined by a “header-class-combination”. Two plane-independent classes are defined for aggregating or detailing. Using vertical relations a designer is able to develop a heterogeneous IPS^2 concept model combining top-down and bottom-up methodologies. Instantiating a vertical relation basically corresponds to generating additional levels of detailing on a respective modelling plane.

Although, **parallel relations** have not been implemented as a functionality of the software demonstrator they need to be considered at least theoretically to be able to take changeability into

account. This type of relation is meant to be used to store modelling information of different conceptual solutions, which result from a portfolio of options defined in the dynamic target system (see chapter 2.4). Contrary to the aforementioned types of relation, parallel relations are just represented in a data model that contains all modelling information the IPS^2 concept. Parallel relations are used to save certain types of changes in concurrent versions of such data models.
In contrast to the plane-specific relations that are exclusively defined to link modelling elements on a certain modelling plane, **associations** are used to link system elements across modelling planes. An association can be perceived as a "pointer" that is able to address IPS^2 functions, IPS^2 objects or IPS^2 processes. Meshing system elements across modelling planes using associations is done only in the underlying data model.

4.4 Model representation

A suitable model representation is required to ensure that the conceptual components of the heterogeneous IPS² concept modelling approach can be applied and used for IPS^2 concept development. Figure 4 shows model representations used to describe modelling planes, system elements as well as their respective horizontal relations.

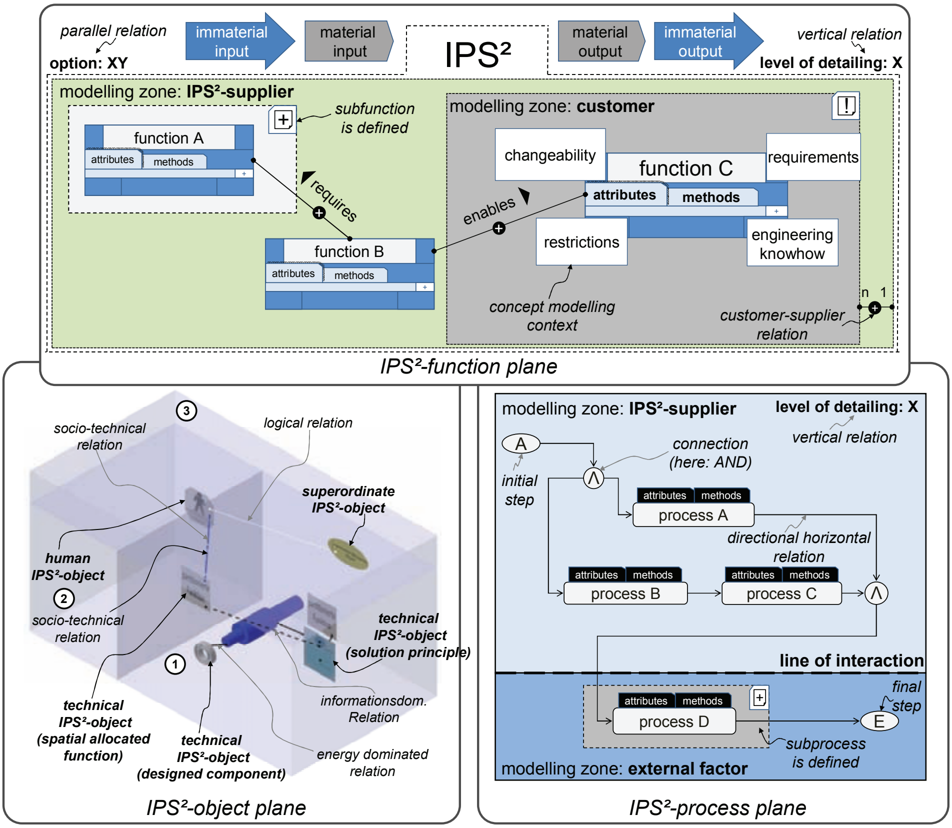

Figure 4. Representation forms of a heterogeneous IPS² concept model

The way of modelling on the IPS^2 function plane is presented in the upper part of Figure 4. Within the system boundary of an IPS^2, visualized by a dotted line, supplier and customer modelling zones are defined by two rectangular areas in different colours. IPS^2 functions are represented by rectangles. Horizontal relations between IPS² functions are pictured by unidirectional lines. Vertical relations used for detailing or aggregating system elements are not visualized in this figure but can be represented by additional levels of detailing. They are only denoted at the top of the modelling plane. Associations to link IPS² functions to system elements on other modelling planes are specified in IPS² functions themselves.

At the bottom left of Figure 4, the IPS² object plane is represented by a three-dimensional modelling space. This is divided into three spatial modelling zones as defined in chapter 4.2. The cube in the foreground (1) is used for modelling technical IPS² objects. The cube (2) that is in behind is intended for modelling human IPS² objects. The respective modelling zone (3) to model superordinate IPS² objects spans both cubes. Figure 4 also shows model representations for the heterogeneous description of IPS² objects and their horizontal relations. Except technical IPS² objects that are modelled 3D all other modelling constructs on this modelling plane are visualized using 2D elements.

