A MODEL TO DESCRIBE USE PHASE OF SOCIO-TECHNICAL SPHERE OF PRODUCT-SERVICE SYSTEMS

Hollauer, Christoph; Venkataraman, Srinivasan; Omer, Mayada
Technische Universität München, Germany

Abstract

Development processes of product-service systems are faced with an increased complexity, among other reasons due to a larger number of stakeholders. This makes it necessary to focus development not only on the technical aspects of product-service systems but also on the sociotechnical aspects. It also becomes important to foster system understanding over a number of domains in early development phases in order to manage this increasing complexity. In this paper, a use-case-based approach for the identification of product-service-system elements such as requirements, functions, components and services is presented. The approach supports the identification of use cases by using a method from the domain of user experience design and subsequently offers support in graphically modeling the use case scenarios and in identifying system elements. Experimental application of the method has been conducted in the context of an academic case study.

Keywords: Product-service systems (PSS), use case modeling, Design methods

Contact:
Christoph Hollauer
Technische Universität München
Institute of Product Development
Germany
hollauer@pe.mw.tum.de

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1 INTRODUCTION

A Product-Service System (PSS) is a combined offering of products and services, which delivers value in use to its customers (Baines *et al.*, 2007). A PSS can be seen as a combination of social and technical components, which together comprise hardware, software and humans, in offering services to customers. PSS are often seen as a way towards more environmentally sustainable offerings although they are not inherently so but need to be designed this way (Tukker and Tischner, 2006). In any case, they can act as vehicles to create more innovative and thus more competitive offerings (Tukker, 2004). Due to the added complexity resulting from the larger number of involved parties in this multi-stakeholder environment, the execution of the innovation process consumes an increasing amount of time and effort. (Schenkl *et al.*, 2013).

The work presented in this paper is the result of a project within the author's multidisciplinary collaborative research centre concerned with the topic of cycle management in innovation processes, focussing on the development of product-service systems (http://www.sfb768.tum.de/). The project focusses on research questions regarding the the capture and analysis of various forms of complexity within the sociotechnical system comprising a PSS and their impact on the PSS, using a model-based systems engineering approach together with dynamic modelling techniques such as System Dynamics and Agent Based Modeling. The focus thereby lies on evaluative (caused by differing stakeholder needs and values), nested (resulting from two-way interactions between technical and organizational systems) and dynamic complexity (caused by difficulty in predicting system behaviour as well as subtle and unobvious cause-and-effect relationships) (Sussman, 2000; Mostashari and Sussman, 2009; Senge, 1994).

Cycles are reoccurring structural or temporal patterns that can be divided into individual phases. A cycle has characteristic properties such as "repetition, phases, duration, trigger and effects". The effects of one cycle may lead to another cycle. These external and internal cycles have a large impact on innovation processes within product development. The overall goal of cycle management is to support a fast and efficient development and realization of more innovative PSS (Schenkl *et al.*, 2013).

Before addressing the dynamics of cyclic interactions, it is important to characterise the sociotechnical perspectives of PSS. In other words, it is important to identify the following: sociotechnical elements of PSS such as stakeholders and components, their requirements and functions within PSS, interactions among elements, etc. Further, these will be used to model and dynamically simulate the functioning of PSS to analyse the dynamics of cyclic interactions. Of the PSS archetypes proposed in literature, this paper will focus on use-oriented PSS, where the product ownership does not change from provider to user. Examples are product leasing, renting and pooling such as car sharing schemes or shared printers in office buildings (Tukker, 2004).

To address the questions raised in the project, a model-based systems engineering (MBSE) approach coupled with the application of dynamic modelling and simulation is used. In the scope of this paper, an overview is given over the approach for the identification of elements of the PSS in question, based on use case scenarios. The approach is applied to a case study. Due to the chosen sociotechnical perspective, the identified elements span requirements and functions, stakeholders, infrastructure and system components (Hardware, Software and Services), interactions as well as occurring structural and temporal cycles. These elements will then be used to describe the use phase of the PSS and form the basis to conduct investigations into the dynamic behaviour using dynamic modelling and simulation techniques such as Agent Based Modelling and System Dynamics.

This paper is structured as follows: Important findings from previous work are reported in Section 2, specific objectives of this paper are outlined in Section 3, research approach is shown in Section 4, results are presented in Section 5, significance of these results are discussed in Section 6, and summary, conclusions and directions for future work are shown in Section 7.

