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Procedia CIRP 16 (2014) 68 – 73

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Product Services Systems and Value Creation. Proceedings of the 6th CIRP Conference on Industrial Product-Service Systems

# Validation of Product-Service Systems – A Prototyping Approach

Konrad Exner[a]*, Kai Lindow[a,b], Christian Buchholz[a], Rainer Stark[a,b]

[a]Chair of Industrial Technology, Technische Universität Berlin, Pascalstraße 8-9, 10587 Berlin, Germany
[b]Division of Virtual Product Creation, Fraunhofer IPK Berlin, Pascalstraße 8-9, 10587 Berlin, Germany

* Corresponding author. Tel.: +49-30-39006-247; fax: +49-30-39006-246. *E-mail address:* konrad.exner@tu-berlin.de

**Abstract**

Product-Service Systems (PSS) combine tangible products and intangible services in an integrated system which is offered to the customer as an individual solution. Due to interdependencies between these different system elements the complexity of PSS is very high, thus preventing a simple transfer of validation methods of classical product development or service engineering. This leads to a lack of validation methods for the testing of PSS. Within the paper the processes, methods and tools of prototyping are analyzed and possibilities are determined how existing methods can be used for PSS-Prototyping, at which point they can be applied and which aspects of PSS can be validated. Afterwards, a new prototyping approach for PSS is presented in a use case.


Selection and peer-review under responsibility of the International Scientific Committee of "The 6th CIRP Conference on Industrial Product-Service Systems" in the person of the Conference Chair Professor Hoda ElMaraghy"

*Keywords:* Product-Service Systems; PSS; prototyping; PSS-Prototyping; validation

## 1. Introduction

Product-Service Systems (PSS) incorporate a system of products, services and infrastructure to fulfill individual customer needs. Therefore, the development of PSS is an extension of the traditional engineering design process, which mainly refers to purely tangible products or intangible services, to an integrated development process of products and services. In research regarding the development of PSS a variety of proven processes, methods and tools, in particular for the planning and design phase, already exist.

The use of PSS in industry is not new in a broader sense. There are plenty of examples for the use of PSS ever since the industrial revolution. However, the concept of integrated planning, development, supply and usage is in the focus of several research groups. A commitment in industry regarding the further development towards a solution provider is hardly noticeable. [1]

Besides the problems referring to acceptance and initial difficulties, the low degree of maturity of PSS methodologies has to be considered too. At this time, a consistent methodology does not exist and the aspect of prototyping is basically not discussed. Therefore, PSS-Prototyping can be seen as a desideratum in the scientific field of research.

Concluding this thought the following thesis can be derived: One reason for the slow penetration of PSS in industry is caused by the lack of validation methods.

Therefore, a new method for the integrated validation of products and services especially the prototyping of PSS should be developed. In the following chapters validation and prototyping methods of the classical product and service development as well as current PSS validation approaches are discussed. Finally a new concept of PSS-Prototyping is introduced in a use case.


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doi:10.1016/j.procir.2014.03.004

## 2. Validation methods

The validation in development processes is a key factor to a successful design process. It can be enabled with different methods or tools to allow a testing of different design parameters, e.g. technical requirements or usability. In this context, prototyping is an option but not inevitable for validation processes. Regarding PSS, the validation aspect of property assurance will be described for both product and service development.

### *2.1. Validation in product development*

Traditional development process methodologies – from “classical” approaches as VDI 2221 up to new, integrated approaches such as “Model based systems engineering” are basically product centered. In contrast, new approaches focus on entire system development (including software, electronic and mechanical engineering). These new approaches demand a continuous assurance of system properties. This could be done by both verification and validation.

Firstly, verification describes the correlation between the specifications that the process gets as input, and the product as the output of the process. Secondly, validation means testing whether the product is suitable for the purpose it is developed for or not. [2]

Physical validation ranges from low fidelity level approaches as paper-based prototyping with simple paper prototypes over high fidelity prototyping approaches as Physical Mock Up (PMU) with its detailed physical prototypes up to the high end generation of fully functional pre-series prototypes.

For virtual validation different technologies and methods are available. For instance, Computer Aided Engineering (CAE) is used for property analysis, e.g. stress analysis using Finite Elements Methods (FEM) or spatial analysis using Digital Mock Up (DMU).

The permeation and maturity of these validation methods is high regarding process robustness and user acceptance for PMU and DMU Beside those approaches used in today’s daily practice there are research investigations regarding the extension of the DMU with functional elements to a Functional Digital Mock Up (FDMU). This research topic aims to run functional analysis – as they are in today’s practice done with pre-series prototypes – with purely virtual prototypes.

