Hybrid fuzzy methodology for the evaluation of criteria and sub-criteria of product-service system (PSS)

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Abstract

The world economy has seen the evolution of predominant economic activities. From pre-industrial society based on extractive activities (primary sector), through the industrial era characterized by the production of consumer goods (secondary sector), to the post-industrial age with predominance of the service sector (tertiary sector). In addition, more recently, it has been integrated with the products, i.e. PSS (Product-Service System) an integrated combination of products and services. A PSS can be thought of as a market proposition that extends the traditional functionality of a product by incorporating additional services. The primary aim of this paper is to evaluate the criteria and sub-criteria of the implementation of PSS (point of view of operations), based on the quality dimensions, through of hybrid methodology (Fuzzy Delphi – FDELPHI and Fuzzy Analytic Hierarchy Process – FAHP). The fuzzy Delphi method was used to validate the criteria and sub-criteria taken from the literature. FAHP method to calculate the relative weights of the selected criteria and sub-criteria. The questionnaire (based on the quality dimensions) was applied to a large company located in Paraná, Brazil, which has the intention of implementing PSS. The results show that the criteria that were relevant to the company: C3 (Restructuring) had the high weight (17.80%), C9 (Assurance) (15.38%) and C4 (Innovation and Technology) (13.26%). Regarding sub-criteria (global weight), the most influential are “Sc46 (learning and understanding of requirements of necessity and customer satisfaction) 5.55%), Sc14, Sc15, Sc17 and Sc18 (Restructuring) (3.54%, 3.35%, 3.30% and 3.00% respectively). Thus, this work is expected to contribute to improvement in the management of product-service system (PSS) innovation and to provide competitive advantages.

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1. Introduction

The logic of this evolutionary process shows that the service society, characterized by intangibility of its products, directs you to a society based on experiences where the final product is being offered as required to experienced process. In the 1990s, new studies were conducted with the purpose of identifying evidence in the relationships of economic interdependence and procedural dynamics of innovation across sectors of industry and services. In this context, Product-Service System (PSS) is highlighted. Product-service systems (PSS) are a specific type of value proposition that a business (network) offers to (or co-produces with) its clients. One definition of PSS is ‘a mix of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling final customer needs’ [1-2]. Therefore, this study aims to evaluate the criteria and sub-criteria of implementation of PSS (point of view of operations), based on the quality dimensions through of hybrid methodology (Fuzzy Delphi – FDELPHI and Fuzzy Analytic Hierarchy Process – FAHP). This paper is organized into five sessions. The context of the research is described in session 1. Session 2 explains the background; session 3 shows the methodology used. In session 4, its application and results (case study). Finally, in session 5 the conclusions.
2. Background

The subsequent literature review addresses the PSS.

2.1. Product-Service System (PSS)

The union between products and services initially emerged as a way to create entry barriers to new competitors and increase the portfolio of customers of these companies, such as new products, but without much differentiation in manufacturing. The concept of “Servitization” [4-5] products, “Productization” [6] services and more recently the Product-Service System (PSS) or Integrated Product-Service System (IPS2).

Productization traditionally appeared in service companies such as banks, which started using products to facilitate and deliver their services. Subsequently, they were given a broader control over the design specifications of products used to produce and deliver the service. Productization is the evolution of the services component to include a product or a new service component marketed as a product. Servitization is the innovation of an organization’s capabilities and processes to better create mutual value through a transition from selling product to selling PSS.

The integration of goods and services brought challenges regarding product design, which began to be considered with a packaging or the offer of solutions. In this way, the production processes need to be rethought. This is also true for the delivery of the product. The product life cycle becomes a challenge considering that it will not add associated services. PSS is a business strategy, and has major potential to generate solutions that meet the needs of not only industry but also clients through the delivery of integrated products and services.

The PSS uses a new service structure to facilitate sustainable production and consumption [1], [8] and its effect is significant to the countries that are often a concern in industries that consume development resources [9] [10]. The PSS can be defined as a social system that increases social and economic values for stakeholders, by offering products, services and product-services within the system [11]. Hence, intensive forms of utilization of product are replaced by the possibility to fulfil consumers’ needs through the provision of more dematerialized services, which are also often associated with changes in the ownership structure.

Therefore, various approaches and trends towards development and the PSS can be described as [12]:

- PSS1: Product-oriented services – the provider not only sells a product, but also offers services that are required during the use phase of the product. This can imply, for example, a maintenance contract, a financing scheme or the supply of consumables, but also a take-back agreement when the product reaches its end of life.
- PSS2: Use-oriented services – Here, the product does not move in ownership. The provider maintains ownership, and is often responsible for maintenance, repair and control [18]. The lease pays a regular fee for the use of the product; in this case he normally has unlimited and individual access to the leased product.
- PSS3: Result-oriented services – based on the provision of solution or a result of replacing only a tangible product. The companies offered a personal service or a product mix with ownership of the company (manufacturer or service provider). In addition, consumers pay only for results [7]. He/she does not use the product, only benefits from results of functions created by the product in use.

