Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnline 58-08 (2024) i–vii

International Federation of Automatic Control

6th IFAC Workshop on Advanced Maintenance Engineering, Services and Technology AMEST 2024

Cagliari, Italy, June 12 – 14, 2024

PROCEEDINGS

Edited by
Simone Arena, University of Cagliari, IT
Irene Roda, Politecnico di Milano, IT
Alexandre Voisin, University of Lorraine, FR
Ajith Kumar Parlikad, University of Cambridge, UK
Christos Emmanouilidis, University of Groningen, NL

ELSEVIER

IFAC Proceedings Volumes (IFAC-PapersOnline) — ISSN 2405-8963

IFAC PapersOnline — ISSN 2405-8963

Published by:
International Federation of Automatic Control (IFAC)
Hosting by Elsevier Ltd.

Available online at

www.sciencedirect.com

Publication date
June 2024

Copyright conditions

6th IFAC Workshop on
Advanced Maintenance Engineering, Services and Technology
AMEST 2024

Sponsored by

International Federation of Automatic Control (IFAC)

- Manufacturing Plant Control, TC 5.1.

Co-Sponsored by

International Federation of Automatic Control (IFAC)

- TC 5.2. Management and Control in Manufacturing and Logistics
- TC 5.3. Integration and Interoperability of Enterprise Systems
- TC 6.4. Fault Detection,Supervision&Safety of Techn.Processes-SAFEPROCESS

Organized by:
- Università di Cagliari
- Politecnico di Milano
- University of Lorraine

Supported by
- IFIP - International Federation for Information Processing,WG5.7 Advances in Production Managent Systems
- ESRA - European Safety and Reliability Association
- PHM Society - Prognostics and Health Management Society

Financial sponsorship by:
- SARAS
- Intellimech
- OM3
- ECOS ELETTRONICA
- A.I.M.A.N

International Programme Committee

Christos Emmanouilidis, NL (IPC Chair)
Ajith Parlikad, UK (IPC Co-Chair)
Alexandre Voisin, FR (IPC Co-Chair)
Riccardo Cozza, IT (IPC Vice-Chair from Industry)

Ait-Kadi D., CA
Andrews J., UK
Antosz K., PO
Arena S., IT
Arnaiz A., ES
Barata J., PT
Barbieri G., CO
Berenguer C., FR
Bokrantz J., SE
Bousdekis A., GR
Carnero C., ES
Chiacchio F., IT
Crespo-Marquez A., ES
Dehombreux P., BE
Do Van P., FR
Duran O., CL
El-Thalji I., NO
Emmanouilidis C., NL
Franciosi C., FR
Fumagalli L., IT
Guillen A., ES
Holgado M., UK
Iung B., FR
Ivanov D., DE
Jasiulewicz – Kaczmarek M., PO
Kiritsis D., CH
Kristjanpoller F., CL
Levrat E., FR
Lezoche M., FR
Lu C., P. R. CN
Macchi M., IT
Marange P., FR
Martorell Alsina S., ES
Mossa G., IT
Negri E., IT
Nguyen T., FR
Orrù P. F., IT
Papadopoulos Y., UK
Parlikad A., UK
Peres F., FR
Peron M., FR
Polenghi A., IT
Puig V., ES
Roda I., IT
Romero D., MX
Simeu-Abazi Z., FR
Sgarbossa F., NO
Skoogh A., SE
Starr A., UK
Szpytko J., PO
Tchangani A., FR
Trapani N., IT
Tucci M., IT
Voisin A., FR
Zolghadri M., FR

National Organizing Committee

Simone Arena, IT (NOC Chair)
Irene Roda, IT (NOC Co-Chair)

Chiara Franciosi, FR
Adalberto Polenghi, IT

FOREWORD

According to technological and market analyses and forecasts, maintenance and asset lifecycle management have grown in significance and are expected to continue strengthening, driven by their increasing contribution to industry and society. With predictive maintenance acknowledged as among the prime use cases of the accelerating technological change brought by Industry 4.0, and with lifecycle engineering, management, and associated services recognised as key contributors to sustainability and resilience across sectors as diverse as public infrastructure, manufacturing, transportation and logistics, aerospace and defence, energy and utilities, and healthcare, the field receives heightened attention from scientific and industrial communities. Activities across the lifecycle of physical assets, including design, operation, maintenance and end of life management are increasingly seen less as cost contributors but as essential value adding processes. It is within this global context that the 6th IFAC Workshop on Advanced Maintenance Engineering, Services, and Technology (AMEST2024) was held, bringing together international experts from academia and industry to present and debate the latest advances in Maintenance and Asset Lifecycle Management in support of the transition to sustainable, human-centric and resilient industrial systems, aligned with Industry 5.0 aims.

