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A FRAMEWORK FOR DOMAIN ALLOCATION IN EARLY PHASES OF INDUSTRIAL PRODUCT-SERVICE SYSTEM DESIGN

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Keywords: (industrial) product-service systems (PSS/IPS²), product service design, conceptual design phase, creativity

1. Introduction

In recent years, the increasing variety of customer demands, technological advances and strong dynamics of global markets, have prompted enterprises to shift their business focus from merely designing and selling technical products to offering product and service integrated solutions. The combination of products and services ranges from established after-sales services (e.g. maintenance, repair, re-use, recycling and training courses) through to (industrial) Product-Service Systems (PSS/IPS²) [Meier 2010]. Within a Product-Service System, products and services are no longer regarded as separate sales objects but as a bundle that can be offered to a customer to generate an added-value. The integration of products and services can maintain or enhance functionality of a product or a service or even implement new functions, which are not available without integration. PSS are proposed as tailor-made solutions to fit individual customer needs during the entire lifecycle. In contrast to Product-Service Systems (PSS), which focus on customer, lifecycle, and foremost sustainability oriented solutions, industrial Product-Service Systems (IPS²) represent business-to-business applications. IPS², which are focused in this paper, are characterized by an integrated and mutually determined process of planning, developing, delivering and using manufacturing systems and industrial services containing their immanent software components [Meier 2010].

The integrated design of products and services is a very complex task. Research concerning the support of the IPS² design process has been carried out for many years and in various disciplines. Particularly, the systematic consideration of the interdependencies between technical elements and services throughout the entire development process is very important and requires novel design guidelines, design methods and modeling tools as well as a rethinking of the developers involved in the process.

In particular, the support of the conceptual design of IPS² during the early development phase through appropriate methods and tools is crucial for the initial determination of product and service components and their interdependencies. The conceptual design of an IPS² follows up the planning phase (cf. Figure 1). Thus, an IPS² idea or a brief concept, the requirements and properties of the business model (for example the allocation of property rights and the revenue model) are the basis for the development of IPS² concepts. Furthermore, technical and organizational restrictions concerning the IPS² provider, the customer and possible network partners as well as business conditions have a significant influence on the development of appropriate IPS² concepts. The conceptual design phase focuses on the definition of IPS² functions as well as the subsequent determination, variation, analysis and selection of solution principles for product and service components. An IPS² concept includes all selected solution principles and describes the structural interaction between them as well as their logical functionality. Consequently, an IPS² concept serves as a basis for the subsequent detailed and

embodiment design of mechatronic subsystems and the further development and optimization of service processes.

