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ORIGINAL PAPER

Development of sustainability evaluation model for implementing product service systems

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Abstract A new business model, product service systems, is proposed to promote a shift in focus from selling purely products to selling functions. This is achieved through a mix of products and services that fulfill the same consumer demands, while eliciting less environmental impact. Development of product service systems has become an increasingly important strategy in achieving social, economic, and environmental sustainability because product service systems advocates reducing resource consumption, while delivering better and more widely available goods and services. This paper proposes an evaluation framework of sustainable performance to implement product service systems. A literature review discusses 32 criteria categorized into two aspects: product and organization. The fuzzy Delphi method is then applied to identify the consistency of criteria. The relative weights of the selected criteria are determined using Fuzzy analytic hierarchy process. Results indicate that the top three criteria in product aspect are maintenance system (weight = 0.172), use time or frequency (weight = 0.145), and price of the product (weight = 0.132). For the organization aspect, the top three criteria are integrated service plan (weight = 0.197), product development and design (weight = 0.144) and optimized transportation network (weight = 0.089). The demand for implementing product service systems is completely different from selling traditional goods because product service systems must consider the issue of sustainability. The proposed evaluation framework can help companies identify the potential products suitable in implementing product service systems.

Keywords Delphi method · Fuzzy analytic hierarchy process · Sustainability

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Introduction

In recent years, climate change has made environmental protection a crucial topic. The European Union (EU) has established “the directive on prevention and control of pollution in industry (OPPC),” making pollution an illegal act in some countries (Dodić et al. 2010). Many studies have mentioned the benefits of environmental sustainability to businesses, such as financial benefits, standardization of environmental management procedures for internal operations, saving resources and reducing wastage for corporate management, improving corporate image for marketing purposes, enhancing environmental awareness of suppliers for supplier relations; organizational benefits, human resource related benefits, commercial benefits, communication benefits, and so on (Hillary 2004; Zeng et al. 2005; Seiffert 2008). However, if businesses want to reap these benefits, they must be willing to make investments and incur some costs (Dodić et al. 2010).

Under highly competitive, the businesses have to invest in environmental protection. Therefore, businesses need a new business model to deal with this trade-off situation. A new business model using the concept product service systems (PSS) has been proposed to promote a shift in focus from selling purely products to selling functions through a mix of products and services to fulfill the same consumer demands with less environmental impact (Goedkoop et al. 1999; UNEP & PSS 2001; Manzini and Vezzoli 2003; Mont 2003).

The development of PSS has become an increasingly important strategy in achieving social, economic, and environmental sustainability. PSS advocates reducing resource consumption but delivering better, more widely available goods and services (Mejcamp 2000; UNEP & PSS 2001; Mont 2003). Many studies (Goedkoop et al. 1999; Mejcamp 2000; Charter and Tischner 2001) have indicated that PSS could ensure coordination and synergy among profits, competitiveness, and environmental interests. Without being irresponsible, businesses implementing PSS can not only reap economic profits, but also contribute to society and the environment. PSS has already been implemented in several countries, in various development stages (Shih et al. 2009). In the case of European and American countries, literature shows many positive benefits of the PSS in the economic, environmental, and social aspects. In addition, the research of Tukker and Tischner 2006 has mentioned that proper application of PSS could improve business competiveness. However, the kind of product or service most suitable when applying PSS does not have an effective evaluation model. This paper, through a review of literatures, will determine the evaluation criteria and apply the fuzzy Delphi method (FDM) to confirm evaluation hierarchy. After constructing the evaluation hierarchy, this study applies fuzzy analytic hierarchy process (FAHP) to determine the weight and hierarchical ranking of each criterion. This will provide an evaluation model for products or services that can be used to assess the suitability of using the PSS.

The paper is structured as follows: "Materials and methods" reviews related literature to introduce PSS. In "FDM", an evaluation hierarchy for PSS was constructed and FDM was applied to confirm this hierarchy. "FAHP" describes the methodology and process for FAHP, as well as the result of the analysis. "Results and Discussion" is a discussion of the results, while "Conclusion" presents the conclusion.

Materials and methods

Concept of PSS

A product service system has been described as "a system of products, services, supporting networks, and infrastructure that is designed to be competitive, satisfy customer needs, and have a lower environmental impact than traditional business models" (Mont 2002). The core of the PSS concept is based upon a fundamental shift in the relationship between the producers and the consumers of a product or service. PSS is not like the traditional forms of sale, ownership, consumption and disposal of products. The purpose of PSS is to provide a function to the customer. Manzini et al. 2004 described PSS as the provision of combinations of products and services that are capable of "jointly fulfilling user needs." PSS offers a model for products throughout their lifecycle to minimize environmental impacts and to identify alternative profitable revenue streams (Tukker and Tischner 2006).

The key idea behind PSS is that consumers do not specifically demand products, but rather seek the utility of these products and services (Goedkoop et al. 1999; Mont 2003). According to Tischner (2004) and Tukker (2003)'s researches, PSS can be classified as product-oriented PSS, use-oriented PSS, and result-oriented PSS (See Fig. 1), the more detail of PSS with different kinds are presents as follow.