The distinguished role of digitalization and interoperability in the field was highlighted by three inspiring keynotes on “digital transformation in maintenance and asset management”, on “modular and adaptive field – level automation architectures to support predictive maintenance”, and on “ontology-based asset information modelling for predictive maintenance”. The keynotes offered an excellent overarching setting for a series of sessions covering thematically the latest advancement in the field, as follows:

- **Digital Twins for Maintenance Applications**, focused on the application of digital twin concepts and associated technologies across various industries including railway, manufacturing, energy, and steel manufacturing. This theme explored how digital twins can support decision-making covering regulatory compliance, integrated maintenance and energy decision-making, ontology-based decisions, and joint planning for maintenance and production.
- **Artificial Intelligence for Maintenance and Asset and Product Lifecycle Management** highlighted how the rapidly advancing field of AI contributes to improving maintenance and extending the asset lifespan. In particular, contributions presented AI methods applied to quality control, fault diagnosis, and zero-defect manufacturing applications.
- **Maintenance Strategies, Simulation, and Optimization of Complex Systems** included contributions on strategies, methodologies, and solutions for optimizing maintenance processes, such as business intelligence applications for maintenance, lifecycle cost analysis, smart maintenance, and optimizing maintenance strategies post-COVID. It also covered simulation techniques and their applications in various maintenance scenarios.
- **Reliability, Dependability, and Risk-Based Approaches** addressed dependability analysis models, alarm dynamics frameworks, reliability-centered maintenance, risk-based vs. time-based maintenance, and optimization models, targeting and showing benefits for manufacturing and infrastructure sectors.
- **Industry 5.0, Human Factors, Education, and Skills in Maintenance** emphasized new approaches for competencies building in maintenance, the use of augmented reality solutions, decision support systems for Industry 5.0, and integrating machine learning into educational activities. It also discussed sustainability and human factors in maintenance management.
- **Digitalization for Asset and Product Lifecycle Management** explored Internet of Things (IoT) platforms in asset management digitalization, predictive failure modeling, and efficiency improvements in maintenance operations. It also covered the integration of Building Information Modelling (BIM) with digital twins, interoperability testing, and the application of cyber-physical systems for inspection.
- **Prognostics and Health Management, Condition-Based Maintenance, and Condition Monitoring** was another discussed topic**.** This theme covered adaptive learning methods for machine tool prognostics, collaborative frameworks for anomaly detection, data-driven fault detection techniques, and enhanced feature extraction for sensor fault detection.

- **End of Life Management of Complex Systems** addressed strategies for managing the end of life of products and assets. This comprised contributions on decision-making approaches for end-of-life management, impacts of obsolescence and shortages and their management, circular product designs, and resilience strategies to extend the lifespan of complex systems.
- **Product-Service Systems for Maintenance and Asset Management** focused on the design of smart product-service systems, the use of smart devices in remote maintenance, predictive maintenance servitization, and requirements for digital servitization in asset lifecycle management.
- **Resilience and Sustainability** in maintenance covered methodologies for economic and environmental sustainability in maintenance decision-making, resilience in hydrogen terminals, spare parts planning, emerging technologies for sustainability, and broadly Industry 4.0 frameworks for Maintenance (Maintenance 4.0).
- **Maintenance, Product, and Asset Lifecycle Management** targeted the need and introduced methods for investment evaluation in condition monitoring, current and future trends in asset performance management, efficient spare parts management, decision-making frameworks, digitalization in the energy sector, and predictive modelling for for road infrastructure.

The workshop successfully pursued the cross-fertilisation of ideas in the above areas by bringing together support from highly relevant scientific and industrial communities. Specifically, it was fully supported and sponsored by the IFAC TC 5.1. Manufacturing Plant Control, and co-sponsored by TC 5.2. Management and Control in Manufacturing and Logistics, TC 5.3. Integration and Interoperability of Enterprise Systems (I2ES) and TC 6.4. Fault Detection, Supervision & Safety of Technical Processes – SAFEPROCESS, the workshop was also supported by the International Federation for Information Processing (IFIP) WG5.7 Advances in Production Management Systems, the Prognostics and Health Management (PHM) Society, and the European Safety and Reliability Association (ESRA).

The papers presented at AMEST2024 brought a diverse range of topics that reflect the forefront of research and innovation in maintenance and asset management. Central themes included the transformative role of digital twins and artificial intelligence in optimizing maintenance strategies, enhancing reliability, and integrating advanced predictive models. The focus on digitalization, including IoT platforms and cyber-physical systems, underscores the drive towards smarter and more efficient operations. Human factors and Industry 5.0 highlight the critical importance of skills development and human-centricity in modern maintenance practices. Sustainability and resilience are pivotal, emphasizing the need for environmentally conscious and economically viable solutions. Finally, the integration of product-service systems and effective end-of-life management strategies showcases the holistic approach required for robust asset lifecycle management. Together, these themes illustrate a comprehensive vision for the future of maintenance and asset management, driven by innovation, digitalization, and a commitment to sustainability practices.