Many studies have explored how PSS can create the advantage of environmental sustainability [14-16], [17]. In PSS, the ultimate goal of adding services to traditional products lies in the achievement of sustainability [18]. Sustainability can be achieved through the transition towards functional economy by changing customers’ behavior from product ownership to relevant function usage [19-22].

Through this change, the use of resources can be optimized by sharing or collectively utilizing the products or managing the product lifecycle. This resource optimization can be linked to the concept of dematerialization in PSS [23], which refers to the opportunity that a PSS offers to break the link between value delivered to the customers, and the amount of tangible material needed to create the value [7]. All these activities can contribute to reducing environmental impact, thus achieving sustainable development [15].

Therefore, it is possible to foresee a generation of service-oriented solutions [18] based on company-led innovations, shifting a company’s focus from products to services. PSS has the potential to open new markets. In reality, if they are successful, it will be because the product service mix offered is recognized by the potential customers (companies or individual consumers) as better than existing solutions, or they are meeting previously answered demands.

3. Methodology

In this paper, the mathematical modeling was based on FDELPHI and FAHP hybrid methodology to assess the criteria and sub-criteria of implementation of PSS (from the point of view of operations), based on the quality dimensions. The use of a hybrid approach is justified: the fuzzy method Delphi shows itself useful due to the fact the discussion with experts about what they want to work on, not counting the fact that this method provides a refinement in the search instruments (for example, in the questionnaire). As for the FAHP, this method is the most spreading in literature and the fuzzy logic compensates for its imprecision and uncertainty that originates in the judgment of the decision maker(s). Since the peer-to-peer
comparison in the AHP is inadequate, inaccurate and conventional, in capturing the degree of importance of the decision-maker(s) in the evaluation of alternatives.

A hybrid mathematical modeling was based on two steps: in the first place, decision-makers identify the problem, criteria and sub-criteria to the implementation of PSS, based on the quality dimensions (Table 1). The FDELP/HI was used to validate criteria and sub-criteria present in the implementation of PSS and, FAHP method was applied to calculate the relative weights of the selected criteria/sub-criteria.

The initial Step 1 was conducted through the fuzzy Delphi method with 5 expert implementation of PSS. As result of fuzzy Delphi method (see Chang & Wang [39], Kuo & Chen [40], Hsu et al. [41], Wang & Durugbo [42]), obtained a questionnaire validated by experts. Subsequently, this was applied to a large company situated in the central region of Parana, Brazil. The company is planning to implement PSS. The study is characterized as a case study. In Step II, a matrix proposed by Chang [38], the vector of weights of paired array was determined. The use of this method is due to the fact that the steps given in Table 2. For it, the approach Wang, Chan and Li [44] was used. The judgment matrix \( \tilde{A} \) is \( n \times n \) and contains fuzzy \( \tilde{a}_{ij} \) numbers, so it is represented by Equation 2.

\[
\tilde{a}_{ij} = \begin{cases} 
1, & i = j \\
3, & 5, & 7, & 9 \text{ or } 1, 3, 5, 7, 9, i \neq j
\end{cases} (2)
\]

\( X = \{x_1, x_2, ..., x_n\} \) is a set of object, and \( U = \{u_1, u_2, ..., u_m\} \) the set of goals. The analysis can be performed with each object and its respective \( g_i \) goal resulting in \( m \) values for each object given target. That is \( M^i_{ji}, M^i_{gju}, M^i_{m, i} = 1; 2, ..., n, \) where all \( M^i_{gju}(j = 1; 22 ... m) \) are TFNs representing the performance of the object \( x_i \) with respect to each \( u_j \) goal.

The scores from the paired comparisons are transformed into linguistic variables [45], which are represented by TFNs. By using TFNs to compare pairs, the fuzzy judgment matrix \( \tilde{A} \) can be mathematically expressed through Equation 1.

\[
\tilde{A} = \begin{pmatrix}
1 & a_{12} & \ldots & a_{1n} \\
\frac{1}{a_{12}} & 1 & \ldots & \frac{1}{a_{1n}} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{1}{a_{1n}} & \ldots & \ldots & 1
\end{pmatrix}
\]

(1)

A comparison of pairs is performed using a ratio scale. The scale used is a nine-point scale with the use of TFNs. These numbers are used to indicate the relative strength of each pair of elements in the same hierarchy. The scores from the paired comparisons are transformed into linguistic variables [45], which are represented by TFNs. By using TFNs to compare pairs, the fuzzy judgment matrix \( \tilde{A} \) can be mathematically expressed through Equation 1.