Product-oriented PSS

The main feature of product-oriented PSS is that the consumer owns the product, including the services attached to the product (SusProNet 2003; Tukker 2003; Tischner 2004). This often occurs in package deals where manufacturers not only sell products, but also provide customers relevant services, including planning, financing, installation, operation, maintenance, upgrading, and recycling. In this case, the product is considered as a means to deliver services (UNEP & PSS 2001).

Use-oriented PSS

Typical examples of the use-oriented PSS are product rental, leasing, or sharing (e.g., car-sharing systems) (Meijkamp 1994; Mejcamp 2000). The manufacturer/provider does not sell the products, but only their usage and functions (SusProNet 2003; Tukker 2003; Tischner 2004).

Result-oriented PSS

In result-oriented PSS, the product is substituted with a service that is owned and run by the manufacturer/service provider; hence, the physical ''product'' may not be easily identified (SusProNet 2003; Tukker 2003; Tischner 2004). The manufacturer/service provider, therefore, is motivated to intensify services and optimize the product's operation to achieve sustainability. Result-oriented PSS means a shift from buying products to buying services that has potential to minimize the environmental impact (Mejcamp 2000).

Benefits and limitations of PSS

The new business model-PSS can bring many benefits; however, it also has many limitations. Manzini and Vezzoli (2003) pointed out that a key interest of PSS is the

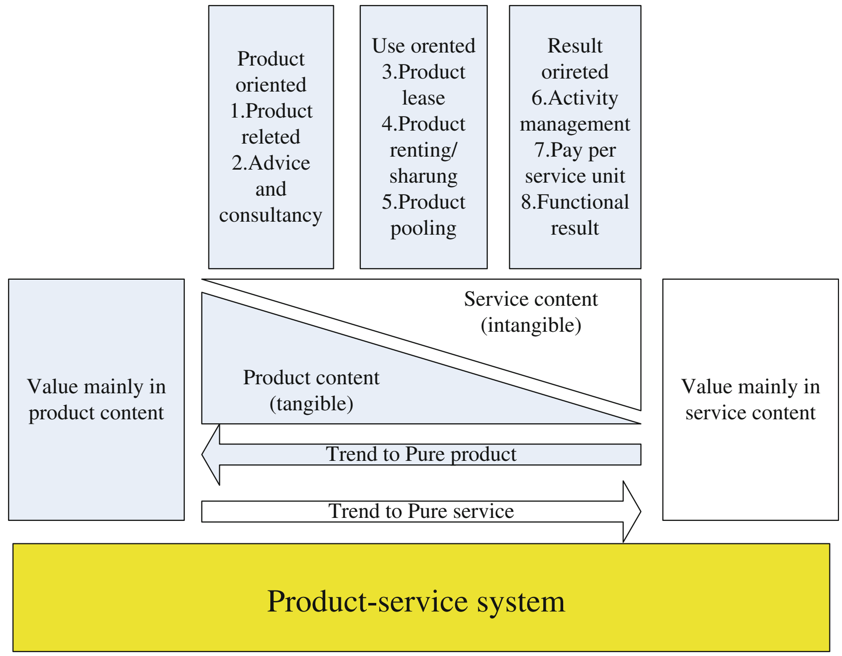

Fig. 1 Eight types of product service system (Tukker 2004)

possibilities that this approach present by producing synergies among profit, competitiveness, and environmental benefits. Maxwell et al. (2006) mentioned that PSS have eliminated/reduced adverse environmental impact, reduced adverse social impact, and provided economic benefit. Williams (2006) pointed out that PSS provide these advantages through new forms of producer–consumer interaction that facilitate customer relationship, product acquisition, environmental benefits, and compliance legislative. Yang et al. (2009) also mentioned that PSS could reduce emissions and waste generation, provide substantial savings from cost, and reduce energy.

Williams in 2006 mentioned that the possible limitations of PSS include (i) constraints on infrastructure capacity, (ii) lack of appropriate technology, (iii) negative environmental aspects of take-back schemes and reverse logistics systems, (iv) difficulty in managing retailer function, and (v) company related barriers such as capacity constraints and cost. Besch (2005) also pointed out barriers in implementing PSS: financial risk for the service provider; concerns on market conditions (i.e., lack of willingness from the customer side to pay a premium price for environmental protection), no legislative pressure, and lack of interest in environmental improvements; and resistance to change since customers are used to buying products.

In view of the above studies, it is important to prove that PSS is an effective business model that could raise profits. It is also important to consider the limitations and barriers when implementing PSS. However, determining whether the new business model-PSS is suitable for a product or service is a complex task. In the next section, an evaluation hierarchy for PSS was constructed which would allow businesses to easily determine whether their product or service is suitable for PSS.

