Managing customer requirements for an effective service implementation in a Product-Service System (PSS)

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Abstract

The research addresses the management of customers' requirements when implementing services in a Product-Service System (PSS) context. Services have expanded throughout recent years, yet their proper management and implementation remains a problematic matter for manufacturers. Uncertainties and ambiguities characterize services due to their intangible nature on one hand and the customers' subjectivities on the other. Hence, when it comes to capturing the customer's requirements for the PSS' services, traditional product design tools such as the Quality Function Deployment (QFD) are limited for their accurate assessment and prioritization in order to develop an adequate service-oriented solution. To address this issue, the QFD is augmented using the fuzzy logic and the Analytic Hierarchy Process (AHP) with the goal of reducing the above inaccuracies. The proposed approach is verified at a manufacturer in the medical field, where few practical PSS investigations have been carried out despite their largely remarked potential.

Keywords
customer requirements; customer requirement management; quality function deployment; product-service systems; service design

1. Introduction
In recent years, the provision of product-based solutions has shifted towards offering service and integrated product-service offerings known as Product-Service Systems (PSSs) (Lindahl et al. 2014). This shift took place as manufacturers and customers alike realized that services have the potential to offer more effective and value augmenting solutions than a stand-alone product (Sakao and Shimomura, 2007; Haber, 2017a; Wang et al. 2017). The potential of integrated services and PSSs has been largely discussed in the literature (Tukker, 2004; Aurich et al. 2010; Tran and Park, 2015; Haber and Fargnoli, 2017a) underlining the advantages and benefits they can offer to the provider in terms of productivity (Matschewsky et al. 2015), to the customer in terms of satisfaction (Meier et al. 2010; Fargnoli et al. 2018) and to the environment in terms of ecological impact (Fargnoli et al., 2012; Haber and Fargnoli, 2017b). In addition, and from a more global perspective, PSSs are recognized as a possible and viable solution of "closing the loop" of product life cycles as a means of meeting "circular economy" goals (EU, 2015; Tukker, 2015; Sakao et al. 2017).
Thus, product development has progressively moved from the design of stand-alone products to the design of PSSs (Mager and Sung, 2011). This transition relies on the adaptation and augmentation of product-centered methodologies towards integrated product-service endeavors focused on delivering a satisfying solution (Oliva and Kallenberg, 2003; Song and Sakao, 2016; Haber and Fargnoli, 2017b). In other words, manufacturing products and providing the customers with their related services consist of activities that should be comprehensively combined in a single system to ensure the feasibility and success of the offered solution (Fargnoli et al., 2014). Both Liu (2009) and Najafi et al.

(2015) explicate the latter by defining a competitive service as one that provides the right functionality to the right customer at the precise time and at an affordable price.

Practically, the proper understanding of the customers' requirements plays a vital role in the design of the proposed solution (Franceschini and Maisano, 2015). These requirements should then be translated into technical attributes through an adequate transformation process that enables the definition of the product and service characteristics of the solution. However, in a PSS context, the service requirements are ambiguous and inaccurate due to the associated intangibility (Aurich et al., 2010; Song and Sakao, 2016). In addition, these concerns can lead to design conflicts that may hinder the design process (Sakao et al., 2017). Therefore, a proper understanding is required to reduce error margins and improve the success of the provided solution (Abdolshah and Moradi, 2013).

In a conventional product development setting, one of the most powerful tools to manage customer requirements for a satisfying solution is the Quality Function Deployment (QFD) method as it underlines the involvement of product users in the development of the offering (Akao, 1990; Revelle et al., 1998; Sakao, 2007; Vinayak and Kodali, 2013; Fargnoli and Sakao, 2017). The benefits of the QFD lie in the effectiveness of its first phase entitled the House of Quality (HoQ) which translates Customer Requirements (i.e. the "whats") (CRs) into technical requirements known as Engineering Characteristics (ECs) (I.e. the "hows") that answer the customers' expectations (Zawati and Dweiri, 2016). Nevertheless, as mentioned earlier, CRs are more subjective and surrounded by more ambiguities than their product counterparts. The latter hinders the design process as it renders the identification and prioritization of the CRs a more challenging task (Kurtulmuşoğlu and Pakdil, 2016). A consequence of this matter is an incorrect evaluation and prioritization of the CRs which is reflected through the ECs which results in an inconsistent PSS solution (Chen et al., 2013; Zhang et al., 2015). However, when the service attributes are accurately defined as well as the product's, the QFD is regarded as a very beneficial and useful tool for the PSS industry (Kurtulmuşoğlu and Pakdil, 2016).

