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► **To cite this version:**

Fabiana Pirola, Giuditta Pezzotta, Veronica Arioli, Roberto Sala. Design and Engineer Data-Driven Product Service System: A Methodology Update. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2022, Gyeongju, South Korea. pp.367-375, 10.1007/978-3-031-16411-8_43 . hal-04768946

HAL Id: hal-04768946

<https://inria.hal.science/hal-04768946v1>

Submitted on 6 Nov 2024

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Design and engineer Data-driven Product Service System: a methodology update

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Abstract. Digitalization, sustainability, and servitization are transforming economy and society globally. Companies are increasingly changing their business model toward providing a data-driven Product Service System (PSS), namely bundles of products and services integrated with some digital technology. Different methods and tools have been proposed to design PSS and, more recently, smart PSS, but they still mainly focus on value propositions and do not address which kind of data can be collected from the operational stage. To overcome this gap, this paper proposes the Data-driven Service Engineering Methodology (D-SEEM) for the design and engineering of data-driven PSS, considering the tradeoff between customer satisfaction and internal efficiency and focusing on data and information. A case study in the professional appliances industry is then proposed to show the application of a part of the methodology in a real context.

Keywords: data-driven product-service system, Data-driven PSS design and engineering, operational data, sustainability.

1 Introduction and literature background

Nowadays, sustainability and digitalization are transforming economy and society at global level. Among the others, Internet of Things (IoT) and machine learning are the key components of industry transformation since they allow to collect and analyze large amounts of data retrieved from industrial assets to make processes more efficient and sustainable [1]. In this context, servitization (i.e., the phenomena leading manufacturing companies to offer services on top of physical products to cope with customers' requirements) is dramatically affected by digitalization, and more and more companies are leveraging on the opportunities offered by digital technologies changing their business model towards the provision of *data-driven Product Service System* (PSS), namely bundles of products and services integrated with some digital technology [2]. In particular, companies are increasingly developing services on top of IoT platforms (i.e., digital environments serving as an interface between the IoT devices and the users [3]) since IoT allows real-time monitoring of assets performance enabling data-driven decision-making related to asset management [4]. Fur-

thermore, providing services, such as maintenance, repair, and remanufacturing, allows providers to reduce the environmental impacts and increase attractiveness and customer satisfaction [5]. Different methods and tools have been proposed to design PSS and smart PSS [2, 6, 7]. However, they still mainly focus on defining value propositions fulfilling customer needs, and do not address which kinds of data are needed and can be collected from the operational stage to make proper decisions enabling the new service offering [8]. Thus, new tools and approaches are required to design and engineer solutions that integrate digitalization and PSSs, using the sustainable dimension [9] and considering the data and information needed to provide PSSs. This paper goes in this direction and aims at integrating the Service Engineering Methodology (SEEM) developed by [10] to cover the design and engineering of data-driven PSS, with a focus on data and information. A case study in the professional appliances industry is then proposed to show the application of a part of the methodology in a real context. The SEEM has been selected since it has a double focus on customer satisfaction and internal company efficiency.

The paper is structured as follows: Section 2 describes the Data-driven Service Engineering Methodology (D-SEEM). Section 3 presents the case study while section 4 provides conclusions and future development of the study.

2 Data-driven Service Engineering Methodology (D-SEEM)

Considering PSS design methodologies available in literature, the Service Engineering Methodology (SEEM) [10, 11] does not address only customer needs, but try to balance the value perceived by customers with internal process efficiency. In doing so, the SEEM framework proposes 4 phases and related methods. The main drawback of such a methodology is that it does not specifically focus on data-driven PSS. The methodology has been updated to overcome this gap by integrating some steps (i.e., steps 2 and 4) more focused on data-driven services. The Data-driven SEEM (D-SEEM) shown in Fig. 1 is divided into four stages:

1. *Definition of PSS solution and related functionalities*: as in the original SEEM, the starting point of PSS (re)-engineering process is the customer, its behaviors and needs, and the critical analysis of the actual company service portfolio. Starting from the customer needs, the company should generate different PSS solutions and select the one (s) to be added to the value proposition. The main outcome of this phase is the PSS solution to be detailed and its main functionalities.
2. *Identification of data and information needed to enable the data-driven PSS provision*: since the methodology deals with data-driven service, an essential point of the methodology is related to the definition of data needed to provide the selected PSS solution and the information supporting the decision making and the service provision.
3. *Design and validation of internal and external PSS related processes*: as in the original SEEM, this phase is related to the (re)design and validation of the service provision processes, comprising both the external processes (towards the custom-

ers) and the internal processes (i.e., any processes affected by the new data and information available). The objective of this phase is to look for a tradeoff between the customer needs fulfillment and company efficiency.