The Editors

Simone Arena, University of Cagliari
Irene Roda, Politecnico di Milano
Alexandre Voisin, University of Lorraine
Ajith Parlikad, University of Cambridge
Christos Emmanouilidis, University of Groningen

Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 58-8 (2024) 318–323

Designing Smart Product-Service Systems: The SEEM-Smart Methodology and Its Application in the Electrical Industrial Sector

Vanessa Zani*, Vicente Gonzalez-Prida Diaz, Veronica Arioli*, Roberto Sala*, Fabiana Pirola*, Antonio J. Guillén López***, Adolfo Crespo Marquez****

**Department of Management, Information and Production Engineering, University of Bergamo, via Marconi 5, 24044, Dalmine (BG), Italy (e-mail: v.zani2@studenti.unibg.it; veronica.arioli@unibg.it; roberto.sala@unibg.it; fabiana.pirola@unibg.it)*

***Department of Industrial Management, School of Engineering, University of Seville, Spain (e-mail: vgonzalezprida@us.es; adolfo@us.es)*

****Department of Business Organization, Complutense University of Madrid, Madrid, Spain (e-mail: anguil02@ucm.es)*

Abstract: Regarding the implementation of smart technologies in Product Service Systems (PSS), this research proposes the SEEM-Smart Methodology as a model aimed at promoting innovations that provides better support for the development of Smart PSS. The methodology builds further by taking a data driven approach ensuring that both customer needs and company objectives are achieved. The research applies a case study approach studying the use of SEEM-Smart Methodology within the electrical industrial sector, specifically focusing on the analysis and conceptualization phases. This approach is characterized by its five interconnected phases: analysis of the customer needs, conceptualization of the PSS solution, design of PSS-related components, development and validation of the PSS proof of concept, and finally data monitoring. The results show that the SEEM-Smart Methodology is a useful approach to designing and engineering Smart PSS, indicating an organized, dynamic, iterative process facilitating ongoing enhancement. As a comprehensive design model that can be easily applied in the industrial context, the study finds that SEEM-Smart Methodology has significant value when it comes to Smart PSS. It fills gaps between customer orientation in the design and implementation of smart systems.

Keywords: Customer Needs Analysis; Data-Driven Design; Electrical Industrial Sector; IoT Platform; PSS (Product-Service System); SEEM Framework; Smart Technologies; Sustainable Innovation.

1. INTRODUCTION

Companies belonging to the manufacturing sector are increasingly shifting their businesses from traditional product-centric business models to product-service combinations in order to cope with competitive market dynamics, changing customer needs, and growing technological innovations in both finished products and production equipment (Johnson et al., 2008, Baines et al., 2017). These business models are known as Product-Service Systems (PSS) and are defined by Boehm and Thomas (2013) as "an integrated bundle of products and services which aims at creating customer utility and generating value".

The integration of smart technologies has become a crucial component in the changing landscape of PSS with an emphasis on innovation, process optimization, and competitive advantage (Das et al., 2023). This contribution focuses on the Smart PSS environment, which is a complex range of solutions that consist of digital components, services, and products that are interconnected to offer clients more value (Pirola et al., 2020). The motivation for this research was to design and engineer Smart PSS in a systematic manner so that they fit both the customers' expectations on the quality of services, as well as company objectives. This is especially relevant in sectors where technology advancements are quickly transforming how services are designed, provided, and consumed.

The research proposes an application of an innovative approach that enables the development of Smart PSS through a data-driven perspective, it is a dynamic and iterative process that emphasizes ongoing enhancement in the data-driven design of Smart PSS. The methodology utilized is named SEEM-Smart (Arioli et al., 2023). SEEM is the acronym for Service Engineering Methodology and it is mainly suited for supporting the development of PSS while balancing the performance of product-service provider with customer's value. SEEM-Smart was also developed specifically to address problems PSS solutions experienced with the integration of smart technologies.

The goal of this research is therefore to apply a systematic approach to help companies in the electrical industrial sector, among others, overcome the challenges associated with Smart PSS design and installation. The research question that simplifies the objectives of this study is:

How can the SEEM-Smart methodology be effectively implemented in a manufacturing company context wishing to introduce Smart-PSS solutions into its portfolio of offerings for the first time?

10.1016/j.ifacol.2024.08.140

The paper is organized as follows. After a literature background on Smart PSS and methodologies for supporting its design and installation (section 2), this paper presents the five phases of the SEEM-Smart Methodology (section 3). Later, a case study describes in practice how the methodology was used, with special focus on analysis and conceptualization phases (section 4). Finally, the paper concludes with conclusions and future steps (section 5).

2. LITERATURE BACKGROUND

The literature on Smart Product-Service Systems (Smart PSS) is rapidly increasing and several publications have focused their discussion on the obstacles and potential that lies in using smart technologies to develop traditional PSS.