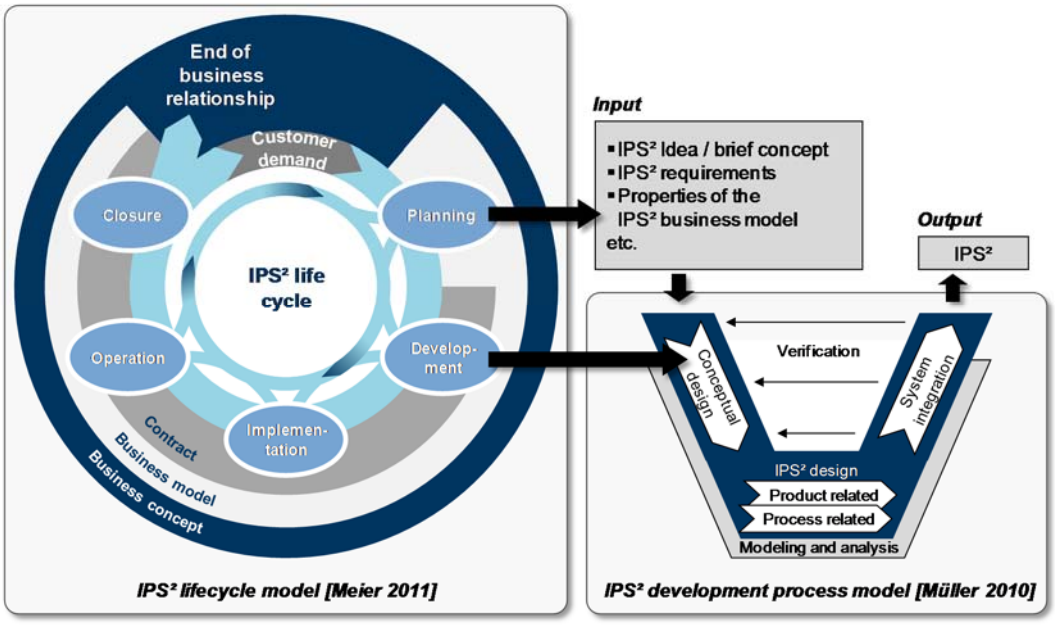

Figure 1. The conceptual IPS² design phase

IPS² fulfill their functions by a synergetic interaction of product and service components. On one hand, this requires a close cooperation between experts of the different disciplines during conceptual IPS² design. On the other hand, the combination of design principles from different domains (here, technical products, service processes, software and human resources etc.) as well as the possibility of mutually interchanging products and services, leads to a large number of possible solutions for a given design task. In order to achieve the desired optimum with a minimum of time-consuming iterations, a systematic approach for domain allocation within conceptual design of IPS² is desirable.
In order to respond to this demand, a model-based method for IPS² domain allocation is developed, which can support a designer to create and vary IPS² concepts systematically. The domain allocation method is based on a deliberate and explicit choice of domains. In this contribution, challenges concerning IPS² domain allocation during conceptual IPS² design are discussed first by using an IPS² specific issue in the micro manufacturing industry. Afterwards, an iterative procedure for IPS² domain allocation is proposed. Based on a basic solution, this procedure can be used to develop and optimize an IPS² concept gradually. Furthermore, a game-based method is presented in section 4, which supports the development of an appropriate IPS² basic concept. Accordingly, this method helps both, to structure the problem and to systematically determine and analyze interrelations of product and service components at the beginning of IPS² domain allocation process.

2. Challenges of domain allocation during conceptual IPS² design

2.1 IPS² scenario – The wide variety of choices

In this section, challenges of domain allocation during conceptual IPS² design are determined on the basis of an IPS² example. The IPS² example relates to the manufacturing of micro components in the watchmaking industry. Due to the rebirth and steadily increasing demand of mechanical watches, especially in the luxury segment, a growing demand for micro-manufacturing processes can be revealed. The production of components of mechanical watches, such as movements, shafts and hands requires utmost precision. In the following example, a supplier of the watchmaking industry intends to use a micro-milling machine for mass production of clockwork components. To meet tolerances in µm-range, it is necessary that process parameters have to be adjusted in an optimal manner. Therefore,

the ramp-up requires a high degree of process knowledge, which is only available at producers of specific micro-manufacturing systems. Instead of selling a micro-milling machine, a company offers the availability of the machine as an industrial Product-Service System. In addition, the IPS² provider committed to bring in necessary process knowledge into the value chain of the watch supplier.

