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An IPA based method for PSS design concept assessment

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Abstract

Literature and field study research highlight that transiting toward PSS means for many companies to either miss interesting business opportunities or to bet on the wrong solution concept. Early stage assessment activities play a crucial role in this respect, guiding the selection of a value-adding PSS while preventing commitment of resources on poor design alternatives. Emerging from empirical studies in the manufacturing industry, the paper highlights the need for systematic procedures, tools and metrics able to encompass customer satisfaction together with the producer's value perspective in such assessment. The paper proposes a 2 step assessment method based on the Importance Performance Analysis (IPA) matrix enabling the integration of customer and provider value and supporting early stage PSS design decision making. Verification activities highlight the positive implications of balancing the trade-off between customer and provider value during the PSS assessment phase.

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Keywords: Product-Service System;Early design; Concept Assessment;IPA;TOPSIS; Pugh Matrix

1. Introduction

An extensive data analysis on 12,521 companies [1] shows that, while servitized firms boast higher revenues, they tend to generate lower net profits compared to pure manufacturing firms. They appear unable to create enough revenues to cover the servitization investments, often above those made by pure manufacturing firms. More recent literature [2] elaborates further on such economic impact of servitization, recognizing that sometimes "firms will either miss interesting business opportunities or bet on the wrong PSS in the wrong markets".
Documented success factors for managing the transition towards becoming a Product Service System (PSS) provider are both a strict front-end stage-gate development process and the ability to ensure a good 'fit' with the firm's existing unique competencies, experience and reputation [3]. These elements point out the importance of systematic procedures, tools and metrics to guide the assessment of PSS concepts so that companies avoid committing large amount of money on a wrong idea [4]. As explained by [5], "insufficient evaluation of the PSS solutions allows poor design alternatives to operate in practice, and causes damage which can rarely be compensated at the later stage".
In spite of its criticality, few of the existing assessment methods [6] [7], are applicable in the early design stage of a PSS, mainly because they are unable to adapt to situations where information is scarce or unstable with regards to costs, markets, prices and processes. Another issue is that they often "pay little attention to producer and cost perspectives, which are also crucial in the process of PSS evaluation and operation" [8]. As a consequence of this lack of fit-for-purpose, firms have been observed to use informal procedures and qualitative methods that primarily hinge on human intuition and experience [9].

2. Objective and methodology

The purpose of this research is to develop a decision making method for the early stage of PSS design. The objective is further to present a method that considers both customer value (CV) and provider value (PV) since the early stage assessment

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of PSS concepts, to guide cross-functional design team in progressively recombining and refining solution principles. The method builds on previous work related to the Importance Performance Analysis (IPA) framework [10], and on existing Multi Criteria Decision Making (MCDM) methods, such as the Pugh matrix [11] and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [12]. Managerial implications and findings emerge from the application and analysis of the proposed method on test cases conducted in collaboration with a road construction equipment manufacturer and a power and automation technologies' provider, both based on the following research question:

"How to assess PSS concepts in the early design phase?"

The research presented throughout this work is carried out using a qualitative research approach. Based on literature review a first proposal of a method was presented. Then, through focus groups empirical data have been collected both physical and virtual meetings. Discussions and workshops have contributed to the clarification of the problem domain, to the definition and validation of the proposed method, and to reflection activities.

3. Literature review

A process of systematic review was carried out in the Web of Science, Scopus and Ebsco databases to uncover existing contributions in literature that relate to the studied research question. The keyword "Product-Service System" was searched together with "concept assessment" OR "concept evaluation" OR "concept selection", resulting in a total of 95 articles (Table 1).

Table 1 Keyword search results

Keywords	Web of science	Scopus	Ebsco
Product-service system, concept assessment	23	1	4
Product-service system, concept evaluation	40	4	7
Product-service system, concept selection	13	0	3
Sum	**76**	**5**	**14**

Once duplicated entries were removed, irrelevant articles not dealing with concept evaluation methods, or mentioning them only in the abstract or incidentally, were also excluded by using filters at title, abstract and full-text levels. Snowballing ensured access to other contributions relevant for the given research question, for instance CIRP IPSS conferences' proceedings not indexed in the Scopus database. A total of 19 contributions was eventually found to deal with models and methods for PSS assessment: among them only 11 deal with the PSS early design stage (Table 2). These results highlight the dispersed nature of contributions concerning PSS concept assessment.