### *2.2. Validation in service development*

In the field of service validation three different approaches can be distinguished.

Firstly, the most basic test procedure is a pure process analysis with flow charts. In the area of service engineering service blueprints is the most common technique. It divides the process through the line of interaction, the line of visibility and the line of internal interaction. Based on this visualization service processes can be structured and optimized. [3, 4]

Secondly, the testing of concepts through the integration of focus groups with dialogues and questionnaires is of high relevance [3, 4]. Unexpected events or situations as well as real interaction with the customer regarding the service processes are not covered with these methods.

Thirdly, the simulation of the service process is another possibility to validate services. That means to simulate the environment as well as the service processes including all necessary actors. The complexity and effort and therefore the costs increase with a more realistic and accurate implementation of the service, for instance building replicas of a store for test launches. [3]

For this reason, the research community started to substitute elements of the environment with virtual components. The development and implementation of virtual methods regarding services started in the last decade but still remains a new field of exploration. One of the pioneers in this domain is the ServLab of the Fraunhofer IAO in Stuttgart (Germany), using Virtual Reality (VR) to create a realistic test environment. For this approach the level of application especially in practical usage is still very low. [5]

Other service validation methods like Quality Function Deployment (QFD) or Failure Mode and Effect Analysis (FMEA) do not enable a real testing or prototyping of services, but only a theoretical validation [5].

Summarizing the experience and the level of application regarding testing or prototyping in early development phases of services is hardly developed. New research focus mainly on virtual techniques. Analyzing methods like service blueprinting or QFD are better known since they exist for decades.

### *2.3. Gap in validation of PSS*

As described in the previous chapters the integrated validation of PSS in the development process regarding tangible and intangible elements is an essential factor. Therefore, the current research in this field needs to be considered.

In recent research the validation of PSS take up a minor role. Regarding the key subjects of the last IPS² conferences [6, 7, 8, 9, 10] a clear reference to the validation of PSS through specific topics is missing: From five IPS² conferences only two topics regarding the validation of PSS were discussed: “Evaluation Methods” in 2011 and “Modeling and Simulation” in 2013. Furthermore, an analysis of 323 publications of the proceedings of IPS² results in only 34 papers which refer to validation aspects of PSS. Only a few of them have a link to design in early development stages. Most of these cases adapt or extend already existing methods for the implementation of PSS. At this time, a consistent methodology does not exist and the aspect of prototyping is basically not discussed. Therefore, PSS-Prototyping can be seen as a desideratum in the scientific field of research.

In conclusion, existing methods cannot be easily adapted due to the complexity and interdependencies between PSS elements. A new integrated validation method, like prototyping of PSS needs to take this into account.

## 3. Prototyping approaches

In current state of the art definitions for prototyping and prototypes are described insufficiently. For example the terms model and prototype are used interchangeable. [11, 12]

Furthermore, each domain entails a differentiated view on the terminology of prototyping. In the field of architecture there is barely any distinction between a prototype and final product. The finished building consists of both. Also in the conventional product development the physical prototype is used as a sample for the preparation of serial production. This understanding has become more and more obsolete. It is increasingly replaced by the virtualization of the product development process and new technologies, e.g. Rapid Prototyping [13].

The research field of Prototyping offers innovative possibilities of implementation in the area of PSS. The most promising two perspectives for a prototyping of PSS, low and high fidelity prototypes and smart prototyping, are shown in this chapter.

### *3.1. Low fidelity vs. high fidelity prototypes*

One important aspect is the comparison of traditional and IT-based (physical towards virtual) prototyping methods. It can be described as high and low fidelity prototypes as well [12]. Table 1 provides an overview of different prototypes and their characteristics:

Table 1. Summary of prototypes.

| Processes, Methods and Techniques for Prototyping | Degree of Fidelity | Realization |
|---|---|---|
| Clay Model | Low | Physical |
| Paper Model | Low | Physical |
| Physical Mock-Up (PMU) | Both | Physical |
| Sketches | Low | Physical |
| Wood Model | Low | Physical |
| Augmented Reality | High | Both |
| Functional Mock-Up (FMU) | Both | Both |
| Rapid Prototyping | Both | Both |
| CAD | High | Virtual |
| CAE-Simulations | High | Virtual |
| Digital Mock-Up (DMU) | High | Virtual |
| Mixed Reality | High | Virtual |

Conventional methods for prototyping, e.g. clay or wood models, focus on the physical realization of the product. A particular advantage is the application of human manual skills. This implies, for example, that a prototype shape made of clay can be changed by the sensitive feeling of a human hand [14]. Furthermore, Physical Mock-Up´s provide the possibility to experience the final product in 1:1 realization with its entire features and real dimensions. Due to complexity and time-consuming construction physical prototypes are rather costly and unfavorable for the aim of reducing development effort [15]. Especially in the early phase of product development the final product design is often changing and therefore physical prototypes need to be adapted with high expense.

