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Abstract. Resources depletion, emerging competition, and increasing individual customer requirements are among the most common trends shaping nowadays manufacturing industry. Product-Service Systems (PSS) are put forth as a potential means for meeting these challenges due to their intrinsic characteristics such as dematerialization, multi-actor perspective, inimitable service know-how, and customer closeness. The scope of this paper falls under a wider topic relating to the development of PSS solutions for the steel sludge treatment sector. More specifically, the paper reports on a combined performance measurement and PSS design approach to support the decision making process on the PSS implementation. The approach takes into account the need for a collaborative effort among the PSS value network actors to successfully implement PSS offers. A case study from the sludge treatment sector is used to illustrate the synergies between performance measurement and decision making, in the PSS context.

Keywords: Product-Service Systems, decision making, performance, sludge treatment, recycling.

1 Introduction

The last few decades witnessed a paradigm shift through the development and spread of servitization and Product-Service System (PSS) concepts. Goedkoop et al. [1] define PSS as ‘a system of products, services, networks of 'players' and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models’. Since then, most contributors have broadly adopted this definition. As already stressed by many authors such as Goedkoop et al. [1] and Meier et al. [2], PSSs are generally delivered by a network of partners. A PSS is the result of a value co-production process within such a partnership. Therefore, PSS business models call for a continuous collaboration process that involves both the buying and the selling organizations, and other external and complementary partners. The stakeholders, whether they are producers, retailers, customers or end-of-life managers, require connected economic interests and shared vision of desirable outcomes for a system resource optimization

[3]. The scope of this paper falls under a wider topic relating to the development of PSS solutions for the steel sludge treatment sector. More specifically, the paper reports on a combined performance measurement and PSS design approach to support the decision making process on the PSS implementation. The approach takes into account the need for a collaborative effort among the PSS value network actors to successfully implement PSS offers. A case study from the sludge treatment sector is used to illustrate the synergies between performance measurement and decision making, in the PSS context. The novelty of this paper lies in the use of performance measurement and analysis at the PSS design stage. The remainder of the paper is organized as follows: section 2 sheds more light on performance measurement from a PSS perspective. Section 3 describes the proposed approach combining PSS design and performance measurement. Section 4 illustrates the approach with a case study. Conclusions and research perspectives are detailed in section 5.

2 Performance Measurement from a PSS Perspective

Performance measurement is a well-established concept in the operations management literature. The ultimate goal of the current research is to extend performance measurement to the PSS context; in particular by supporting the decision making process during PSS design.

Performance measurement definition and issues relating to PSS. Performance measurement is an activity aimed at reaching predefined goals that are derived from the company's strategic objectives by using performance indicators (PIs) [4]. A PI is a variable that expresses quantitatively the effectiveness or efficiency or both, of a part of or a whole process or system against a given norm or target [5]. Performance measurement represents the concrete formulation of firm's strategic choices and has been closely related to supply chain and extended enterprise [6]. Lohman et al. [4] highlighted the need to measure the supply chain performance as a whole and to be able to drill down to different measures and different levels of details. Folan and Browne [6] assume that performance measurement has moved towards examination of the organization as a whole and impacting to a greater extent upon strategy. They assume that performance measurement would have an impact outside organization (i.e. external environment).

Among the difficulties shaping the performance measurement in the PSS context, and in extended enterprises at large, is the decentralized nature of the value network leading to uncontrolled growth in indicators. Basically, this stems from the connection of several companies to deliver the PSS [7]. This potentially leads to inconsistencies among the indicators used by the value network actors. The impact on the decision making is thus obvious as the performance is evaluated from single points of view. A multi-actor based indicators system reflecting all points of view of the value network actors is thus required and would be of much support to the PSS network management, which is a crucial task for the PSS [7]. Such indicators systems can act as a common platform from which all members of the value network can draw knowledge [6,8].

Performance Measurement as a Support for the Decision Making Process. As the performance measurement has evolved from measuring and monitoring to supporting decision making, proper tools and methods should be created as substitute of historical data [4,6,8]. Consistently with the above evolution, simulation is among the most used approaches to support the decision making. It allows replicating the actual behaviour of the real system at different granularity levels, ranging from value network actors down to production and service delivery activities. As such, the simulation, be it a discrete-event, an agent-based or a system dynamic based one, is a corner stone of the performance measurement, and thus of the decision making process [9,10], and the performance indicators are its backbone. Several research works used the simulation to support the decision making process in the context of PSS [10, 11,12] . Among the most common questions addressed in this context is the shift from a mere product oriented offer to a PSS oriented offer. The simulation here supports the performance measurement by evaluating different envisioned shifting scenarios using quantitative measures. Yet, in order for the decision makers to measure and improve the performance of their production systems, firms or even supply chains, there is a need to capture the most impacting performance drivers and align the decision making process with them. Consequently, several methods and tools have been used to deal with this appealing concern of exploiting performance measurement by decision makers. An example of these are multi-criteria decision methods which allow to combine a set of performance measures into a fewer ones, or even a single holistic index [13]. Another relevant means for understanding the most impacting performance drivers are decision trees which are the result of different classification algorithms [14]. These trees allow for a quick and clear graphical representation of the impact of different decision levels. The nodes of the trees represent the performance drivers, classified in order of their relevance; the most relevant drivers are linked to the root of the tree, while drivers with the lowest importance are at the bottom. The branches are labelled with the separating input variables (i.e. drivers).