As summarized in table 2, an analysis of the literature identified in relation to how the design methods assess the value of PSS concepts has been also conducted. It is noticeable that, while all methods deal either with customer (CV) or provider (PV) perspectives, they often fail in integrating the two perspective in a holistic way and in guiding the identification of a proper trade off.

Table 2 Summary of literature review

No.	Ref.(s)	Early concept assessment	CV	PV
1	[13]	✓	✓	✓
2	[5] [14]	✓	✓	×
3	[15]	✓	✓	Only resource constraints
4	[16]	✓	✓	×
5	[17]	✓	✓	×
6	[18]	✓	×	✓
7	[19]	✓	×	✓
8	[20]	✓	Indirectly	Indirectly
9	[21]	✓	✓	Only costs
10	[22]	✓	✓	Only costs
11	[23]	×	✓	✓
13	[24]	×	×	×
14	[25]	×	Indirectly	Indirectly
15	[26]	×	Partially	Partially
16	[27] [28]	×	✓	×
17	[9]	×	×	✓

3.1. MCDM methods for PSS assessment

The assessment of PSS concepts is often seen as a "complicated multi-criteria decision-making problem" [15]: multiple alternatives must be compared considering their relations with multiple criteria. Analytic Hierarchy Process (AHP) is one of the most common MCDM methods adopted to prioritize customer requirements in PSS design [7], to measure the effectiveness of a service [29], to determine the initial importance weights of engineering characteristics [22], and to measure the uncertainty in PSS network [30]. An extension to AHP that uses Rough Group theory to evaluate requirements under vagueness, considering the customer activity cycle, has been also proposed [31].

The application of more sophisticated MCDM tools, such as TOPSIS, VIKTOR, ELECTRE and PROMETHEUS [32] is less common [6]. VIKOR is mostly adopted in the selection of PSS suppliers [33] whereas TOPSIS is used by [30] in PSS risk management. The only significant contribution available in literature with regards to the research question is the TOPSIS-based approach proposed by [34].

4. Industrial needs analysis

The empirical study carried out in collaboration with the abovementioned companies, confirms a need for a more systematic approach in PSS concept selection, as well as for a decision making method able to communicate the twofold meaning of the 'value' associated to PSS options, from a customer vs. provider perspective. In this respect, practitioners

expressed a preference towards methods able to underline situations where the design team erroneously concentrates its effort on developing i) extremely low-cost and low-effort PSS solutions that have no market because customers do not value them (quite common) or ii) innovative PSS offers with undisputed CV that are generating a loss to the company.
This is accompanied by the need for an intuitive and visual way to frame both PV and CV in the same picture to support the identification of tradeoffs, and by the need to communicate the difference between innovative designs vs. a given baseline (for instance, an existing offer) to highlight the magnitude to the change.

They further confirm existing observations [17] suggesting the main industrial requirements for PSS design support: i) being easy to adopt and implement, and ii) being understandable by individuals without engineering background. The latter is a critical feature to foster discussion within the cross-functional PSS design team to unleash all relevant lifecycle knowledge. This could contribute to filter out the PSS concepts believed unable to deliver the expected level of CV within the investment constraints. In synthesis, the method shall work as a boundary object between design team participants [35] so they can compare ideas, exchange feedback, and eventually recombine solutions.

5. Two steps IPA-based method for PSS assessment

Figure 1 describes the overall structure and steps of the proposed IPA-based method for PSS concept assessment. Importantly, all the described steps are carried out by focus groups in a workshop-like setting, involving participants from different organizational functions (mainly R&D, marketing, sales and finance), and, when possible, customers.
The process kicks-off by requesting the workshop participants to generate a first list of PSS concepts, which are defined as a product enabling a series of services processes, activities and service resources [adapted from [34]].
Step 1 is designed to accommodate PSS concepts that are very heterogeneous in nature, (spanning from pure products to pure services [36]) that would be difficult to benchmark quantitatively even with full information available. The field study suggests that assessment methods at this stage need to be flexible, simple and intuitive, all characteristics that point for the adoption of Pugh matrixes (see rationale in Table 3).