To address these matters, several tools and approaches have been introduced to the HoQ such as the Kano model (Tontini, 2007), the Analytic Hierarchy Process (AHP) (Shad et al., 2014), the fuzzy logic (Kamvysi et al., 2014), and the Law of Comparative Judgments (LCJ) (Franceschini and Maisano, 2015) among others. The introduction of these tools and approaches was aimed at a better understanding and evaluation of the CRs especially when requirements and their associated importance levels are expressed through linguistic variables.

Yet despite these advances, an optimal decision-making method for prioritizing the CRs with respect to the manufacturer's resources is still lacking (Percin and Min, 2013). Additionally, when manufacturers operate with limited resources and technical know-how, the selection of the appropriate tool to increase the effectiveness of the HoQ is problematic (Chowdhury and Quaddus, 2016). This is predominantly true in a PSS context where a manufacturer seeks to increase its offering's value by integrating services with its products (Satapathy and Mishra 2013; Roghanian and Alipour, 2014; Haber 2017b). Accordingly, the paper seeks to answer the following Research Question (RQ):

RQ. How to effectively define and interpret customer needs into service/engineering characteristics when implementing a PSS?

To answer the RQ, we propose an augmented HoQ to define and assess the service design characteristics. The problem of the PSS implementation is addressed from the point of view of a manufacturer seeking to augment its current solution through a PSS approach. In detail, we developed two approaches based on the fuzzy logic and the AHP to increase the effectiveness of the HoQ when handling a PSS. In fact, several researchers have criticized the weaknesses presented by the HoQ regarding the assessment, evaluation and prioritization of the CRs (Chen et al., 2013; Franceschini et al., 2015; Zhang et al., 2015). Furthermore, Kamvysi et al. (2014) stated that in a PSS setting, manufacturers and service providers have to deal with a "fuzzy front-end" when it comes to properly capturing the voice of the customers (i.e. their requirements) and handling the ambiguities and subjectivities associated to their judgments.

The remainder of this research is articulated as follows: the literature concerning the implemented criteria in the research approach is shown in section 2. Section 3 illustrates the research approach through a case study at a manufacturer in the medical sector. The achieved results are discussed in section 4 while section 5 concludes the article and addresses further research work.

2. Research approach

The QFD is made up of four phases relying on sets of matrices that guide engineers from the product planning phase (Phase 1) to the production planning phase (Phase 4) (Revelle et al., 1998). The first phase is the most vital one as it translates the voice of the customer (i.e. customer requirements) into engineering characteristics as the cornerstone of the development of the solution.
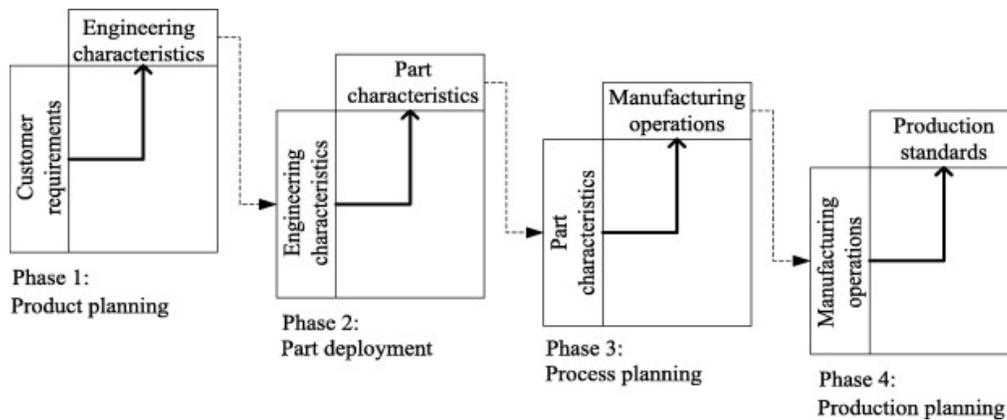
Figure 1. The traditional QFD scheme

