Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 00 (2015) 000–000

www.elsevier.com/locate/procedia

7th Industrial Product-Service Systems Conference - PSS, industry transformation for sustainability and business

Towards a meta-model for the description of the sociotechnical perspective on Product-Service Systems

Christoph Hollauer[a*], Julian Wilberg[a], Sebastian Maisenbacher[a], Mayada Omer[a]

[a]*Institute of Product Development, Technische Universität München Boltzmannstraße 15, 85748 Garching*

* Corresponding author. Tel.: +49-89-289-15136; fax: +49-89-289-15144. *E-mail address:* hollauer@pe.mw.tum.de

Abstract

Due to the increased pressure from today's globalized economy, companies need to develop innovative systems in order to achieve greater market competitiveness. Product-Service Systems (PSS) are one possibility to realize this. In order to successfully realize PSS, their surrounding social subsystems containing vital stakeholders such as suppliers and service providers, legislative bodies and users, need to be designed and developed along with the technical components. In order to achieve this, the modelling of large and complex sociotechnical systems becomes necessary. These sociotechnical systems result from the existence of multiple social and technical subsystems within PSS that are highly interconnected. Various tools for the analysis of complex sociotechnical systems exist, however there are currently no systematic approaches available in PSS research to describe these sociotechnical systems in order to create comparable system models. This paper describes the development of a metamodel for modeling of such sociotechnical systems. The approach applied is a combination of a literature survey into existing approaches of PSS metamodeling and the abstraction of concrete models created based on a case study of a bike sharing system developed by students. In the future, the metamodel will be refined, formalized, and used as a basis to conduct e.g. complexity analyses of sociotechnical systems of PSS.

Peer-review under responsibility of the International Scientific Committee of the Conference is co-chaired by Prof. Daniel Brissaud & Prof. Xavier BOUCHER.

Keywords: sociotechnical, metamodel, product-service system

1. Introduction

1.1. Initial Situation

Product Service Systems (PSS) are combined offerings of technical products and intangible services in order to deliver value-in-use to the customer [1]. PSS are an approach for companies to create more innovative and thus competitive market offerings and deal with challenges such as environmental sustainability [2].

According to Tukker [3], three main types of PSS can be characterized: 1) Product-oriented PSS, focused on product sales aided by the addition of some services such as product maintenance. 2) Use-oriented PSS where the focus shifts from product sales to e.g. renting, sharing or pooling. 3) Result-oriented PSS, where results are agreed upon by provider and user instead of determining a product from the beginning.

Offering PSS increases the complexity of innovation and development, as compared to purely technical products, due to a higher number of involved stakeholders, engineering domains, and necessary competencies. For example, this makes the synchronization of hardware and service engineering necessary. Closely connected to the developed products and services are the social subsystems necessary in order to allow the development, production and eventual use of the PSS in question, including: Stakeholders such as engineers, suppliers, providers, and organizations such as legislative bodies but also the eventual users. This holistic, sociotechnical view on PSS,

Peer-review under responsibility of the International Scientific Committee of the Conference is co-chaired by Prof. Daniel Brissaud & Prof. Xavier BOUCHER.

investigating closely intertwined technical and social subsystems that influence each other (hence sociotechnical systems) will be called the sociotechnical perspective in the context of this paper. Due to the increased amount of effort necessary for synchronizing and coordinating tasks and processes in these sociotechnical systems, the innovation process consumes an increasing amount of time while markets demand new innovations in quick succession [4].

The sociotechnical systems considered in the context of this paper can be rather large and complex, consisting of multiple social and technical subsystems with numerous components and dependencies. They are highly interconnected, e.g. in the form of supply chains, tight networks of service providers, individual PSS users organized in social networks, and various other institutions and organizations such as legislative entities. Each sociotechnical system is unique in its individual characteristics and multiple distributed complex sociotechnical systems may themselves be intertwined and related, thus creating sociotechnical “systems-of-systems” [5].