The study by Pezzotta et al. (2014) has played a significant role in balancing provider quality against customer worthiness and established the basis for the Service Engineering Methodology (SEEM) to design traditional PSS. However, the fast evolution of smart technologies calls for a new approach that could be able to face complexities compared with smart PSS design. Won et al. (2014) And Oh et al. (2021) use simulation to model complex relationships among the actors involved in PSS and evaluate their performance. Song and Sakao (2017) proposed a customization-oriented framework for the design of sustainable PSS; in this framework, a modularization strategy is used to cluster and then select PSS components that meet specific customer requirements. Pezzotta et al. (2018) proposed the Product Service System Lean Design Methodology (PSSLDM). It aims to cover all phases of the PSS lifecycle by collecting data useful for improving the PSS offering and its design process, reducing waste in the initial design phase. Fargnoli et al. (2018) presented a methodology based on the analysis of customer requirements by integrating with the Quality Function Deployment (QFD) method for PSS. Furthermore, Jiang at al. (2020) propose a methodology where Design starts from the product, and services are added gradually. The same year Belkadi et al., (2020) proposed an integrated, collaborative platform for the design and development of a product service system and Cong et al. (2020) present Information-driven design entropy theory for Smart PSS development which utilizes a novel concept of design entropy to consider the process of information prediction, summarization, conversion, and updating overall; the methodology they propose is based on information theory.

Most recent frameworks do not fully exploit all possible benefits of available intelligent technologies. Therefore, Arioli et al. (2023) suggested a SEEM methodology update for Smart PSS design and engineering, the SEEM-Smart Methodology, which extends the structure originally proposed by including a data-oriented viewpoint. This work makes a valuable contribution by proposing a case study in the manufacturing sector, but it mentions the need of applying such methodology in other industries and sectors for further validating it. For this reason, an application in the electrical industry is presented below, which is currently limited to the initial phases of the methodology and does not advance into detail about its later stages.

3. METHODOLOGY: SEEM-SMART

The SEEM-Smart Methodology Shown in Figure 1 integrates the phases of the original SEEM, proposed by Pezzotta et Al. (2014), with a data-driven perspective. It consists of five interconnected phases that are supported by different methods; to complete all steps, communication within the different areas of the company and with the customer are essential. The activities that make up each phase are detailed below; they have outputs that result in inputs for the follow ones.

3.1 Analysis of the customer needs and as-is product service solutions and process

The PSS (re)engineering process starts with the definition of the target customers and the consequent analysis of their characteristics and behaviors to better understand and meet their needs. It is important to have direct contact with customers and possible tools can be interviews, meetings or existing reviews and feedbacks 'analysis. For gathering information on customers and defining their needs, the Personal Model (PM) is suggested (Pruitt & Adlin, 2016).

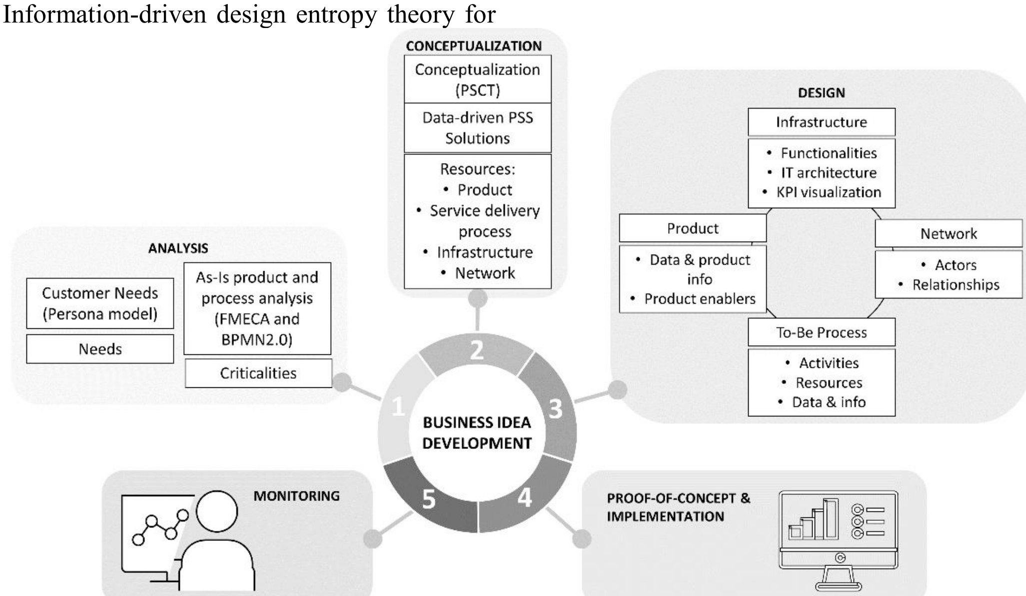

Figure 1. SEEM-Smart Methodology phases (Arioli et al., 2023).