2 LITERATURE SURVEY

2.1 Model Based Systems Engineering

Instead of traditional, document-based approaches for requirement elicitation and system design, the focus is shifting towards a digital model-based approach, known as model-based systems engineering (MBSE). To implement MBSE, various methodologies exist, which entail the related processes, methods and tools to support systems engineering. Some of these methodologies are for example (Estefan, 2008):

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- SYSMOD
- CONSENS

Advantages of the application of MBSE are an improved communication and ability to manage complexity through a single design repository, the possibility of an automated requirements traceability throughout the product lifecycle and the reusability of information and knowledge once it has been captured (Murray, 2008).

Most of the MBSE methodologies contain a step containing analysis of needs as well as the creation of architecture, but the process of identifying architecture elements based on use cases or the design of the system architecture in general is not well explained. Also, MBSE methodologies rooted in traditional systems engineering are not well suited to the development of PSS because they are mostly focused on the development of hardware.

For creating engineering system models in general, two basic approaches can be pursued: using either standard modelling languages such as SysML (*Systems modelling language,* for modelling complex systems including hardware, software, processes etc.) which is based on UML (*Unified Modeling Language*, focussing on describing software systems), or self-defined, problem- and domain-specific languages rooted in formal metamodels. Models of two domains can be transformed into the other domain, as long a as formal metamodels of the modelling domains are available (Estefan, 2008, Helms, 2013).

2.2 PSS design methodologies and models

A successful PSS design methodology needs to address the following points (Vasantha *et al.*, 2012):

- Dynamically identify stakeholder requirements
- Aid in understanding issues between the product and the services it is to deliver throughout its lifecycle
- Capture interdependencies between system components and subcomponents
- Clearly define design processes in order to avoid misinterpretations
- Comprehensively evaluate the conceptual and strategic alternatives
- Identify areas of risk and uncertainty in the product lifetime
- Promote design transparency

A number of PSS design methods have been described in literature thus far. Vasantha *et al.* (2012) list eight specific PSS design methodologies that fulfil certain criteria such as a certain level of detail, industry application, publication and applicability in business-to-business contexts. Examples of such methodologies are “Service CAD”, “PSS Design” and “Integrated product and service design processes”. Also, certain gaps in research have been identified, especially the identification and description of requirements. Further gaps that need to be addressed by PSS design methodologies are for example the sociotechnical aspects of PSS due to the tight integration of products and services and the resulting complexity due to the increased number of stakeholders. Thus it becomes important to identify stakeholders in the first place as well as to map their roles and capabilities as well as relationships between each other. So far, only the network formulation of stakeholders has been addressed. Another important aspect is the use phase of PSS: Environmentally conscious design and manufacturing are strongly considered in the consumers’ behaviour in the use phase of PSS.

Altogether, model-based methodologies can be seen as a way to address some of these gaps through their strengths.

2.3 Use Case Modelling

One of the motivations of developing PSSs is to encourage use rather than ownership for its customers. For this reason, Maussang *et al.* (2009) argue that easiness of use for customers and service units to interact with its elements have to be addressed. Therefore, envisaging scenarios will enable description of actions between user and PSS, and elements within PSS.

Use Case modelling is an important step in the development of complex systems (as it often is a part of Systems Engineering methodologies for requirement elicitation), yet there seems to be a lack in the consistent development of use cases and the systematic utilization of these use cases for the identification of system architecture, especially in the context of PSS. A use case describes a behaviour of the system that yields an observable result to an actor and is focused on the functionality (Holt, 2012). There are existing approaches that can be used for the description of use cases to various extent. These are primarily textual descriptions of use cases, such as presented by Cockburn (2001), and SysML use case diagrams.

Use scenarios are mentioned and described in literature several times as methods to support the development of product service systems, such as by Morelli (2003, 2006) and, to an extent, Maussang *et al.* (2009). One of the problems associated with use cases is finding the right level of detail (Holt, 2012, pp. 74ff). In the context of this paper, "use case" refers just to the title of one use case, such as "booking of bike", whereas the term "use case scenario" refers to the detailed textual or graphical description of a use case.

3 OBJECTIVES AND CASE STUDY

The objective of this paper is to identify and model sociotechnical elements in PSS, such as overall and sub-functions, stakeholders and system goals, infrastructure, system components and services, interactions between system elements as well as structural and temporal cycles. For each of the elements, possible alternatives should also be investigated. The developed models will later serve as a basis for dynamic simulations, such as agent-based or system dynamics models with which various strategic alternatives can be evaluated using a set of key performance indicators.