3 A Combined Design and Performance Measurement Approach for the PSS

This section reports on a combined design and performance measurement approach for PSS. Unlike the traditional and most common performance measurement systems, the current approach uses performance measurement a-priori, as a supporting tool for the decision making process regarding the relevance of PSS solutions and delivery systems. The foundations of the current approach are detailed further in [4, 6, 10, 12]. More specifically, the methodological guidance combines the steps of building and using performance measurement systems [4] with the methodological support for defining PSS scenarios [12]. The performance measurement is enabled by a simulation approach inspired by Medini et al. [10]. The combined approach is structured in four steps which are detailed in the following.

Context analysis combines the firm's mission, objectives and functional areas relating

to these objectives, in keeping with [4]. More broadly, 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 are needed in order 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 expectations of both customer and other actors of the PSS value network. 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 network. Finally these scenarios are filtered in order to narrow the scope of the subsequent quantitative evaluation. The filtering criteria stems from the context analysis and the stakeholders' experience, and are defined during face-to-face meetings.

Select or develop performance measures consistently with the firm's objectives behind the PSS implementation. More specifically, this step aims to define the performance indicators for each actor involved, then identify physical and financial flows that should be modelled in order to enable indicators calculation by use of simulation. Then, questionnaires are built upon these models and are used for data collection. Indicators should comply with the multi-actor perspective, meaning that the final set of performance measures should accommodate the points of view of all the actors of the PSS value network.

Evaluate scenario performance: this step is critical in supporting the decision making process as it provides an evaluation of several alternative scenarios, thus helping to put the focus on the most interesting ones according to the performance measures. To this end, a three-stage process is deployed:

- *Building an experimentation plan* is concerned with the a priori identification of potential performance drivers according to PSS actors' know-how.
- *Evaluating scenario performances* uses simulation to compute the performance measures, based on replication of the real operations within the PSS production and delivery network.
- *Identification of performance drivers* is performed out of the simulation results. The tools used at this stage are decision trees, which form an efficient and comprehensive tool to identify the impact of different decision levels on the performance. Thresholds can be defined based on this analysis, in order to specify the circumstances under which the PSS implementation would be potentially successful.

4 Illustrative Case Study

Usually, machining sludge generated by manufacturers is collected and treated by specialized companies. The envisioned PSS solution is built around a briquette-

making equipment which allows the compacting and briquetting, and makes the sludge reusable. The compacting and briquetting result 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. The actors involved in the envisioned PSS value network are: i) an equipment provider (i.e. briquette-making), 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 of the produced briquettes.

Context analysis relies on semi-structured interviews with manufacturers, (who generate different types of sludge), with equipment provider, and with smelters. The interviews resulted in the identification of several alternative organizational scenarios that were filtered to come up finally with 6 relevant ones. The current paper is limited to the two following ones:

- U1a: 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 smelters.
- S1a: 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.

The selection of proper performance indicators was straightforward since the main concerns of the involved actors (i.e. equipment provider, manufacturer, and smelter) relate basically to costs and benefits. In the following, the analysis will be focused on the profit indicator, which is a result of the above ones. A deterministic continuous simulation model is used to evaluate the performance of the scenarios and is implemented under Excel in Visual Basic language. The back bone of the simulation model is a set of mathematical equations depicting the interdependencies between the physical and financial flows [10]. The simulation inputs are data about the value network activities (e.g. cost, input and output flows), contracts (e.g. duration, installation costs, and ascribed services), services (e.g. costs), market (e.g. scrap cost, market demand, sludge characteristics), roles (e.g. actors responsibilities in terms of services and activities). The aim of the evaluation is to identify the main economic performance drivers for the value network actors, so as to provide a support for the decision making process of these actors regarding PSS implementation alternatives. To this end, an experimentation plan was adopted and is represented in Figure 1, showing the combination of the input variables for each of the two scenarios. The simulation horizon covers a 10 years period.

The simulation results are processed using the R software[1] and the Analysis of Variance (ANOVA) method [15]. The output is structured in three regression trees representing the performance drivers of the profit indicators. Figure 2a indicates that organizational scenarios are the main drivers of the equipment provider profit. Generally, the PSS scenario (S1a) allows for more profit which ranges from $80k€$

[1] http://www.r-project.org/

when services are not included in the offer, to $130k€$ when they are included. The sales scenario (U1a) allows for a lower profit which culminates at about $60k€$, when the services are also offered in addition to the sale contract. Manufacturers' and smelters' profits are mainly impacted by the market volume, as shown in Figures 2b and 2c; the bigger are the market volumes, the higher is the generated profit. The other drivers of profit for these two actors are the waste treatment cost (wCost) and the scrap cost (sCost), respectively. The manufacturers profit reaches its highest values when waste treatment costs are high.