After this short presentation of the initial situation and the definition of the problem in the next section, the paper is structured as follows: Section 2 offers a short overview over the research methodology, while section 3 contains the background in metamodeling, ontologies and an introduction of an integration framework for PSS modeling that has been developed so far. Section 4 contains the overview over the conducted review concerning PSS metamodels and ontologies, an introduction to the case study and the abstraction of concrete models. Section 5 presents the developed, preliminary metamodel for modeling the sociotechnical system of a PSS and section 6 concludes the paper and gives a short outlook on future work to be done.

1.2. Problem Statement

In order to deal with the increased complexity of developing and offering PSS (due to a large number of stakeholders with individual and sometimes conflicting objectives) and to achieve a joint optimization of social and technical subsystems of the PSS, the understanding, design, and management of socio¬technical systems becomes a vital factor already in early phases of the PSS development process. For this, adequate design tools and modeling techniques are necessary in order to capture the elements and relationships that lead to an increased complexity.

Such complex systems can be analyzed using available methods, for example from the domain of structural complexity management or dynamic simulations, e. g. System Dynamics or Agent Based modeling ([6], [7]). However, the comparability of analysis results between different topologies of sociotechnical systems offers another challenge, due to a lack of communality when it comes to modeling of socio-technical systems.

Based on these two identified problems, the definition of a metamodel that allows a (formal) description of sociotechnical systems in relation to PSS seems suitable to support the capture and analysis of the systems complexity (i.e. the elements and relationships involved) and at to achieve an increased comparability between system models.

The preliminary metamodel presented in this paper offers a theoretical contribution to the field of the investigation of the sociotechnical perspective on PSS. The first draft of the metamodel presented in this paper is focused on use-oriented PSS. The expansion to include other forms of PSS is subject to further work in this field.

2. Research Methodology

In this section, a quick overview of the research methodology applied in this paper is presented. A graphical illustration of the research methodology is depicted in **Fehler! Verweisquelle konnte nicht gefunden werden.**. At first, a literature survey is conducted in order to clarify the research field and identify the topics necessary to create a metamodel of sociotechnical systems specifically in the context of use-oriented PSS. In a second step, existing approaches towards meta-modeling of PSS will be collected and evaluated with regard to their focus on a sociotechnical perspective, in order to collect root concepts and already identified relationships between them. The existing metamodels will be further enhanced as necessary, using the abstraction of concrete models developed in the context of this project. The concrete models are based on the case study of a pedal-electric bike sharing system which is presented in section 4.3. Based on the findings of the previous steps, the metamodel will be compiled from existing and newly defined elements. The developed metamodel can then again be used for the creation of concrete models in order to evaluate the approach and identify potential for improvement.

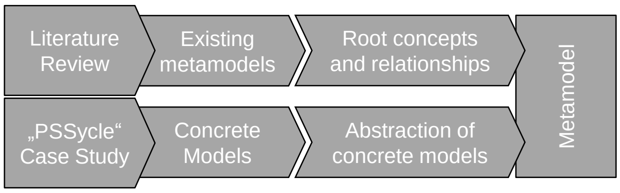

Figure 1. Overview over research methodology

3. Background

Section 3 presents the theoretical background of the research being done. First, the necessary research topics, metamodels and ontologies, are being discussed. The concluding section of section 3 introduces a cross-disciplinary integration framework for PSS modeling. The work done in this paper is intended to contribute to this modeling framework eventually and extend it to towards the modeling of the sociotechnical perspective on PSS.

3.1. Metamodels

A metamodel can be defined as the model of a modeling language or as “model of models”, meaning the description of a set of models. Important is however the distinction that a metamodel is not just the model of a model (singular). Creating a metamodel thus means creating a modeling language that has the capability to describe all relevant aspects of a subject under consideration ([8], [9]). The relationship between models, metamodels, and modeling languages is represented in Figure 2. A model of a subject (e.g. a PSS) is created using a modelling language which in turn is described by a metamodel. In practice, the description of the meta²-level is often reflexive and thus the creation of further metamodels is not necessary [9].