The Failure Mode, Effects, and Criticality Analysis model (FMECA) (Chen et al., 2012) model can be used to identify critical components of an asset and potential areas for improvement while BPMN2.0 is the method proposed to describe the internal and external perspective of the service delivery process (Aagesen & Krogstie, 2009).

3.2 Conceptualization of the PSS solution and related resources

Once the customers' feedback is collected, several PSS solutions are proposed and then those ones that offer value for both customer and supplier are selected and implemented. Product-Service Concept Tree (PSCT) method, based on a hierarchical structure, is used to identify possible PSS solutions. It is divided into four levels (Pezzotta et al., 2018):

- Needs (N): elements identified in the first phase that customer consider essential or desirable.
- Wishes (W): refer to how customers want to meet their needs, in relation to company business.
- Solutions (S): possible solutions (i.e., products, services, or a bundle of them) that the company can identify to fulfill customers' wishes and needs.
- Resources (R): the main human/software resources and/or products necessary to implement the identified solutions. They can be new or existing resources.

The next step is a first evaluation of the solutions proposed in the PSCT, the analysis of the value considers the difficulty that the company could find during the implementation and the possible impact, in this way it is possible to identify the most appropriate solution(s). Depending on the case, qualitative or quantitative evaluations can be made.

3.3 Design of PSS-related components

To support the new offering, the main elements involved in service provision and data flow are examined and designed: product, new infrastructure, network and To-Be Processes. The last one is designed considering all the processes affected by the new data flow generated by the new service offering, tools such as flowchart or BPMN2.0 can be used.

3.4 Development and validation of the PSS proof of concept and the related infrastructure

This phase includes the development of a proof of concept of the PSS offer, definition of the required infrastructure and the final delivery process. The proof of concept is a sort of prototype of the final solution and its performances must be validated e.g., through simulation systems. When all the potential scenarios are reviewed and decisions about the final PSS solution are made, it is ready for delivery to the market.

3.5 Monitoring of the results

The solution produced and distributed to the market needs to be monitored to always be effective and efficient according to customer requirements. For this reason, an initial list of KPIs is proposed at this stage and will be finalized when all components of the PSS are implemented. The frequency with which customers provide feedback to the company is established, so that their level of satisfaction can always be monitored.

4. CASE STUDY

In this section, the SEEM-Smart methodology is applied to a business case, more specifically to a company based in Spain that operates internationally in the electrical industrial sector. The company's core business is the design and manufacture of electrical switchboards that find application in many areas: high or low voltage switchboards, control and protection switchboards, equipment for all types of industrial, energy and service installations, modular solutions for electrical rooms, turbine control centers or power rooms. Over the past ten years the company has begun to open its doors to new applications in the renewable energy sector, it has acquired expertise in the development of photovoltaic inverters and energy storage.

Until now, the company has mainly focused on the production, integration and installation of equipment, but many customers also require a more comprehensive service package. The services currently offered are few and elementarily structured and customer service processes are not well defined, it follows that the relationship between customer and service provider has potential for improvement. With the advent of digitalization, the company grasped the potential of digital servitization and decided to try and expand its service catalogue. To do so, it took part in a call launched by Red.es, a public business entity linked to the Spanish Ministry of Digital Transformation, and in collaboration with several entities, including the University of Seville, it created a project specifically aimed to generate an evolution in the Product-Service System currently offered.

The tools used to achieve the final objective are manifold, including the SEEM-Smart. The following sections provide a full overview of the methodology's first two steps. The last three phases are not covered in this study due to the timing of the work but the full implementation and a robustness analysis of the methodology will be addressed in future development.

4.1 Analysis

The starting point was the analysis of the customer and the definition of its needs. To achieve this objective, the research team formulated a series of questions to investigate the customer's needs and wishes. Specifically, they formulated around thirty questions, which were classified into five different thematic blocks: (i) the first block contains general questions on the *purchasing process*; (ii) the second is focused on *maintenance*; (iii) the third is aimed at *performance monitoring*, (iv) the fourth focuses on the *product life cycle*; and the last one (v) on *technical support and warranty*. These thematic areas were chosen in order to cover the entire life cycle of the asset. In this way, it was possible to assess the quality perceived by the customer throughout its relationship with the provider, from the offer generation phase to the end of the PSS useful life. Particular attention was paid to after-sales (ii,iii,v), since it was identified by the company as an area to be strengthened. The questionnaire brought to light two primary needs:

1. Improvement of the bidding process;

2. Eco-efficient maintenance management.

Not only the customer needs were investigated in this phase but also an internal critical analysis of the company's actual service offerings was performed. Researchers looked the services currently present within the offer catalogue and their delivery processes. The main services offered are:

- Product and performance warranty;
- Corrective and preventive maintenances;
- O&M training courses.

Warranty and maintenance contracts are often standard contracts based on periodic replacement of asset components; sometimes replacements are made because they are contractually planned but without real evidence that they are needed. The training courses offered are optional, the client choses if integrate them in the offer proposal or not; this means that not all customers are completely familiar with the product they are purchasing.

