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RESEARCH PAPER

An analysis of critical success factors for product-service systems in an emerging economy

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ABSTRACT

Goal: To identify and analyze critical success factors (CSF) related to product-service system (PSS) use and implementation.

Design / Methodology / Approach: Firstly, CSF were identified in literature and grouped in three PSS dimensions: (i) offering, (ii), consumer, and (iii) provider. Secondly, a questionnaire was applied to scholars to assess and prioritize those factors through field research. Finally, hypotheses were formulated and statistically verified through Kolmogorov-Smirnov tests.

Results: There is an agreement between the expert assessment and the literature on PSS. For instance, life-cycle perspective and PSS cost-benefit needed to be considered since PSS design. However, there are some contingencies about the product dematerialization, as well as to the reduction of environmental impacts.

Limitations of the investigation: The CSF were prioritized by the assessment of a limited number of scholars and practitioners from an emerging economy.

Practical implications: The CSF of PSS identified and prioritized in this work can offer directions the academics and practitioners, which intend to implement a PSS business model to establish and improve their practices.

Originality / Value: PSS is currently considered an alternative to mitigate environmental impacts since one of its purposes is consumption towards dematerialization. Although the concept of PSS has evolved in the past years, the literature is scarce of publications discussing the CSF that could favor its implementation, especially in developing countries.

Keywords: Product-service system; PSS; Critical success factors.

INTRODUCTION

Product-service system (PSS) is an alternative that refers to a system of products, services, support network, and infrastructure, considering the three dimensions of sustainability (environment, society, and economy), generally focusing on the environment (Beuren et al., 2013; Tukker, 2015; Mahut et al., 2017). The PSS's benefits are mainly related to continuous improvement in quality and customer satisfaction, resulting in a loyal customer (Beuren et al., 2013), more stable incomes, possible higher profit margins, and differentiation from competitors (Ayala et al., 2019). PSS also emerges to enhance competitiveness through strengthening activities and new business offerings (Mahut et al., 2017).

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Research on PSS emphasizes that this subject has been exponentially increasing (Li et al., 2020; Moro et al., 2022).

The transition to offers focused on product performance requires the development of innovative business models (Evans et al., 2017; Moro et al., 2022), which may be a challenging endeavor (Rodríguez et al., 2020). Resistance to changing established habits and the product-focused mindset are the most prominent difficulties that PSS business models may face in increasing its usage (Tukker, 2015; Mahut et al., 2017; Moro et al., 2020). Moreover, there is still a lack of emphasis on operational and practical instruments that could foster PSS introduction (Annarelli et al., 2018). In this sense, the co-creation integrating the three dimensions of sustainability is a challenge (Evans et al., 2017).

Sundin et al. (2010) point out that the practical implementation of the PSS has to overcome several barriers. The implementation and diffusion barriers could be internal, for the customers and context based (Vezzoli et al., 2015; Moro et al., 2020). These barriers exist because the PSS is more complex than products or services, as they incorporate tangible and intangible components on the same offer (Maleki et al., 2018). The barriers should be then investigated to identify the main critical factors that make the PSS so successful. More studies are needed on the difficulties involved with the PSS and possible solutions to advance knowledge about the implementation of PSS (Matschewsky et al., 2018).

In this sense, this paper aims to identify a set of critical success factors (CSF) to PSS and analyze their relevance. Previous works have investigated specific CSF for PSS, for instance, those related to lean practices (Elnadi and Shehab, 2015) or in the marketing of the PSS in the electric car industry (Cherubini et al., 2015). However, the CSF could also be related to the context in which the PSS will be inserted. PSS literature origins are mainly from developed countries (Tukker, 2015; Pallaro et al., 2017). Therefore, PSS business models are generally developed considering the critical criteria for those countries (Pallaro et al., 2017). In emerging countries, PSS may offer different opportunities. Generally, in emerging economies, services are used to leverage their product sales (Ayala et al., 2019). Actually, contrasts between developed and developing countries have been mentioned as PSS research gaps (Moro et al., 2020), especially with regard to CFS. Thus, this work focuses on CSF for PSS in the context of an emerging economy (Brazil).

Background on product-service system

Product-service systems have great potential to decouple consumption from economic growth, often outlined as one of the potential enablers for configuring new business models for circular economy, stimulating life-extension and product take-back (Pieroni et al., 2019). Nevertheless, there are several changes that must be considered when implementing a PSS business. For example, there is a reduction in the number of products to be manufactured, where the PSS aims at increasing their reutilization (Kimita et al., 2009). For a successful PSS, each stage of its life cycle must be analyzed through systemic thinking (Nunes et al., 2021). Managers should plan an integrated offering according to their goal and their competitive position (Zheng et al., 2019). It is important that managers see the PSS as an experience, which should be implemented by considering each step in the life cycle as well as its context, and making possible customer participation in these building steps, linking up with the service which will consume. This decreases the distrust in the new product and causes customers to learn more about PSS, resulting in increasing chances of success (Ceschin, 2013).

A PSS can be divided into three complementary dimensions (Sakao et al., 2009a): (i) offering; (ii) consumer (or user); and (iii) provider. Offering dimension refers to the products and services developed by the providers and presented to the consumers. The previous authors add that this dimension is responsible for the physical product's life cycle and the service activities. In addition, the authors state that a PSS successful design depends on a deep understanding of its life cycle. Nunes et al. (2021) highlights the importance and growth of studies related to the analysis of the life cycle and PSS, being a sustainable alternative capable of mitigating negative externalities to the environment and human health. Offering dimension should (Kohlbeck et al., 2022): invest in eco-innovation and to restructure business propositions through servitization or the sharing economy; upgradability, prevent a product or service from becoming obsolete and extending its useful life.

Consumer dimension addresses the evolving needs of consumers in relation to the offered products and services. The individual wishes of consumer are constantly evolving, and it is crucial to the services and products providers to be able to anticipate consumer reactions to new offerings. According to Sakao et al. (2009a), it is important to be flexible during the development of the PSS in such a way as to absorb possible changes in consumer needs and wishes. Consumer dimension should (Kohlbeck et al., 2022): adopt sustainable consumption; acquiring knowledge about sustainable development; reduce consumerism and wastage, emphasizing the relation with the sustainable development goals (SDG).