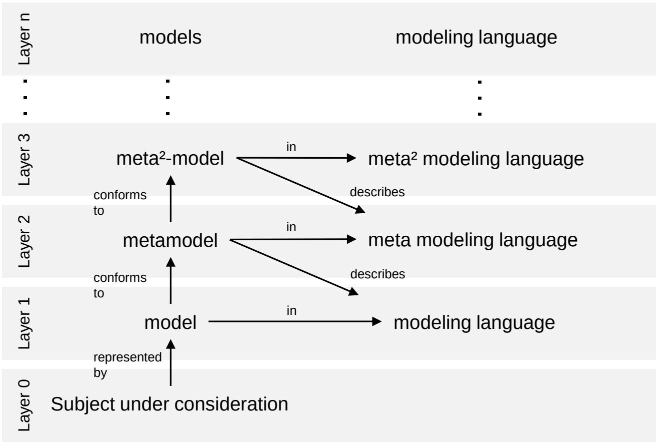

Figure 2. Metamodeling hierarchy [9]

3.2. Ontologies

A differentiation exists between the concepts of metamodels and ontologies, although they are closely related in practice. The basic distinction according to Höfferer [7] lies in that metamodels provide syntax for a modelling language (i.e. the definition of modelling constructs and their valid combinations) while ontologies provide semantics.

The concept of ontologies originates in the field of philosophy where their basic goal is to describe reality [9]. Ontologies are widely applied in the domain of computer science and related research fields, in a capacity originally defined by Gruber [10] as a “formal, explicit specification of a shared conceptualization”, where the term conceptualization is an abstract and simplified view of reality that is being presented with a specific purpose in mind. The formality aspect implies ontologies are machine-processable while “shared” implies a degree of consensus in the applying community. The conceptualization contains a set of entitites (objects, concepts etc.) important for the domain under observation and the relationships or dependencies that exist among them [11].

Uses of ontologies are for example the support of communication by providing common frameworks, improving inter-operability between different users that need to exchange data or between different software tools by creating an integrative environment [12].

3.3. PSS Integration Framework

The PSS Integration Framework (PSSIF) as described in [13] and [14] is a flexible and extensible framework for the cross-disciplinary development of PSS and allows the transformation of various discipline-specific models, e.g. SysML, event-driven process chains, business process model notation (BPMN) etc. It already includes edges for information, energy, material, control and value flow as well as a number of generic relationships. Also, the meta²-layer of the PSSIF as depicted in Figure 3 is reused in the metamodel of the sociotechnical perspective. In general, the PSSIF presents a more high-level approach to capture different modeling approaches while the metamodel presented in this paper has the focus on modeling sociotechnical aspects of PSS. So while the basic structures are similar, the focus is different. The metamodel presented in this paper can extend the integration framework to support the investigation of sociotechnical systems, e.g. by capturing relationships between product and services models defined in SysML or BPMN and the respective suppliers, providers or stakeholders formulating system requirements.

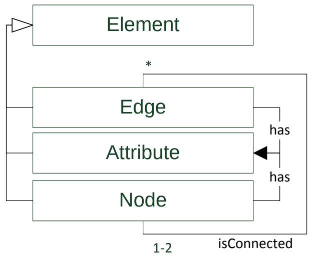

Figure 3. Top-level structure of PSSIF from [13]

4. Approach

The following section contains the conducted literature survey and the obtained results in the form of existing metamodels and ontologies for the description of PSS. From the results of the survey, a lack of focus on the sociotechnical perspective of PSS can be deduced. Further, the context of the case study is presented in 4.2.

4.1. Literature Review - Existing Metamodels, ontologies and PSS design methodologies

First, existing metamodels concerned with the description of PSS have been collected, explicitly focusing on the literature on PSS modeling and design. An important point for the evaluation of the existing metamodels and ontologies is their suitability for the description and modeling of the social sphere of PSS, such as important stakeholders and their relationships with each other as well as the PSS.

Table 1. Selection of PSS metamodels and ontologies from literature

Source	Comment
[15]	Development of an ontology on PSS research. The root concepts of PSS have been identified and consensus has been found. However, the ontology has not been evaluated and relationships have not been fully detailed. Some sociotechnical aspects such as stakeholders (suppliers, providers) and supply networks are included, but no detailed description. The goal of the ontology is the improvement of the communication of top-level PSS concepts.