4. *Creation and validation of the PSS proof of concept and the related infrastructure:* this phase deals with creating a proof of concept of the offer (e.g., dashboards of an IoT platform).

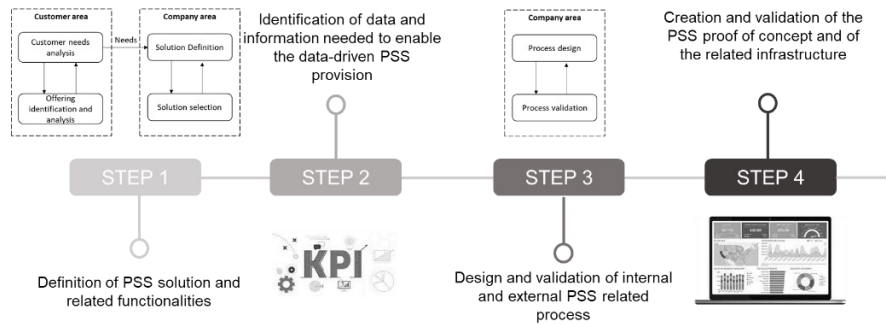


Fig. 1. Data-driven Service Engineering Methodology (D-SEEM)

For each phase, methods and tools are suggested to achieve the objectives proposed. In Step 1 the Persona Model (PM) is proposed to collect and present information about customers and define the needs used as the starting point of the Product Service Concept Tree (PSCT). This method, based on design thinking and functional design principles, aims to define possible PSS solutions to be provided to fulfill customers' needs and the related provider's resources. These solutions must then be assessed considering costs and benefits, and the one(s) to be engineered must be selected and the main functionalities defined. This solution and its functionalities are the input of the following step 2. The main data needed to provide the PSS must be defined in this step. For this purpose, classical methods from asset management manufacturing operations theories can be exploited. For example, in case of a solution dealing with the provision of condition-based and/or predictive maintenance, the Failure Mode, Effects, and Criticality Analysis (FMECA) [12] can be adopted to select the asset components to monitor and the data needed to implement status recognition and predictive algorithms. Indeed, FMECA allows to prioritize asset components based on frequency, criticality, and editability of failures and only the most critical components will be object of a condition-based and/or predictive maintenance policy. Once the PSS solution and the data and information needed to provide it are defined, the related internal process are (re)-designed. The method proposed to describe the service delivery process is BPMN2.0. Focus of the modeling activities are not only the processes towards the customers, but also the internal process that may be affected and improved by the PSS solution and the new information available. For example, if the solution is related to asset monitoring and predictive maintenance, the data retrieved by the field related to asset performance may be a relevant source of information to improve product design. This phase deals also with the validation of the process, and then the assessment of performance of alternative service provision processes, as well

as the identification of the most suitable process and its best resource configuration. This phase can be performed leveraging on process simulation. The last step deals with creating a proof of concept of the selected solution, both in terms of data-driven services, the needed infrastructure to enable them and the final provision process.


3 Case study

In this paper, a case study methodology has been applied to illustrate new and innovative practices that organizations are adopting, as suggested by [13]. The case study focuses on a medium Italian company (Alpha hereafter) working in the professional appliances industry and producing professional dishwashers and fryers. The company has always been strongly product-oriented and sells the products to the end users (e.g., bars, restaurants located all over the world) through distributors. These distributors provide after-sales assistance to the end users, but only corrective maintenance is in place. The main criticalities of the market are the following: i) Alpha company usually does not get in touch with the end users, and it does not even have visibility on the installed base; ii) the product is considered critical by end users, but they are not prone to invest in technology, iii) most of the distributors are micro-small companies (until 10 employees), well organized and recognizing the advantages coming from technology; iv) distributors usually have a high workload, tight timelines for interventions, limited competence on the product since they are multi-brands and have no time to follow training; v) in case of difficulties in problem diagnosis and resolution, or case of products under warranty, the distributors contact company Alpha asking for immediate support. Starting from these assumptions, Alpha, leveraging on digitalization and the increased connectivity available, is willing to move towards the provision of a data-driven PSS to better support the distributor during maintenance provision, increase final user loyalty and satisfaction, and gain more knowledge on the installed base. For this purpose, the company implemented the above-reported methodology. Hereafter, the implementation of the first three steps is described.

