Smart Product-Service Systems: A Review and Preliminary Approach to Enable Flexible Development Based on Ontology-Driven Semantic Interoperability

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Abstract. This research conducts a systematic literature review on Smart Product-Service Systems (SPSS) to identify the current state of research and the gap related to flexibility issues by the views of semantics, requirements, and design methodologies. The review covers studies published between 2000 and 2022 in and finds a lack of systemic approaches on standardized formalization models, interoperability, context-aware systems, and self-adaptation. This gap in knowledge makes it difficult for companies to fully understand and implement a seamless and flexible SPSS development lifecycle. In response to this gap, the research proposes a preliminary approach for the implementation and management of SPSS, offering a possible solution for companies looking to understand and implement SPSS. The approach suggests that companies should technically focus on use of Artificial Intelligence (AI) technologies to support decision-making, and on formal standardized models to represent knowledge, helping to enable semantic interoperability across the development lifecycle. The proposed preliminary approach is a starting point for companies and for future research in the field.

Keywords: Smart Product-Service Systems, Ontology, Semantic Interoperability, Artificial Intelligence, Literature Review.

1 Introduction

The concept of Product-Service Systems (PSS) originated as a way for manufacturers to offer a comprehensive after-sales service to their customers, ensuring that products continue to function optimally over their lifetime [1]. Over time, the concept of PSS has expanded to include a range of services that go beyond just after market applications, incorporating value-added services such as product upgrades, extended warranties, and even access to digital content, among other examples [2].

Concurrently, with the advent of the Internet of Things (IoT) and advanced technologies, PSS has evolved into a smart and connected system that can collect and analyse data from products and services in use [3]. This data can be used to predict and prevent product failures, offer personalized services, and create new revenue streams for manufacturers [4].

Smart PSS represents a shift in the traditional PSS approach by increasing the degree of co-creation value proposition, where the focus is creating a superior customer experience and maximizing the value derived from the product whilst involving stakeholders across the entire development process [5][6]. In this context, Smart Product-Service Systems (SPSS) have become a popular strategy for companies to improve their value offer and providing a more holistic deliver to attend customer needs. However, despite the growing interest in this field, there is still a lack of understanding when it comes to the implementation and management of SPSS when considering the dynamic nature of its requirements and design flexibility across its development lifecycle [7]. In this context, this research aims to identify the current state of research in the field of SPSS, with a specific focus on issues concerning semantics, requirements, and flexibility in design methodologies.

Following the study of this research gap, the paper proposes a preliminary framework for the implementation and management of SPSS considering the developmental issues in the areas approached by the literature review. This continuous and evolving framework can be a starting point for companies and academics looking to understand and implement flexible development of SPSS in their operations, and for future research in the field.

1.1 Methodology

The exploratory goals of this research are applied in nature and qualitative in approach. A systematic literature review and content analysis are the research methods [8]. The four steps of the methodical procedure are Problem Identification, Systematic Literature Review, Content Analysis, and Solution Proposal, as shown in Figure 1.

Fig. 1. Methodological Procedure.

Problem identification (Detail 1 of Figure 1) is a crucial step in the research process as it sets the foundation for the entire project. In the context of this research, the problem identification process involved a comprehensive analysis of the existing approaches to the development of Smart Product-Service Systems (SPSS), as approached in the introductory section of this research.To gather relevant information on SPSS and related fields, a systematic literature review is proposed (Detail 2 of Figure 1). This review covers various databases, by a database aggregator engine, to collect and analyze the most relevant studies in the field. The literature review will help to identify the current state of the art in the theme and gaps in the current approaches.

The results of the literature review will be then analyzed using a qualitative content analysis technique to identify main contributions and limitations used in research (Detail 3 of Figure 1). The content analysis will help identify some of the key factors that that have been addressed by research and general points for improvement. Based on the results of the content analysis, a preliminary framework for the development of more flexible SPSS will be proposed (Detail 4 of Figure 1). The framework aims to provide a flexible and adaptable approach to the development of SPSS that can be adapted to different scenarios and dynamic requirements. The framework provides a systematic approach to the development of SPSS that can be used by engineers, designers, and other stakeholders in the development process.

2 Systematic Literature Review

2.1 Review Methodology

A systematic literature review will be conducted to gather relevant information on Smart Product-Service Systems (SPSS) and related fields by the perspective of issues related to design, requirements, and semantics. The review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure the quality and rigor of the process [9]. The methodology provides a standardized framework for reporting on the quality and rigor of the review process, being widely recognized and used in the scientific community to ensure the transparency and quality of systematic literature reviews. (Figure 2).