Analyzing the delivery processes of these services, they are not regulated by specific procedures, but the plan of action depends on each case and is flexible. The same thing occurs to the flow of communication between customer and supplier. It was also highlighted that the resolution of incidents takes quite a long time as the company, which operates internationally, does not have technical support teams located in the various geographical areas nor tools capable of resolving incidents remotely. In addition, predictive maintenance is not considered.

4.2 Conceptualization

From the identified needs and the initial snapshot of the services currently offered, the PSCT was developed to identify possible PSS solutions. This phase required brainstorming with different business areas and many expert opinions within the research team.

This resulted in two PSCTs, one for each need, which present possible solutions to meet customer requirements. In this paper, only the need that emerged at the maintenance level will be explored, since this is the area that most interests the company and is best suited to the integration of data-driven approaches. The acronyms used in PSCT graph illustrated in Figure 2 are explained in Table 1. Improving eco-efficiency in maintenance management (N1') led to the identification of thirteen different solutions.

The company should propose more structured and clear warranty plans (S1') to the customer, in which the responsibilities of each par are better defined. Maintenance plans (S2') should be customized to specific needs and structured in order to optimize the overall performance of the plant. Maintenance planning must consider the scalability and adaptability of the equipment because the customer could consider the possibility of future expansion or modification of the equipment. Communication between customer and supplier should be more fluid (S3') and easy and for this reason a communication system (R3') can be a useful tool. Diagnostic and data analysis (R4') would allow to predict and prevent failures, as well as optimizing equipment performance throughout its useful life (S4'). All the collecting data could be joined into a digital knowledge base (S5') to extract and organize information from maintenance reports, it is considered useful to quickly find solutions to frequent problems and improve autonomy of the customer (W3').

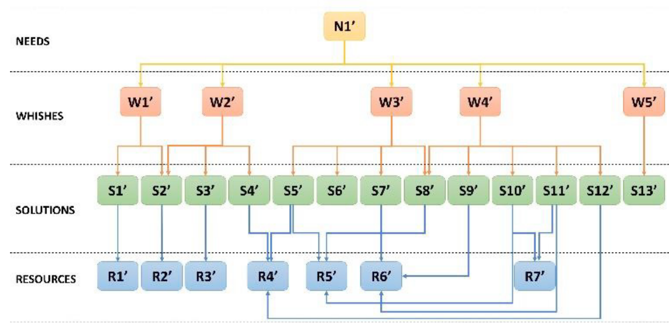

Figure 2. PSCT - Eco-efficient maintenance management

Table 1. PSCT - Description

Level	Acronym	Description
Need	N1'	Maintenance management eco-efficiency
Whishes	W1'	Better structured maintenance interventions plans
	W2'	Availability and extension of the useful life of the asset
	W3'	Improvement of support documentation (self-management)
	W4'	Quick response time and quick intervention time
	W5'	Integration of maintenance systems with other plant management systems
Solutions	S1'	New warranty contracts
	S2'	New Preventive and corrective maintenance contract
	S3'	Fluid and transparent communication with suppliers
	S4'	Optimization of the equipment life cycle
	S5'	Creation of a Digital knowledge base
	S6'	Technical support training
	S7'	Detailed procedures for maintenance recording
	S8'	Rapid action protocols for critical incidents
	S9'	Digital link with the inventory management process
	S10'	Real time monitoring
	S11'	Maintenance teams with specific training and access to technical information
	S12'	Manufacturer involvement in problem resolution
	S13'	Development of standardized communication interfaces and protocols
Resources	R1'	Health analysis
	R2'	Maintenance planning and scheduling tools
	R3'	Communication system
	R4'	Diagnostic and data analysis tools
	R5'	Maintenance Data
	R6'	Computer Aided Maintenance Management systems (CMMS)
	R7'	IoT Sensors

Always with the aim of making the customer more autonomous, the company could create rapid action protocols for critical incidents (S8') and offer technical training programs (S6'): virtual or in person training sessions, as well as remote technical support to resolve incidents quickly and efficiently. To record maintenance actions and keep track of them, detailed procedures should be established (S7'): this allows the creation of a comprehensive history of verifications and resolution of incidents that would facilitate reference in case of similar failures in the future and allow a continuous and proactive monitoring of the system.

Customers value a quick first response time in the maintenance package offered (W4'), which implies efficient resolution of incidents, especially those of very specific nature requiring contact with the original manufacturer. In this regard, it would be good to have a digital link with the inventory management process (S9'), to have maintenance teams with specific training and access to technical information (S11') and for the manufacturer to be involved in problem-solving since the early contractual stage (S12'). Moreover, the integration the maintenance systems with other plan management systems (W5') seems to be valuable for the customer which implies efforts to develop standardized communication interfaces and protocols (S13'). An innovative solution has emerged: real time monitoring (S10'); using IoT sensors is possible to gain efficiency and productivity and to improve performance for both client and provider.

