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MODEL-BASED SUPPORT FOR PRODUCT-SERVICE SYSTEM PLANNING

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1. Introduction

As sole product businesses often do not sufficiently satisfy customer needs any longer, companies frequently switch to offering solutions instead of products alone. These solutions contain - besides the actual product - services that provide a specific additional value for customers and enable companies to separate themselves from competitor products [Goedkoop et al. 1999], [Schenkl et al. 2013]. Thus, a so called Product-Service System (PSS) "consists of a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs" [Tukker and Tischner 2006]. Prominent examples for such solutions are renting- or sharing offerings: customers typically are not the owner of a certain product any longer, but use them within previously defined utilization scenarios and profit from additionally provided services. In this case, the 'sale of use' rather than the 'sale of product' is in the focus, so the stakeholders benefit from a restructuring of the risks, responsibilities and costs traditionally associated with ownership [Baines et al. 2007]. Hence, PSS have the potential to bring about changes in production and consumption patterns that might accelerate the shift towards more sustainable practices and societies [Mont 2002]. At the same time companies face new challenges with respect to their existing core competences that now have to be expanded, the requirements that have to be fulfilled, the corresponding increase in complexity, as well as the applicable methods and tools for development.

In order to bring the right PSS to the right market at the right time, strategic planning and transparency within PSS development is of high importance [Hepperle et al. 2010]. But as especially the early phase of innovation processes, the planning phase, is characterized by essential decisions and numerous uncertainties, so methodological support for developers is crucial. It is essential for the development of successful PSS to gain an overview of their future characteristics and properties as early as possible. For this purpose graph-based or matrix-based product models offer the possibility to structure the data and enable information management throughout the product development.

While numerous concepts exist in the fields of separate product- and service modelling, integration of both areas has so far not been adequately investigated [Mont 2002], [Baines 2007], [Sadek 2012]. But especially the intangible and flexible service parts of a PSS set new demands on a model serving as support of development activities. Furthermore, there is a significant increase in available information within development that has to be handled. Thereby, especially the requirements on a PSS take a central role, as they are essential for the entire development process [Szeghö 2011]. Based on these requirements, the entire solution space has to be considered within modeling, i.e. modeling has to take place on different levels of concretization - from the given requirements to the resulting structure of the PSS and on different timely planning horizons. The following contribution addresses these issues and thus gives a possible approach for the model-based support of PSS planning and design.

The paper continues by a description of the state of the art which ends with the demonstration of existing research gaps (section 2). These research gaps are addressed in the description of the PSS-Concretization Model (section 3). Afterwards the application in an academic example is shown (section 4). Finally, the results are discussed (section 5) and an outlook is given (section 6).

2. State of the art

During the early phase of development processes essential decisions for the success or failure of products, services or PSS have to be made. These decisions have enormous influence on the following lifecycle-phases as they define the system's essential properties. Yet, the planning phase is characterized by uncertainties, as information about the object in development is vague at that early point in time. Additionally, the earlier possible changes of the system can be made, the cheaper they are [Ehrlenspiel 2009]. Thus, PSS designers have to be supported by methods and models [Sadek 2012] in order to handle this task find solutions and make decisions on a reasonable and comprehensible basis. The following section is giving an overview of existing approaches in product-, service- and PSS-modeling. The existing PSS-modeling approaches are evaluated according to the degree of fulfillment of the stated requirements on a support for PSS planning. By analysing the results, research gaps could be identified. They are addressed in the PSS-planning model presented in section 3.
Section 2.1 and 2.2 present the results of a structured literature review in the area of stand-alone product- and service modeling. Section 2.3 gives an overview of existing integrated PSS-modeling approaches published between 2006 and 2016. They have been identified in a structured literature review conducted by means of 4 literature databases (Google Scholar, Science Direct, Web of Science and Scopus). After setting up a research strategy, defining the search terms and selecting the combinations of the search terms the search was conducted by using logical operators covering the whole search field. In each database the first 500 results were checked by means of the headline. Hence, in a first step 89 relevant papers were identified, and further investigated. After checking the abstracts, 11 approaches remained which were analysed in detail.