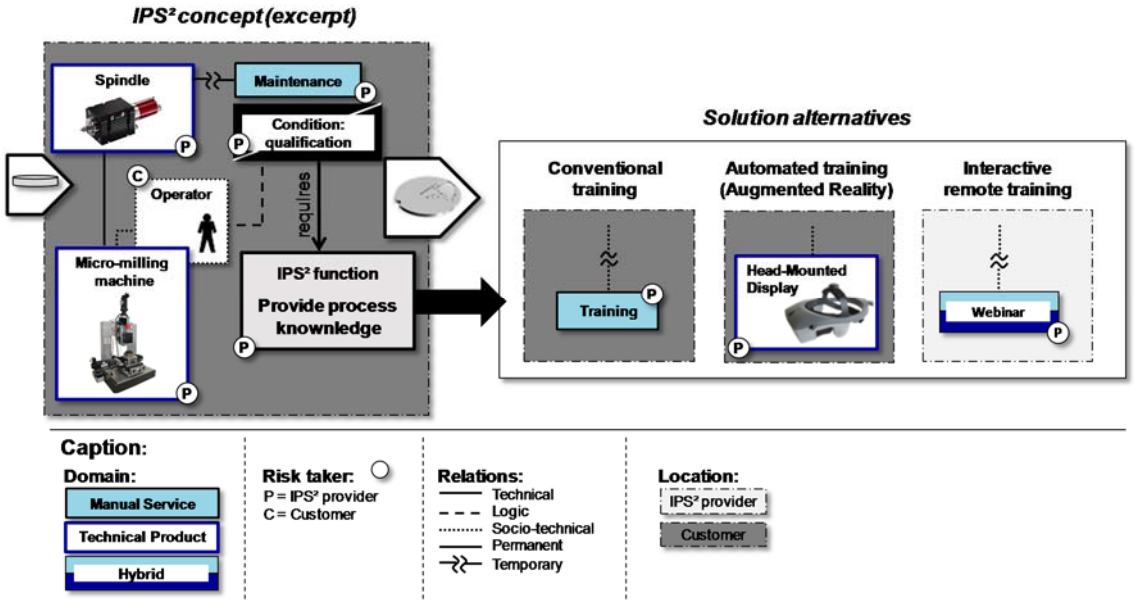

Figure 2. Domain allocation in conceptual IPS² design

During conceptual IPS² development, appropriate solution principles to fulfill the IPS² function *provide process knowledge* have to be generated. Intuitively, different solutions to meet the considered IPS² function can be determined. In Figure 2, three different examples are compared. These solutions result from a fortuitous combination of product and service components. A domain allocation, thus the explicit mapping of solution elements to the product or service domain occurs unconsciously and is therefore only implicit. Thus, the solution principles shown in Figure 2 can differ from manual provided services to technical products up to hybrid. A solution principle which can be characterized as hybrid corresponds to a combination of technical elements and services. All solution elements are linked through specific relations. Considering the effective period (permanent or temporary) physical, logical and socio-technical relations can be distinguished. The basic structure of the IPS² concept consists of a micro-milling machine. To ensure availability of the micro-milling machine, maintenance services are integrated into the concept. In this regard, the spindle drive is particularly addressed as a potential weak spot. An operator performs the manufacturing process of the clockwork parts. To achieve an optimal adjustment of process parameters, the operator's skills have to be increased. This requires the additional IPS² function *providing process knowledge*, for which solution principles have to be determined. A service-dominated solution, for example is a conventional training which takes place at the customer. This training will be provided manually by a human solution element, a trainer. In contrast to that solution, it is possible to use an augmented reality system. This technically-dominated solution is characterized by a high degree of automation. Here, the customer's operator is permanently connected to a head-mounted display. A possible third, hybrid solution might be for instance a webinar. This solution is characterized by mainly organizational components, which allow the transfer of knowledge using the internet. Furthermore, important elements of this solution would be at the IPS² provider's site.

2.2 Lessons learned

The simple example from the previous chapter has clarified, that due to the integration of products and service, IPS² functions can be fulfilled by a variety of suitable solution principles. In order to achieve an optimal IPS² concept for a given design task, the selection and aggregation of solution principles

considering existing boundary conditions represents a particular challenge. Due to the integration of technical products and services, the process of IPS² domain allocation is much more complex than domain allocation of merely technical systems. In general, contemporary manufacturing systems fulfill their functions by the synergetic integration of mechanic, electronic and software components (mechatronic systems). The domain allocation of mechatronic systems is therefore limited to these three engineering domains [Jansen 2007]. In the majority of cases, an IPS² function can be realized through different solution principles, both in the product or service domain. In extension to the domain allocation of mechatronic systems, IPS²-specific dimensions for domain allocation has to be considered, for example, which are determined by the underlying business model (cf. Figure 3).