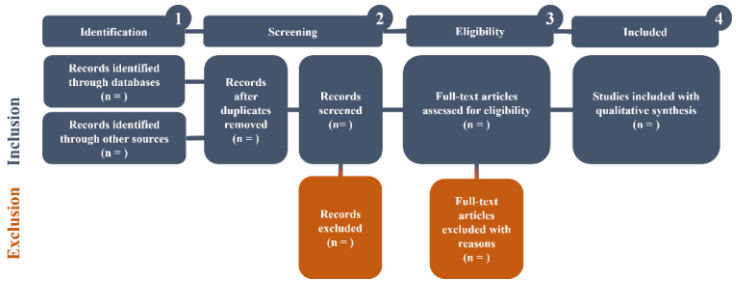

Fig. 2. PRISMA.

The review covers various databases, by using LENS.ORG, a scientific database aggregator comprising a vast number of bases such as Springer, Science Direct, Scopus, Emerald Insight, IEEEXplore, Taylor & Francis Online and many others. The search will be conducted using clusters of keywords related to each of the main issues studied in the review through a previous study [10] such as “Product-Service System”, “Hybrid Product”, “Smart Product-Service Systems” (for PSS design issues); “Requirements Elicitation”, “Requirements Specification”, “Requirements Validation” (for requirements issues); and “Semantic Interoperability”, “Semantic Interop”(for semantic issues). The inclusion and exclusion criteria will be established across review phases to ensure that only relevant studies are included in the review.

The results of the literature review will be then analyzed to identify the current state of the art in the development of SPSS and to identify the gap in the current approaches. The final analysis will be conducted using content analysis techniques to identify the key themes, tools, contributions, and limitations in the research.

2.2 PRISMA

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a guideline for conducting systematic literature reviews and meta-analyses, which focuses on delivering a standardized approach for reviews in many fields of research [11]. In this study the review will be split into the four main phases of PRISMA. In terms of objectives, this literature review should answer the following questions:

1. **What are the most relevant works, from the last 20 years, that approach identifying/reducing/solving issues related to semantics, design and requirements' structure in the development of Product-Service Systems?**
2. **What are the main contributions and limitations of these papers?**
3. **Which tools, methods and/or technologies from these works were applied to reduce/solve such issues?**

Identification

In this research, the identification phase started out by defining the criteria for surveying the literature, establishing period range, language, type of publications, and area of concentration/domain within area of concentration. A summary of the identification criteria is depicted in Table 1.

Table 1. Identification Criteria.

Search Criteria
From 2000 – 2022
English written papers
Related to Manufacturing Engineering AND/OR Systems Engineering and its adjacent areas
Journal Papers AND/OR Conference Papers AND/OR Book Chapters

Then, the querying method was established, based on the combinations of keyword clusters triple-wise (one cluster of each theme) and pairwise (a cluster from one theme combined with another). Additionally, 136 additional papers were added to the analysis based on papers discovered during the exploratory investigations. The results of this phase were the identification of n=9112 papers for further screening, bringing an overview of more than two decades in the field of study and adjacent areas.

Screening

Using the aid of a spreadsheet software, the screening procedure began by eliminating any duplicates from the total number of papers discovered during the previous phase.

The unique registers of the total number of entries led to a total of n=5901 publications being left for screening based on title and DOI.

Table 2. Screening Criteria.

Screening Criteria
Peer-Reviewed
Title or abstract approaches: (PSS Development) **AND/OR** (Flexible Design) **AND/OR** (Interoperability) **AND/OR** (Requirements) **AND/OR** (Semantics)
Paper in the field of interest and adjacent areas
Approach still in use (if applicable)

The screening process then, as shown in Table 2, examined the titles and abstracts of each of the distinct registries, using as a basis for exclusion papers that did not have peer review and/or did not have a defined strategy for resolving issues of interest and/or did not have outdated strategies and/or did not have familiarity with the field of interest and its surrounding areas. As a result of this analysis, n=274 papers were chosen as eligible from the n=5901 publications examined.

Eligibility

The Eligibility step of this literature review started by analyzing general aspects from selected papers from the screening process. From the 274 papers left after the screening process, 201 were eligible to be assessed, based on paper availability using the institutional access in research databases. Classification criteria for publications were established based on each of the major topics covered in the review. Based on the literature that was discovered and the primary research problem interests, an affinity score ranging from 0 to 3 was used to determine the affinity of the following criteria:

- Flexibility in Design: The degree to which the paper addresses how design choices can impact the flexibility of a system development.
- Flexible Requirements Management: The degree to which the paper presents methods to elicit or manage flexible requirements.
- Standardised and/or Well-defined Representation: Analyse the extent of how papers address the importance to standardised and/or well-defined knowledge representation (addressing semantics or not).