New methods of virtual prototyping assist the creativity of the developer and detect first discrepancies that will complicate subsequent manufacturing [14]. CAD and CAE tools enable any modification of the product in a fast and simple way. Besides, virtual prototyping methods provide the possibility to add or delete components at each time and each part. Moreover, virtual, augmented and mixed reality techniques simulate a real prototype in a virtual environment that can be perceived with human senses.

Furthermore, some prototyping approaches combine physical and virtual components, e.g. Rapid Prototyping. Some of these technologies need virtual models to create low or high fidelity physical prototypes and in this way complement each advantage. This aspect is the core thought of a new technology called Smart Hybrid Prototyping and is presented in the use case.

### *3.2. Smart prototyping approach*

A broad variety of prototypes and prototyping methods are used for the validation of product models within product development, e.g. virtual prototypes during the design phase and physical prototypes before the start of production [3]. Compared to product development the situation in service prototyping is different. A literature review has shown that service prototyping methods are usually based on the well-known and well-established methods of product development [16]. However, these are rarely used due to the intangible nature of a service in an industrial environment. Furthermore, the modeling of service prototypes has not been into research focus sufficiently.

Prototypes are used for validation and verification of designed products and services in terms of their functionality and performance. In terms of PSS two key challenges occur:

1. A prototypical model has to represent both the product and the service elements accurately and realistically.
2. The prototypical model has to be of a quality that the performance of the entire PSS can be assessed reliably.

The study of Bading et al. [17] confirms these two challenges. Additionally, it can be concluded that only a few appropriate practices and development methods already exist for a possible PSS-Prototyping, although companies have recognized the added value of the use of PSS-Prototypes.

In the following, two different prototyping methods (product-in-the-loop and service-in-the-loop) are proposed whereas the aim is to integrate both methods into an integrated smart prototyping approach.

Within the product-in-the-loop method a virtual product is adapted to different service situations. In this case, the prototype of a product is adapted in several iterations in order to support different customer wishes and specifications. Due to the potential of product changes this method can be particularly effective in the early phases of product development.

Within the service-in-the-loop method a service is adapted to different product designs. In this case, prototypes of essential services can be applied to an existing product in order to improve the service offering. The purpose is to develop the service as realistic as possible due to its applicability.

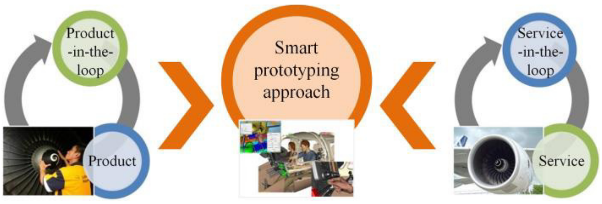


Fig. 2. Product-Service-in-the-loop.

The new approach needs to combine the product-in-the-loop and the service-in-the-loop methods into an integrated smart prototyping approach (see fig. 2.)

## 4. Case study: Validation of PSS via Smart Hybrid Prototyping (SHP4PSS)

To develop a fully aligned PSS-Prototype regarding the integration of high fidelity virtual and low fidelity physical prototypes as well as the smart prototyping approach the concept of Smart Hybrid Prototyping (SHP) provides an opportunity. Therefore, the technological approach of SHP has been applied in a case study to validate PSS. SHP was developed at the Technische Universität Berlin and Fraunhofer Institute for Production Systems and Design Technology. SHP integrates technologies of different domains and originally provides interaction between mechatronic products and the user (see fig. 3) [18].

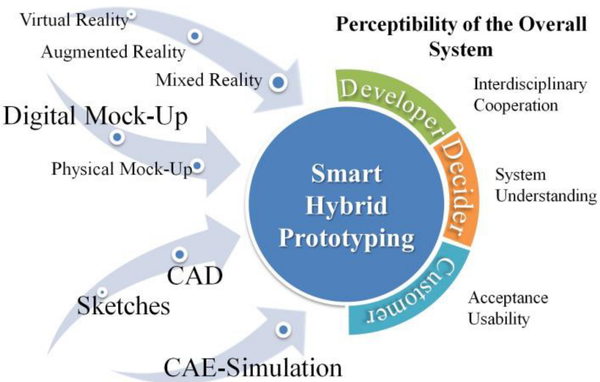


Fig. 3. Smart Hybrid Prototyping. [18]

To enable SHP two major aspects need to be developed [19]:

1. A visualization of the environment of the use case, e.g. the implementation in Virtual Reality.
2. Smart hybrid prototypes (physical prototypes) to integrate the digital model with a physical representative to allow haptic feedback.