The HoQ is characterized by the relationship matrix that addresses the relationships between the Customer Requirements (CRs) and the Engineering Characteristics (ECs). In detail, market surveys and questionnaires filled by the customers enable the definition and assessment of the CRs. The importance levels of the CRs are most commonly noted through a Likert scale ranging from 1 (not important) to 5 (very important) (Likert, 1932). The ECs are defined by the manufacturer's experts and the relationships between the ECs and CRs are evaluated by these experts using 1-3-9 scoring criteria indicating a weak, medium or strong relationship respectively.

Despite the widespread use of the approach, several drawbacks hinder the effectiveness of the QFD (Carnevalli and Miguel, 2008; Zare Mehrjerdi, 2010; Xie et al., 2016; Chavoshi et al., 2017). The latter is due to the uncertainties that arise when trying to quantify the customer's qualitative judgments (expressed in linguistic variables) on one hand and the ambiguity and subjectivities that surround the evaluation of the CRs. To address these limitations, the research proposes the combined use of the fuzzy logic (Zadeh, 1965) and the Analytic Hierarchy Process (AHP) (Saaty, 1990). Such a combination (i.e. Fuzzy AHP (FAHP)) is exhibited in several studies (e.g. Ho, 2008; Saaty and Sodenkamp, 2008) as a means of effectively handling imprecisions and subjectivities to improve the transparency of the CRs (Kwong and Bai, 2010).

In detail, the fuzzy logic minimizes the inaccuracies of customer judgements by transforming the crisp importance ratings of the CRs into fuzzy numbers (Kaharaman et al., 2003). Furthermore, the fuzzy logic is suggested by Abdolshah and Moradi (2013) and Liu and Tsai (2012) to eliminate biasness when designing a solution. The most commonly used fuzzy numbers are triangular ones defined by three parameters L (lowest value), M (most promising value) and U (largest possible value) (Zaim et al., 2014). The AHP on the other hand utilizes pairwise comparisons to assess the CRs in a more comprehensive manner by evaluating their importance among each other (Liu, 2009). In other words, the importance of a CR is defined against the importance of another CR (Ho et al., 2012). The pairwise comparison scale is shown in Table 1 and an example is portrayed in Figure 2.

Table 1. The AHP pairwise comparison scale and its fuzzy number conversion

Linguistic definition	Rating Scale (crisp)	Equivalence in Fuzzy numbers	
		TFNs*	Reciprocal TFNs**
Equally important	1	(1, 1, 1)	(1, 1, 1)
Intermediate	2	(1, 2, 3)	(1/3, 1/2, 1)
Moderately more important	3	(2, 3, 4)	(1/4, 1/3, 1/2)
Intermediate	4	(3, 4, 5)	(1/5, 1/4, 1/3)
Strongly more important	5	(4, 5, 6)	(1/6, 1/5, 1/4)
Intermediate	6	(5, 6, 7)	(1/7, 1/6, 1/5)
Very strongly more important	7	(6, 7, 8)	(1/8, 1/7, 1/6)
Intermediate	8	(7, 8, 9)	(1/9, 1/8, 1/7)
Extremely more important	9	(8, 9, 10)	(1/10, 1/9, 1/8)