2.1 Product modeling

In the literature there is a plurality of formal modelling approaches for supporting the product development. As a basis for systematically gathering the information there is support for structuring the design process itself like the FBS-model [Gero 1990], the Munich Concretization Model [Ponn and Lindemann 2011] or the systematic engineering design approach [Pahl and Beitz 2013]. For documenting the information gathered in the process, there are graph-based or matrix-based models for depicting the actual product structure like SysML [Friedenthal et al. 2014], DSM/DMM/MDM [Browning 2001], [Lindemann et al. 2008] or functional, behavioral and structural models [Ponn and Lindemann 2011]. Finally, the basic framework for product design is formed by approaches like the product spectrum [Baumberger 2007] which divides the solution space into several areas (e.g. scalable, optional, alternative), to which a product's structural elements can be allocated and gathered within.

2.2 Service modeling

Analogous to the development of physical products, there is also a great number of approaches and tools for supporting service-development. The systematic proceeding for creating new services is supported by e.g. the service engineering process [Bullinger and Scheer 2003], [Fähnrich and Meiren 2005] or life cycle oriented design [Aurich et al. 2006]. The respective structure and arrangement in terms of service-modules in a visual manner is enabled by the service modules approach [Böttcher and Klingner 2011]. Based on this structural approach, the actual procedure of a service's performance can be derived and depicted graphically by means of approaches like PERT-diagrams [Eppinger 2005], event-driven process chains [Keller et al. 1992], or service-blueprints [Shostack 1982].

2.3 PSS modeling

Especially the integrated character of tangible and intangible elements poses additional challenges on support tools for designing PSS. The integrated lifecycle model [Hepperle et al. 2010] or the methodology for structuring a PSS design process [Maussang et al. 2009] offer an overview of the different lifecycle-phases and the included activities. Thus, they can be used as a checklist of activities, which support a systematic procedure within PSS-development. For assisting the actual PSS development there are several approaches like the idea generation and evaluation [Akasaka et al. 2012], the HyproDesign-tool [Becker et al. 2009], the product-service blueprint [Geum and Park 2011], PROTEUS [Hellek et al. 2013], the PSS representation method [Kim et al. 2011], service CAD [McKay and Kundu 2014], the PSS development support [Sadek and Köster 2010], the IT-based assistance system [Uhlmann and Bochnig 2012] and the functional hierarchy modelling [van Ostaeyen et al. 2013].

2.4 Requirements on the PSS planning support, evaluation and conclusion

In the following, the approaches mentioned in section 2.3 are evaluated according to their ability to satisfy the requirements made on a PSS-planning support. These requirements originate from [Abramovici et al. 2009], [Orawski et al. 2012] and [Bochnig et al. 2013] and comprise the holistic visualization of a PSS (requirements, product- and service hierarchy, interconnections and relations), a support for the planning process (illustrate change impacts, support for mastering complexity, variants- and alternatives management) and finally the consideration of diverse temporal planning horizons. The result of the evaluation can be seen in Figure 1.

○ not satisfied
◐ partly satisfied
● complete satisfied

	Holistic visualization								
Source	Requirements	Product	Service	Interconnections	Complete hierarchy	Support for the planning process	Modularization	Variants Alternatives	Diverse temporal planning horizons
[Akasaka et al. 2012]	◐	◐	◐	◐	◐	◐	○	○	○
[Becker et al. 2009]	◐	◐	◐	◐	◐	◐	◐	◐	○
[Geum & Park 2011]	○	◐	◐	◐	◐	◐	○	○	○
[Hellek et al. 2013]	◐	◐	◐	◐	◐	◐	◐	◐	◐
[Kim et al. 2011]	◐	●	●	●	◐	◐	○	○	○
[Maussang et al. 2009]	◐	◐	◐	◐	◐	◐	○	◐	○
[McKay & Kundu 2014]	○	◐	●	○	◐	◐	◐	◐	○
[Sadek & Köster 2010]	●	●	●	●	◐	◐	○	◐	○
[Uhlmann & Bochnig 2012]	●	●	●	●	◐	●	○	○	○
[van Ostaeyen et al. 2013]	◐	◐	◐	◐	◐	◐	○	○	○

Figure 1. Evaluation of PSS planning support

The literature study has shown that for specific PSS-modeling, in contrast to sole product- or service-modeling, there are few approaches which can be applied for the consistent representation and management of the complete planning-relevant information of a PSS. Only two approaches meet almost all the requirements for the holistic visualization. Further, the majority of the approaches can serve as a support for the complete planning process. Finally, modularization, the management of variants and alternatives and especially the consideration of diverse temporal planning horizons is hardly addressed. No approach found within the literature review meets the requirements completely. Especially the integration of diverse temporal planning horizons is not sufficiently examined. The implementation of modularization, variants and alternatives management as well as the depiction of diverse temporal planning horizons in the context of the PSS-concretization model is presented in the following.

