Product Service Systems value chain configuration – a simulation based approach

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Abstract

This paper proposes a framework relying on a combination of a methodological approach with a modelling and simulation platform. The methodological approach offers generic tools to collect and analyze the key information required to understand a PSS industrial context. Modelling and simulation are concerned with the specification and evaluation of alternative PSS value-chain configurations. A case study in the field of sludge treatment is used to illustrate the proposed approach. This case study points out the main performance drivers for the different types of actor involved in the PSS. The novelty of the paper is twofold: i) it provides a structural and methodological support to build and evaluate different value-chain configurations aiming at deliver PSS solutions, and ii) it gives a preliminary analysis of the performance drivers of an innovative activity related to sludge treatment.

Keywords: Product-Service Systems; Value Chain Configuration; Performance evaluation; Servitization

1. Introduction

Increasing customer specific demands compel companies to seek more customer-centered business strategies. Subsequently, new forms of supplier–customer relationships arise in the manufacturing sector and aim to maximize the value offered to customers. This is witnessed by the emergence of services in the manufacturing sector. In fact, business is currently shifting from offers based on traditional physical products to offers based on a combination of products and services, known as Product-Service Systems (PSS).

Although the scientific literature indicates that consistent advances have already been made in the technical engineering of PSS solutions [1], tools and methods still lack to support the organizational transition induced by the shift to PSS, in particular at the operational level [2,3,4]. Beyond guidelines for the implementation of PSS, decision-makers require feedback on the viability of PSS solutions in order to make more informed decisions. The development of decision-making approaches that support such goal remains an important objective [1,5]. The aim of this research work is to support the shift towards PSS by providing decision-makers with the practical implications of different PSS value-chain configurations, in order to mitigate the uncertainty they face in the management of the transition to PSS. To this end, we propose a framework relying on a combination of a methodological approach with modelling and simulation. The methodological approach aims to collect and analyze the key information required to understand a PSS industrial context and support the decision makers through the PSS development process. Modelling and simulation are concerned with the specification and evaluation of alternative PSS value-chain configurations. A case study in the field of sludge treatment is used to illustrate the proposed approach.
The remainder of the paper is organized as follows. Section 2 reviews the literature to identify PSS development methodologies and requirements. Section 3 presents the proposed framework. The case study is presented and discussed in Section 4. The paper ends with concluding remarks in section 5.

2. **Product-Service Systems development methodologies**

Service advantages are progressively coming to dominate the business world, leading to an increased servitization of the manufacturing sector. In this sense, offering Industrial Product-Service Systems emerges as a promising business model for manufacturing companies. According to Meier et al. [4] “An Industrial Product-Service System is characterized by the integrated and mutually determined planning, development, provision and use of product and service shares including its immanent software components in Business-to-Business applications and represents a knowledge-intensive socio-technical system”.

Industrial Product-Service Systems (IPSS) exhibit a high benefit potential for all the actors involved, especially higher revenues, longer relationships and increased loyalty of customers, lower environmental impacts, etc. [2,3,4,6,7]. In order to reap these benefits, proper methodologies are needed to jointly develop products and services and monitor PSS throughout the product life-cycle and several analyses of the state of the art on PSS highlight the need for tools to model [2,6,7,9,10]. Such assessment provides valuable inputs for the decision-making process regarding the PSS implementation [4,9]. Authors such as Mannweiler et al. [9] and Meier et al. [4] stressed the relevance of a life-cycle perspective in order to make consistent investment decisions, as purchasing cost, for instance, accounts for no more than 50% of the whole PSS life-cycle costs. On the side of the PSS providers, companies can capture profits throughout the PSS life-cycle and at the same time improve customers’ satisfaction through expanding the scope of their offer by integrating services in the product [10]. Accordingly, there is a need to develop tools that consider service operation, (also mentioned as service production) [4,6]. These tools concern the activities required to deliver the desired services to the PSS customer. Furthermore, as observed by Meier et al. [4] and Kimita and Shimomura [11], all the actors interested in the PSS should be involved in the development process. This is because the PSS, unlike traditional manufactured products, is intended to fulfill specific customer needs and draws upon a lot of internal and external resources [5,11].