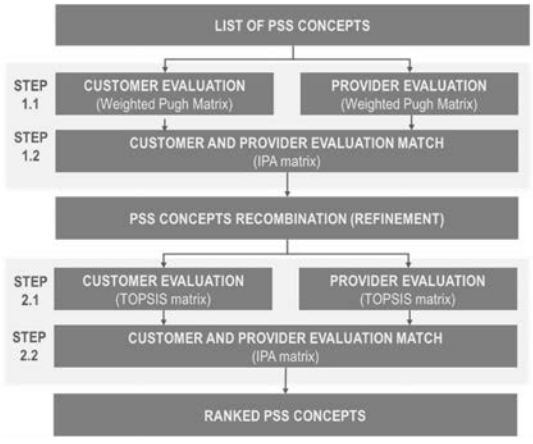

Fig. 1 IPA based method structure

Pugh enables comparison of new concepts based on multiple criteria with respect to an existing baseline defined by the provider, which by definition scores “0” in all chosen evaluation criteria. The evaluation adopts the criteria proposed by [37], an example is also reported in Table 4. All the concepts under evaluation are then assigned a (+), (-) or (0) if they are, respectively, better, worse or equal to the baseline with respect to a single evaluation criterion. Each criterion is weighted by the design team to stress (or not) its relevance. Once the matrix is completed, concepts are given a total score by summing up all “+”, “-“ or “0” obtained. The Pugh assessment is repeated twice, firstly with a focus on the customer criteria, then on the provider ones.

The main purpose of Step 1 is to support design teams in ranking solutions from both customer and provider perspectives, so to identify opportunities for improvement, recombination and refinement. These improved concepts are forwarded to Step 2, where the assessment is supported by a more systematic MCDM technique: TOPSIS [12]. TOPSIS, as emerged by the detailed rationale reported in Table 3 for rationale, has been selected mainly for its algorithm which is easy to use and implement.

Table 3 Rationale for method selection

Method selected	Rationale for selection
IPA [10] [39]	Origins related to the definition of strategic decisions for the company Integration of two perspectives and immediate and clear visualization of the provider/customer trade-off.
PUGH [11]	Commonly used in the product concept selection. No detailed data are required Well known method that is good in “concept recombination” during early stage
TOPSIS [12] [35] [40]	Good in handle human decision making Algorithm easy to use and implement Best and worst solutions are compared quantitatively Most common MCDM method used in PSS literature

TOPSIS is based on a mathematical algorithm measuring the shortest distance from a positive ideal solution and the farthest distance from a negative-ideal solution, maximizing benefit criteria and minimizing the cost criteria. TOPSIS outputs a cardinal ranking of alternatives, does not require attribute preferences to be independent [40] and can manage different type of data at the same time. Moreover, it alleviates the requirement of paired comparisons (required for example by the AHP) and due to this the capacity limitation might not significantly dominate the process. Correspondingly, in this step the TOPSIS assessment is repeated to evaluate customer and provider by use of detailed customer and provider criteria (see [38] for details on the selected metrics).

All along the method, expert judgments are required to assess the solutions:

- For what concern customers, in a value co-creation perspective, the evaluation has to be carried out directly with the support of customers (or focus groups). Sales and/or marketing people can support these phases being those who better know customers' needs.
- The provider value analysis is mainly based on the internal convenience and revenues associated to the PSS concepts. In addition to R&D and Service, all the company relevant departments are also required.

5.1. The IPA matrix

The results of both Step 1.1 and 2.1 render two scores, one related to the customer perspective and the second related to the provider one. In order to facilitate the design team in visualizing the value of each concept, these scores are positioned on a 2-dimensional map (steps 1.2 and 2.2). This is adapted from the IPA [10]. IPA was originally developed to support the synchronous analysis of two different components of customer satisfaction, the importance of the service and the performance of the provider with respect to them. Instead, the proposed IPA features an "importance" axis that displays the customer analysis results, and a "performance" axis that displays the expected value for the provider. (Figure 2).