Provider dimension deals with the evolution of product and service providers, covering issues such as: project planning, organizational streamlining to provide services, and identification of the partnerships necessary for the satisfactory operation of services, both internal and external to the organization (Sakao et al., 2009a). Provider dimension should (Kohlbeck et al., 2022): use technological resources and tools (e.g., ecodesign, service design, etc.); develop a holistic understanding of the worked context; manage life cycle stages with eco-efficiency; promote organizational cultural change; adapt the proposals to the local context, consider the sustainability dimensions, taking advantage of local strengths as well as deploying End of Life (EoL) management strategies.

The services have been increasingly considered as a strategy. They bring about economic opportunities, including customized services and environmental opportunities, generating optimized solutions (Becker et al., 2008). There are three reasons for this dislocation: competitiveness concerning the selling of products, values aggregated from the service providers, and product servitization (Sakao et al., 2009b). However, there is much to be done to educate consumers, as there is still some resistance to the view that they do not have the product (Tokarz et al., 2020). Thus, the necessity of 'having' overrides the need to 'use'. This is still one of the biggest barriers to be overcome both by researchers of the subject and the companies including such proposals. Resistance to change both by providers and customers is one of the most challenging PSS barriers (Annarelli et al., 2018). It is necessary to known methods and tools for the PSS (Tokarz et al., 2022), and understand the system and dimensions of PSS.

RESEARCH METHODS

The CSF are key to define the success or failure of a goal defined by the planning of a particular organization. Rockart (1979) recommended that companies should use a set of key variables, or CSF, to reach the business's goals. Companies found out that the CSF inform the managers about the priorities, directing their efforts (Lam and Chin, 2005). This work identifies, assesses, and prioritizes PSS-related CSF. The CSF identified and assessed may lead to the business's success or failure (Rockart, 1979). This work employed a literature review to search for the CSF, as in Chong et al. (2011). Then, scholars and practitioners (from partner companies) assessed the CSF based on to their field of expertise. Figure 1 summarizes the research approach employed in this work In the first step, a literature review concerning product-service system critical successes factors was conducted. The second step identified and categorized CSF in the PSS dimensions ('offering', 'consumer', and 'provider'), resulting in a preliminary list of the CSF from the literature. In the third step, the CSF are assessed by scholars and practitioners to prioritize the importance of each CSF. The statistical Kolmogorov-Smirnov test (Beri, 2008) was applied to test the hypotheses, described further ahead in this paper.

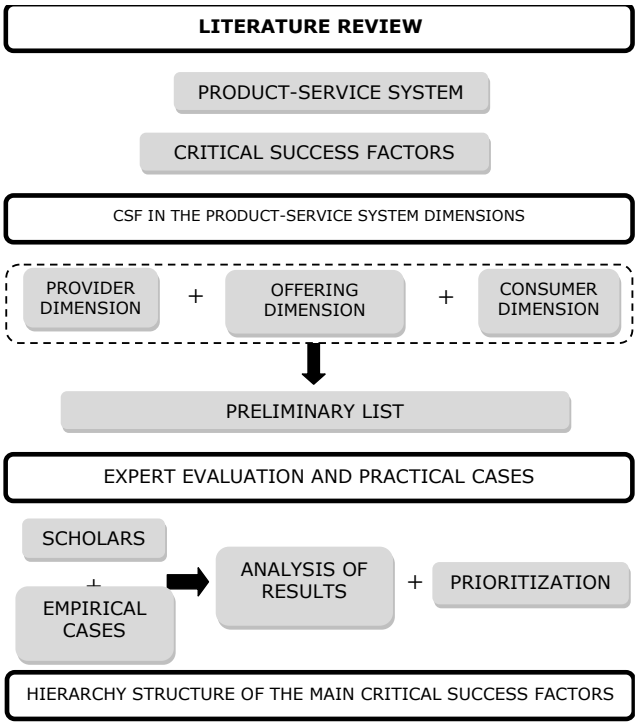

Figure 1 - Research methods and procedures

The literature review included articles published in peer-reviewed journals from Scopus, Science Direct, Springer Link, Web of Science, and Compendex databases. The terms used in the search were: "product-service system" and "PSS", "servitization" and "productization" (based on Baines et al., 2007) and combinations with "sustainability", "remanufacturing", "service design", "service economy", "product substituting service", "dematerialization", "system solution", and "functional economy", that resulted in 505 articles from 2000 to 2019. The titles, abstracts and keywords were read and those that fulfilled the research purpose were selected, resulting in 328 publications (no duplicates as well). The articles were next read thoroughly to identify the CSF of PSS. The terms used for this purpose were also "benefits", "barriers", "threats", and "opportunities", which are compatible with the SWOT analysis (strengthen weakness, threat, and opportunity), as suggested by Rockart (1979). These terms showed value in the identification of the CSF within the PSS context.

The CSF of product-service system were organized according to the dimensions proposed by Sakao et al. (2009a), discussed in the previous section. "Offering dimension" that includes products and services; "consumer dimension" that receives the offer with products and services; and "provider dimension" that offers the product and service to the consumer.

After acquiring previous knowledge concerning the subjects of PSS and CSF, the following research question was raised: "which are the main critical factors that must be considered to assist the companies in the well-succeeded implementation of product-service systems?". From the question, the hypotheses were developed as follows.

H1) *CSF for the offering dimension of products and services are considered critical for the PSS, according to scholars*;

H2) *CSF for the consumer dimension are considered critical for the PSS, according to scholars*;

H3) *CSF for the provider dimension (producers, raw material suppliers, service providers, all the partners in the business that offer solutions to the consumers) are considered critical for the PSS, according to scholars*.

The CSFs in the PSS literature were then assessed to check whether they were essential for PSS perceived by scholars and practitioners experts. The scholars were intentionally selected, as they have experience in PSS, both in academia and in industry. The CSF were assessed through a questionnaire. The instrument was constructed with four sections: (i) the paired comparison scale, where the respondents must compare the CSFs pairwise; (ii) assessing the rejection in relation to CSF presented; (iii) CSF important in a PSS; (iv) Likert scale (from 1 to 5) to check the level of concordance/discordance. The responses were subsequently statistically analyzed by hypothesis test.