However, the life-cycle and multi-actor perspectives put forth another challenge for the PSS viability assessment: the heterogeneity of variables that should be taken into account, such as actors, processes, and performance drivers. Scenarios are seen as an appropriate tool for tackling this issue, due to their ability to represent different variables and to provide a common understanding of the future situation. A scenario can be defined as a “description of a possible future that reflects different perspectives on the past, the present and the future” [12]. As such, scenarios allow the recognition of potential threats prior to implementation of the PSS solution. The factors that make the difference between scenarios are the so-called PSS variants. In fact, to fulfill a customer request, a specific PSS-configuration is necessary, which is a particular combination of product and services [9]. Additionally, it is important to define among the value chain actors the different performers of activities [13]. A scenario is then defined as a combination of a specific PSS-configuration with is performed by specific actors having specific roles; and several scenarios can be defined to fulfill a same customer request.

In summary, from a structural point of view, a multi-actor perspective is required to reflect actors' standpoints. Further on, the processes delivering the integrated PSS solution should be taken into account in the assessment. From a methodological point of view, it can be argued that scenarios are an appropriate tool for conceptualizing the potential value-chain configurations and the interactions between the actors involved in the delivery of a PSS solution. Taking into account these key points and requirements, we propose a methodological framework for PSS value-chain configuration.

3. **Proposed framework**

3.1. **Methodological framework**

The objective of the methodological framework is to support the rapid development of Decision Support Systems (DSS) dedicated to PSS value-chain configuration for SMEs. We consider the case of a PSS where the value chain is configured around a focal company which delivers the PSS to the market. The framework is structured around a methodological approach and a generic platform. The methodological approach (left-hand side in Figure 1) is comprised of four steps: context analysis, usage analysis and scenario prioritization, quantitative modelling and performance evaluation.

- **Context analysis** consists in understanding the company’s industrial context and competition factors. This relies on semi-structured interviews with the PSS key actors. This step provides insights into the PSS development opportunities and the main strategic capabilities of the involved actors with regards to the PSS.

- **Usage analysis and scenario prioritization** aims to define different PSS variants based on the possible different uses of the PSS , and to identify the value-creation potential for the actors involved (provider, customer, and other stakeholders). This step relies primarily on semi-structured interviews, brainstorming, and questionnaires to capture the expectations of both the customer and the actors involved in the PSS delivery. Afterwards, several scenarios are defined consistently with the expected uses of the PSS. Each of the scenarios is defined by a combination of actors and roles within the value chain. Finally these scenarios are filtered in order to narrow the scope of the subsequent quantitative evaluation. The filtering criteria stem from the context analysis and stakeholders experience, and are defined during face-to-face meetings.
Quantitative modelling aims to build a performance-evaluation model that will be used to assess the viability of the identified scenarios during the subsequent step. To this end, the following tasks need to be carried out: i) define the performance indicators for each of the involved actors, and ii) identify physical and financial flows that need to be modeled in order to enable indicators calculation by use of simulation. More specifically, business processes are modelled in order to track all involved flows in the performance indicators calculation. Then, questionnaires are built upon these models and are used for data collection. It is noteworthy, however, that business process modelling is not compulsory and its use depends on the complexity and size of the case study.

Scenario-performance evaluation aims to assess the viability of the identified scenarios in terms of economic and industrial performances. To do so, this step consists in identifying potential performance drivers of the scenarios according to the actors’ points of view, and evaluating the scenario performances using simulation. The identification of potential performance drivers allows to focus the simulation phase on a limited number of simulation input parameters (i.e. drivers) and thus avoids a waste of time. Indicators, which form the output of the simulation, are intended to measure operational performance (e.g. product throughput, replenishment, etc.) and economic performance (sales turnover, total costs, etc.).