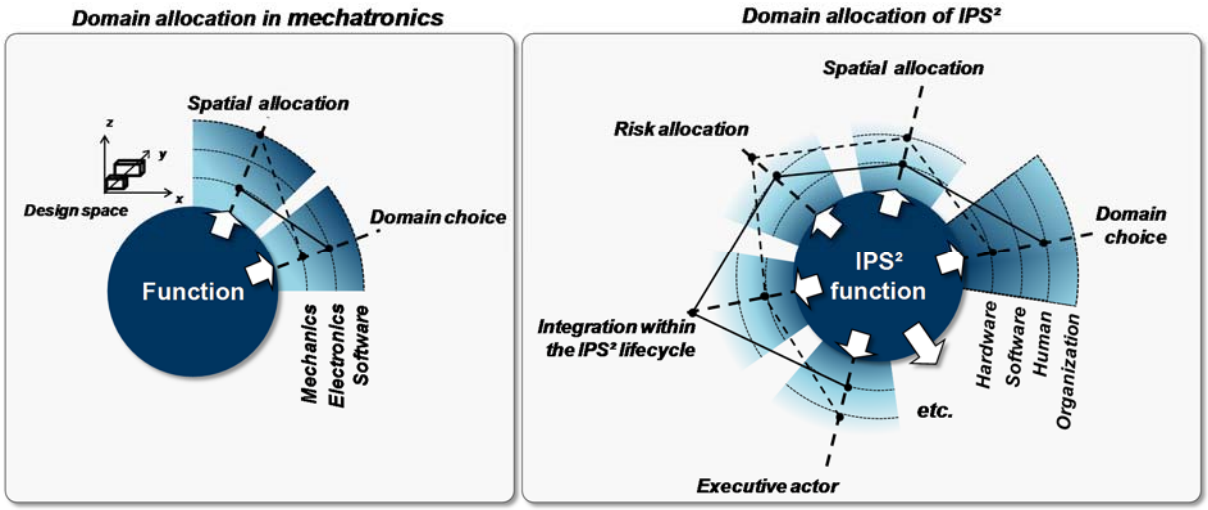

Figure 3. Dimensions of IPS² domain allocation

As illuminated in Figure 3, an IPS² function can generally be realized either by multidisciplinary technical hardware or even software components, by human resources or organizational elements with superordinate properties [Sadek 2011]. The choice of the domain in which the solution should be realized is particularly important in terms of varying solution elements systematically. The dominant transformation (e.g. of material, energy and information) is also associated with the domain choice. Additional domain allocation dimensions relate to characteristics of the IPS² business model. Regarding the business model, the distribution of risk that need to be shared between customer, IPS² provider as well as participating product or service suppliers has to be considered. Accordingly, an IPS² function or rather the derived solution principle has to be allocated to a risk taker. Through an explicit definition and change of the risk allocation of an IPS² concept, it is possible to generate new solution configurations. Furthermore, conscious changes of the risk allocation can also make a positive contribution concerning the generation of novel, IPS²-specific business ideas which are different from existing traditional business constellations. A temporal and lifecycle perspective has also to be considered. An IPS² features long-term business contracts [Sadek 2011]. Therefore, an IPS² has to allow dynamic adaptations to changing restrictions or influencing factors during its long-term delivery and use phase which are realized by partial substitution of constituents of an IPS². This specific feature is considered as "changeability". Therefore, it has to be determined at which time an IPS² function is executed during delivery and use and if the derived solution needs to be changeable. Furthermore, it has to be specified whether a function is permanently or just temporarily connected to other system components. Regarding a spatial perspective, the domain allocation of mechatronic systems is generally restricted to subsystems and components of the system itself. Due to a wider comprehension of the system this is not sufficient for IPS². Therefore, solution principles of an IPS² have to be allocated to different locations for instance. This is also illustrated by the example in section 2.1. 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 IPS² delivery and use. The interaction within IPS² must therefore also be considered. Thus, an IPS² function has to be assigned to an actor (e.g. IPS² provider

or customer), who is responsible for executing and managing IPS² activities. Particular issues also arise if an actor, who is responsible for executing an IPS² function, doesn't take the risk for its outcome. In this particular case, additional solution elements needs to be integrated into the IPS² concept, e.g. specific economic incentives.
Further IPS²-specific perspectives for domain allocation have to be identified and analyzed in further research. Consequently, IPS² domain allocation is a problem of selecting the best combination of solution principles and design characteristics for a specific IPS² function or a set of interrelated IPS² functions. Taking the above mentioned domain allocation dimensions into account, a designer soon encounters limits of intuitive thinking, even in highly circumscribed design problems.

2.3 The conceptual IPS² design process

An optimal IPS² concept can only be determined through the systematic variation and combination of solution principles. Thus, the IPS² domain allocation process corresponds to an optimization [Köster 2011].