As aforementioned, this work focuses on CSF for PSS in the context of a developing economy. In this sense, assessment of the CSF was carried out by experts who deal with this business model in Brazil. Fifteen experts were invited to participate in the research: 11 academic experts and four professional experts. These experts were selected because they were involved with the three dimensions of the PSS ('offering', 'provider', and 'consumer') as well as the sustainability concept. The practitioners from companies were involved with marketing as they are usually closed to the customers and have a better understand of them. Design managers were also consulted since they deal with the offer of product-service. From the 15 set of experts, five academic experts and two professional experts responded. Table 1 summarizes their profile of them).

Table 1 - PSS experts' profile

Academic experts	Education	Main expertise area	PSS experience	Experience on PSS (years)
Expert 1	Doctorate	Design	Academy	3 to 5
Expert 2	Post-doctorate	Design	Academy	5 to 10
Expert 3	Doctorate	Design	Academy	3 to 5
Expert 4	Doctorate	Design	Academy	5 to 10
Expert 5	Doctorate	Environmental Engineering	Academy	5 to 10
Professional experts	**Education**	**Main expertise area**	**PSS experience**	**Experience on PSS (years)**
Expert 6	Master	Administration	Entrepreneurship	3 to 5
Expert 7	Doctor	Production Engineering	Research & Development	5 to 10

The test was employed to verify critical values of difference between real and theoretical (D) so that the maximum allowed value of the CSF. The values are calculated for each level of significance, in this case n = 7 (sample of 7 scholars) and significance level α = 0.2, with maximum critical value

D=0.381 (based on Siegel, 1981). The number of respondents is a limitation of this research due to the low return of experts to participate in the research. To apply the statistical test, the following steps were followed (Beri, 2008).

Absolute score (pa): counting of answers. In this case, the values of the Likert scale:

$$pa = \sum \text{points (CSF)} \quad (1)$$

Relative score (pr): the percentage of points in each scale in relation to the total of points (pt):

$$Pr = pa/pt \quad (2)$$

Relative score accumulated (pra): the accumulated percentage, to each scale, in relation to the total of points:

$$pra = \sum pa \quad (3)$$

Theoretical relative score (prt): the theoretical percentage of points in each scale. The possibility of a non-existent differentiated perception by the respondents is considered:

$$prt = 1/5 \text{ (five scales)} \quad (4)$$

Accumulated theoretical relative score (prta): the accumulated theoretical percentage, to each scale, in relation to the total of points. The possibility of a non-existent differentiated perception of the respondents is considered:

$$prta = \Sigma\ prt \quad (5)$$

Difference between real and theoretical score (Δ): the difference between a real and theoretical score that represents the difference between observed accumulated percentages and theoretical accumulated percentages to each scale:

$$D = pra - prta \quad (6)$$

Finally, a hierarchy structure from the CSF of PSS was obtained. This structure can be applied in different PSS contexts, allowing considering the adequacy of the identified factors to the context of the application as well as including new CSF that were not previously listed. Companies that intend to implement a PSS can use the CSF list as a basis.

Having described the research methods, attention is turned to the results, presented next.

RESULTS

Critical success factors for product-service systems

Figure 2 presents the CSF of a PSS. It represents three dimensions by Sakao et al. (2009a), corroborated by Sakao et al. (2009b) as well as Sundin (2009), and earlier presented in the previous section.

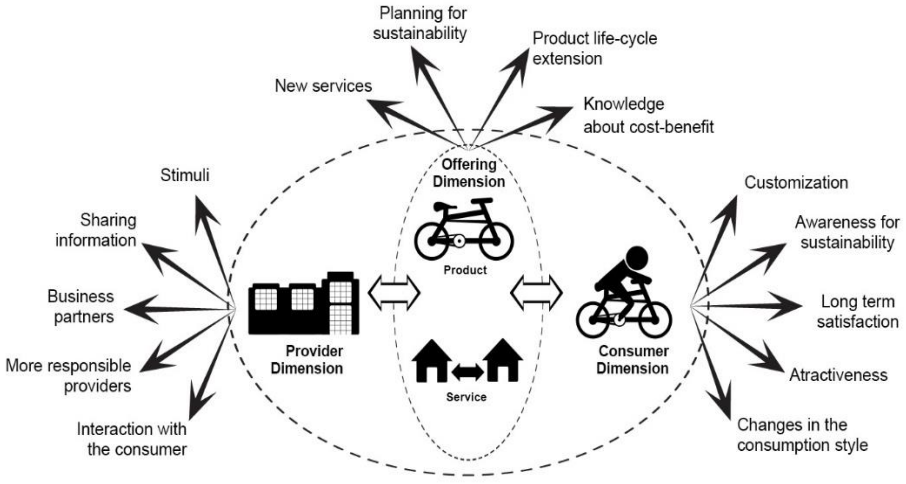

Figure 2 - Critical success factors for a PSS

It is important to categorize the CSF to understand each dimension in order to improve its competitive performance and the system itself (Purcidonio et al., 2020). This considered the three dimensions, with four CSF to "offering" dimension, and five CSF to "consumer" and "provider" dimensions. Table 2 shows CSF categorized in the PSS dimensions, *i.e.*, "offering", "consumer", and "provider".