3.2. Modelling and simulation for PSS configuration

The rationale of the generic platform (right-hand side in Figure 1) is to provide reusable methodological tools that can be re-implemented in several contexts. For the first two steps of the methodological procedure, the generic platform includes generic diagnosis tools (e.g. SWOT, PESTEL) to analyze the company’s context and internal characteristics. The central part of the platform is the Decision Support System (DSS) based on value-chain modelling and simulation which aims to enable the configuration and evaluation of a given PSS offer and the associated delivery value chain, that is of each scenario. As such, modelling and simulation are a way to inform decision-makers of the potential organizational and economic spinoffs of the PSS offer, and to help mitigating the risks related to PSS implementation. However, this step cannot be carried out in isolation, without selecting or defining proper performance indicators reflecting the most relevant decision criteria.

The implementation of the simulation model uses Visual Basic language. Interdependencies between the activities and flows characterizing the value-creation processes are modelled using mathematical equations (Eq. 1 – 10, ∀ p ∈ {1..n_p}), such as p is a given simulation period, and n_p is the number of simulation periods). These represent the core of the simulation. The simulation algorithm is described in the following.

Calculate number of required contracts (in months), according to the market volume during the period (Eq. 1). Contracts can be defined as agreements whose purpose is to mitigate risks by defining obligation of parties. Contracts contain defined service shares and times for each service [4]. In the current simulation algorithm, if the market volume exceeds the capacity made available through ongoing PSS contracts, then new contracts are required to be launched.

\[ n_{req}^p = \begin{cases} \frac{M^p}{c_{pass}} - n_{av}^{p-1}, \text{if } \left( \frac{M^p}{c_{pass}} > n_{av}^{p-1} \right) \\ 0, \text{if } \left( \frac{M^p}{c_{pass}} \leq n_{av}^{p-1} \right) \end{cases} \]

where \( n_{req}^p \) refers to the number of required contracts during period \( p \), \( n_{av}^{p-1} \) designates the number of available contracts at the end of period \( p - 1 \), \( M^p \) refers to market volume during period \( p \), and \( c_{pass} \) is the capacity of the technical systems of the PSS.

If new contracts are needed, assign one or more contract types (characterized with a duration and service package) to the period (Eq. 2). It is assumed that the share of each of the contracts in the portfolio is monitored by a rate defined by the PSS provider.

\[ n^p = n_{req}^p \times r_c \] (2)

where \( n^p \) designates the number of contracts of type \( c \) to be launched at the beginning of period \( p \), \( r_c \) refers to the rate of the contract of type \( c \) in the contracts portfolio.

Check the inventory of product items and returned products and update the in-progress production of required product items (Eq. 3). The production is run only if the volume of returned product items augmented with its available inventory is not sufficient to meet required quantities during next period.

\[ Q^{ip}_{dp} = \begin{cases} Q_{req}^{ip} + Q_{in}^{ip} - Q_{req}^{ip+1}, \text{if } \left( Q_{req}^{ip} + Q_{in}^{ip} < Q_{req}^{ip+1} \right) \\ 0, \text{if } \left( Q_{req}^{ip} + Q_{in}^{ip} \geq Q_{req}^{ip+1} \right) \end{cases} \]

where \( Q^{ip}_{dp} \) refers to the volume of production from item \( i \) to be run during period \( p \), \( Q_{req}^{ip} \) designates the volume of returned product items \( i \) expected at the beginning of period \( p \), \( Q_{in}^{ip} \) refers to the inventory level of product item \( i \) at the beginning of period \( p \), and \( Q_{req}^{ip+1} \) is the volume of required product items \( i \) during period \( p + 1 \).

Update the list of ongoing contracts of the current period (Eq. 4).

\[ n_{en}^p = \sum_i Y^i_c, Y^i_c = \begin{cases} 1, \text{if } start(i) \leq p \leq end(i) \\ 0, \text{else} \end{cases} \]
where \(n^p_{av}^c\) is the number of ongoing contracts, \(\gamma^p_c\) is a Boolean which takes 1 if the contract is ongoing, 0 otherwise, \(\text{start}^p_c\) refers to starting period of contract \(c\), and \(\text{end}^p_c\) designates ending period of contract \(c\).