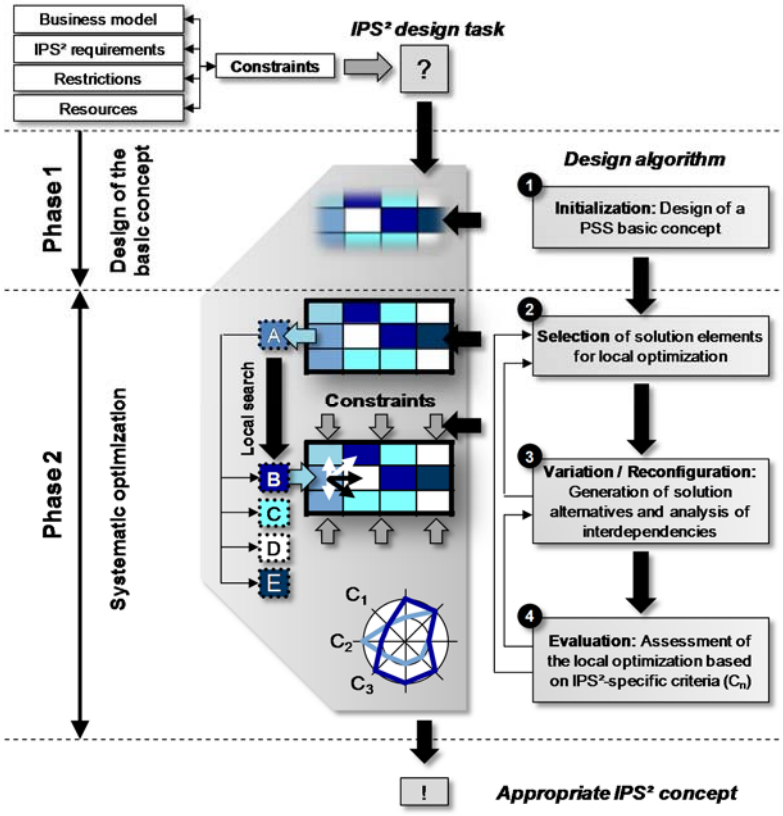

Figure 4. Conceptual IPS² design algorithm

Optimization generally refers to the selection of a best element from some set of available alternatives. The optimum is the best achievable outcome in terms of a trade-off between different parameters, properties and restrictions.
To solve optimization problems, algorithms, iterative methods or heuristics can be used. Due to the multiplicity of boundary conditions and possible solution alternatives the IPS² domain allocation process needs to be treated as a combinatorial optimization problem. In such problems, exhaustive search is not feasible. Besides (finitely terminating) algorithms and (convergent) iterative methods, there are heuristics that can provide approximate solutions to combinatorial optimization problems. However, heuristics do not guarantee that an optimal solution is found in any case.
Due to the complexity and variety of possible combinations, a simple trial and error heuristic without specific guidelines for IPS² designers is not very promising. Consequently, an adapted search method for IPS² domain allocation is presented below that is based on the local search algorithm [Korte 2008].

A local search algorithm starts from a candidate solution, here the IPS² basic concept, and then iteratively moves to a neighbor solution. Typically, every solution element of an IPS² concept has more than one neighbor solution. The choice of which one to move to is taken using only information about the solutions in the neighborhood of the current one, hence the name local search. According to the metaheuristic hill climbing, the choice of a neighbor solution is chosen when the solution locally maximizes the evaluation criteria. The steps of the IPS² concept optimization algorithm are shown in Figure 4. Once the IPS² basic concept has been developed in the initialization step, a solution element to be optimized is chosen in the selection step. This selection should meet critical components of the IPS² basic concept first. In the third step, the variation of the selected solution elements is done through a deliberate and explicit domain allocation. The neighbor solutions found by domain allocation are then integrated into the existing IPS² concept, which leads to a reconfiguration. Due to the varied or new solution elements added in the previous synthesis step, an analysis of the interactions with related, already-existing solution elements is required. This includes not only associated IPS² concept elements, but especially the consideration and analysis of their interdependencies. The degree of influence on the existing IPS² concept depends on the characteristics of the varied and added solution component. The analysis serves as a starting point for iteratively adapting and developing the overall IPS² concept. In the evaluation step, the quality of the varied solutions are assessed. Against IPS² specific evaluation criteria it is determined whether a feasible solution is found. The steps selection, variation/reconfiguration and evaluation will be repeated until an appropriate IPS² concept is determined. In the proposed algorithm, the development of the IPS² basic concept is particularly critical. The better the initial IPS² solution is chosen, the fewer iterations are required for optimization. A suitable methodical support of the first step is particularly relevant. In the following section, the determination of the initial solution is focused and an appropriate methodical approach is presented.

3. Related work

In this section, methods proposed in the literature are discussed with respect to the focus of this paper. Design guidelines and methods, especially for early design phases are proposed by various authors [Kim 2011], [Hara 2009], [Komoto 2009]. The domain allocation is partly mentioned in context of the transition from the related functions to solution elements. Hara and Arai for example analyzed common IPS² types with respect to their functional composition [Hara 2010]. The authors emphasize that functions can be activated either by humanware or by hardware with its related software. They have proposed particular influencing factors on attributes of these two domains. However, a holistic approach or a guideline for the deliberate and explicit choice of product and service elements is not yet suggested.