[16]	Includes a very high level and generic description of stakeholders. However, the focus lies on the representation of value, function, and structures as well as the relationships between them.
[17]	The metamodel contains nine “PSS design dimensions”. No concrete language elements for the modeling of PSS designs have been defined in a more conventional sense of a metamodel.
[18]	Metamodel for sociotechnical systems. However, he underlying understanding of sociotechnical systems is different in this context and more focused in the individual-task relationship and the work system.

Generally, metamodels exist with a focus on specific aspects of PSS modeling. In the context of the literature review, existing PSS metamodels, ontologies and design methodologies have been evaluated to see whether sociotechnical aspects of PSS design have been included. A selection of metamodels and ontologies is presented in Table 1. Also, root concepts relevant for the description of PSS as sociotechnical systems have been identified. For example, [15] describes root concepts relevant for this work, such as:

- Stakeholders
- Suppliers
- Providers
- Supply Network
- Support Systems
- Infrastructure

However, while the root concepts have been identified, relationships between the concepts, further classification and attributes of elements have not been addressed systematically.

Relevant in the context of this paper are metamodels and ontologies that support the concrete design and modeling of PSS. While a number of ontologies and metamodels for the description of specific aspects such as the design of services, products, and infrastructure exists, there is currently no metamodel that has an explicit focus on the modeling and design of the social subsystems of the sociotechnical system of PSS. In recent literature consolidating the state of the art of PSS design methodologies, such as [19], the consideration of the sociotechnical perspective, especially the investigation of stakeholders and their involvement has been found lacking.

4.2. Case Study “PSSycle”

The approach for the definition of a metamodel of the sociotechnical perspective on PSS is partially based on the creation and abstraction of concrete model of a PSS case study, the “PSSycle”. The PSSycle used has been developed as a student project within the context of the collaborative research centre ‘Sonderforschungsbereich 768 – Managing cycles in innovation processes’, to serve as a demonstrator for developed results. The concept represents an innovative pedelec (pedal electric bicycle) sharing system, consisting of the necessary hardware, software, and service components, e.g. for bike booking, navigation, and pay-per-use. Goal of the PSS case study is to offer sustainable (sub-) urban mobility based on a pay-per-use business model. Focus of the student project was the development of the hardware components. Services have been initially defined but not fully detailed. Also, the corresponding social systems have not been described in detail. Hence, in the scope of this work, selected social subsystems such as the supply chain, including service providers, have been developed. First, in order to create more context for the case study, system goals have been defined, such as enabling spontaneous, sustainable mobility, and system requirements have been specified. These system goals are: Offering cheap, environmentally sustainable and flexible mobility to users in urban environments. Based on this system definition, the stakeholder use cases, requirements and system functions have been derived. Consequently, suppliers have been defined, including an initial description of their internal structure, based on existing hardware specifications (e.g. parts lists) and variations of exemplary supply chains have been compiled in SysML. The same way, service providers have been defined in order to perform the individual services for the PSS, such as offering navigation, entertainment or payment processing, in which one provider can provide one or multiple services within the system. Other stakeholders, such as technical control boards and legislative authorities formulate specific requirements, e. g. concerning the road-safety of the pedelecs offered in the context of the business model.

4.3. Model abstraction

Based on the case study described in the previous section, concrete models have been developed that describe different aspects of the system. The models have been implemented in the MagicDraw Software using SysML 1.3. At this point, no specialized profiles or stereotypes of SysML (such as e. g. SysML4*Mechatronics* [20]) have been used to develop the models. The models represent different levels of abstraction and span the range of available SysML diagrams, including structural (e.g. block definition diagrams, internal block diagrams) as well as behavioral diagrams (e.g. state charts, activitiy diagrams). For the initial development of the metamodel, the focus lies on structural diagrams. Developed models include for example:

- The structural description of the PSS in question and its infrastructure (Block Definition Diagram)
- Use cases for system user and supply chain (Use Case Diagram)
- Different types of suppliers and providers along with variations of the supply chain topology (Block Definition Diagram)
- Hierarchies of services (Block Definition Diagram))
- A state chart of the possible states a single PSSycle can exhibit over the course of its life, e. g. “functional”, “reserved”, “in use”, “defect” etc. (State Chart Diagram)

The developed models are analyzed in respect to how they fit to established metamodels and ontologies, thus supporting the identification of common and important elements from the pre-existing metamodels and enriching the elements, especially with relationships and attributes.