*If a CR is more important than another the set of TFNs shown in the first column is adopted;
** If a CR is less important than another CR, the set of Reciprocal TFNs is used (Liu and Tsai, 2012).
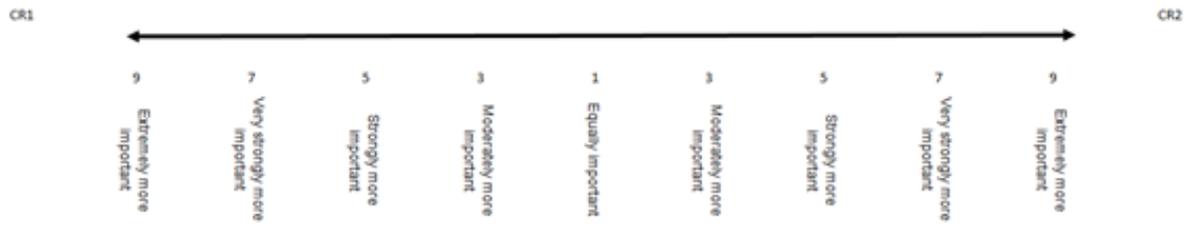
Figure 2. Example of a pairwise comparison between two CRs

With this in mind, the HoQ of the first phase of the QFD is augmented by the two approaches exhibited above to obtain the definition and ranking of the ECs, the Service Characteristics (SCs) in this case. To analyze the effectiveness of the proposed approach, the obtained results are compared to the ones that can be obtained through a traditional HoQ.

In summary, the research approach follows the subsequent steps:
1. Definition of the CRs and SCs
2. Definition of the importance of the CRs
3. Implementation of the fuzzy logic and AHP
4. Analysis of results

3. Case study

3.1 Overview

The following case study is carried out at a manufacturer operating in the medical device sector where an appropriate service strategy is highly stressed (Ulaga and Reinartz, 2011, Lee et al., 2015) and the implementation of services based on the customers' requirements is challenging given the strict regulations that govern this market (Mittermeyer et al., 2011). The manufacturer operates in the renal support market producing hemodialysis devices and providing all the services required for their use.

A group of the manufacturer's experts (i.e. marketing manager, product development manager, customer care manager) conducted a market survey and sent questionnaires to 93 customers (i.e. medical professionals and laboratory technicians) to define their requirements and associated importance levels. 64 respondents provided complete answers. The latter were assessed against 12 calls for tender issued in a 24-month period (2015-2016) to separate the mandatory service requirements for market entry from the ones that might increase customer value and be beneficial for the company in improving its market position. At a first instance, their importance assessment was carried out using the 1-to-5 Likert scale (Table 2).

Table 2. List of CRs

CR Code	CR description	Importance	Relative Importance
CR 1	Ease of use	3.7	12.3%
CR 2	Availability of the equipment	4.4	14.7%
CR 3	System upgradability (software and hardware)	3.0	10.0%
CR 4	Quality of maintenance service	4.6	15.3%
CR 5	Availability of remote technical assistance	4.1	13.7%
CR 6	Inclusion of wearable parts	3.9	13.0%
CR 7	Remote data storage (i.e. cloud)	3.4	11.3%
CR 8	Environmental and safety conformity assistance	2.9	9.7%

Then the Service Characteristics (SCs) were defined in collaboration with the manufacturer's experts (Table 3).

Table 3. List of SCs

SC Code	SC description
SC 1	Device users' training
SC 2	Management and documentation of environmental and safety issues
SC 3	Cloud and/or removable data storage service
SC 4	Provision of wearables and their frequent maintenance accessories (i.e. sterilization)
SC 5	Extended warranty for wearable parts
SC 6	Calendar time of consumables delivery
SC 7	Replacement of malfunctioning devices within 3 working days
SC 8	Repairs within 48 hours from customer notification
SC 9	Extended remote technical support
SC 10	Training of customer care operators
SC 11	Periodic software and hardware upgrades
SC 12	Training when software and hardware upgrades are performed
SC 13	Response time
SC 14	Intervention time (< 24 hours)
SC 15	Service center technicians' training

3.2 Traditional QFD

The traditional QFD was applied (Table 4) utilizing the CRs and SCs defined earlier to determine the Absolute Importance (AI) of the SCs through equation (1).

$$AI_j = \sum_{i=1}^{n=8} CRI_i \times RS_{ij} \qquad (1)$$

Where AI is the importance of a SC as a column entry 'j', CRI is the importance of a CR as a row entry 'i', and RSij indicates the Relationship Score (RS) between a CR$_i$ and SCj defined earlier.