The research approach presented in this paper is based on modelling use case scenarios of a student project developed within the collaborative research centre called the "PSSycle". The PSSycle is a concept of an innovative sharing system for electric bicycles that has been developed within the authors' collaborative research centre. (Kasperek and Maurer, 2013). The PSSycle combines the physical product of a Pedelec (pedal electric bicycle) with services such as booking a specific bike, navigation and payment. The PSSycle was chosen because of the well documented background of its hardware components and the availability of data that can be used.

4 RESEARCH APPROACH

4.1 Overview

The use cases first will be elicited and defined using a storytelling-methodology from the domain of user experience design. This will yield a list of use cases that server as input for the rest of the modelling process. The initial format of the use case scenarios is in textual form. Afterwards they will be detailed and modelled in a graphical format. The graphical representation of the use case scenarios will then be used as a basis for further identification of system elements, e.g. requirements and functions, stakeholders such as organizations and institutions, system components, services and interactions between technical and social elements. Figure 1 presents an overview over the modelling process.

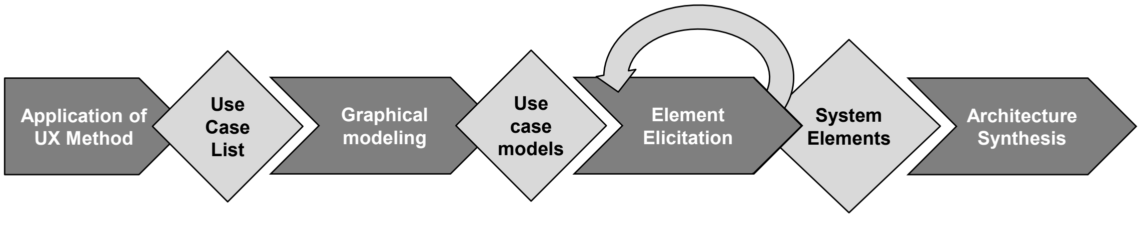

Figure 1. Research approach overview

4.2 System Elements

Using the use case scenarios as a starting point, we identify various elements to describe the PSS: Table 1 contains a list of such model elements which we seek to elicit from the modelled use cases along with a short description of each element.

Table 1. Model Elements Overview

Element	Description
Stakeholders	Various organizations and institutions such as suppliers, service providers, regulatory and governmental institutions that have an interest in the PSS in question. This also includes the eventual system user.
System Goals and Stakeholder Objectives	High-level goals the PSS in question is required to perform and the objectives the individual stakeholders value in relation to the PSS. The goals relate to the goal level proposed in Schenkl *et al.* (2014) and can be split into several categories, such as strategy goals, PSS-specific goals and quality goals.
System Requirements	Requirements are derived from the system goals and used as input to describe system functions.
Functions and subfunctions	Functions and subfunctions are used in functional modelling to represent technical systems and create understanding, especially in early phases of design (Pahl *et al.*, 2007, Stone and Wood, 2000).
PSS design elements	PSS design elements encompass all components that describe the PSS architecture. This includes hardware (mechanics, electrics/electronics) and software components as well as services.
PSS infrastructure elements	Infrastructure elements can be PSS-specific in that they need to be designed along with the PSS (e.g. charging stations for eBikes) or non-PSS-specific, such as streets and bicycle lanes that have a strong impact on the PSS.
Interactions and dependencies	This includes the interactions and their corresponding processes between system elements. Interactions can be of cyclic and non-cyclic as well as dynamic (changing over time) or static nature. For example, this could be an interaction between the system user and a terminal manage bookings for eBikes
Cycles	Temporal and/or structurally cyclic patterns that can be divided into individual phases and has certain properties such as "repetition, phases, duration, trigger and effects" (Schenkl *et al.*, 2013)

For each of these elements and thus the use case scenarios themselves, different alternatives on different levels (e.g. weighing of system goals, choice of suppliers and design elements) can be identified and modelled. These alternatives can later be investigated and compared using derived KPIs in order to find the optimal system design.