Table 2 - Critical success factors for the product-service system

Dimensions	Offering			Consumer					Provider					
CSF/ ARTICLES	New services	Planning for	Product life-cycle	Cost-benefit	Customization	Awareness for	Long term satisfaction	Attractiveness	Changes in the	Interaction with the	More responsible	Business partners	Sharing information	Stimuli
Ahamed et al. (2012)	X	X		X	X	X	X		X	X			X	
Alonso (2007)	X	X	X	X	X	X				X	X			
Akasaka et al. (2012)					X		X			X				
Baines et al. (2007)		X	X		X	X	X	X		X	X	X	X	X
Becker et al. (2009)	X					X						X		
Becker et al. (2008)	X									X		X		
Beuren et al. (2013)		X	X	X			X				X		X	
Beuren et al. (2017)			X			X		X	X	X	X			
Brandstotter (2003)		X	X	X		X					X	X		
Bandinelli and Gamberi (2011)	X				X		X							
Cherubini et al. (2015)	X		X			X	X		X		X	X	X	X
Colena and Lambrechta (2013)			X	X				X	X			X	X	X
Cook et al. (2006)		X	X		X	X	X				X	X		X
Cook (2014)	X	X												
Durugbo et al. (2011)		X				X								
Elnadi and Shehab (2015)				X	X		X				X	X	X	
Fan and Zhang (2010)	X	X			X			X						X
Goedkoop et al. (1999)									X					
Hussain et al. (2012)	X		X		X		X			X	X	X	X	
Kang and Wimmer (2008)		X	X			X	X	X						
Kimita et al. (2009)		X		X	X		X		X		X	X	X	
Khan et al. (2018)			X	X			X				X			
Kuo (2011)	X		X							X				
Luiten et al. (2001)		X				X	X		X			X		
Manzini and Vezzoli (2003)		X					X	X			X			
Mashhadi et al. (2019)				X						X				X
Matzen et al. (2005)												X		
Mont (2002)	X	X	X	X							X			X
Morelli (2002)			X			X	X				X			
Morelli (2006)								X				X	X	
Park and Lee (2009)							X							
Pieroni et al. (2019)				X		X	X							
Ping and Jia (2010)	X	X									X			
Sakao et al. (2009a)		X	X			X					X	X	X	
Sundin et al. (2010)			X			X						X		
Tukker (2004)	X	X					X				X			
Unep (2004)		X	X									X		X
Vezzoli and Sciama (2007)		X								X		X		
Vezzoli et al. (2015)	X	X	X			X								
Wang et al. (2014)	X		X		X					X				
Williams (2007)			X						X	X	X			X
Williams (2006)		X	X		X	X		X		X		X	X	X
Wu and Gao (2010)	X	X	X		X					X	X			

Yang et al. (2010)	X	X	X		X		X	X			X		X	X
Yang et al. (2009)	X		X										X	
Zhen (2012)	X			X	X		X			X				
Zheng et al. (2009)		X				X	X	X		X		X		X
Zheng et al. (2019)			X			X				X				

Table 3 displays the description of each CSF.

Table 3 - Description of PSS CSF identified in literature

CSF	Offering Dimension
New services	Increased customization of services, and pursuit of higher sustainability are relevant (Wang et al., 2014). The market is saturated with products that end up becoming commodities (Cook, 2014). A possible alternative to differentiate and increase the products' value is the demand for services (Alonso, 2007)
Planning for sustainability	Development of solutions that aim at social equity, economic viability and reduced environmental impacts (Cook, 2014).
Product life cycle extension	PSS can be based on multiple life cycles to foster product use extension, allowing better exploiting natural resources usage (Moro et al., 2021)
Cost-benefit	Information on the cost-benefit ratios of tangible products and PSS business models (Colena and Lambrechta, 2013) throughout their life cycle, facilitating customer decisions regarding the best solutions (Ahamed et al., 2012)
CSF	**Consumer Dimension**
Customization	Offer of products and services, which aim to improve personalization, according to the customers' individual preferences (Wang et al., 2014).
Awareness for sustainability	The maturity of the population concerning sustainability is low. It is highlighted that the consumer's participation in the development, experiment, and use of the offer is important, educating them for sustainability. The awareness about the successful adoption of sustainable business models is scant (Evans et al., 2017)
Long-term satisfaction	Offer solutions that satisfy the consumer's needs in the long-term, trying to make them loyal. New ideas that continuously prioritize and improve consumer satisfaction must be searched (Akasaka et al., 2012)
Attractiveness	Besides being functional, the idea must be attractive to motivate the companies and the consumers to move its production and consumption for the PSS
Changes in the consumption style	The shifts in consumption styles may challenge customers' current paradigms (Mahut et al., 2017)
CSF	**Provider Dimension**
Interaction with consumers	Interactions with customers could be done using different tools and practices such as voice of the customer, customer feedback on PSS performance, and engagement of customers in managing and improving the solutions (Elnadi and Shehab, 2015)
More responsible suppliers	Consider the bigger involvement and responsibility from the suppliers' part is their offer, trying to improve the life cycle of their products and services constantly. The provider has bigger participation on the project to be handed to the consumer on the development, during, and after the use (Hussain et al., 2012)
Business partners	From a systemic view, it is necessary to involve partners from different business types to totally offering the consumers' needs (Colena and Lambrechta, 2013). The development and delivery of a PSS requires the construction of strong collaboration among partners (Vezzoli et al., 2015)
Sharing information	The sharing of information aims to strengthen the exchange of knowledge and experience during all the business life cycles. Adopting experimental learning and a network-based management approach can increase the chances of success (Ceschin, 2013)

Stimuli	Some stimuli like governmental incentives should help the companies and the consumers accept the PSS implementation. Both direct and indirect incentives could be helpful to the development of the PSS mass market (Cherubini et al., 2015)

Data analysis and statistical test

Data were tabulated, statically tested, and ranked. Each CSF was counted, in order to consider the most frequent, before each pair of combinations. Since the CSF were organized in the three PSS dimensions, the counting was separately by dimension. The offering dimension had six combinations (Table 4) because it has four CSF. Consumer dimension resulted in 10 combinations as well as and provider dimension, both with five CSF each.

The total counting is added up once the respondents identified a CSF as the most important before the pair combination. Table 4 shows that the "product life cycle extension" CSF had the lowest score, so the less important considering the expert perceptions.

Table 4 - Data tabulation

OFFERING DIMENSION						
Critical Success Factors	Academic Scholars: 5		Business Scholars: 2		TOTAL: 7 experts	
	Scores	%	Scores	%	Scores	%
1-New services	6.0	20.0	6.0	50.0	12.0	28.6
2-Planning for Sustainability	10.0	33.3	1.0	8,3	11.0	26.2
3- Product life cycle extension	4.0	13.3	3.0	25.0	7.0	16.7
4-Cost-benefit	10.0	33.3	2.0	16.7	12.0	28.6
MAXIMUM SCORE	**15.0**	**100.0**	**6.0**	**100.0**	**21.0**	**100.0**

The same counting was conducted for the consumer dimension (the CSF "awareness for sustainability" had the lowest score). For the provider dimension, the "stimuli" presented the lowest score resulting in the least important in the experts' view.