As suggested by the SEEM-Smart methodology, the solutions should be carefully evaluated in order to drive the efforts on the most appropriate ones. In this case, the Delphi method was used to carefully evaluate all the identified solutions (Crawford & Wright, 2016). Each one was given a certain level of implementation difficulty and a level of expected impact. Based on company reality and expert opinions, difficulty was assessed according to three criteria: *Technical complexity*, *Resource allocation,* and *Change Management*. While the expected impact was assessed according to four criteria: *Efficiency gains*, *Economic impact*, *Employee well-being* and *Environmental impact*. The possible responses were limited to Low, Moderate and High. The evaluations were carried out by members of the research team and by internal company figures operating in different company areas. The final evaluation is the result of the weighted average of all individual evaluations in which the opinions of internal staff had a higher weight.

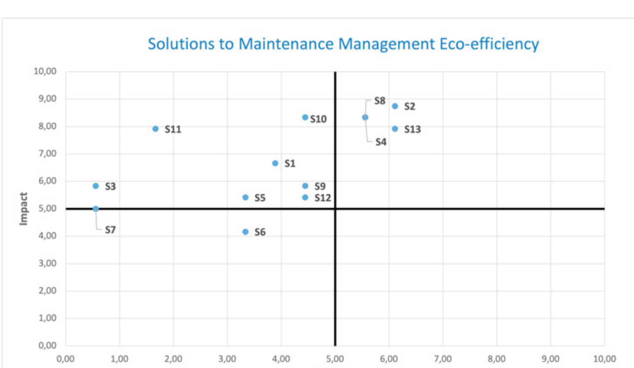

Figure 3. Impact/difficulty matrix resulted from the Delphi study

Fig. 3 provides the results obtained from the assessment using the Delphi method. Since not all selected subjects have provided an evaluation so far, the matrix shows the preliminary results. Anyway, the solutions located in the upper left quadrant, with low implementation difficulty and high impact, are that worth implementing for now. We notice that some solutions (S3', S5', S9', S10', S11') within this quadrant can be considered part of a broader overall solution: a cyber-physical system (i.e., IoT platform) that supports the digital management of assets and related services to provide the user and the company with various functionalities. For instance, the IoT platform can make communication between customer and supplier easier by being the single point of communication (S3'), it also can store data related to the product creating a digital knowledge base (S5'), and it can allow for real-time monitoring (S10'). All these data can be used to better train the maintenance teams (S11') thus supporting the need of having an eco-efficient maintenance management system. In this way, smart technologies are integrated into the company's business model and all possible benefits are fully exploited.

Therefore, the next steps of the SEEM-Smart Methodology are built from the selection made in this important step.

4.3 Next steps

The PSS solutions selected from the previous step must be properly designed, meaning that the elements and processes impacted by the adoption of the solutions must be reviewed. The evaluation of a Proof of concept of the PSS solutions and enabling technologies (i.e., Platform IoT) could be useful before the real implementation and launch on the market. Hereafter, the monitoring of the solutions, with proper indicators and specific threshold values, would follow as measure of the level of customer satisfaction. This phase is not only the last step of the methodology, but it could also be the starting point for a new customer needs analysis. SEEM-Smart is in fact a dynamic and iterative process aiming at continuous improvement.

5. CONCLUSIONS

The SEEM-Smart Methodology allows to overcome the 'service paradox' (Gebauer & Fleisch, 2005) by implementing Smart PSS considering both the interests of the customer and of the company. The service provider must fully understand the needs of the customers, who occupy a central position in the service business, and establish a solid relationship with them. To design and engineer a Smart PSS appropriately, communication within all business areas must not fail and the service provider must actively participate in the implementation of all steps of the methodology. Only in this way is it possible to offer valued and profitable services.

The use of the SEEM-Smart methodology in a firm operating in the electrical industrial sector was successful in driving the discovery and selection of several product-service solutions to fulfill the customer requirement of having an eco-efficient maintenance management system, which concretely would be enabled by smart technologies (i.e., IoT platform). As initially mentioned, the last three phases of the methodology are not covered in this publication, this is mainly due to the timing of the work. However, collaboration with the company will continue until all the SEEM-Smart phases and the project itself are completed. Future work is already well planned and some information have been provided in Section 4.3.

ACKNOWLEDGEMENTS

The following research is based on the ongoing project with the company CEN Solutions, "PS/DS". The Power System Digital Services "PS/DS" project has obtained a grant under the 2021 call for aid for research and development projects in artificial intelligence and other digital technologies and their integration into value chains C005/21- ED and the call for aid from the Andalusian Technological Corporation.

REFERENCES

Aagesen, G., Krogstie, J. BPMN 2.0 for Modeling Business Processes (2015). In *Handbook on Business Process Management 1*, pp. 219–250. Springer: Berlin/Heidelberg, Germany.