Based on this, three layers that structure the social sphere of influence have been identified. These represent organizations and their networks, intra-organizational structures, and individuals. In the process of creating the concrete models, a number of stakeholder attributes and functions have been identified that are partly lifted to the metamodel. For sake of readability, the attributes have been omitted in the following figures. However, as relevant attributes have for example been identified, among others: The geographic location, the financial position, and the available inventory and tier of suppliers.

As a next step after the abstraction of the elements, the identified elements are merged with the ones from literature, with the specific focus on the interaction between stakeholders as well as the interface between stakeholders and elements of the PSS.

5. Metamodel for the sociotechnical perspective on PSS

The resulting, preliminary metamodel describes the various layers that exist within the social sphere, the relations within and between them as well as the relations with the technical systems of the PSS. Figure 4 represents the structure of the sociotechnical system as it is observed in the context of this paper.

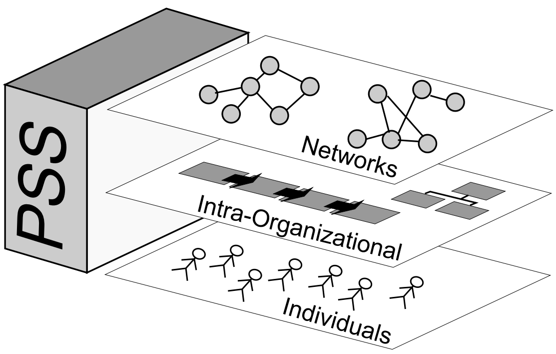

Figure 4. Structure of the sociotechnical perspective

The model consists of several layers: The top layer represents a macroscopic perspective, the large-scale networks in which individuals as well as organizations are connected. The middle layer contains the intra-organizational perspective, detailing the internal layout of organizations, e.g. the elements of the value chain such as inbound logistics and operations as well as team-structures. The bottom layer represents the individuals that form the basis of the other two layers as well as their interactions with the PSS in question. Interactions between social sphere and technical systems in a PSS such as the PSSycle can be observed on all layers, with increasing specificity from top to bottom layer, or aggregated from bottom to top, depending on the required perspective.

A section of the class diagram containing the classes defined for the description of social subsystems is presented in Figure 5. In terms of flow classes, the metamodel extends the flows of the PSSIF by adding monetary flow. Abstract Classes that cannot be instantiated directly are written in Italics.

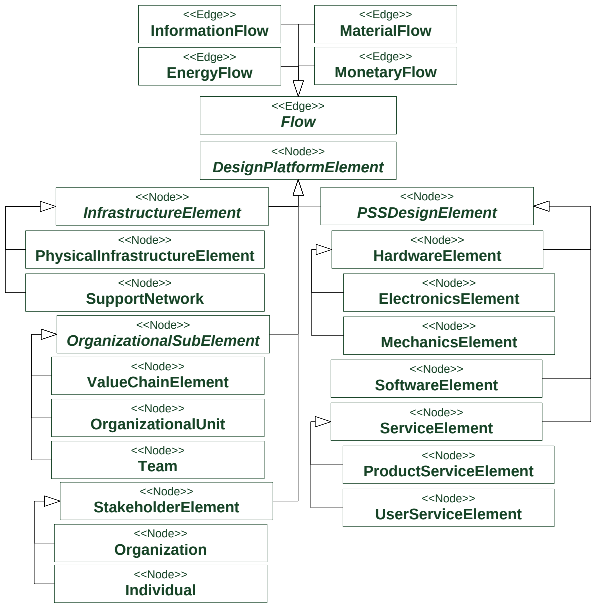

Figure 5. Metamodel Class Diagram

Figure 6 shows a section of the metamodel focused on relationships between classes and instances of the three layers as well as with the PSS. For example, the SupplyChainNetwork is an instance of the class SupportNetwork In the representation, a *<<Node>>* represents an element type which can be used in a model. Relationships between elements have a direction, description and multiplicity on either end. *Inheritance* relationships are represented using a white arrowhead [21].