The conceptual approach for using SHP to enable PSS-Prototyping has already been discussed as SHP4PSS in Exner et al. [19]. In the application of SHP4PSS several challenges have been identified that are now being addressed within the PSS validation process of the following case study.

For the case study a PSS in the area of urban mobility has been chosen. Therefore, the idea of a bike sharing system has been developed including the core product "Smart Tripelec" (see fig. 4). Additional product (e.g. two-seater Smart Tripelec, stair assistant) and service (e.g. maintenance, repair and overhaul) components as well as software and infrastructure are integrated in the PSS and ensured by the provider.

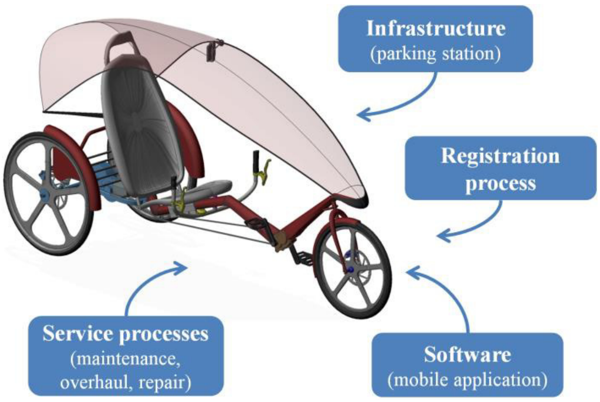


Fig. 4. Smart Tripelec and service components.

According to the generic PSS development process model by Müller [20] a comprehensive market and customer analysis has been conducted in the beginning of the planning phase. The first overall concept of the PSS is specified and illustrated in multiple layers (e.g. customer needs/values, deliverables, actors etc.) using the PSS layer method by Müller [21]. As a result, first requirements can be derived for the PSS with a requirement checklist for the PSS components. [22]

For a broader range of variety three case scenarios for the PSS were developed differing in structure, additional components, degree of service etc. Therefore, the validation of the scenarios considering these characteristics is the aim of the following step. As it can be seen from table 2, life cycle activities are listed in combination with the dimensions of product, service and product/service. For each life cycle activity the correlative manifestation of each scenario is assigned.

Table 2. Extract from the morphological chart of the PSS use case.

| | Dimensions | | |
|---|---|---|---|
| **Lifecycle activities** | Product | Service | Product/Service |
| **#1** Information procurement & registration | Customer needs to go to Service Center | Assistant comes to customers´ home | Customer uses online self-registration via web/app |
| **#2** Access | Regional network of Tripelec parking stations is available for customer | Care Assistant delivers the Tripelec to any place the customer whishes | Customer owns a private Tripelec parking station shared with neighborhood |
| **#3** Usage | Customer uses only the Tripelec (core product) | Customer uses the Tripelec with care assistant | Customer uses the Tripelec plus the integrated support device for vertical mobility |
| **#4** Communication between customer and provider | No communication exists | Care assistant enables permanent communication | Customer communicates via online platform if required |

Finally the PSS scenarios will be implemented while using the Smart Hybrid Prototyping approach. The development of several components in a Virtual Reality aims to fulfill a comprehensive experience of a prototypal embodiment of the PSS. Therefore, a survey of the morphological chart results in a list of lifecycle elements which are possibly realizable with SHP4PSS. In a first step, the following elements have to be developed:

- Digital model of the Smart Tripelec (fig. 4)
- Smart hybrid prototype of the Smart Tripelec (fig. 5)
- Digital city model
- Software application to rent the Smart Tripelec

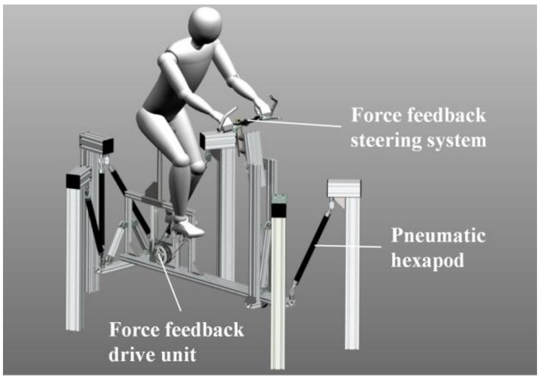


Fig. 5. Smart hybrid prototype of the Smart Tripelec.