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\vdots & \vdots & \ddots & \vdots \\
\frac{1}{a_{1n}} & \ldots & \ldots & 1
\end{pmatrix}
\]

(1)
Equation 8 takes the form of Equation 9.

\[
v(M_1 \geq M_2) = kgr(M_1 \cap M_2) = \mu_{\omega}(d) =
\begin{cases}
1 & \text{if } m_2 \geq m_1 \\
0 & \text{if } l_i \geq l_i \\
\frac{l_i - l_i}{m_i - m_i} & \text{if } l_i < l_i
\end{cases}
\] (8)

\[
d^{(k)} = \min \{v(S_j \geq S_i)\}
\] (9)

For \( k = 1; 2; \ldots; m; k \neq i \). Following the weight vector (Equation 10) is given by:

\[
W = (d^{(1)} A_1, d^{(2)} A_2, \ldots, d^{(k)} A_k)^T
\] (10)

where \( A_i (i = 1; 2; \ldots; n) \) has \( n \) elements.

**Step 4:** The level of possibility for a convex fuzzy number to be greater than \( k \) convex fuzzy numbers can be defined by Equation 11.

\[
v(M_1, M_2, \ldots, M_k) = kgr[M_1 \cap M_2 \cap \ldots \cap M_k] = \mu_{\omega}(d) = \begin{cases}
1 & \text{if } m_2 \geq m_1 \\
0 & \text{if } l_i \geq l_i \\
\frac{l_i - l_i}{m_i - m_i} & \text{if } l_i < l_i
\end{cases}
\] (11)

**Step 5:** through standardization, Equation 12 normalizes the weight vectors.

\[
W = (d^{(A_1)} d^{(A_2)} \ldots d^{(A_k)})^T
\] (12)

where \( W \) is a non-fuzzy number.

To compare \( M_1 \) and \( M_2 \) the values \( V(M_1 \geq M_2) \) and \( V(M_2 \geq M_1) \) are needed.

**Step 6:** Calculation of overall weights [50-51] for the sub-criteria. The overall weights of sub-criteria are calculated by multiplying the weight of the sub-criteria with the weight of the criteria to which it belongs. The overall weights are denoted by \( w_{sub} = (w_{11}, w_{12}, \ldots, w_{ini}) \), where \( n_i \) is the number of sub-criteria with respect to the \( i \)-th criterion.

### 4. Application of FDDELPHI

Following is the first stage of the methodology used for evaluating the criteria and sub-criteria to the implementation of PSS, using the Fuzzy Delphi (FDDELPHI) method. An initial questionnaire with 11 criteria and 91 sub-criteria (based on the literature and interviews with experts responsible for implementing the PSS). In total, 4 rounds were performed. After Step I the next (Step II) was the application of FAHP in a large company that is planning the implementation of PSS.

#### 4.1. Application of FAHP

**Step 1:** The formation of the comparisons of pairs of attributes for the criteria was carried out using the fuzzy numbers. The same for the sub-criteria.

**Step 2:** The value of the fuzzy synthetic measure initially performed for the criteria were:

\[
\sum_{j=1}^{m} S_{M_j} = (1.1, 1) @ (1/7, 1/7, 1/5) @ \ldots @ (3.5, 7) = (10.86, 16.86, 23.2)
\]

\[
\sum_{j=1}^{m} S_{M_j}^{sub} = (12, 14, 19, 40)
\]

\[
\sum_{j=1}^{m} S_{M_j}^{sub} = (10.86, 16.86, 23.2) \oplus (16, 29, 50, 29) \oplus (38, 58, 10, 37) = (216, 283, 300)
\]

\[
\left| \sum_{j=1}^{m} M_j \right|^{-1} = \left( \frac{1}{216}, \frac{1}{283}, \frac{1}{300} \right) = (0.003336, 0.003533, 0.004629)
\]

The same procedure was performed for the sub-criteria.

**Step 3:** The degree of possibility of \( S_j = (l_j, m_j, u_j) \geq S_i = (l_i, m_i, u_i) \) can be calculated by comparing the values of \( S_j \) and \( S_i \).

\[
S_j(S_i) = (0.121934, 0.1776960, 0.2333020)\]

\[
S_i(S_j) = (0.089275, 0.111537, 0.1703470)
\]

\[
V(S_1 \geq S_2) = 0.1219340 - 0.1703470 = 0.0483
\]

The results for the degree of possibility for the criteria and sub-criteria.