Each CSF rejected by the respondents was also counted, and those were considered non-critical. The CSF that had the highest index of rejection was the "awareness for sustainability" and "stimuli". For both the academic and business scholars, the "awareness for sustainability" depends on the company's strategy because is important if the strategic focus is towards sustainable innovations. Regarding the consumer, he/she can acquire a PSS, most of the time considering economic benefits and not by awareness of the environmental or social impacts the PSS offers. The "awareness for sustainability" CSF was rejected by 43% of the respondents. For the "stimuli" CSF, the scholars offered PSS examples that operate without governmental incentives. This CSF was then considered not fundamental for the PSS, with 43% rejection rate from the respondents.

After verifying which CSF has the highest level of rejection, suggestions of other possible CSF were raised based on the respondents' perceptions. The respondents suggest that other factors should be considered besides the CSF identified in this work. By analyzing the suggestions, on may concluded that the CSF cited by the respondents as new CSF are somewhat related with the CSF from the literature. Therefore, they were not added in the complementary list of CSF.

In the sequence, the frequency of the scores attributed to the CSF was also counted. Based on Beri (2008) and Lam and Chin (2005), the Likert scale was used,to verify the other stage of the CSF prioritization. First, the CSF was separated according to the PSS dimensions (Table 5). After that, the importance given to each CSF was attributed and presented. It was added up in the 1 to 5 scale to verify the prioritization amongst the CSF. These data were also used for statistical analysis.

Table 5 - Data of frequency of the scores attributed to the CSF

CSF – Offer Dimension	Academic Scholars		Business Scholars		TOTAL	
	Scores	%	Scores	%	Scores	%
1-New services	17	22	10	30	27	24
2-Planning for sustainability	20	25	8	24	28	25
3- Product life cycle extension	20	25	7	20	27	24
4-Cost-benefit	22	28	9	26	31	27
TOTAL SCORE	**79**	**100**	**34**	**100**	**113**	**100**

Table 5 shows that the "new services" CSF had the lowest score compared to other CSF, according to the scholars. However, for the business scholars, this particular CSF had the highest score. These data were then statistically tested, with the purpose of checking whether the "new services" CSF were really critical for the PSS. The same was done to the consumer dimensions, where the "awareness for sustainability" CSF had the lowest score compared to the other CSF.

To conduct the statistical test, it was necessary to select a proper one, so the Kolmogorov-Smirnov statistical test was applied. This test concerns the agreement level between a theoretical and a real distribution, aiming to identify the divergences between them (Beri, 2008). From this divergence, some data can lead to the rejection or not of the H_0. By rejecting the H_0, it can be understood that the CSF part of this hypothesis is really critical for the PSS, according to the field scholars' view.

After identifying the adequate statistical test, the significance level of α=0.20 was established. This significance level was used because this research includes seven respondents, increasing the margin of error in relation to the rejection of the H_0.

After that, the sample distribution of the statistical test under the null hypothesis H_0 was determined. The relative and the relative accumulated frequencies were determined, as well as the theoretical and the theoretical accumulated frequencies, to obtain the difference between them for each CSF, using the data of the seven components (7 scholars). The difference amongst accumulated frequencies results in a value that is used to reject or not a CSF.

Thus, based on the previously identified data, it was also necessary to define the region of rejection of the null hypothesis (H_0), which depends on how H_1 was formulated (Beri, 2008). The hypotheses are pointing out towards the predicted direction. An example of Hypothesis I would be the CSF for the offering dimension being considered critical for the PSS, according to scholars experienced in the field. The test is one-sided.

The probability that the H_0 was in the rejection zone was α = 0.2, as mentioned before. Then, the value of the statistical test is calculated from the sample data. This value is also called the calculated value, where the differences between the observed and theoretical accumulated frequencies are accumulated to identify the maximum difference observed (Dmax).

Finally, a decision was made concerning the acceptance or the rejection of the null hypothesis (H_0). According to Beri (2008), having the tabled price (Dtabled=0.381), the calculated value (Dmax=biggest difference observed for each situation) and the rejection zone (α=0.2) can decide by the rejection or not of the H_0.

To reject the null hypotheses and consider a CSF as critical for the PSS, the difference between the real and the theoretical score (D=pra-prta) must result in a value equal to or superior to the tabled value for a sample of 7 components, i.e., this value must be equal to or superior to D=0.381 for the significance level α=0.2. In this sense, the following tests are presented for each CSF according to their respective dimensions.

Table 6 presents the data for the "new services" CSF, which is part of the offering dimension. The same was done with other CSF for the consumer and provider dimensions.

Table 6 - Data for the offering dimension: "New services"

CSF– 1 New Services	Frequency					Difference between real and theoretical (D=pra-prta)
	Absolute (pa)	Relative (pr=pa/pt)	Relative accumulated (pra)	Relative accumulated theoretical (prta=∑prt)	Relative accumulated theoretical (prta=∑prt)	
Totally Disagree	0	0.000	0.000	0.200	0.200	0.200
Partially Disagree	1	0.143	0.143	0.200	0.400	0.257
Agree/Disagree	1	0.143	0.286	0.200	0.600	**0.314**
Partially Agree	3	0.429	0.714	0.200	0.800	0.086
Totally Agree	2	0.286	1.000	0.200	1.000	0.000
	7	1.000		1.000		

Taken into account the respondents' viewpoint, Table 6 shown the maximum difference accumulated between the scales (1 to 5) of Dmax=0.314, which is lower than the tabled value (Dtabled=0.381). However, the "new services" CSF is not valid for a sample of 7 components with this significance level remains to be accepted by the majority of the scholars. As Ayala et al. (2019) pointed out that the service offering is essential to obtain the PSS benefits, thus, this CSF was maintained.