4.3 Modeling Process

4.3.1 User Experience Methodology

Before the application of the story-driven methodology, a general definition of the PSS in question has been developed. This systems definition contains: geographical boundaries, system mission and goals. Specifically for this exemplary case, the system mission is a sharing concept for electric bicycles (Pedelecs), that links together campuses of the University of Munich, based on the hardware concept of the PSSycle. Furthest travel distance between the campuses is about an hour. The high-level system goals are to offer cheap, environmentally sustainable and flexible mobility to the user groups working and studying at the campuses as well as to establish a profitable business model for the PSS operator.

In the first step of the modelling process, the methodology developed by Michailidou *et al.* (2013) will be applied, in order to create user experience stories based on individual use cases. The methodology is based on ten steps: First, the methodology starts with identifying psychological motives and needs that drive the user and that the PSS in turn should fulfill. The next step in the methodology is the creation of a character who drives the story. This will be the main actor of the identified use cases.

Depending on the development objective, a typical or an atypical user of the PSS can be created, as well as multiple characters for multiple storylines, in order to describe a range of scenarios (e.g. young students, elderly people with special needs, etc.). Form sheets can be used for character creation. As the fourth step, the methodology suggests listing items that are highly relevant to a holistic user experience. Within the fifth step, the concrete use cases are being collected. Focus is on use cases that are particularly critical to the user experience story. The identified use cases can be chronologically classified into pre-use, during use and post-use. Key events that represent for example the problems solved by the PSS in development are defined in step six. Step seven contains the development of a plot line along which the use cases and key events will be arranged. In steps eight and nine, the use cases are detailed and textually developed into substories. Eventually, step ten calls for an appropriate visualization of the story, e.g. in the form of text, as a storyboard or film. The strengths of this methodology is the support of a user-centered concept-development, explicitly incorporating user needs and motive and allowing to develop a variety of alternative scenarios.
In the context of this paper, this methodology will be used as a framework to guide the identification of use cases. The defined use cases are initially written down in a textual format. The eventual visualization of the use cases will then be conducted in a graphical format using a domain-specific language of own definition.

4.3.2 Graphical representation of Use Cases

From the two existing approaches for graphical modelling described in section 2.1, for the initial application and evaluation of the approach the DSL-approach has been chosen. A DSL has been developed that contains the necessary elements to represent the use case scenarios. These elements include on the one hand flows such as information, material, energy and money, on the other hand nodes such as PSS design elements, infrastructure and stakeholders such as the main actors and other organizations and institutions. A selection of elements of the language is shown in figure Figure 2.

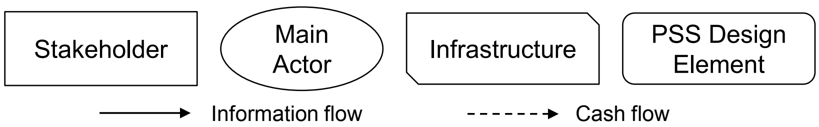

Figure 2. Selected elements of the domain-specific language to model use case scenarios

For the graphical representation, modelling began with the most important use case. This might be one that is the most defining for the PSS, the most often triggered, the most important one for customer satisfaction etc. Successively with each modelled use case, the basis of identified system elements grows and thus the logical architecture grows. Already identified elements can then be used to describe and detail further use cases. An example for a modelled use case is presented in Figure 3, describing the use case of a PSS user booking a bicycle.
For each use case, the first step was to identify the main actor as well as the relevant stakeholders that will be addressed in the use case. After that, PSS design elements the user interacts with as well as infrastructure elements that link PSS design elements to stakeholders and stakeholders to each other are included. Lastly, the interactions necessary to perform the actions that yield an observable result from the system are modelled.
The next step concerning the graphical use case modelling is the representation of the use case scenarios in the standard modelling language SysML. Using SysML aids in the creation of more specialized diagrams, for example sequence diagrams to model the temporal succession of interactions. Thus, the combination of specialized diagrams and the creation of a model base that has a broader application in the development process can further aid in identifying PSS architecture elements. However, this step is not represented as part of this paper.