As already mentioned in the previous chapter, a particular challenge is to determine the IPS² basic concept for the given IPS² design task. The IPS² concept represents the overall architecture of the solution in which the dynamic interactions of product and service components are predetermined from a systems perspective. The solution architecture serves as an integration platform for subsequent design activities in which domain-specific issues (product and service engineering, marketing, sales management etc.) are focused. Therefore, the development of the IPS² concept requires a focused team-based cooperation of various disciplines and a strong verbal communication. Moreover, the success of the conceptual design phase stands and falls by creativity. The generation of ideas as well as the detection and resolution of conflicts has to be supported sufficiently. Group creativity techniques like brainstorming, mind mapping, 6-3-5 brainwriting etc. are commonly applied for this purpose. These techniques are methods that encourage creative actions in groups. They focus on a variety of aspects of creativity, including techniques for idea generation and divergent thinking, methods of re-framing problems, changes in the affective environment and so on. In engineering research and practice, especially TRIZ has been proven as a problem-solving, analysis and forecasting tool. TRIZ has been derived and continuously improved from a study of patterns of invention in the global patent literature. Kamita et al. for example integrated TRIZ into a design method for Product-Service Systems in order to address conflicts in the early development phase [Kamita 2010].

A set of novel practices for facilitating creativity and innovation, which are particularly practiced in the business world are known as gamestorming [Gray 2010]. Gamestorming as a term suggests the use of games for brainstorming. A game may be thought of as an alternative to the standard business meeting. Most games involve 3 to 20 people and last from 15 minutes to an hour and a half. A game suspends some of the usual protocols of life and replaces them with a new set of rules for interaction. Games may require a few props such as sticky notes, poster paper, markers, random pictures from magazines, or thought provoking objects. Gamestorming skills include asking questions, structuring large diagrams, sketching ideas, fusing words and pictures into visual language, and most importantly, improvising to choose and lead a suitable game or invent a new one. The application of gamestorming to support multi-discipline interaction indicates great potential and should therefore also be considered within conceptual IPS² design. In order to go deeper into the system description once main solution elements of the IPS² (physical objects, service units etc.) have been identified, Maussang et al. suggest the development of functional and operational scenarios [Maussang 2010]. With regard to IPS² domain allocation, the development of scenarios to analyze different IPS² concept alternatives can support an explicit choice of solution principles which meet the constraints in an optimal manner. In order to identify, design and analyze changeable IPS² concept elements, scenarios can also be a useful approach. Besides, the development of scenarios can be integrated easily and very effectively into a gamestorming approach.

4. Concept of a methodical support for phase 1 of IPS² domain allocation

4.1 Basic components of the gamestorming approach

As already discussed in chapter 3, an intensive interdisciplinary collaboration and a creative problem-solving process are decisive for the success of the conceptual IPS² development. Through a game-based approach it should be achieved that engineers, who are not conversant with IPS² design, easily become familiar with the IPS² mindset and are confronted with IPS²-specific issues. Moreover, a rethinking in the problem-solving process towards product and service integration should be encouraged. This fact is very important especially for professionals of the product domain, who have mind patterns, which are oriented more in traditional, product-dominant business models. Concerning an efficient conceptual IPS² development, it is particular crucial that participants are motivated to think about the counterpart, accordingly the service that is connected to the product and their interdependencies. Furthermore, novel solutions should predominantly be considered, which can only be generated by the combination of product and service, which might have a completely unconventional character, but possibly have a special potential for innovation.

To develop a gamesstorming for conceptual IPS² development, basic elements have to be designed, shown in Figure 5. First of all, it has to be clarified, which actors should actively participate in the game, like development engineers (product, service and process engineers etc.), IT-developers and even the customer. In order to promote efficient cooperation and to specifically take advantage of the natural ambition of the participants to win the game, the participants are divided into teams. The moderation of the game and the instruction of the participants could be done by the so-called IPS² architect [Lindow 2011]. According to Lindow et al. the IPS² architect is a new role that has to be established within an organization in order to perform the moderation of IPS² idea generation and the documentation of management of IPS² ideas, requirements and concepts. The IPS² architect is also responsible for the IPS² development project management and the quality and IPS² validation management. Therefore, the IPS² architect has to be a specialist in IPS² development and must be able to transfer IPS² thinking into the “language” of the engineers and the customers.

The second essential element of the game that has to be defined is the objective. The participants of the gamestorming should be forced to combine products and services within a concept and identify interdependencies. Furthermore, the participants are encouraged to exchange solutions from the product to the service domain and vice versa in order to investigate potentials for the partial substitution of product and service components. Therefore, the participants should be motivated to explore the possible solution space and to gather information about its limits. Accordingly, the objective of the game is “product vs. service”.