3. PSS-Concretization Model - planning-model for integrated PSS-development

As a basis for the PSS-Concretization Model existing approaches out of the areas product-, service and PSS-modelling were analysed and relevant elements or ideas were adopted and embedded in the integrated planning model to meet the requirements towards a planning support. Process-related, graph-based as well as matrix-based approaches have influenced the approach at hand. It is based on a stepwise concretization of given requirements concerning the respective PSS. Requirements are the starting point for the derivation of the resulting product- and service-structure via functions and processes. This principle is illustrated in Figure 2. The model is basically divided into a requirements-area, which contains all planning-relevant requirements and a solution-area consisting of the resulting structure of the PSS on different concretization-layers [Kammerl et al. 2014]. Every single layer within the solution area thereby represents a concretization step on the path from given requirements to the final structure of the PSS. The product view is represented by functions, working principles and components. Similarly, functions, processes and resources describe the services. In that manner, the structure of a PSS as a result of the given requirements can easily be portrayed and understood. The model was implemented in an IT-based support tool, where the underlying meta-model is dynamic and thus can be adapted to the different needs of different product designers.

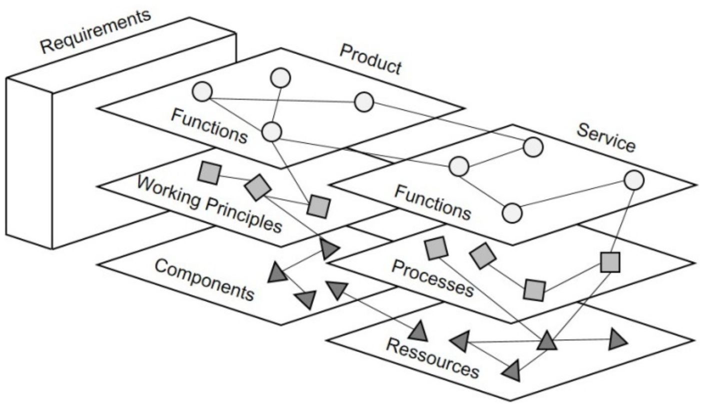

Figure 2. Conceptual PSS-Concretization Model [Kammerl et al. 2014]

In the following sections the implementation of modularization, management of variants and alternatives and the consideration of temporal planning horizons is described. This was achieved by adding new nodes for depicting modules and alternatives as well as new edges for depicting the temporal evolvement of the PSS portfolio.

3.1 Modularization

The idea of modularization is already well known and frequently used in product development [Bauer et al. 2014]. But also in the case of services, this concept becomes more and more an issue [Böttcher and Klingner 2011]. Modularization helps developers to meet certain optimization-targets, e.g. the creation of product-platforms or modular construction systems. These design optimizations enable companies to individually adapt to customer requirements and wishes as well as to offer a broad range of variants with little effort. Thereby, modules can generally be seen as units of a system, which are characterized by a high functional and geometric independency from the rest of the system. Thus, they can be developed as prefabricated autonomous components [Bauer et al. 2014].

In order to guarantee a clear representation within the integrated PSS-model, parts of the PSS, that have a high internal crosslinking-density, but only few relations to other parts of the system, can be aggregated to modules. Therefore, a higher-level element is used, that "capsules" the subordinate elements. As a result, a higher level on abstraction, a clearer arrangement of the model and reusability of the modules is reached. The software tool used supports the automated arrangement of the elements according to their interconnections and thus proposes elements which are supposed to be in one module. The modules are marked and integrated by a module element, see Figure 6.

3.2 Variants- and alternatives management

A PSS-portfolio can be divided into different product variants, base variants and product families, using different module configurations [Bauer et al. 2014]. In reverse, this means, to gather different variants

these modules can be systematically varied and combined. In the case of PSS-modelling, the modules do not consist only of material but also immaterial elements, so services can be included.
For supporting the management of variants and alternatives within the model, there are the so called decision-points. They indicate that for example for the implementation of a certain working principle several components can be used out of which at least or exactly one has to be chosen. Hence, the designer has an indication where he must decide which features or modules shall be used within the respective development context. The variants- and alternatives management can be applied in all abstraction levels and across these levels. The application can be seen in Figure 7.