Indeed, the PSS helps avoiding the costs that are traditionally incurred by the manufacturers when they want to get rid of their produced sludge. Further on, for the smelters, the scrap cost is an important driver, after the market. This is explained by the fact that smelters profit comes from the savings generated out of purchasing the briquettes at a lower price than traditional steel scrap, thus the higher the scrap costs are, the higher is the smelters profit.

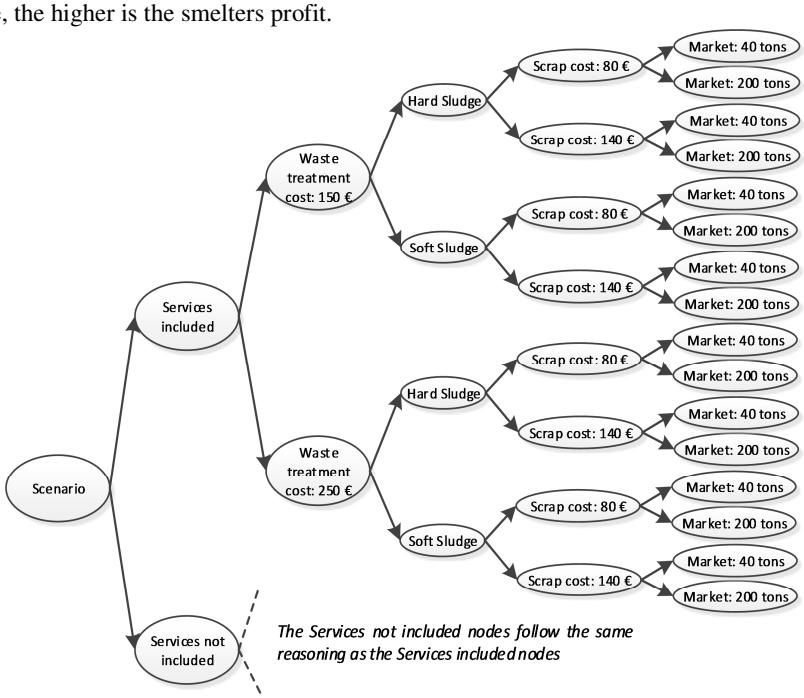

Fig. 1: Experimentation plan

The above analysis provides the different value network actors with some useful inputs regarding their decision making process, through the most relevant drivers for profit. The focus can thus be put on these specific drivers to define trade-offs taking into account all the actors points of view and thus easing the implementation of a win-win PSS solution.

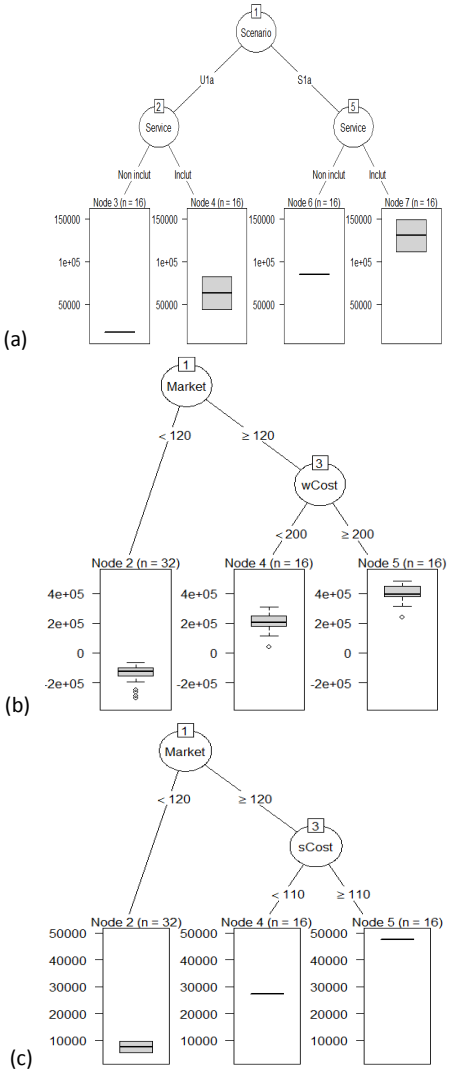

Fig. 2: Regression trees of the a. equipment provider profit, b. manufacturers profit, c. smelters profit

5 Conclusion

The current paper reports on a combined performance measurement and design approach to support the decision making process and thus mitigate the uncertainty at the PSS design stage. The basic prerequisite of this approach is a strong collaboration among the PSS stakeholders from the early design phases of PSS solutions.The case

study shows the ability of the approach to determine the key performance drivers for the PSS actors and to identify the most relevant PSS value network configurations prior to the PSS implementation. The current work, however, has limitations and thus, opens further research perspectives. First of all, the performance system implemented (based on the industrial consortium requirements) can be enriched further with other indicators in order to better reflect the service perspective. Additionally, the simulation model opens many opportunities regarding the quantification of uncertainty and its impact on performance measurement. Basically, this would strengthen the decision-aid provided to PSS actors.

7 References

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