At the bottom right of Figure 4 visualizing IPS² process structures is presented. The sub-division of the IPS² process plane into “supplier” and “external factor” modelling zones is graphically represented by two differently coloured rectangular areas. These areas are separated from each other by the “line of interaction” pictured by a bold dotted line. IPS² processes are represented by rectangles with rounded edges. Arrows represent horizontal relations. Beside arrows, symbolically represented association-rules can be used to link IPS² processes to parallel or alternative process chains. Associations and parallel relations are not visualized in this figure, but are part of the data model.

5 SOFTWARE DEMONSTRATOR AND EVALUATION EXAMPLE

The prototypic transfer of the heterogeneous IPS² concept modelling approach into a software tool shown in figure 5 has been carried out using the object-orientied paradigm [15].

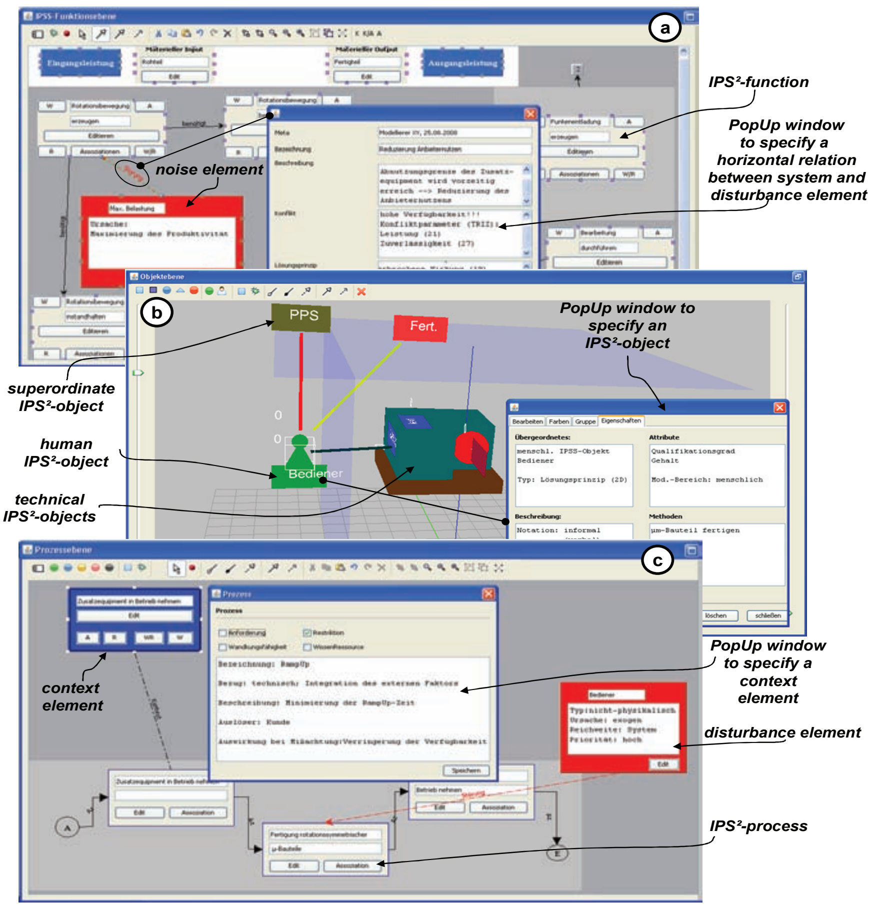

Figure 5. Realized software demonstrator

This is particularly suitable since the modelling planes, model elements and relations between them can be interpreted as data objects and represented with data classes. Data objects derived once from those classes can be stored, duplicated and used in other IPS² development projects. Thus, it is possible to reduce work to design IPS² concept modells. The software demonstrator has been realized by use of the programming language Java that implicates the advantage of platform independence, strict object orientation and free availability. For the realization of three dimensional shapes for IPS² objects, Java3D has been used which extends Java by an efficient class library. The developed software is marked by a structural separation of classes for data storage, presentation and processing which are implemented in different libaries. This opens up the opportunity to extend the developed demonstrator by additional functionalities or to easlily exchange and update certain classes. Figure 5 shows screenshots of GUIs of the software demonstrator. These GUIs are integrated into a so-called "mainframe" that is basically used to provide fundamental operation to administrate IPS² concept development projects, such as opening and saving of heterogeneous IPS² concept models, for instance.
To evaluate the modelling approach the software demonstrator has been used to model an IPS² specific issue in the field of micro manufacturing. Based on requirements and restrictions which have been elaborated to specify the problem of performance-based production of rotationally symmetric µm-parts a suitable conceptual solution has been developed and modelled as a heterogeneous IPS² concept model. Excerpts of modelling the evaluation example can be taken from the screenshots presented in Figure 5.
Screenshot a) shows heterogeneous modelling on the IPS² function plane using system and disturbance elements. Screenshot b) depicts the three dimensional modelling space, which is used to model IPS² objects. Here, a technical and a human IPS² object are combined to form a socio-technical system. The exemplary specification of the human IPS² object "user" is modelled in a separate pop-up window, also displayed in this screenshot. The application of the software demonstrator to modell IPS² process structures is shown in screenshot c). In this excerpt of the heterogeneous IPS² concept model a certain superordinate IPS² process has been detailed to model its sub-elements and the interaction with external factors. In this example some technical resources of the customer are used to manufacture certain µm-parts.