3.3 Temporal planning

For avoiding development effort which is not compliant to the long-term goals of a company, it is essential to take into account not only short-term planning horizons but also middle-term and long-term ones. Therefore, different temporal planning horizons have to be defined at first. In a second step, the structure of the respective PSS is depicted for every of these time ranges. Thereby the current PSS-portfolio is shown within the short-term horizon, whereas the middle- and long-term horizons show the development goals for the respective later points in time. These later points in time then represent the future structure of the PSS, i.e. how it shall develop according to the strategic goals of the company. Caused by the greater uncertainty and the lower data quality the greater the planning horizon becomes, the PSS-portfolio cannot be depicted as detailed as for the current situation, hence, only certain trends or rough concepts can be predicted. Nevertheless, these predictions help estimating change efforts, which are required to reach those goals. In order to do so, the different structures of the respective planning horizons are compared, out of which the differences between them can be derived. On this basis one can finally determine the needs for action to realize the desired goals and therefore estimate the required efforts.
In that manner, different concepts and design alternatives of a PSS can be evaluated and the decision-making process is supported. Thereby, the alternative with least development effort is chosen in general (provided that it fits with the company's goals). But this choice has to be made with respect to both, the middle- as well as the long-term perspective. E.g. a certain alternative may be easy to realize on the middle-term, but may not automatically fit with the respective long-term goals and thus another, better fitting option has to be chosen, even if it may not be the better option on the middle-term view, see Figure 3.

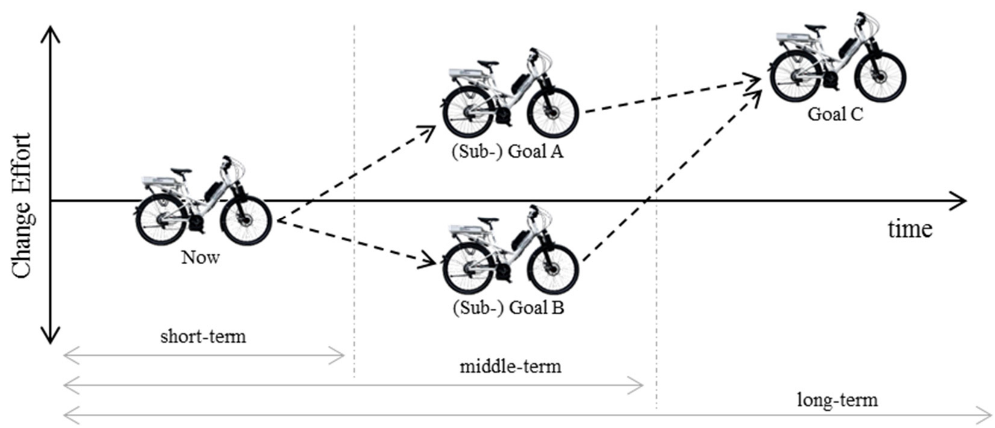

Figure 3. Temporal coordination of PSS-planning according to [Orawski et al. 2010]

To implement the temporal planning each element within the PSS-Concretization Model has a time stamp which indicates the time span in which an element is active. Hence, it is possible that for middle- and long-term planning further elements have to be implemented to grant the desired functionality or to meet the set requirements. By means of matrix subtraction the commonalities and the differences can be identified. Differing elements can be connected by a "becomes" relation to indicate the togetherness and thus the temporal development of the element. By selecting the respective elements the direction of middle- and long-term development can be set an thus the result can serve as the basis for a technology roadmap.

4. Case study

In the following, a practical implementation of the previously presented framework for modeling PSS shall be presented. The data originate from an academic case study. The model served as a support tool to structure the planning-relevant information. It was used to support modularization, derive variants and to detect gaps in the model. Temporal planning was not considered in this case.

As example, we use a bike-sharing concept called PSSycle, which was developed within a student's project. PSSycle is an interdisciplinary project for "selling" mobility. The general concept is to offer a rentable pedelec. Customers pick it up at certain spots within a pre-defined area, use them and have the possibility to leave them somewhere else. Therefore, besides the actual e-bike, a smartphone application has been developed that allows users to track available pedelecs near them and to reserve them. Also the paying-procedure is arranged via the app. In addition to the pedelec and the app, there are further services included to complete the offer and enable a pleasant user experience, e.g. navigation to points of interest, maintenance or the re-collection of pedelecs.