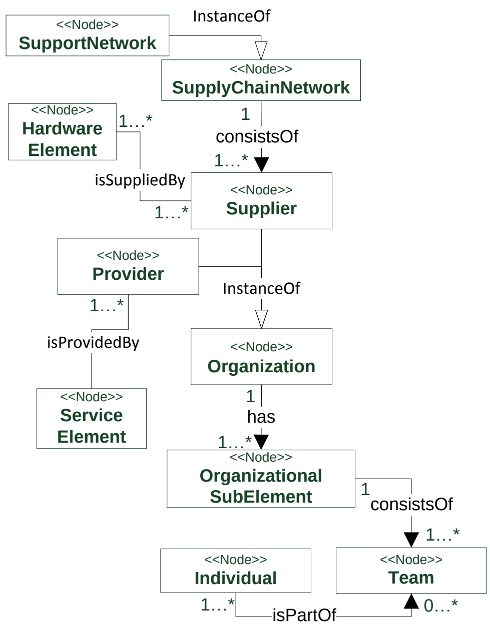

Figure 6. Example for relations within the metamodel

For an easier visualization, the dependencies within the metamodel are contained in multiple diagrams, representing coherent subsystems (e.g. representing the layers of the model presented in Figure 4) of the relationships within the metamodel.

For example, the relationship of a supplier with the PSS, supplying a specific component such as bicycle brakes can be described rather generically as “Supplier supplies brakes”. However, the relationship can be broken down into more specific (sub-) relationships if necessary such as “Outbound logistics (OrganizationalSubElement) ships brakes”, for a more detailed description.

Since the focus is on the description of the PSS during its use phase, development artefacts such as requirements are currently not included in this metamodel. The focus instead lies on solution artifacts which in this metamodel are called “PSS Design Platform Elements”. If the necessity arises, due to the extensibility of the metamodel, further elements can be included by adding them to the class diagrams and establishing the necessary relationships. Furthermore, the presented metamodel focusses on the layout of the sociotechnical perspective of PSS as seen from the PSS operator. Other aspects have been disregarded so far.

6. Conclusion & Outlook

In this paper, a preliminary metamodel for modeling the sociotechnical perspective on PSS, focusing on the social subsystems, such as stakeholders, organizations etc. and their interaction with the technical subsystems of the PSS has been presented. The creation of the metamodel has been motivated by the identified need to support the systematic description of the sociotechnical perspective on PSS and capture its complexity on different levels in order to support the design, management and joint optimization of sociotechnical systems. The creation of a systematic description of sociotechnical systems can support the comparability of different sociotechnical systems and the deduction of implications for the social sphere from the structure of the technical systems.

The next step will be the implementation of the full metamodel in an appropriate software tool in order to fully codify it and enable a graphic representation. Furthermore, based on the implementation the metamodel can be iteratively extended and improved, e.g. the list of attributes with which individual stakeholders as well as the relationships are described and instantiated can to be further detailed and the set of possible relationships between stakeholder and PSS can to be extended based on empirical data. To achieve a wide ranging consensus, the metamodel needs to be evaluated by a broader spectrum of experts from research and practice. The metamodel can enable the extension of consistency and constraint analyses from the technical subsystems to the sociotechnical level, thus including social subsystems, e.g. organizations and their networks such as suppliers and service providers.

Acknowledgements

We thank the German Research Foundation (Deutsche Forschungsgemeinschaft – DFG) for funding this project as part of the collaborative research centre ‘Sonderforschungsbereich 768 – Managing cycles in innovation processes – Integrated development of product-service systems based on technical products’.

References

[1] T. S. Baines, H. W. Lightfoot, S. Evans, A. Neely, R. Greenough, J. Peppard, R. Roy, E. Shehab, A. Braganza, A. Tiwari, J. R. Alcock, J. P. Angus, M. Bastl, A. Cousens, P. Irving, M. Johnson, J. Kingston, H. Lockett, V. Martinez, P. Michele, D. Tranfield, I. M. Walton, and H. Wilson, “State-of-the-art in product-service systems,” *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, vol. 221, no. 10, pp. 1543–1552, Jan. 2007.