5 CONCLUDING REMARKS

IPS² is a problem solution for B2B markets and is targeting a long-term supplier-customer relationship. Taking interdependencies in to account already in the early phase of IPS² development is especially important to ensure the synergetic interaction of IPS² artefacts during their life cycle and to offer an integral customer-specific solution. Thus, a novel modelling approach has been proposed, called heterogeneous IPS² concept modelling. Its development is based on a new paradigm that dissolves fuzzy distinctions between product and service. This leads to the definition of the IPS² artefact and the IPS² basic structure. Elaborating the theoretical framework of heterogeneous IPS² concept modelling is based on these definitions as well as heterogeneous modelling in mechatronics. Distinguishing IPS² functions, IPS² objects and IPS² processes is the "backbone" of the proposed modelling approach. To show its feasibility it has been implemented as a software demonstrator and evaluated based on an IPS²-specific issue in the field of micro manufacturing.

REFERENCES

[1] Oliva, R.; Kallenberg, R.: Managing the Transition from Products to Services. In *International Journal of Service Industry Management 14*, 2003, pp. 160–172.

[2] Welp, E.G., Sadek, T., Müller, P., Blessing, L.: "Integrated modelling of products and services – The conceptual design phase in an integrated IPS² development process". *Proceedings of CIRP Design Synthesis*, Delft, Netherlands, 2008.

[3] Gordijn, J.; Akkermans, H.; Van Vliet, J.: Business modelling is not process modelling. In: *Conceptual Modeling for e-business and the web (ECOMO-2000)*, Salt Lake City: Springer-Verlag GmbH, 2000.

[4] Burianek, F.; Ihl, Ch.; Reichwald, R.: Vertragsgestaltung im Kontext hybrider Wertschöpfung. *Arbeitsbericht Nr. 02/2007 des Lehrstuhls für Betriebswirtschaftslehre - Infor-mation, Organisation und Management der TU München*, München, 2007.

[5] Sadek, T.: Ein modellorientierter Ansatz zur Konzeptentwicklung industrieller Produkt-Service Systeme. *Doctoral thesis, Ruhr-University Bochum, Institute Product-Service Engineering*, 2009.

[6] Welp, E. G.; Sadek, T.: Conceptual Design of Industrial Product-Service Systems (IPS²) Based on the Extended Heterogeneous Modelling Approach. In: *Proceedings of 10th International Design Conference.* Dubrovnik, Croatia, 2008.
[7] Welp, E. G.; Meier, H.; Sadek, T.; Sadek, K.: Modelling Approach for the Integrated Development of Industrial Product-Service Systems. In: *Proceedings of 41st CIRP Confer-ence on Manufacturing Systems.* Tokyo, Japan, 2008.
[8] Pahl, G., Beitz, W., Feldhusen, J., Grote, K. H., Engineering Design, A Systematic Approach, *3rd Edition, Springer-Verlag, London*, 2007.
[9] Tan, A. R.; Andreasen, M. M.; Matzen, D.: Conceptualisation of Product/Service-Systems through structural characteristics. In: *Proceedings of 10th International Design Conference.* Dubrovnik, Croatia, 2008.
[10] Trigeorgis, L.: Real Options – Managerial Flexibility and Strategy in Resource Allocation. *Cambridge, MA: MIT Press,* 1996.
[11] Jansen, S. Welp, E.G.: A heterogneous modelling approach for domain allocation in mechatronics. In: *Proceedings of International conference on Engineering Design (ICED)*, Paris, Fance, 2007.
[12] Jansen, S.: Eine Methodik zur modellbasierten Partitionierung mechatronischer Systeme. *Doctoral thesis, Ruhr-University Bochum, Institute Product-Service Engineering*, 2007.
[13] Oliva, R.; Kallenberg, R.: Managing the Transition from Products to Services. *International Journal of Service Industry Management 14,* 2003, pp. 160–172.
[14] Shostack, G. L.: Designing services that deliver. In: *Harvard Business Review, Vol. 62*, 1984.
[15] Rumbaugh J. et al: Objektorientiertes Modellieren und Entwerfen. *Hanser-Verlag*, München, 1993.

Contact: Tim Sadek
Ruhr-University of Bochum
Chair of Engineering Design, Institute Product and Service Engineering
Universitätsstraße 150
44801 Bochum
Germany
Tel: Int +49 234 3222477
Fax: Int +49 234 3214159
E-mail: sadek@lmk.rub.de
URL: www.lmk.rub.de

Tim Sadek, born 1979, studied mechanical engineering with focus on integrated product development at the Ruhr-University of Bochum. He graduated 2004. Since then he has worked as research assistant at the chair of engineering design. He finished his PhD “A model based approach for conceptual development of industrial product-service systems” in February 2009.