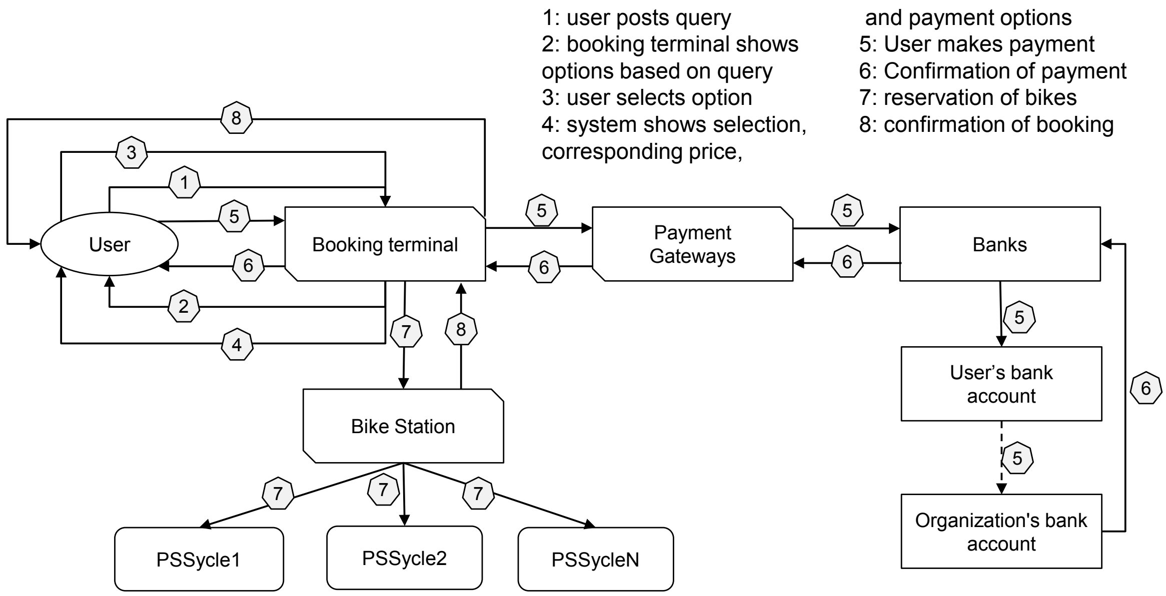

Figure 3. Detailed use case scenario for the use case "bike booking"

4.3.3 Elicitation of model elements

Based on the modelled use cases, apart from the main actor, further stakeholders that need to be addressed in a certain scenario can be identified. To support a systematic and methodological identification and definition of the system elements described in section 4.2, a process is necessary. Figure 4 shows a preliminary version of this process. After the generation of the PSS idea and the specification of system goals, the use cases are defined and the scenarios detailed. Then, in iterative steps, stakeholders, requirements, functions, system elements and interactions are identified and the use case scenarios are further detailed and refined, if necessary. After the complete identification of the relevant elements, analysis considering structural and temporal cycles within the use phase of the PSS can be done.

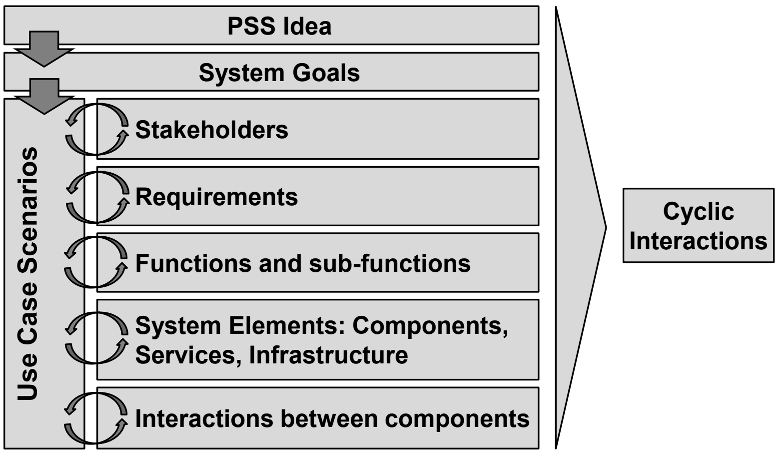

Figure 4. Process for element identification

Applied to the initial use case scenario developed in Figure 3, it becomes quite clear that in a apparently simple process such as booking a bicycle, a number of stakeholders are involved besides the user and the operator providing the infrastructure, for example the respective banks handling the monetary transactions. An alternative for the design of the process could even integrate a third-party provider handling the transactions. Since all involved parties pursue their own goals (like making a profit off of each transaction), a number of different requirements not just concerning the technical systems but also the social structure and corresponding contracts arise. Functions for conducting the transactions and sub-functions such as maintaining data integrity need to be considered during development. Concerning the physical embodiment, the user needs to be provided with at point of access (hard- and software) to initiate and conduct the payment process, such as his own smartphone, a mobile terminal on a bike or a fixed terminal on a station, having severe implications for the embodiment of PSS and supporting infrastructure. Lastly, the use case presents several cyclic interactions (structural and temporal) such as between user and terminal and between stakeholders such as banks and infrastructure.