For the representation of the planning model of the PSSycle, the software tool Soley (www.soley-technology.com) was used. Within this tool, the PSS elements are depicted with the help of differently shaped nodes in order to be able to distinguish between service- and product parts as well as the respective concretization stages within the framework described in section 3. In that manner, all components, resources, working principles, service processes, functions as well as the underlying requirements that belong to a PSS can be depicted.

The nodes are connected by edges on the basis of previously defined rules for modeling (e.g. a function always has to fulfil a requirement), if there is a relation between them. Thereby the edges can either originate from tangible relations, like the geometrical relation between product components, or intangible ones, as the relation between a certain function and the requirement that it is caused by. Finally all nodes as well as the connecting edges are depicted within an integrated graph. This graph offers a holistic view of the entire PSS as it is shown in Figure 4.

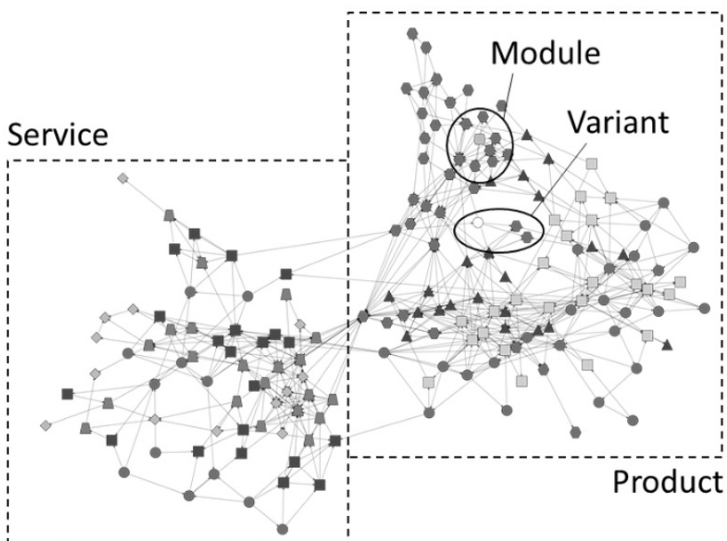

Figure 4. Overview of the integrated PSS-model

It shows the two main parts of the PSS: the product part and the service part. Furthermore, the interactions between these two parts become obvious and critical elements can be identified. In the example of the PSSycle the most critical element turned out to be the smartphone, as it can be understood as the interface between the pedelec and the offered services. This key-role is also emphasized by its

central position within the graph, where the smartphone is the linking element between product- and service parts.
As already mentioned, the connections between the elements of the PSS follow certain rules [Schmidt et al. 2015] that describe the respective relation between them. Besides obvious relations, like geometrical dependencies, one thereby can further depict causal dependencies between elements, e.g. "a product component fulfils a technology", "a technology fulfils a function" or "a function fulfils a requirement". In that manner, existing components of the PSS can be continuously traced back to the requirements they originate from, as it is shown in Figure 5.

Figure 5. Example: rule-based modeling

As indicated in Figure 4, it is also possible to detect modules within the model, as highly cross-linked elements are arranged near to each other. For the purpose of reaching higher clearness within the model, an arbitrary amount of elements that belong to a module can be capsuled with the help of a superior element, as it is shown in Figure 6 for the case of the pedelec's gear unit.

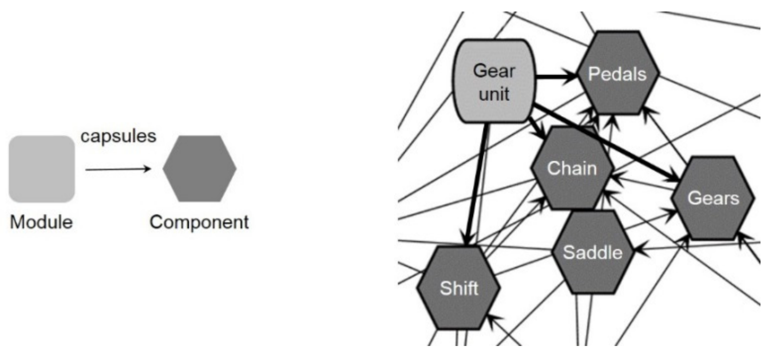

Figure 6. Example: modularization

Furthermore, different forms of realizing certain specifications, i.e. variants, can be depicted. Therefore, a node is used, that illustrates these so called decision points, which mark the places, where different alternatives for a specific problem occur. The subordinate elements are the selectable alternatives. The superior element is the one, from which the subordinate ones result, e.g. a requirement, a function or a working principle in the case of product parts. In the given example of the PSSycle, see Figure 7, one may for instance chose between two kinds of batteries, that differ with respect to their power-supply, dependent on what range the respective e-bike shall be used for.