3.1 Definition of PSS solution functionalities

The starting point is the analysis of the customers and the definition of their needs. To this purpose, the customer identified is the distributor and its Persona Model has been developed thanks to interviews with the marketing & sales, and service managers (Fig. 2). Summarizing, while the distributor characteristics are summarized above, its needs have been defined as follows: enhance service interventions; know in advance the spare parts/products delivery times to inform end users; have good product knowledge for end user pre-sale support.

To identify possible PSS solutions the Product-Service



Name:
Marco Rossi

Age:
30

Role:
Distributor

Company:
DISH SERVICE srl

High workload, tight timelines for interventions, limited competence on the product since they are multi-brands and have no time to follow trainings. He recognizes the advantages coming from technology

Needs:

- Enhance service interventions
- Know in advance the delivery times of the spare parts/products
- Have good product knowledge for end user pre-sale support

Fig. 2. Persona Model of the distributor

Concept tree (PSCT) has been developed in a brainstorming session with the marketing&sales manager, the service manager, and the product designer. The PSCT (summarized in Table 1) is divided into 4 levels:

- *Needs* (N): main needs of the customers identified in the Persona Model;
- *Wishes* (W): how customers' wish to satisfy their needs;
- *Solutions* (S): possible PSS solutions (product, services or a bundle of them) that the company can identify to fulfil customers' wishes and needs;
- *Resources* (R): the main human/software resources and/or products to implement the solution.

Table 1. PSCT element description

PSCT element	Description
Needs	The main need of the distributor is: "enhance service interventions".
Whishes	To meet this need, four areas of intervention have been outlined: i) better planning of interventions; (ii) clear knowledge of the product; (iii) reduction of intervention time; (iv) clear and accessible service support.
Solutions	Definition of a preventive maintenance contract to offer to end users; Creation of a system with alerts when preventive maintenance must be performed; Remote monitoring system with a guided diagnostic procedure, which allows to geolocalize the interventions and classifies them according to the severity of the alerts; Data collection system that is manually entered and stored with a guided diagnostic procedure; List of authorized installers; Easy visual instructions/manuals, via APP or PDF, of the product specifications, able to guide the interventions; Online system for spare parts and products purchase; Internal ticketing system for assistance, exploitable also for internal analysis of needs.
Resources	Platform that allows both remote and manual data collection and that guides the diagnosis procedure; Company website with the list of authorized dealers and visual instructions; E-commerce platform with products and spare parts, simple and connected to the site; Internal ticketing system for collecting service information.

Since the main issue related to the relationship with the distributors lies in the difficulty of managing maintenance and repair interventions, the company decided to focus on enhancing distributors' interventions by giving them a solution that would allow the rapid identification of faults, even in case they are not trained. Thus, after an internal and qualitative cost & benefits analysis of the PSS solutions identified, the company decided to focus on supporting distributors while delivering maintenance through a platform able to provide the following functionalities (derived from the solutions defined in the PSCT):

- Health status remote monitoring of the dishwashers connected through IoT, which allows to geolocalize the product and provide alerts when the health status of one of the components is deteriorating, suggesting the need for an intervention;
- Manual collection of data related to products identification and problem diagnosis;
- Guided diagnostic procedure: following a checklist, the distributor will be able to

identify possible causes of the failure;

- Easy and fast retrieval of technical information related to the dishwasher.

This PSS solution is a data-driven solution since it is based on digital technologies (i.e., digital platform fed with data coming from the connected products, from distributors interventions and with applications supporting interventions).