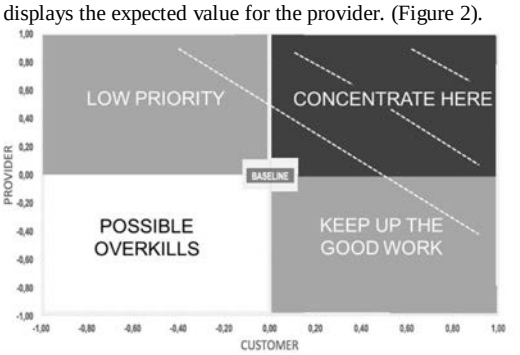

Fig. 2 IPA revised structure

Given point (0,0), which represents the baseline, the map can be divided into four quadrants:

I. PSS concepts in Quadrant I (QI – Concentrate here) have higher value than the baseline for both customer and provider. They are in general approved for being forwarded to the next step, still further evaluation, improvements or developments are advised.
II. PSS concepts in Quadrant II (QII – Low priority) have higher value for the provider and lower value for customers. In Step 1, this highlights the opportunity for borrowing features from concurrent options to increase the latter. The evaluation criteria where the concepts scored "-" in the Pugh matrix can support the identification of improvement areas (e.g., the same concept based on a different business model can be a possible evolution). In Step 2, concepts in this quadrant are discarded if Q1 is not empty.
III. PSS concepts in quadrant III (QIII – Possible Overkills) have lower value for both the customer and the provider. Being worse than the baseline, it is suggested to kill their development already in Step 1. It is still interesting to carry on positive features (e.g., for a subset of the assessment criteria) into new concepts.
IV. PSS concepts in quadrant IV (QIV – Keep up the good work) have higher value for the customer but lower for the provider. In Step 1 (as for QII), these concepts are worth additional analysis and can be further modified to be increased later. In Step 2, concepts in this quadrant are discarded if QI is not empty.

The main function of the proposed IPA method in Step 1 is to facilitate the communication and the knowledge sharing inside the design team about possible refinement of the concepts. In Step 2 its function is fundamentally different, which is to support the design team in completing the selection process of the PSS concept(s) for the follow up in the detailed design stage. Ideally the one(s) that gets closer to the top-right corner of Q1 quadrant (Figure 2).

6. Application of the IPA method for asphalt roller design

The process described in Figure 1 was tested in collaboration with two multinational manufactures working in the road construction equipment and the power and automation technologies. In the next paragraph, the case related with the design of an innovative solution for asphalt compaction is presented to better describe the method application. In detail, the test case has been conducted in form of a student project involved in a design project of an innovative solution for asphalt compaction for one of the abovementioned companies. The activity pushed the development, selection and prototyping of new products as well as services/PSS solutions. The project spans a period of 5 months, from September 2016 to January 2017.

A total of 13 solutions were generated by the team at the end of the ideation phase (see Figure 3). They have been classified in 2 families by adopting the PSS categorization proposed by [36]: 6 concepts belonged to the 'product' category (i.e., Pure product or Product oriented PSS), while 7 belonged to the 'service' category (i.e., Use oriented PSS, Result oriented PSS and Pure service).

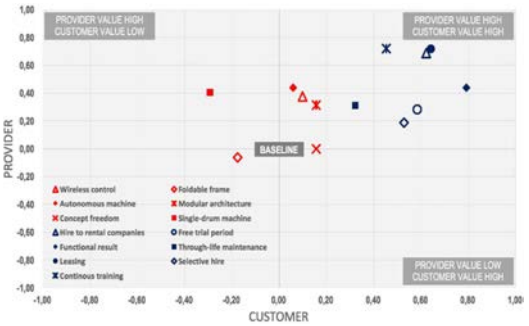

Fig. 3 IPA representation of 1st step results

The team was guided in the selection of these concepts through the process described in Figure 1. In Step 1.1 the design team was asked to define contextualized the method metrics to capture value generation both for the provider and the customers, as well as to define the rank weights for such dimensions. Concepts were then benchmarked from both points of view using the Pugh matrix (see the extract of the provider evaluation in Table 4).