Table 4. Results of the traditional HoQ

	Importance	Relative Importance	CR ranking	SC 1	SC 2	SC 3	SC 4	SC 5	SC 6	SC 7	SC 8	SC 9	SC 10	SC 11	SC 12	SC 13	SC 14	SC 15
CR 1	3.7	12.3%	5	9		3	3					3	3	9	9			
CR 2	4.4	14.7%	2							9	3	9				1	9	3
CR 3	3.0	10.0%	7	3									3	9	9			1
CR 4	4.6	15.3%	1							9	9	3	9			9	9	9
CR 5	4.1	13.7%	3								1	9	9			9		
CR 6	3.9	13.0%	4				9	9	9									
CR 7	3.4	11.3%	6	1		9									3			
CR 8	2.9	9.7%	8	1	9	1		1						1				
SC importance				48.6	26.1	44.6	46.2	38	35.1	85.1	58.7	101.4	101.3	70.5	60.3	82.7	81	57.6
SC relative importance				5.2%	2.8%	4.8%	4.9%	4.1%	3.7%	9.1%	6.3%	10.8%	10.8%	7.5%	6.4%	8.8%	8.6%	6.1%
SC ranking				10	15	12	11	13	14	3	8	1	2	6	7	4	5	9

3.3 Fuzzy logic and AHP implementation

The FAHP was implemented where the CRs are compared between them (Table 5), and then 'fuzzified', assessed and 'defuzzified' following the approach proposed by Liu (2009). The pairwise comparison matrix is checked for consistency and afterwards normalized. From the normalized matrix, a column vector emerges representing the fuzzy importance levels which are then 'defuzzified' as to obtain the crisp input of the HoQ (Table 6). Details regarding the fuzzification and 'defuzzification' process can be found in Ho et al. (2012).

Table 5. Example of a pairwise comparison (excerpt from 1 customer for 3 CRs)

	CR 1			CR 2			CR 3		
	L	M	U	L	M	U	L	M	U
CR 1	1	1	1	1/8	1/7	1/6	1	1	1
CR 2	6	7	8	1	1	1	6	7	8
CR 3	1/4	1/3	1/2	1/8	1/7	1/6	1	1	1

Table 6. Results of the HoQ augmented by the FAHP

	Importance	Relative Importance	CR ranking	SC 1	SC 2	SC 3	SC 4	SC 5	SC 6	SC 7	SC 8	SC 9	SC 10	SC 11	SC 12	SC 13	SC 14	SC 15
CR 1	0.813	9.9%	4	9		3	3					3	3	9	9			
CR 2	2.896	35.3%	1							9	3	9				1	9	3
CR 3	0.307	3.7%	8	3									3	9	9			1
CR 4	2.058	25.1%	2							9	9	3	9			9	9	9
CR 5	0.932	11.4%	3							1	1	9	9			9		
CR 6	0.361	4.4%	7				9	9	9									
CR 7	0.442	5.4%	5	1		9									3			
CR 8	0.393	4.8%	6	1	9	1		1						1				
SC importance				9.08	3.54	6.82	5.69	3.65	3.25	45.52	28.15	43.07	30.67	11.41	10.08	29.81	44.59	27.52
SC relative importance				3.0%	1.2%	2.3%	1.9%	1.2%	1.1%	15.0%	9.3%	14.2%	10.1%	3.8%	3.3%	9.8%	14.7%	9.1%
SC ranking				10	14	11	12	13	15	1	6	3	4	8	9	5	2	7