**Step 4:** as a result, we obtained the following weight vector (criteria):

\[
W = (0.060, 0.105, 0.178, 0.133, 0.081, 0.070, 0.050, 0.112, 0.154, 0.050)
\]

**Step 6:** Calculation of the global weight of the sub-criteria. Table 3 shows the results for all sub-criteria.

| Criteria | Sub-criteria | Local Weight | Local Weight (%) | Global weight | Global weight (%) |
|----------|--------------|--------------|------------------|---------------|------------------|
| C1       | S1           | 0.1020       | 10.20            | 0.0681        | 0.61             |
| C1       | S11          | 0.1200       | 12.00            | 0.0072        | 0.72             |
| C1       | S12          | 0.1115       | 11.15            | 0.0067        | 0.67             |
| C1       | S13          | 0.1200       | 12.00            | 0.0054        | 0.54             |
| C1       | S14          | 0.0900       | 09.00            | 0.0132        | 1.32             |
| C1       | S15          | 0.2200       | 22.00            | 0.0144        | 1.44             |
| C1       | S16          | 0.2400       | 24.00            | 0.0155        | 1.55             |
| C1       | S17          | 0.1458       | 14.58            | 0.0127        | 1.27             |
| C1       | S18          | 0.1200       | 12.00            | 0.0244        | 2.44             |
| C1       | S19          | 0.1933       | 19.33            | 0.0020        | 0.20             |
| C1       | S20          | 0.1311       | 13.11            | 0.0139        | 1.39             |
| C1       | S21          | 0.1800       | 18.00            | 0.0191        | 1.91             |
| C1       | S22          | 0.1987       | 19.87            | 0.0354        | 3.54             |
| C1       | S23          | 0.1864       | 18.64            | 0.0335        | 3.35             |
| C1       | S24          | 0.1641       | 16.41            | 0.0292        | 2.92             |
| C1       | S25          | 0.1852       | 18.52            | 0.0330        | 3.30             |
| C1       | S26          | 0.1685       | 16.85            | 0.0300        | 3.00             |
| C1       | S27          | 0.0960       | 09.60            | 0.0171        | 1.71             |
| C1       | S28          | 0.2003       | 20.03            | 0.0266        | 2.66             |
| C1       | S29          | 0.1801       | 18.01            | 0.0259        | 2.59             |
| C1       | S30          | 0.1145       | 11.45            | 0.0152        | 1.52             |
| C1       | S31          | 0.1558       | 15.58            | 0.0207        | 2.07             |
| C1       | S32          | 0.1042       | 10.42            | 0.0138        | 1.38             |
| C1       | S33          | 0.1751       | 17.51            | 0.0232        | 2.32             |
| C1       | S34          | 0.0700       | 07.00            | 0.0093        | 0.93             |
| C1       | S35          | 0.1507       | 15.07            | 0.0123        | 1.23             |
| C1       | S36          | 0.1905       | 19.05            | 0.0155        | 1.55             |
| C1       | S37          | 0.2409       | 24.09            | 0.0196        | 1.96             |
The criteria C3 (Restructuring) had the highest weight (17.80%), C6 (Assurance) (15.38%) and C5 (Innovation and Technology) (13.26%). I.e., the more influence in implementation of PSS. The sub-criteria (Table 6) with greater weight (%): Sc46 (learning and understanding of the requirements of necessity and customer satisfaction – Assurance) (36.08%); Sc49 (company always provide the best service to the customer – Empathy) 33.00%, Sc53 (reduce waiting time to receive the service – Communication), 28.71%, and Sc45 (access to information of the product-service performance during use – Communication).

As for the global weight of the sub-criteria, the following are highlighted: Sc46 (learning and understanding of requirements of necessity and customer satisfaction – Assurance) (5.55%); Sc40 (the PSS concept must be consistent with the firm’s strategic orientation – Restructuring) (3.54%); Sc11 (creation of a project team to perform the PSS design activities – Restructuring) (3.35%), Sc17 (requirements of necessity and customer satisfaction – Assurance) (3.30%).

Therefore, one can see that the relevant criterion was “Restructuring”. It shows that for the implementation of such a system the organization needs to review its present management, policies, goals and routines.

5. Conclusions

This paper aimed to evaluate the main criteria and sub-criteria for the implementation of the PSS (from the point of view of operations), through a fuzzy methodology. Initially, we used the fuzzy Delphi to validate (with experts) the criteria and sub-criteria for the implementation of SSP through a questionnaire (based on the quality dimensions) elaborated on from the literature. Next, it was applied to a large company that is planning to implement PSS. Four rounds were carried out until they reached the end questionnaire (10 criteria and 55 sub-criteria). It was observed through data the need that organizations must review their management for the implementation of PSS. Therefore, barriers and challenges in implementation of PSS certainly exist, and range from resistance of the companies to take on more responsibility and the necessary competence grace. Also, consumer resistance in not understanding or accepting the non-ownership of the property. In addition, especially on perceived value, as it passes from the tangible to the intangible. As for suggestions for future research, it is recommended that application of the research be from the client’s point of view.

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