The same analysis with the other CSF was made for the offering dimension:

- "Planning for the sustainability": Dmax=0.314, which is lower than the tabled value. However, the CSF was considered not valid for a sample of 7 components, but it tends to be accepted by the majority of the scholars.
- "Product life cycle extension": Dmax=0.457, which is higher than the tabled value (Dtabled=0.381) with significance level α=0.2. However, the CSF was considered valid for a sample of 7 components within this significance level.
- "Cost-benefit": Dmax=0.457, which is higher than the tabled value. The CSF is considered valid for a sample of 7 components.
- Aiming at verifying if there is any differentiation that might reject a CSF in the offer dimension, they were prioritized according to the data tabulation in Table 7.

Table 7 - Offering dimension data from the Kolmogorov-Smirnov test

OFFERING DIMENSION						
CSF	Frequency					Difference between real theoretical (D=pra-prta)
	Absolute	Relative (pr=pa/pt)	Relative accumulated (pra)	Relative Theoretical. (prt=1/5)	Relative Accumulated. Theoretical (prta=∑prt)	
4-Cost-benefit	31	0.274	0.274	0.250	0.250	0.024
2-Planning for Sustainability	28	0.248	0.522	0.250	0.500	0.022
1-New services	27	0.239	0.761	0.250	0.750	0.011
3- Product life cycle extension	27	0.239	1.000	0.250	1.000	0.000

The same analysis was made with the 'consumer' dimension CSF:

- "Customization": Dmax=0.514, which is higher than the tabled value (Dtabled=0.381) for the significance level α=0.2. However, the CSF was considered valid for a sample of 7 components with this level of significance.
- "Awareness for sustainability": Dmax=0.200 is lower than the tabled value. However, the CSF was considered not valid for a sample of 7 components with this level of significance, nor it presented a tendency in relation to the majority of the scholars' acceptance.

The remaining of CSF ("long-term satisfaction"; "attractiveness"; and "changes in the consumption style" were considered valid for a sample of 7 components.

Table 8 was developed to verify whether any differentiation can be considered pertinent for the CSF rejection in the consumer dimension. This table presents all the CSF in the consumer dimension, prioritized according to the data tabulation.

Table 8 - Consumer dimension data from the Kolmogorov-Smirnov test

CONSUMER DIMENSION						
CSF	Frequency					Difference between real and theoretical (D=pra-prta)
	Absolute (pa)	Relative (pr=pa/pt)	Relative accumulated (pra)	Relative theoretical (prt=1/5)	Relative accumulated theoretical (prta=∑prt)	
8-Atractiveness	32	0.213	0.213	0.200	0.200	0.013
7-Long term satisfaction	32	0.213	0.426	0.200	0.400	0.026
9-Changes in the consumption style	32	0.213	0.639	0.200	0.600	0.039
5-Customization	31	0.207	0.846	0.200	0.800	0.046
6-Awareness for sustainability	23	0.153	1.000	0.200	1.000	0.000

The same analysis was carried out with the provider dimension:

- "Interaction with the consumer": Dmax=0.600, which is higher than the tabled value (Dtabled=0.381) and the significance level α=0.2.

However, the CSF was considered valid for a sample of 7 components. The same occurred with other CFS ("more responsible partners"; "business partners"; "sharing information"; and "stimuli").

Table 9 shows all the CSF in the provider dimension, and they were prioritized according to the data tabulation.

Table 9 - Data for the provider dimension from the Kolmogorov-Smirnov test

PROVIDER DIMENSION						
CSF	Frequency					Difference between real and theoretical (D=pra-prta) (1-2)
	Absolute (pa)	Relative (pr=pa/pt)	Relative accumulated	Absolute (pa)	Relative (pr=pa/pt)	
Atractiveness 10- Interaction of the supplier with the consumer	33	0.214	0.214	0.200	0.200	0.014
12-Business partners	33	0.214	0.428	0.200	0.400	0.028
11-More responsible partners	31	0.201	0.629	0.200	0.600	0.029
13-Sharing information	30	0.195	0.824	0.200	0.800	0.024
14-Stimuli	27	0.175	1.000	0.200	1.000	0.000

The maximum difference accumulated (Dmax=0.029) to the provider dimension points out that the CSF did not present differentiation amongst them. Additionally, they present a correlation under the view of the respondents.

Table 10 summarizes the prioritization of the CSF according to the statistical tests.

Table 10 - Prioritization of the CSF according to the Kolmogorov-Smirnov test

Critical Success Factors	Difference between real and theoretical score (Likert)	Rejection for the respondents
OFFERING DIMENSION		
3- Product life cycle extension	0.457	0%
4-Cost-benefit	0.457	0%
1-New services	0.314	0%
2-Planning for sustainability	0.314	29%
CONSUMER DIMENSION		
7-Long term satisfaction	0.600	0%
8-Attractiveness	0.514	0%
9- Changes in the consumption style	0.514	0%
5- Customization	0.514	14%
6- Awareness for sustainability	0.200	43%
PROVIDER DIMENSION		
10-Interaction of the supplier with the consumer	0.600	0%
11-More responsible suppliers	0.514	0%
12-Business partners	0.514	0%
13-Sharing information	0.514	14%
14-Stimuli	0.200	43%

Table 10 shows the empirical and theoretical score obtained from the Likert Scale results, which is approximated to the results presented by the respondents. Thus, before the tabulation of the data obtained from the questionnaires sent to the scholars in PSS, as well as from the application

of the statistical test, quantitative data were obtained, which are the base for the classification of the CSF of PSS.

DISCUSSION OF RESULTS

Regarding hypothesis I (H1), the CSF to the offering dimension or products and services are not considered critical for the PSS context, according to scholars. The null hypothesis can be rejected in 50% of the CSF, for the maximum differences (Dmax) calculated for each CSF had half of their Dmax higher than the Dtabled, and the other half lower than the Dtabled. “New services” and “planning for sustainability” CSFs do not present enough data in 50% of the CSFs to verify whether they are really critical for the PSS. They present a tendency to be accepted by the majority of the respondents. In future research, it would be important to analyze the CSF with a higher number of respondents. The “product life cycle extension” and “cost-benefit” CSF are critical for the PSS, based on the respondents.