4. Discussion of results

The case study targeted the early stages of the service development in a PSS context by identifying the CRs and assessing them. The information can assist manufacturers in augmenting the product-related service offerings (i.e. the hemodialysis device in this context). The three approaches implemented led to a different understanding of the needs of the customers which was explicated through the different importance levels of CRs and subsequently their different priorities (i.e. ranking). In detail the FAHP augmentation (i.e. fuzzy logic and pairwise comparisons) provided the most distinct and sensible assessment of the CRs resulting in a 31.6% variation range whereas the traditional approaches resulted in a smaller variation range 5.7% (Figure 3). Accordingly, we can note that the FAHP enables a clearer distinction of the CRs highlighting the most important requirements in a more distinct manner than the traditional QFD.

Regarding the SCs, their importance levels differ less than the CRs: the FAHP led to a variation range of 14.0% compared to 8.0% for the and traditional approach (Figure 4).

Hence, the customer requirements are discerned more evidently, and the service characteristics are clearer which allows a better direction of the design and development process.
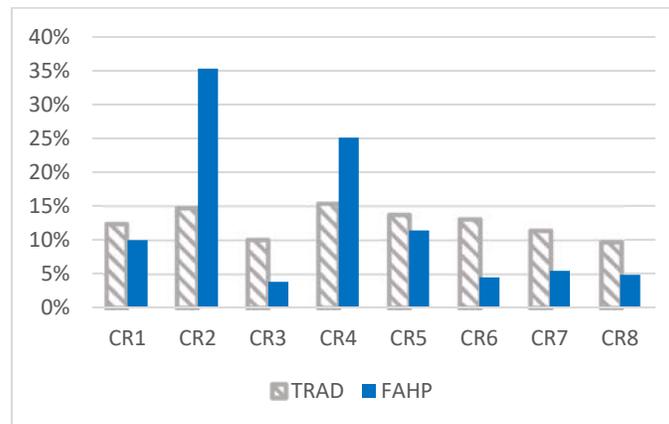

Figure 3. Comparison of the relative importance of the CRs (normalized values (%))
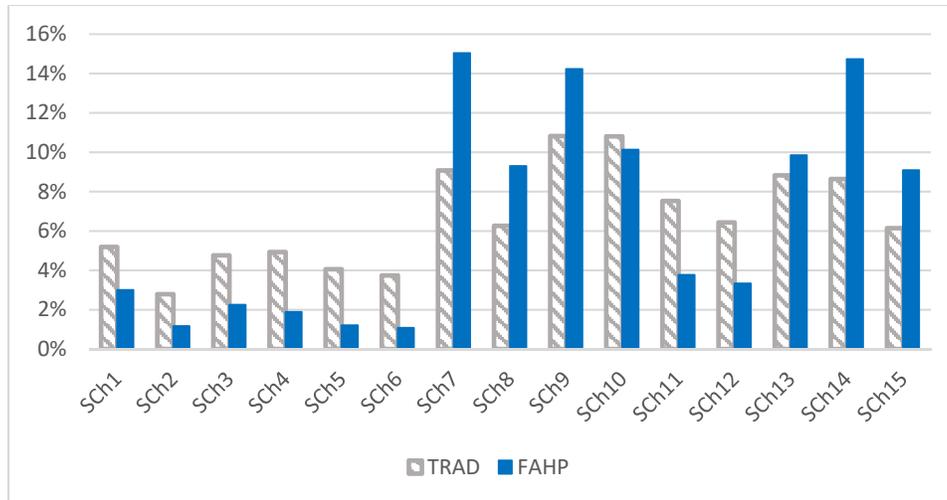
Figure 4. Comparison of the relative importance of the SCs (%)

Furthermore, the ranking of the CRs and SCs differed as each approach led to a different prioritization of the CRs and the measures (i.e. SCs) to satisfy them (Table 7).