Arioli, V., Ruggeri, G., Sala, R., Pirola, F., Pezzotta, G. (2023). A Methodology for the Design and Engineering of Smart Product Service Systems: An Application in the Manufacturing Sector. *Sustainability*,15,64.

Baines, T., Ziaee, A.Z., Bustinza, O.F., Shi, V.G., Baldwin, J., Ridgway, K. (2017). Servitization: revisiting the state-of-the-art and research priorities. Int*. J. Oper. Prod. Manag,* 37 (2), pp.256–278.

Belkadi, F., Boli, N., Usatorre, L., Maleki, E., Alexopoulos, K., Bernard, A., Mourtzis, D. (2020). A knowledge-based collaborative platform for PSS design and production. *CIRP Journal of Manufacturing Science and Technology*, 29 (Part B), pp.220-231.

Boehm, M., Thomas, O. (2013). Looking beyond the rim of one's teacup: A multidisciplinary literature review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design. *Journal of Cleaner Production*, 51, pp.245–250.

Crawford, M. & Wright, G. (2016). Delphi Method.

Chen, Y., Ye, C., Liu, B., Kang, R. (2012). Status of FMECA Research and Engineering Application. In *Proceedings of the IEEE 2012 Prognostics and System Health Management Conference*, PHM-2012, Beijing, China, IEEE: Piscataway, NJ, USA, pp. 1–9.

Cong, J., Chen, C.H., Zheng, P. (2020). Design entropy theory: A new design methodology for smart PSS development. In *Advanced Engineering Informatics*, 45, pp.101-124

Das, R.P., Muduli, K., Singh, S., Behera, B.C., Ramasamy, A. (2023). Unveiling the Role of Evolutionary Technologies for Building Circular Economy-Based Sustainable Manufacturing Supply Chain. In: *Kamble, S.S., Mor, R.S., Belhadi, A. (eds) Digital Transformation and Industry 4.0 for Sustainable Supply Chain Performance.* EAI/Springer Innovations in Communication and Computing. Springer, Cham.

Fargnoli, M., Francesco, C., Di Gravio, G., Tronci M. (2018). Product service-systems implementation: A customized framework to enhance sustainability and customer satisfaction. *Journal of Cleaner Production*. 188.

Gebauer, H., & Fleisch, E. (2005). Overcoming the Service Paradox in Manufacturing Companies. *European Management Journal.*

Jiang, S., Feng, D., Lu, C., Li, J., Chai, H. (2020). Research on the Construction of the Spiral Evolutionary Design Methodology for a Product Service System Based on Existing Products. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., 234, pp.825–839.

Johnson, M., Clayton, M., & Christensen, K. (2008). Reinventing your business model. *Harvard Business Review*, pp.59-68.

Oh, S., Hong, Y.S., Lee, J., Kim, Y.S. (2021). An Evaluation Method for Business Models in Product-Service Systems Design. In *Proceedings of the Design Society,* ICED21, Gothenburg, Sweden.

Pezzotta, G., Pinto, R., Pirola, F., and Ouertani, M.Z. (2014). Balancing Product-Service provider's performance and customer's value: the service engineering methodology (SEEM). *Procedia CIRP 2014*, 16(31), pp.50-55.

Pezzotta, G., Pirola, F., Sala, R., Margarito, A., Pina, P. (2018). Identify New PSS Concepts: The Product Service Concept Tree Tool. In *Enterprise Interoperability;* John Wiley & Sons, Inc.; NY, USA, pp. 367–372.

Pezzotta, G., Sassanelli, C., Pirola, F., Sala, R., Rossi, M., Fotia, S., Koutoupes, A., Terzi, S., Mourtzis, D. (2018). The Product Service System Lean Design Methodology (PSSLDM). *J. Manuf. Technol. Manag*., 29, pp.1270–1295.

Pirola, F., Boucher, X., Wiesner, S., Pezzotta, G. (2020). Digital technologies in product-service systems: a literature review and a research agenda. *Comput. Ind.*

Pruitt, J.S., Adlin, T. (2006). *1—THE NEXT FRONTIER FOR USER-CENTERED DESIGN: Making User Representations More Usable*. In *The Persona Lifecycle*; Pruitt, J.S., Adlin, T., Eds.; Interactive Technologies; Morgan Kaufmann: San Francisco, CA, USA, pp. 2–45.

Song W., Sakao T. (2017). A customization-oriented framework for design of sustainable product/service system. *J Clean Prod.*, pp.1672-1685.

Won, J.H., Kim, Y.S., Lee, J.H., Hong, Y.S. (2014). Association of Product-Service Systems Design Concepts with Business Models and Their Evaluation Method. In *Proceedings of the 2014 International Conference on Engineering, Technology and Innovation: Engineering Responsible Innovation in Products and Services,* ICED 2014, Bergamo, Italy.