Regarding hypothesis II (H2), the CSF to the consumer dimension are not considered critical for the PSS context, according to the scholars. The null hypothesis II can be rejected because four CSF had their Dmax higher than the tabled difference (Dtabled), and they were accepted by the respondents. There was a CSF that had its Dmax lower than the Dtabled difference, which shows the lowest difference between the real and the theoretical, indicated by 43% of the respondents for rejection. Therefore, the CSF to the consumer dimension can be considered critical for the PSS. The “awareness for sustainability” CSF does not indicate a tendency to its acceptance. It would be necessary to test it with more respondents to then decide on its rejection. This was not carried out in the present study and deserves further work.

Regarding hypothesis III (H3), the CSF to the provider dimension is not considered critical for the PSS context, according to scholars in the field. The maximum differences (Dmax) calculated for each CSF that belongs to hypothesis III were: four CSF had their Dmax higher than the tabled difference (Dtabled), accepted by the respondents, and one CSF had its Dmax lower than the Dtabled. It presents a lower difference between the real and the theoretical, also indicated by 43% of the respondents to rejection, as well in hypothesis I. For a significance level of α=0.2 this null hypothesis can be rejected. Thus, the CSF to the provider dimension are considered critical for the PSS context, where the majority of the votes are in the scales of a higher concordance of the CSF (‘I partially agree’ and ‘I totally agree’). The “stimuli” CSF does not present enough data to prove as critical for the PSS. A higher number of respondents is necessary to verify if it really can be considered a CSF for the PSS.

Before considering the hypothesis as critical, it should be evaluated by a higher number of respondents to confirm if they can really be rejected. This research does not reject any CSF; it only presents them in a prioritization order so that future works can test and verify their possibility of rejection.

Prioritization of the critical success factors to PSS

The CSF identified in the present work could be relevant in three main circumstances: (i) to help managers identify the necessary information to ensure the success of the PSS; (ii) to assist the organization with strategic and long-term planning; and (iii) to assist the organization with the planning process of the PSS. Occasionally, it is not feasible for the company to adopt all identified CSF. So, it is important to prioritize them so that the company can acknowledge the most critical CSF to be considered.

Figure 3 shows a hierarchy structure with the main CSF divided into the PSS dimensions. This hierarchy can be applied in PSS contexts, considering the adequacy of the identified factors in the application's context. Companies that have or plan to work with businesses of this nature can use this structure as a base for verifying the CSF related to them.

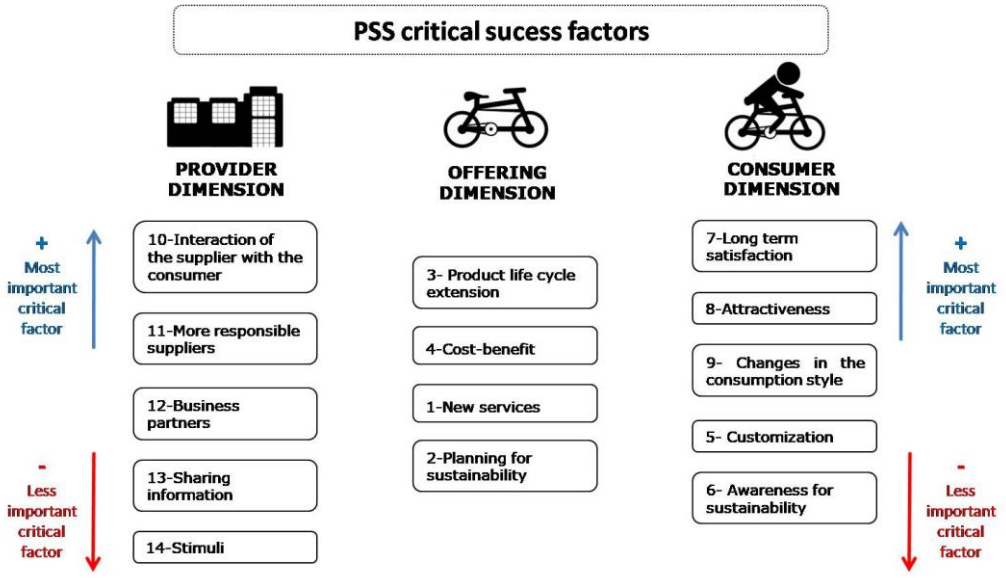

Figure 3 - Hierarchy structure of the CSF to PSS

As shown in Figure 3, for the offering dimension, the main factor is the "product life cycle extension". When planning a PSS, it is necessary to plan the material used to make it durable, considering a life-cycle perspective (Rodríguez et al., 2020; Nunes et al., 2021). This is also in accordance with literature as it is one of the most prominent strategies to improve PSS eco-effectiveness (Moro et al., 2021). PSS cost-benefit is another CSF verified; therefore PSS developers may try to balance this trade-off to ensure PSS competitiveness. PSS operating costs tend to be higher when compared to a product, as a PSS can include intensive use of labor and transaction costs (Tukker, 2015). To manage this, PSS cost estimation frameworks need to be developed (Rodríguez et al., 2020). Extending the product life cycle and improving maintenance could be some strategies to reduce PSS costs (Annarelli et al., 2018).

A practical implication for companies and practitioners in a bike sharing example, the CFS for offer dimension would be:

(a) Product life cycle extension - It is important that the bicycle be made with high quality materials to increase its durability and has little maintenance;

(b) Cost-benefit - A product PSS must have more quality if compare with a traditional product. A PSS bicycle PSS is different from a traditional bicycle because the consumer understands that he has more advantages when paying for the use of the bicycle instead of buying the product;

(c) New services - Maintenance services, cleaning, applications that personalize the service, contribute to customer service;

(d) Planning for sustainability - The bicycle is planned to be used by more people, which is planned to respect the environmental (materials with less environmental impact), social (respect for people) and economic (business opportunity for companies) aspects.