3.2 Definition data and information needed to provide the PSS

Since the selected solution entails the remote monitoring of products through IoT for preventive maintenance purposes, it becomes relevant to understand the most critical components and the data needed to monitor the health status. Through interviews with the service manager and the product designer, a FMECA has been performed referring to a "standard model" of dishwasher representative of several models. This choice has been mainly supported by the structural, technological, and functional similarities that the models, although different, demonstrate. The FMECA is a reliability analysis at a different level of the decomposition of the product, and consists in the determination of modes, causes and effects of failures, to appropriately evaluate the criticality of the entity under analysis. The FMECA analysis carried (see an excerpt in Fig. 3), followed this procedure:

1. Functional breakdown of the product adopting a hierarchical-functional criterium that allowed to define 4 levels (group, system, equipment, sub-equipment);
2. Definition of criticality drivers to calculate the Risk Priority Number (RPN), that is the product of three drivers:
 - a. *Probability (P)* of occurrence of the failure.
 - b. *Severity (S)* of the failure. Two areas of severity have been identified, one related to the severity of the failure (i.e., the impact of the failure on the functioning of the machine) and the other associated with the reparability of the fault or the substitutability of the part. When calculating the RPN, it was decided to consider, for each mode of failure, the driver with the highest score.
 - c. *Detectability (D)* of the failure.

Four levels have been defined for each driver, from 1-low to 4-very high.

3. Analysis of modes, causes and effects of failures and calculation of RPN.

	Mode of failure	Cause of failure	Effect of failure	P	S1	S2	D	RPN
Group: Hydraulic part								
System: Rinsing circuit								
Equipment: Load solenoid valve	Clogs	Mains water is not clean (rare); Water goes back from the tub	Does not charge water or the flow rate is reduced	2	2	2	3	12
Equipment: Boiler Group								
Sub- equipment: Boiler resistors	Burn	The resistor loses insulation because it remains uncovered or because it is isolated	The machine does not start - The possibility of segregation of the resistance is activated	4	4	3	2	32

Fig. 3. Excerpt of the FMECA analysis of the dishwasher

After calculating the RPN indices for the different failure modes, several analyses were conducted to identify the most critical modes and causes. The FMECA shows

that the most critical components are related to electronics, rinsing circuits, and opening systems. Furthermore, a deeper analysis showed that 8 out of 55 failure modes detected (or 14%) cover 50% of the criticality associated with the product. Based on these results, the following activity has identified improvement actions at the level of sensors installed (or installable) on the product. In particular, the focus was on the failure modes with higher criticality, especially in terms of detectability (that is the factor that mostly benefits from the introduction of new sensors on the machines). Thus, the analysis focuses on identifying elements and sensors contributing to the measurement of variables representing the health status of the machine. The analysis shows the need for sensors to detect door closing status and water leaks and measure water temperature, water level, and resistors power absorption.

3.3 Internal and external process design and validation

The third step is the (re)design of service provision processes, referring to how the new solutions are delivered to customers and how the internal activities and decision-making will change given the information available by the PSS solution. For this purpose an analysis of actual criticalities through BPMN 2.0 has been performed through interviews with service manager and direct observation of service employees. The analysis showed the main criticalities (divided into internal and external) of actual processes and how the identified solution can help overcome them.

Table 2. Analysis of actual process criticalities and definition of the improvements

Type	Criticality description	Improvement
Internal	Manual internal priority call management	The platform will provide an index of severity of the failure and a priority for the customer
Internal	No unique way to contact the service, but it can be reached by mobile phone or through the switchboard	The platform will be the main way to reach the service
Internal	The service department manually fills an excel file with customer and intervention details	The customers will fill in the needed information on the platform allowing the company service to save time
External	No support for the distributor and the internal service department to carry out fault analysis.	The platform will have a guided checklist based on the FMECA analysis
External	Technical information on machines not easy to retrieve from the website or manuals	The platform will integrate a document management system to help distributors retrieve the information needed
External	The distributors do not have information about the return status	The platform will allow tracing the order status of the distributor, both related to spare parts and items returned

4 Conclusion

From a theoretical point of view, this paper, proposing the Data-driven Service Engineering Methodology (D-SEEM), aims at filling the gap in literature, namely the

lack of methods and tools to design and engineer data-driven PSS balancing external and internal performance and specifically addressing the selection of data and information needed in the operational stage. Indeed, the proposed methodology has a strong focus on the definition of data, information and operational processes needed to deliver the selected solution. To demonstrate its applicability in industrial context, a case study in the professional appliances industry is proposed to show the application of the first three steps of the methodology in a real context. The case study demonstrates that the D-SEEM allows to achieve satisfactory results also with SMEs and could be applied in any sector since the steps and methods can be customized for different context. Further improvements are needed to improve the selection of PSS solutions in the first step and a complete implementation in more sectors and companies is required to validate it.

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