Update the list of available contracts at the end of the period (Eq. 5).

\[
n^p_{av} = \sum_c n^p_c, \quad \rho^p_c = \begin{cases} 1, & \text{if } p \geq \text{end}^p_c \\ 0, & \text{else} \end{cases}
\]

where \(n^p_{av}\) is the number of available contracts at the end of period \(p\), \(\rho^p_c\) is a Boolean which takes 1 if contract \(c\) ends during period \(p\), 0 otherwise.

Update performance indicators (Eq. 6 – 10). The indicators are updated based on the output of the above computing steps. Equations 6 and 7 calculate the unitary costs of given product item and service, respectively. These two results are used to calculate total costs incurred by a given actor in the value chain, according to Equation 8. The rent value per period is calculated according to Equation 9, and the sales turnover of a given actor is deduced according to Equation 10.

\[
c^i_{det} = \sum_j c^i_{act,j}
\]

where \(c^i_{det}\) refers to unitary cost of product item \(i\), and \(c^i_{act,j}\) designates the unitary cost of activity \(j\) involved in producing product item \(i\).

\[
c^j_{ser} = \sum_i c^{ij}_{det} + \sum_i a_j c^{ij}_{pat}\]

where \(c^j_{ser}\) refers to unitary cost of service \(j\), \(c^{ij}_{det}\) designates the unitary cost of product item \(i\) consumed by service \(j\), \(c^{ij}_{pat}\) refers to the unitary cost of operators from category \(l\) involved in service \(j\), \(a_j\) is the average time spent by operators from category \(l\) on service \(j\).

\[
\text{Cost}^p_a = \sum_j \sum_i c^i_{ser,c} f^p_j + \sum_i c^p_{pat}\]

where \(\text{Cost}^p_a\) refers to total costs for actor \(a\) during period \(p\). \(c^i_{ser,c}\) designates the unitary cost of service \(j\) included in contract \(c\), \(c^p_{pat}\) refers to total cost of product items \(i\) that are not included in service packages, during period \(p\), and \(f^p_j\) is the frequency of service \(j\) during period \(p\).

\[
r^p_c = \sum_i c^{ij}_{ser,c} \times f^p_j \times m^p_{ser} + \sum_i c^{ij}_{pat} \times m^p_{pat}\]

where \(r^p_c\) is the rent value of contract \(c\) during period \(p\) for actor \(a\), \(m^p_{ser}\) designates services margin rate, \(c^{ij}_{pat}\) refers to depreciation cost of product item \(i\) during period \(p\), and \(m^p_{pat}\) is the margin rate of product items.

\[
\text{tr}^p_a = \sum_p r^p_c\]

where \(\text{tr}^p_a\) refers to the turnover of actor \(a\) during period \(p\). These equations represent fundamental interrelationships shaping the simulation. It should be noted, however, that additional equations need to be developed if additional parameters are to be introduced in the model, notably to calculate additional performance indicators.

4. Case study – value chain configuration

4.1. Context analysis and scenario identification

Usually, machining sludge generated by manufacturers is collected and treated by specialized companies. The idea suggested by the Cetim – Technical Center for the Mechanical Industry calls for a fundamental shift away from getting rid of the sludge towards making money out of it and saving natural resources. The traditional (a) and suggested (b) figures are represented in Figure 2. The suggested PSS solution is built around a briquette-making equipment which allows the compacting and briquetting, and makes the sludge reusable. The compacting and briquetting results in two reusable products, i) briquettes, which can be sold to and used by smelters, and ii) cutting fluid extracted from the sludge, which can be used by the manufacturers themselves. But beyond reusing the sludge, additional activities are needed and several services can be offered (e.g. maintenance, installation, etc.), and new actors may be involved in the new value-chain.

The actors involved in the value chain are: i) a manufacturer providing briquette-making equipment (i.e. equipment provider), which is a part of the PSS solution, ii) manufacturers producing sludge and representing potential customers of the envisioned PSS solution, and iii) smelters using electric arc furnaces for melting steel scrap and other metals who are potential customers for the produced briquettes. For confidentiality reasons, specific information about the case companies and institutions will not be disclosed.