For the consumer dimension, the most important factor is the "long-term satisfaction", where the consumer feels satisfied from the beginning until the end of the negotiation. Customer satisfaction is important to determine a company's positive performance (Annarelli et al., 2018). As PSS involves a service, long-term satisfaction is expected to maintain customers using and therefore, paying for the solution. Attractiveness of PSS should also be explored as a CSF. Customers can perceive PSS as an offer with less tangible value (Baines et al., 2007; Tukker, 2015). Therefore, PSS researchers need to explore more PSS benefits to customers (Matschewsky et al., 2018) and how they could favor PSS adoption (Moro et al., 2020). In the same way PSS developers need to focus on PSS attractiveness to increase the adoption of this kind of solution.

A practical implication for companies and practitioners in the case of a bike sharing example, the CFS for consumer dimension would be:

(a) Long term satisfaction - The company that rents the bike has consumer loyalty because it offers services that meet their needs periodically, such as preventive maintenance and cleaning;

(b) Attractiveness - The product and the service must attract the consumer both for the innovative design and for the services offered. The consumer prefers personalization;

(c) Changes in the consumption style - Bike sharing is a way of showing the importance of changing consumption for the consumer. People can live well with fewer products;

(d) Customization - The dematerialization of the product is a way of making consumers aware

of the need to own products. in the bike sharing model, consumers use the product when they need it, paying for the time of use and not for the product; and

(e) Awareness for sustainability - Show that bike sharing is a way to raise awareness, to reduce the number of cars on the streets, that it is good for health and that it is a profitable business.

For the provider dimension, the most important factor is the "interaction with the consumer", where both exchange information. The interaction could favor the development of solutions aligned with customers' needs and expectations. 'More responsible providers' is also a key CSF. As already stated by Annarelli et al. (2018), the relationship with suppliers plays a vital role in the success of a PSS offering. The factors that need the engagement of multiple stakeholders are critical, and it would be appropriate to manage them strategically to obtain long-term results (Cherubini et al., 2015).

A practical implication for companies and practitioners in a bike sharing example, the CFS for provider dimension would be:

(a) Interaction with the consumer - It is important to interact with the consumer throughout the period that he is using the product. Bike sharing has an app that helps with this approach. This interaction contributes to understanding whether the product is working well, what can be improved, among other services that can be incorporated to continuously improve contact with the consumer;

(b) More responsible providers - Providers are responsible for offering a quality product and receiving that product with the consumer not wanting it anymore;

(c) Partner business - The stakeholders, including the consumer, should be partners, exchanging information and using the best practices of each one;

(d) Sharing information - All the stakeholders must share information in order to offer the product and service that best serves the consumer. The consumer needs to satisfy himself in a way that he does not want to look for a competitor. The services are strategic, difficult to be copied and with them the company can differentiate itself in the market;

(e) Stimuli - It is important that companies have government incentives to implement PSS business models.

All the CSF identified are important for the PSS success, but they are presented according to the prioritization order shown by the scholars in the area. Although highly emphasized by literature, planning for sustainability (e.g., Mont, 2002; Akasaka et al. 2012; Vezzoli et al., 2015) and its awareness on the consumer side (e.g., Alonso, 2007; Pieroni et al., 2019) were not revealed as CSF by the respondents of this study. One reason may be that publications focus on specific points of sustainability, as highlighted by Mahut et al. (2017). Moreover, PSS sustainability involves many sources of value creation and also depends on the interactions among diverse stakeholders to be fulfilled, as emphasized by Evans et al. (2017). Another reason may be that the strategies that could be used to achieve sustainability on the three dimensions depend highly on other factors, such as the product and PSS type, the size of the market, and the relevance of the service to meet customers' basic needs. In the same way, incentives were not perceived as a CSF, and need an increase in the number of respondents to be better evaluate, probably because the respondents have different opinions based on their previous knowledge about a specific example of PSS.

Another essential point to be considered is that this study considered subjective opinions of respondents living in a developing country, on contrast to the majority of the studies considered in the literature review. This contrast among scenarios has already been mentioned as important to identify differences and patterns (e.g., Moro et al., 2020). Therefore, the CSF pointed out by this study could be explored in-depth, as well as the disparity compared with other scenarios.

Concluding remarks

This work has the main objective to identify, evaluate, and prioritize the CSF of product-service systems. The CSF were identified in the literature, assessed by Brazilian scholars and practitioners, and they were prioritized. The three dimensions of the PSS were considered, amongst them the offering dimension, where the most important CSF was the "product life cycle extension". The consumer needs to know the benefits of a PSS to be able to compare it to a traditional business and then decide on the best offer. In the consumer dimension, the most important is the "long term satisfaction". The consumer does not want the product to be only functional but also innovating. In the provider dimension, the most important CSF was the "interaction with the consumer". The direct and continuous contact with the consumer should always be taken into account, from the development of the project, as in the product's use, to the search for continuous improvement.

Theoretical and practical contributions

As theoretical contributions, the fourteen PSS critical success factors identified and prioritized

in this work may offer directions to the academia and industry. It opens opportunity to implement a PSS business as well as goals to establish and improve their practices. It is relevant to point out that these identified success factors are generic and should be adapted to any specific scenario. Once the CSF are identified and prioritized, they serve as a guideline for developing new PSS and contribute to improving an already existent business.

This study also may contribute in a practical level to the development of novel product-service systems based on sustainable considerations. The practical contributions of this research are related to understanding, based on the literature, the main crucial factors for anyone thinking of developing a PSS and applied on the practical your knowledge. Knowing the advantages of the PSS, it can be applied in practice.

Opportunities for future research

As further work research, these critical success factors should be applied to different types of PSS in order to analyze their prioritization as well as their contribution to the PSS development. Analyzing and contrasting CSF for different PSS types (product-, use-, or result-oriented) may be a promising future research opportunity. It is worth emphasizing that this research is limited in terms of external validity since was conducted in a specific context. However, we may have an analytical generalization despite the emerging economy context. Another viewpoint is related to the academic and professional experts. They were experienced in multinational companies with more than 10 years working on product-service systems. Thus, expanding to the analysis of a larger number of experts is a research opportunity as well.

Other future works should be developed with a focus on stimulating business models that aim at the dematerialization of products, such as the PSS. Finally, the academia should foster activities that encourage the development of business models such as the product-service system, which can contribute to the goals of the United Nations 2030 Agenda.

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