Included

Ultimately, the rules for paper inclusion and exclusion were determined, in order to determine the most relevant papers in the field concerning the main issues addressed by this literature review, being the Rule for acceptance a grade ≥ 2 in more than one criterion; and for rejection a grade = 0 (in any criteria) OR Grade < 2 in more than one criterion.

Table 3. Selected Papers.

Id	Selected Paper	Id	Selected Paper	Id	Selected Paper
1	Khedr, M., & Karmouch, A. (2004) [12]	13	Maleki, E., Belkadi, F., Zhang, Y., Bernard, A. (2016) [35]	25	Liu, Z., Ming, X., Zhang, X. (2019).[4]
2	Durugbo, C., Hutabarat, W., Tiwari, A., Alcock, J. R. (2010) [14]	14	Estrada, A., Romero, D. (2016). [37]	26	Wang, Z., Chen, C. H., Zheng, P., Li, X., Khoo, L. P. (2019).[24]
3	Akmal, S., Batres, R. (2011) [16]	15	Lazoi, M., Pezzotta, G., Pirola, F., Margarito, A. (2016). [39]	27	Liu, Z., Ming, X., Qiu, S., Qu, Y., Zhang, X. (2020).[26]
4	Berkovich, M., Leimeister, J. M., Hoffmann, A., Krcmar, H. (2011) [18]	16	Trevisan, L., Brissaud, D. (2016).[41]	28	Chen, Z., Ming, X., Wang, R., Bao, Y. (2020).[28]
5	Berkovich, M., Leimeister, J. M., Krcmar, H. (2011) [20]	17	Wiesner, S., Lampathaki, F., Biliri, E., Thoben, K. D. (2016).[43]	29	Farsi, M., Erkoyuncu, J. A. (2020).[30]
6	Dong, M., Yang, D.; Su, L. (2011) [22]	18	Scholze, S., Correia, A. T., & Stokic, D. (2016).	30	Watanabe, K., Okuma, T., Takenaka, T. (2020).[32]
7	Berkovich, M., Leimeister, J. M., Hoffmann, A., Krcmar, H. (2012) [23]	19	Neves-Silva, R., Pina, P., Spindler, P., Pezzotta, et al. (2016).[45]	31	Zhang, X., Ming, X., Yin, D. (2020).[34]
8	Akasaka, F., Nemoto, Y., Chiba, R., & Shimomura, Y. (2012) [25]	20	Zhang, J., Ahmad, B., Vera, D., Harrison, R. (2016).[13]	32	Zuoxu, W., Xinyu, L., Pai, Z., Chunhsien, C., Pheng, K. L., Pss, A. (2020). [36]
9	Akmal, S., Batres, R., & Shih, L. H. (2013) [27]	21	Correia, A., Stokic, D., Siafaka, R., Scholze, S. (2017).[15]	33	Li, X., Chen, C. H., Zheng, P., Wang, Z., Jiang, Z., Jiang, Z. (2020). [38]
10	Schmidt, D. M., Malaschewski, O., Fluhr, D., Mörtl, M. (2015) [29]	22	Wu, Y., Lee, J. H., Kim, Y. S., Lee, S. W., Kim, S. J., Yuan, X. (2017).[17]	34	Guillon, D., Ayachi, R., Vareilles, É., Aldanondo, M., Villeneuve, É., Merlo, C. (2021).[40]
11	Peruzzini, M., Marilungo, E., Germani, M. (2015) [31]	23	Wiesner, S., Westphal, I., Thoben, K. D. (2017).[19]	35	Rosa, M., Wang, W. M., Stark, R., Rozenfeld, H. (2021). [42]
12	Zhu, H., Gao, J., Cai, Q. (2015) [33]	24	Savarino, P., Abramovici, M., Göbel, J. C., Gebus, P. (2018).[21]	36	Yang, X., Wang, R., Tang, C., Luo, L., Mo, X. (2021).[5]
				37	Wu, C., Chen, T., Li, Z., Liu, W. (2021).[44]

As seen in Table 3, this selection of papers answers the first question of the literature review:

1. What are the most relevant works, from the last 20 years, that approach identifying/reducing/solving issues related to semantics, design and requirements' structure in the development of Product-Service Systems?

Based on the rigorous analysis of literature from the past twenty years, it can be said that the papers selected in this literature review brought a holistic view on the studied issues.