[2] A. Tukker and U. Tischner, “Product-services as a research field: past, present and future. Reflections from a decade of research,” *J. Clean. Prod.*, vol. 14, no. 17, pp. 1552–1556, Jan. 2006.

[3] A. Tukker, “Eight types of product service system: Eight ways to sustainability? Experiences from Suspronet,” *Bus. Strateg. Environ.*, vol. 13, no. 4, pp. 246–260, Jul. 2004.

[4] S. a. Schenkl, F. G. H. Behncke, C. Hepperle, S. Langer, and U. Lindemann, “Managing Cycles of Innovation Processes of Product-Service Systems,” *2013 IEEE Int. Conf. Syst. Man, Cybern.*, pp. 918–923, Oct. 2013.

[5] M. Jamshidi, “System of systems engineering - New challenges for the 21st century,” *Aerosp. Electron. Syst. Mag. IEEE*, vol. 23, pp. 4–19, 2008.

[6] U. Lindemann, M. Maurer, and T. Braun, *Structural Complexity Management-An Approach for the Field of Product Design*, no. July. Berlin: Springer, 2008, p. 248.

[7] A. Borshchev and A. Filippov, “From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools,” 2004.

[8] J.-M. Favre, “Foundations of meta-pyramids: Languages vs. metamodels Episode II: Story of thotus the baboon,” *Lang. Eng. Model. Softw. Dev.*, vol. 4101, pp. 1–28, 2005.

[9] P. Höfferer, “Achieving Business Process Model Interoperability Using Metamodels and Ontologies.,” *ECIS*, pp. 1620–1631, 2007.

[10] T. R. Gruber, “A translation approach to portable ontology specifications,” *Knowl. Acquis.*, vol. 5, no. 2, pp. 199–220, 1993.

[11] S. Mostefai, A. Bouras, and M. Batouche, “Effective Collaboration in Product Development via a Common Sharable Ontology,” *Int. J. Comput. Intell.*, vol. 2, no. 4, pp. 206–212, 2005.

[12] M. Uschold and M. Gruninger, “Ontologies: Principles , Methods and Applications,” *Knowl. Eng. Rev.*, vol. 11, no. 2, 1996.

[13] K. Kernschmidt, T. Wolfenstetter, C. Münzberg, D. Kammerl, S. Goswami, U. Lindemann, and H. Krcmar, “Concept for an Integration-Framework to enable the crossdisciplinary Development of Product-Service Systems,” in *Proceedings of the 2013 IEEE IEEM*, 2013.

[14] T. Wolfenstetter, K. Kernschmidt, C. Münzberg, D. Kammerl, S. Goswami, U. Lindemann, and H. Krcmar, “Supporting the Cross-disciplinary Development of Product-Service Systems Through Model Transformations,” in *Proceedings of the 2014 IEEE International Conference on Industrial Engineering and Engineering Management*, 2014.

[15] R. Roy, Y. Xu, B. G. Annamalai, R. Hussain, M. Cakkol, S. Evans, and A. Tiwari, “An Ontology for Product-service Systems,” 2011.

[16] Y. S. Kim, E. Wang, and M. W. Park, “Value-Function-Structure Modeling in an Ontological Representation of Product-Service Systems,” in *International Conference on Engineering Design ICED*, 2009, pp. 359–370.

[17] P. Müller and T. Sakao, “Towards consolidation on product-service systems design,” in *CIRP IPS2 Conference 2010*, 2010, pp. 219–225.

[18] S. Alter, “Metamodel for Understanding , Analyzing , and Designing Sociotechnical Systems,” *Work. Pap. Inf. Syst.*, vol. 9, no. 2009.

[19] G. V. A. Vasantha, R. Roy, A. Lelah, and D. Brissaud, “A review of product–service systems design methodologies,” *J. Eng. Des.*, vol. 23, no. 9, pp. 635–659, Sep. 2012.

[20] K. Kernschmidt and B. Vogel-Heuser, “An interdisciplinary SysML based modeling approach for analyzing change influences in production plants to support the engineering,” in *9th annual IEEE International Conference on Automation Science and Engineering (IEEE CASE)*, 2013, pp. 1113–1118.

[21] B. Helms, “Object-Oriented Graph Grammars for Computational Design Synthesis,” 2013.