In order to document information during the gamestorming, for instance about the developed IPS² concept and constraints of solution elements as well as to describe the progress of the game, specific artifacts have to be designed, for example sticky notes, which can be fixed on a whiteboard. In order to influence the game play and to stimulate the participants' creativity, common gamestorming techniques can be applied, like randomness and reversal. Furthermore specific strategies should be developed to help the participants to play the game successfully. During the gamestorming, predetermined rules of interaction and the superordinate game rules have to be observed. With the progress of the game, the resulting IPS² concept is changing gradually since either the game time is expired or one of the parties has won the game through the achievement of victory points.

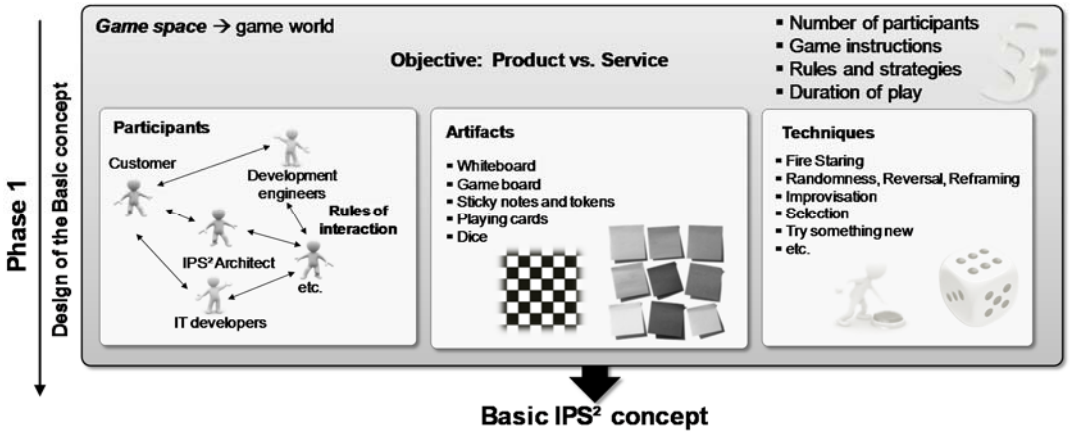

Figure 5. Basic components of gamestorming

4.2 Concept of the game "product vs. service"

The concept of the Gamestorming approach "product vs. service" consists of four main elements (cf. Figure 6). The moderator, who manages the game and provides the necessary incentives, the participants, which are grouped into two or more teams, the board game and specific tools to support the moderation of the gamestorming. These include incentive cards, a checklist and a whiteboard to promote discussions and to document ideas and sketches. The gamestorming also contains a board game, which is used for the game-based development of an IPS² concept. Using the artefacts of the board game, the participants can describe the developed solutions. These artifacts include tokens to describe product components (core products, periphery and weak spots) and tokens to describe service components (planning, advice, training, logistics, maintenance, operation and optimization). A head-mounted display for example can be represented as a *technical periphery,* which is required for automated training services, which again can be described by the artifact *training*. To support the problem-solving process and to stimulate a brainstorming about solution alternatives, the artifacts to describe the components of the IPS² concept are explicitly kept abstract and solution neutral. With these artifacts, other solution alternatives can be derived and represented as well, like a conventional training or a remote training (see section 2.1). The board game consists of a board that can be assembled flexibly by hexagonal elements. Each element represents a resource (physical resource, human resource, technology, know-how or tools and utilities), which the participants can gather by rolling the dice. The participants of the gamestorming can use the resources to buy product and service elements and place the corresponding tokens on the board. The chosen classes of resources represent essential requirements for the creation and delivery of IPS² in an abstract way, for example, human resources, know-how and tools are needed to perform training services. Depending on the preferred business model (product- or service-oriented), the arrangement and quantity of the five types of resource cards can be varied on the board, so that the probability of building either product or service elements is increased. The product and service tokens can be linked by relations in order to analyze their interdependencies. Furthermore, specific game mechanisms are integrated into the board game to consider IPS²-specific key questions, like which suppliers should be integrated, what uncertainties and risks exist and which actors are in charge of specific concept elements. The participants can earn

victory points in various ways, for example by developing and varying solution elements or by specifying relations.