Context analysis relies on semi-structured interviews with manufacturers, (who generate different types of sludge), with briquette-making equipment manufacturers, and with smelters. The interviews resulted in the identification of 18 alternative organizational scenarios. Afterwards, two meetings were held in order to filter scenarios according to i) compliance to regulations, ii) added value for the customer, and iii) added value for the other value-chain actors. The subsequent organizational scenarios are the following:

- **S1**: the briquette-making equipment is sold to a manufacturer who is in charge of the compacting, briquetting and maintenance operations, retrieves cutting fluids and sells briquettes to the smelters.
- **S2**: the briquette-making equipment remains the provider’s property, and the manufacturer pays for its use in his premises according to a “rental” contract. The
equipment maintenance can be included as a service in the contract and is then performed by the briquette-making equipment owner, otherwise, it is considered as an internal activity of the manufacturer.

- S3: the briquette-making equipment is purchased by an intermediary who is in charge of the compacting, briquetting and maintenance operations and sells briquettes to the smelter.
- S4: the briquette-making equipment remains the provider’s property but is made mobile and moves periodically between different manufacturers.

For each actor involved (equipment provider, intermediary, manufacturer, and smelter), the following indicators were used: total costs, total benefits, profit, and cash-flows. The current paper will be limited to the briquette-making equipment provider and manufacturers’ points of view.

4.2. Data collection and implementation

Data collection is a challenging task because of the multi-actor perspective and the heterogeneity of the required data (e.g. activities, envisioned services, market, etc.). The collection process of this data involves different actors of the value chain, depending on their roles and field of specialization. The collection process is based on questionnaires sent to the respective actors and on face-to-face meetings. Although indicators should be taken with precaution because there is some missing data and the simulation is partly based hypotheses defined with the decision-makers, they still provide a good insight into the spins-offs of the newly-studied activity. The simulator was implemented using visual basic, which resulted in a practical tool for configuring and evaluating the different value-chain configurations in the field of sludge treatment. Table 1 summarizes the main simulation inputs.

4.3. Identification of performance drivers

Interviews with the different actors involved helped to identify the potential economic drivers of the innovative activity for sludge treatment. They include for instance the scrap cost, the sludge type, the market volume, etc. Figure 3 represents all the variables considered in the experimentation plan, representing the main candidate drivers and their different potential values. These values are chosen according to their relevance to the industrial context of the case study.

![Image](image-url)
The tool used to support this analysis is the Salford Predictive Modeler® software suite.

It is obvious from the regression trees that scenarios are the most important drivers of performance. Therefore, the configuration of the value chain, which defines the roles assigned to each actor, has a notable leverage effect. As regards the briquette-making equipment provider, scenarios 1, 2 and 3 are more interesting than scenario 4, as they induce positive average values of the profit. As shown in Figure 5, scenario 2 is costly for the manufacturers who are supposed to pay for the compacting and briquetting service (monthly rental contract) and whose average profit has a negative value. This means that a trade-off should be made due to capacity utilization, which increases with high volumes of sludge being treated. This figure is different in low-market volumes leading to under-utilization of the briquette-making equipment.

The results of the case study indicate that there exist several drivers for the actors’ performances, such as the market volume, and roles assigned to actors within the PSS value chain. This provides a reasonable foundation for further investigation regarding the impact of other specific parameters, such as geographical dispersion of the actors (for scenario S4 where the equipment is movable) or possible demand thresholds.

5. Conclusions and research perspectives

The framework proposed in this paper is built upon the conceptualization of the underpinnings of a Product-Service System. These underpinnings have been identified from the literature addressing PSS engineering methodologies. The framework provides a methodological guidance that meets complementary objectives: rapid specification, development then implementation of a simulation-based DSS adapted to a PSS context; and operational evaluation and configuration of concrete PSS value chains. The case study provides evidence on the relevance of the framework for the sludge sector. The evaluation results show that the main drivers in the performance of the value chain actors are the market volume and the actors’ roles in the value chain. These are assumed to be among the most critical parameters that should be fully considered prior to moving forward to scenario implementation.

References