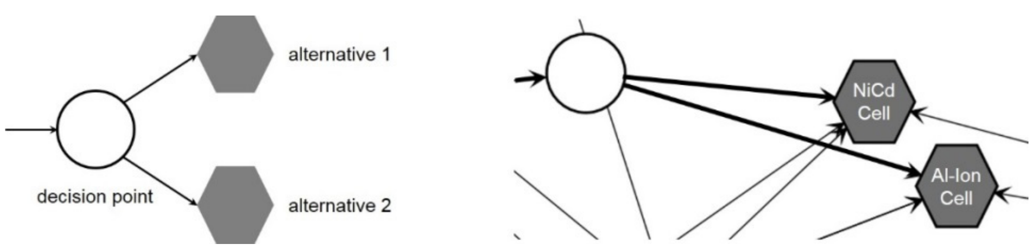

Figure 7. Example: alternatives

On the basis of this modeling approach, future change efforts may also be analyzed as described in section 3.3. Therefore, different models for the respective periods in time (short-, middle-, long-term) have to be generated.
Occurring changes between the PSS-generations can thus be detected easily by comparing the resulting models and analyzing which elements differ. A possibility to do so is to "subtract" the models from each other so that only the changing elements remain and the other ones disappear. Although a model that anticipates possible future scenarios surely is not as detailed as the one that shows the current state, required development activities can finally be derived in that manner as central change areas can be detected.

5. Discussion

The presented framework for modeling PSS enables users to depict all tangible and intangible parts of a PSS in an integrated manner and thus supports consistent procedure and documentation within development. Especially the lack of possibilities to detect and capsule modules within the structure, to depict alternatives and variants as well as to take into account temporal planning aspects has been addressed. Finally, the connection of the model's different parts and its implementation within the software tool Soley gives a holistic and intuitive overview of a PSS's structure.
Particularly for PSS, consistent linking of different model parts is of great importance, as there are many different perspectives on them, due to their integrative and interdisciplinary character. Thus, also many different modeling-approaches exist. But in order to develop a PSS successfully, a consistent modeling approach, and hence a consistent linkage of different models, is essential. To harmonize various already existing modeling approaches, there often have to be applied expensive and time-consuming methods for identifying and eliminating inconsistencies [Feldmann et al. 2015]. In order to avoid such a need for rework, the presented approach offers consistent possibilities for the description of PSS and the linkage of different model parts from the very beginning.
A disadvantage of the presented model is the subjective election of the respective level of abstraction. Development teams are not supported in setting a suitable level of detail for the representation of a PSS. On the one hand, this allows an individual adaption to specific development circumstances or situations, but on the other hand this adaption often seems to be made arbitrarily.
Furthermore, the depiction of modules and their elements within the model may possibly lead to confusion within the model. While the intention is to give a holistic overview of the entire PSS and all of its parts, it is just this depiction of all elements, i.e. all modules, sub-modules and components, which may make the model not intuitively comprehensible anymore.
As shown in section 2.4 only few approaches meet the requirements regarding modularization, variants and alternatives management as well as depicting diverse temporal planning horizons. The integration of these aspects into the PSS-Concretion Model was presented in this paper. Hence, the approach at hand addresses all the requirements a model support for the planning phase of a PSS must meet.

6. Summary and outlook

On the basis of an extensive literature study on the state of the art of product- and service modeling as well as existing approaches for PSS modeling, an existing framework for depicting PSS is further expanded within this paper. The developed extensions include possibilities for supporting modularization, enabling the choices between variants and taking into account different temporal planning horizons. Thus a holistic model of a PSS could be derived. The presented approach was finally applied within a university project for the development of an e-bike sharing concept.
This modeling approach enables development teams to depict a PSS in the early phase of development and thus gain a holistic overview of the desired structure. Occurring uncertainties can thus be overcome and decisions can be made on a reasonable and comprehensible basis. But as every human activity, this decision-making process cannot be free of faults. A possibility to deal with these risks of faulty decisions is to introduce consistency- and plausibility checks at fixed points in time within the development phase. How and to which extend such checks can be included in the presented model is to be analyzed and specified within future research activity. Furthermore, to minimise the additional effort for the designer, the automated import of existing data has to be investigated.

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