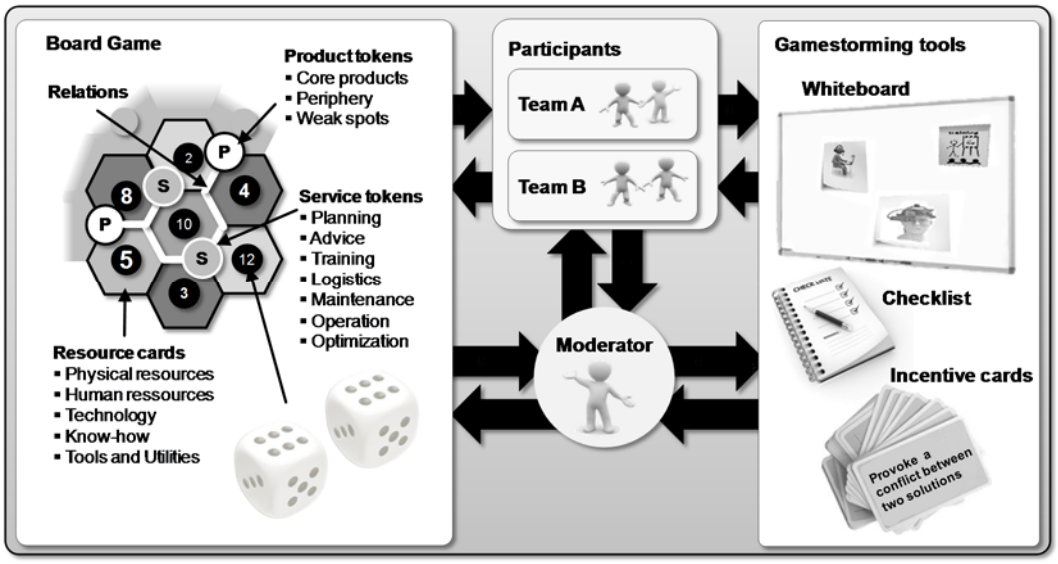

Figure 6. Components of the gamestorming approach "product vs. service"

The moderator has the most important role in the gamestorming. He has got several tools to influence the progress of the game and to stimulate the participants' creativity. On one hand, he can use a whiteboard together with specific elements to discuss and concretize the abstract solutions that are derived through the board game. Furthermore, strategies and guidelines can help the moderator, especially for the exploration of the possible solution space together with the participants. In order to influence the behavior of the player und to guide discussions, incentive cards are used. These cards contain actions which has to be performed by the player, for example they should provoke conflicts between solution elements, deliberately change or scrutinize solutions elements, abstract or concretize solutions, discuss possible actors, suppliers, failures and weak spots in the concept, etc. In order to monitor and document the game's progress a checklist is used. The results of the gamestorming, a snapshot of the game board as well as sketches, written sticky notes and discussion recordings form the basic IPS² concept, which is further progressed in the subsequent design and optimization process of conceptual IPS² development.

5. Summary and outlook

The possibility of mutually interchange products and services leads to an expansion of the solution space and complicates the development of an industrial Product-Service System (IPS²) concept that meets the requirements in an optimal manner. This paper contributes an IPS² domain allocation method which is based on a deliberate and explicit choice of domains as well as their combination to IPS². This approach aims at supporting a designer to create and vary IPS² concepts systematically. Further research has to cover a further development and evaluation of the proposed methodical concept, particularly of the second part of the domain allocation algorithm by using different IPS² case studies in the production area (IPS² for micro manufacturing and surface coating) and the energy sector (IPS² for industrial waste heat recovery using mobile latent heat accumulators). Key elements of the second part of the domain allocation algorithm are domain allocation pattern, which represent the combination of product and service solutions for frequently recurring IPS² solutions either on an abstract or specific level. The domain allocation pattern should particularly support an efficient variation and reconfiguration of solution elements. Furthermore, the generation of suitable solution alternatives should be supported by rules and strategies. The experience gained in research will also be summarized in checklists in order to allow an expeditious introduction to IPS² domain allocation. In order to systematically select advantageous alternatives of concept elements, a compatibility analysis and an assessment of IPS² concepts concerning IPS²-specific criteria should provide a necessary basis

for decision making. Concerning the proposed gamestorming approach, a descriptive study will be conducted. Thereby, the practical usability will be analyzed by two appropriate types of experiments. The first experiments are carried out by a set of test participants, probably students of engineering design (novice designers) without any previous knowledge in the field of conceptual IPS² development. Afterwards, expert designers of the IPS² research community and the manufacturing industry with an extended knowledge of product and service engineering are used as probands. A successful conduction of this experimental study needs an intensive cooperation of engineering designers with psychologists and sociologists in advance, which is already actively pursued.

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