Content Analysis

The topics discussed in these papers relate to the design, development, and evaluation of Product-Service Systems (PSS). These papers cover various aspects of PSS design, such as requirements analysis, ontology development, service selection, customer acceptance, and resource allocation. The authors proposed different approaches and methodologies for PSS design, ranging from QFD-based approaches to ontology-based approaches, and from structured methodologies to Multicriteria Decision-making methods. The Content Analysis thoroughly analyzed each of the 37 papers and found their contributions and limitations, and the main tools, methods and methodologies used in literature, answering the remaining questions of the literature review:

2. What are the main contributions and limitations of these papers?

These papers discuss many facets of design, requirements analysis, and semantics from the viewpoint of ontology development, as well as service selection, client acceptance, and resource allocation as additional areas that were discovered. It was also clear that cooperation and communication amongst the many actors involved in PSS

development are important factors to take into account during development. Numerous tools and modular concepts were developed to manage the interfaces between different players in order to address this issue, however one of the major drawbacks noted in numerous articles was the absence of contemporary computational and standardized methodologies and implementations towards Industry 4.0 concepts, as well as clearly defined development methodologies. This impacts not only the scalability of such solutions but also hinders the validation of them under multiple scenarios.

3. **Which tools, methods and/or technologies from these works were applied to reduce/solve such issues?**

An evaluation of the tools and techniques discovered in the literature review has demonstrated that not all solutions explored are fully integrated or interoperable, needing additional exploration to overcome the limits of the research. By suggesting the integration of various technologies that could facilitate the development process and deal with the reconfiguration of Smart Product-Service Systems in response to the primary studied issues, the suggested solution for the research problem will complement the solutions offered in the found papers with new elements.

3 Preliminary Approach for Flexible Smart PSS Development

Based on the limitations and technologies found on current literature, a preliminary approach for flexible design in Smart Product-Service Systems, adapting/combining steps from products/services/systems' well explored development methodologies such as Integrated Product Development Process (IPDP), DevOps and Model-Based Systems Engineering (MBSE), is proposed, including tools found on selected literature based on Ontologies, Recommender Systems and Multicriteria Decision-Making (MCDM). A representation of the approach is depicted in Figure 3.

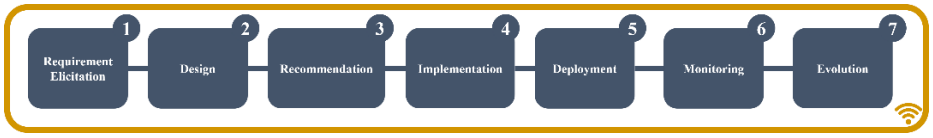

Fig. 3. Preliminary Approach.

The steps and tools of the proposed approach are:

1. Requirement Elicitation: Identifying the specific needs of the customers and the corresponding requirements for the Smart Product-Service System. This step defines the weights for development features (decision criteria), extracts information from customer and system feedback and identify patterns and trends through Natural Language Processing (NLP), Multicriteria Decision Making (MCDM) and chatbots.
2. Design: Approaches the conceptual design of the system (new or existent), including the product and service components, their interactions, and the overall system

architecture in form of Ontology models that represent the domain knowledge, entities, and concepts of the system.
3. Recommendation: Analyze the impacts of new and existing requirements, providing a suggestion of best resource allocation based on resource limitations, recommends features based on gathered requirements, and suggests design alternatives for new features based on MCDM and Recommender Systems with aid of Ontologies.
4. Implementation: Building and testing the system, including the development of the software and hardware components, and the integration of the product and service components by the aspect of new features.
5. Deployment: Deploying the system in the field, including the installation and commissioning of the product and service components, and the training of users and maintenance personnel.
6. Monitoring: Continuously monitoring the system and its components, and performing maintenance and updates as needed to ensure optimal performance.
7. Evolution: Continuously adapting and evolving the system to meet changing customer needs and market trends.

This is still a preliminary version of the solution, containing some of the found tools in the systematic literature review and adding some new tools to the process (such as Natural Language Processing and Chatbots). The main focus of this approach is to provide a deeper analysis of the requirements and focusing on scalability and implementation of techniques in the scope of Industry 4.0 (the main identified gap between selected papers). This approach will need high synergy and connection with development methodologies to be fully embraced but has the potential to manage requirements in an easier, more complete and holistic manner.

4 Conclusion and Future Works

The study aimed to address the challenges faced in the design of Smart Product-Service systems by proposing a preliminary solution that addresses the issues of requirements, design methods, and semantics. It conducted an extensive literature review and analysed various works on the field of study. The results of this analysis provided a basis for the development of the proposed solution.

The review provided a deeper analysis of the current state of research on the field of flexibility in design for Smart Product-Service Systems while exploring the main contributions, limitations and tools/methodologies used by authors to overcome the challenges. Additionally, the preliminary approach promotes the integration of new technologies and innovations, allowing organizations to enhance their solutions and improve the customer experience. However, more studies are necessary, and a deeper analysis of the proposed solution is necessary to provide further insights.

For future works, based on the current limitations of the research, the application and further development of the approach are recommended, while updating the literature review to more recent works and methods. Another possible outcome is working on the potential complexity of the framework, particularly in the areas of technology integration and implementation.

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