Table 7. Ranking of the CRs and SCs using the traditional and FAHP approaches

Customer Requirements (CRs)			Service Characteristics (SCs)		
CR Code	CR Ranking		SC Code	SC Ranking	
	Traditional	FAHP		Traditional	FAHP
CR 1	5	4	SC 1	10	10
CR 2	2	1	SC 2	15	14
CR 3	7	8	SC 3	12	11
CR 4	1	2	SC 4	11	12
CR 5	3	3	SC 5	13	13
CR 6	4	7	SC 6	14	15
CR 7	6	5	SC 7	3	1
CR 8	8	6	SC 8	8	6
			SC 9	1	3
			SC 10	2	4
			SC 11	6	8
			SC 12	7	9
			SC 13	4	5
			SC 14	5	2
			SC 15	9	7

Concerning the CRs, it can be noted that despite the ranking differences, the same three CRs are the most important despite a different ordering (CR2, CR4 and CR5). While regarding the SCs, two remain within the three most important characteristics while SC14, which resulted significant in the FAHP), had a considerably lower ranking through the traditional approach (rank 5).

The obtained results underline the limitations of the traditional QFD when intangibilities and subjectivities are involved (i.e. in a PSS). The latter is portrayed through the smaller variation ranges regarding CRs and SCs. The FAHP augmentation however, was more effective in quantifying the subjectivities of services for a better assessment enabled by the pairwise comparisons and fuzzy logic which reduced ambiguities and imprecisions. The latter allowed a better determination of the SCs to implement.

The benefits achieved through the FAHP augmentation correspond to the findings of Kurtulmuşoğlu and Pakdil (2016) who emphasized the necessity of an accurate and precise evaluations of the customer's needs when it comes to developing services. In line with Shad et al. (2014), the FAHP-augmented QFD enabled a more sensible and precise evaluation of the CRs underlining its effectiveness in managing customers' requirements. In fact, the pairwise comparisons permitted a holistic understanding of the CRs by considering the relations that tie them.

From a more general standpoint, the case study illustrated a promisingly effective approach to address and manage customer requirements in a PSS setting. The approach is based on the practical needs of a manufacturer who seeks to improve its services as to augment customer value to better satisfy his customers and attract potential ones. The results obtained showed that, although the company operates in a regulated market where availability and customer care are the core-requests of the calls for tender, the implementation of additional supporting services can increase the customers' satisfaction. In particular, services related to the environmental aspects of the PSS, such as the SC2 (environmental conformity (Fargnoli et al., 2013)) and SC3 (dematerialization of data storage) can offer the company the possibility to expand its business providing customized solutions (Sakao and Shimomura, 2007; Sakao and Fargnoli, 2010; Turki et al., 2017). Hence, they are worth further investigations.

Nevertheless, despite the positive aspects of the approach, it should be noted that the manufacturer operates in a business-to-customer context where associated costs cannot be overlooked and should hence be considered when developing a solution (Rexfelt and Ornas, 2009). Further work to incorporate the economic aspects is planned and underway.

5. Conclusion

Given the growing importance of services in today's market on one hand and the increasing competition between manufacturers on the other, an effective implementation of services for increase value has become essential. Nevertheless, traditional product design and development tools (i.e. QFD) are limited when service attributes are involved.

This paper contributes to the present research literature by proposing the FAHP augmentation to a service-oriented QFD as a means of addressing the intangibility and subjectivity of services. In fact, the FAHP augmentation resulted in a higher variation range concerning the CR priorities which facilitates the decision-making process and enables manufacturers a clearer choice when addressing the SCs. From a managerial perspective, the proposed approach can contribute to the practical needs of manufacturers that deal with the necessity to find a good balance between the improvement of product and service components to provide more convenient offerings. Despite this aspect being more relevant to practice in industry, the achieved results can be considered useful to augment scientific knowledge regarding ontologies in the PSS domain (Ki Moon et al., 2009).

The case study demonstrated how the approach can be applied in a practical context, yet future research work is needed to refine it. For instance, the use of the Analytic Network Process (ANP) should be investigated as it enables a more comprehensive evaluation of the CRs by incorporating the SCs and their interrelationships for the prioritization of the customers' requirements. In addition, the adoption of other fuzzy numbers (i.e. trapezoidal) may be explored.

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