5 RESULTS

The presented approach allows the user-focused definition of use cases and the graphical modelling of the use case scenarios. With the help of this approach, first a list of critical use cases has been developed using a typical character that might use the PSSycle system. These use cases span the phases before, during and after usage, such as booking a bike, navigating to a desired location, payment and triggering the repair service. Using a DSL, the use cases have then iteratively been refined and detailed. Based on the detailed use case scenarios the necessary functions of the PSSycle system have been identified, for example to enable to use case of booking a bike. Furthermore, hardware components such as booking terminals and connectivity to the internet have also been identified as well as interactions that connect these elements. Closely connected with these elements are the requirements that are necessary to fully specify the intended design.
Within the scope of the project, a value chain model has initially been defined in order to describe the internal structure of PSS. This value chain model has originally been described in Omer *et al.* (2014). A further use of the use case scenario models was to challenge this model and evaluate the validity of its first draft. The result was that the value-chain-based model has validity to it, but in order to fully represent different PSS, it needs to be more flexible.

6 DISCUSSION

The presented modelling approach extends existing use-case approaches to support the development of PSS (cp. Section 2.3) in two ways: First, the presented modelling approach is based on a methodology from the domain of user experience design. This methodology naturally focuses on the system end-user. While it may be possible to apply the methodology to other system stakeholders, such as suppliers and service providers, adaptions might be necessary. This is rooted in the fact that the application of the user experience methodology may prove difficult when no concrete character can be clearly defined, as it is the case with such business entities. To this point, it has only be applied to the viewpoint of the PSS end-user. Applying the methodology to different stakeholders of the system in question should yield different results in the form of new use case scenarios and thus improve the system model. Secondly, the iterative detailing of the developed use case scenarios aids the modeler in identifying connection points between social (system stakeholders) and technical system components with increasing detail.
Considering also the scope of the methodology, it seems best suited for early stages of PSS development, after defining the PSS idea, in order to get an initial picture over the sociotechnical system, its various elements and stakeholders.
Furthermore, the proposed modelling method only allows the identification of stakeholders that are directly related to the use case scenarios. For the systematic identification of stakeholders that are not directly related to use case scenarios, the application of further methods is necessary.
The process for the actual identification and elicitation of system elements needs further refinement in order to provide a systematic way to identify the necessary elements.

7 CONCLUSION AND OUTLOOK

In this paper, the application of a use case modelling approach for the elicitation of sociotechnical system elements has been presented. The approach adapts a methodology developed for the domain of user experience design for the definition of use cases. The resulting use cases are then detailed using a DSL. The modelling approach yields results in the form of PSS elements such as stakeholders, requirements, functions and subfunctions, PSS design elements such as hardware components and services, infrastructure, and interactions between system elements. Thus the approach represents one way to fill the layer models proposed by Schenkl *et al.* (2014) and Kammerl *et al.* (2014) with the respective elements needed to fully describe a PSS

One of the next steps will be the application of the approach and the transfer of the developed graphical models into a SysML-based description, as compared to the domain-specific language that has been used in the context of this paper. For this, for example the ”PSS Integration Framework” developed by Kernschmidt *et al.* (2013) can be applied. With the transfer into a SysML-based description, additional well-established diagrams can be used for the description of the use case scenarios as well as the PSS elements, such as requirements diagrams and activity diagrams.

Based on the findings of the use case modelling done so far, a developed, preliminary metamodel for the description of a sociotechnical perspective on PSS will be improved. Thus, the developed use case scenario models and the identified system elements will be used in the application of a “model-lifting”-approach (i.e. abstraction of the concrete models) in order to extract syntax and semantics for the development of a metamodel (e.g. in the form of an ontology), which can then be used to describe the sociotechnical perspective of a range of PSS in order to improve model comparability. Such an approach is for example described by Höfferer (2007). Consequently, questions regarding the different levels of detail when modelling use cases need to be addressed.

Eventually, based on the system definition, the identified system elements and developed static models (whether in DSL or SysML) will be used to build dynamic models such as agent based or system dynamics models, in order to evaluate strategic PSS design alternatives. To enable this, critical success factors and key performance indicators for the PSS in question will also be developed.

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