Table 4 Extract of Pugh matrix

Provider	Weight	Wireless control	Foldable frame	Leasing	Base-line
Strategic benefits	22%	0.22	0.22	0.22	0
Customer knowledge	13%	0.13	0	0.13	0
Business opportunities	28%	0.28	0	0.28	0
Social benefits	3%	0.03	0	0.03	0
Environmental benefits	6%	0	0	0.06	0
Product/Service costs	28%	-0.28	-0.28	0	0
Sum		**0.38**	**-0.06**	**0.72**	**0**

The results of steps 1.1 were further collected and visualized by the help of the IPA method. In Figure 3, solutions that were classified as 'products' have been represented by red markers, while solution classified as 'service' are represented with blue markers. This representation was used as main reference by the team to identify opportunities for recombining the initial concept descriptions, mostly with the aim to merge product- and service-oriented ideas into a more coherent and exhaustive PSS description.

As a result, the 13 concepts were reduced to 4 main PSS solutions to be further assessed in Step 2. These final concepts were evaluated based on the 2nd step set of value criteria. A 5 point Likert scale was set to include experts' judgments into the TOPSIS matrix: "0" means no value associated to the criteria, "5" indicates that the solution contributes in an excellent way in providing the value. TOPSIS algorithm is adopted to obtain the final ranking of the concepts for both the customer and the provider.

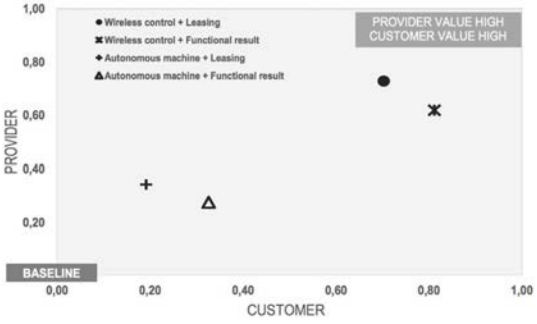

Fig. 4 IPA representation of the 2nd step results

Step 2.2 integrates the results obtained from customer and provider evaluations in step 2.1 (Figure 4) in the IPA representation. In step 2, since the scores range from 0 to 1, the matrix is based on one single quadrant. It can happen that there are outstanding concepts that lay in the top-right corner of the matrix or that a clear selection of the concepts is not possible as in the test case (figure 4). The results, however, show the direction in which the company should go and spur the discussion among the team. It is not excluded that additional concept reworking lead to an iterative application of the assessment method or that the PSS development continues with two concepts.

7. Discussion and conclusions

The literature review and the empirical findings shed the light on the need for a method to support PSS concept assessment during the early design phase. In accordance with this gap and to answer the research question, a 2-step IPA-based method exploiting the Pugh matrix and the TOPSIS assessment approaches has been proposed. Generating consensus, pushing the discussion and the collaboration among team members, and the immediate visualization of CV and PV tradeoff are the main positive implications of the method adoption. In parallel some room for improvement that are worth further analysis emerged.

The definition of a **two-steps** method contributed to the further development of the concepts. In the first step a high level analysis helps the team in bringing some issues at hand about the different concepts, that have been consequently redesigned before the second step. First step is considered essential to generate consensus among the team and to favour the detailed analysis of the 2nd step. In this direction, **Pugh matrix** came out as a good method to spur communication among the team. **TOPSIS,** in step two, provided the expected results to be included into the IPA structure. Other methods are based on the same concepts/criteria matrix but exploit different algorithms. Further comparisons with such methods as VIKOR [33] could be worth. **IPA** based result structure revealed as an immediate and visual method to show the trade-off between CV and PV. The case showed the valuable contribution of the approach in visualizing the results and acting as a boundary object. Further analysis could be carried out to guide the selection of points inside the IPA areas e.g. when many points lay in high CV and PV. In this way, fuzzy method and uncertainly analysis of data could be explored. The results obtained from the matrix are mainly qualitative. They show the direction in which a company should proceed for the development of new PSS. Based on this, and considering the data uncertainty behind, the key message of the method is not the precise point where a concept lays but the area inside the IPA structure. Therefore, a **sensitivity analysis,** changing criteria weights could be included in the analysis to observe how the concepts move around the matrix. This paper presents the proposed method and contextualize it in the PSS literature. In order to support the proposal one case has been described and discussed. Further analysis on the extant literature in the field together with additional cases will be carried out to make the proposal more robust and to highlight the positive implications associated to

its adoption.

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