These elements enable first test scenarios for the PSS. In the next development stages further infrastructures, e.g. parking stations of the Smart Tripelec and service processes, e.g. repair or maintenance, have to be implemented. A fast and cost efficient development of the physical prototypes and different variants is supported by rapid prototyping technologies like 3D printing.

The Digital Cube Test Center (DCTC) (see fig. 6) is a Virtual Reality environment with computer haptic interfaces for multi-modal interactions. It enables an immersive 3D-stereo visualization with 360° panorama view and provides a motion platform with up to 3 translational and 3 rotational degrees of freedom. It is used for the validation of digital models and complex mechatronic systems. The objective in this project is the implementation of all PSS elements in this virtual environment.

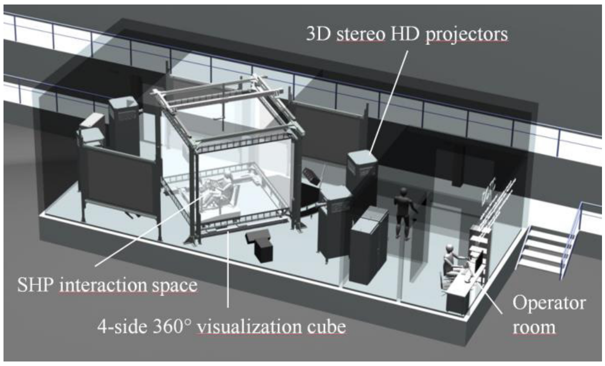


Fig. 6. Digital Cube Test Center.

The aim of this research project is to enable gradually a testing of the PSS lifecycle activities to explore the capability of SHP4PSS regarding:

1. Support of interdisciplinary design teams and enable validation of requirements during the development of PSS: Engineers and designer have been defining requirements regarding all PSS elements. The elements are linked from customer needs up to the development process of specific elements. Based on this validation process an analysis which requirements (service, product, infrastructure etc.) can be validated with SHP4PSS will be determined.
2. Create an environment to increase the understanding of new PSS for manager and decider: The PSS concepts will be presented to managers of the mobility sector. An evaluation regarding the usefulness of SHP4PSS supporting decision for new PSS concepts will be conducted.
3. Enable testing regarding usability and acceptance of new PSS as well as the new approach with the customer: To evaluate the service and product design focus groups will test the SHP4PSS.

## 5. Discussion and outlook

Within this paper processes, methods and tools of prototyping have been analyzed and their possibility for PSS-Prototyping had been determined. For this purpose, the technological approach of Smart Hybrid Prototyping, a combination of virtual and physical prototypes in Virtual Reality, is developed further to PSS-Prototyping. The procedure and the current practical realization (example of a PSS development in the area of urban mobility) are presented in the paper. The difficulty regarding the further development is currently the realization of the different PSS elements. So far it is uncertain whether every service process or infrastructure element is realizable with SHP4PSS in the presented environment (DCTC). Furthermore, heterogeneity and simultaneity of services processes affect the validation and are not managed at this point.

At the moment SHP4PSS attends more to the prototyping of tangible products because SHP derived of the development of mechatronic systems. The challenge is the implementation of service processes to assure an equal testing of service and product components as described with the smart prototyping approach (chapter 3.2). Finally, a sole testing of products and services, e.g. for calibration of single components, should be enabled.

In addition to the SHP4PSS prototyping an evaluation method for the morphological chart based on a utility analysis will be tested. Performing different testing methods, a theoretical and a practical approach, the results can be compared and assessed. Furthermore, a comparison to other possible prototyping approaches is missing. In a further research project a low fidelity prototyping approach is going to be developed. For this purpose the design thinking process after Plattner et al. [23] is analyzed and a PSS-Prototyping method for an early prototyping of PSS will be proposed. The idea is to use paper-based and other low fidelity prototyping techniques combined with validation aspects of service engineering like service blueprinting to an early, fast, low-cost and iterative testing of PSS.

On that basis a further discussion regarding the cost-benefit analysis of SHP4PSS can be performed. The complexity and overhead to accomplish a working environment will be discussed. At this stage the aim of this research groups is to evaluate the potential and limits of the new method.

## Acknowledgements

The authors would like to express their gratitude to the *Einstein Stiftung Berlin* for funding the research project *Rethinking Prototyping*.

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