Construct an evaluating hierarchy

In New Business for Old Europe (SusProNet 2004), 13 types of PSS evaluation methodology are discussed. Among them, 10 methodologies are related to sustainability: (i) Methodology Development and Evaluation of PSS (MEPSS), (ii) Highly Customized Solutions (HiCS), (iii) Eco-efficient PSS-Factory of tomorrow, (iv) Designing Eco-efficient Services (DES), (v) PSS Innovation Handbook, (vi) Sustainable Home Services, (vii) Sustainable Product and Service Development (SPSD), (viii) Business Models for Inherently Sustainable Systems (BISS), (ix) the Kathalys Method, and (x) PSS Innovation Scan for Industry. Among these methodologies, MEPSS is used to evaluate the sustainability of environment, socio-cultural, and economic-oriented products. The MEPSS methodology can be divided into five steps: strategic analysis, exploring opportunities, PSS idea development, PSS development and preparing for implementation (Tukker and Tischner 2004).

In this study, the organizational and product levels were explored separately and the influences of external factors, such as management capabilities were discussed at the organizational level. If consideration is only given at the product level, this does not take into account business conditions; thus, the successful implementation of PSS will be greatly influenced. Since PSS is different from the traditional business model of selling goods, businesses would need some basic conditions to sustain the implementation of PSS. The MEPSS concept and structure were adopted

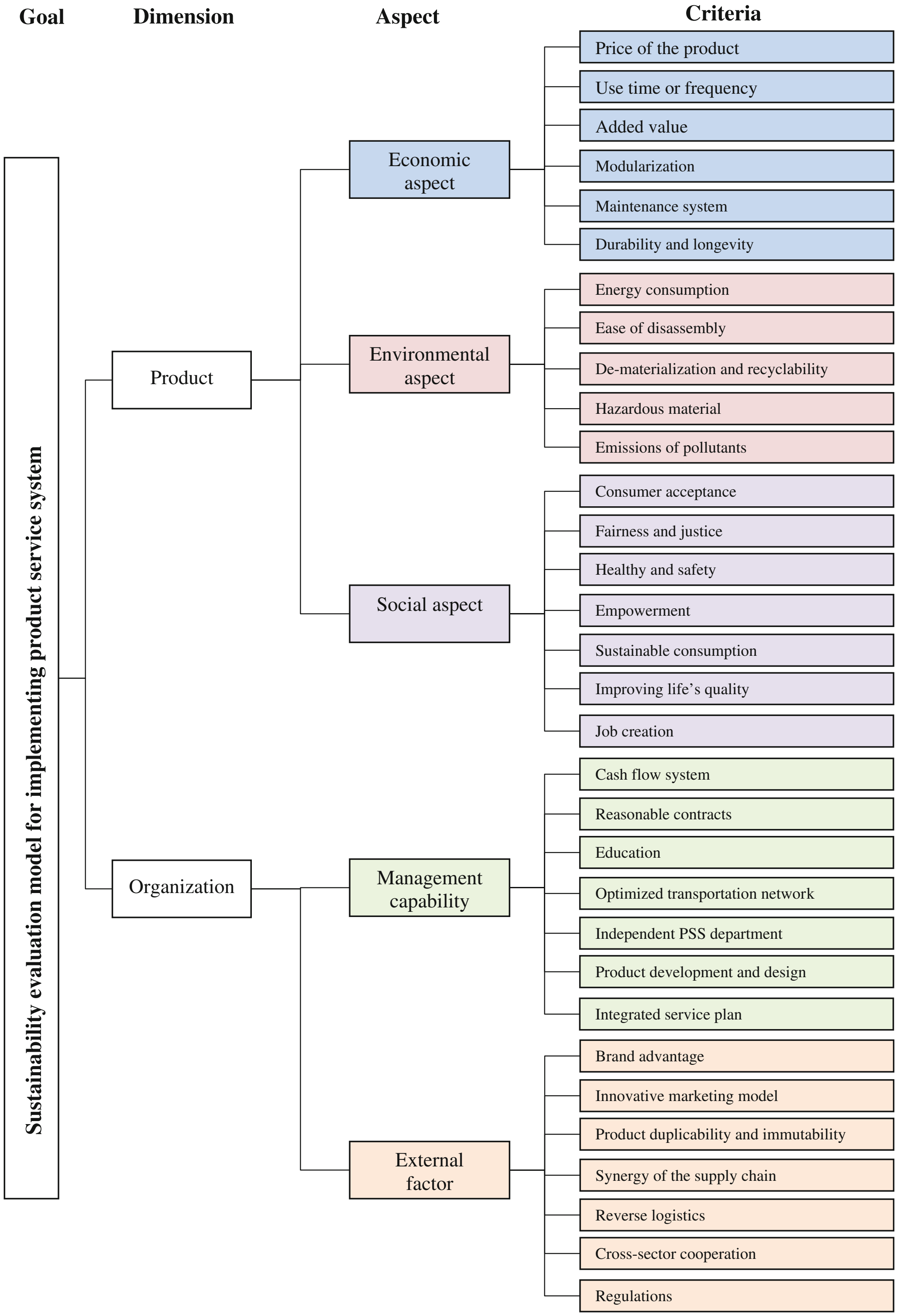

Fig. 2 The evaluating hierarchy of product service system

and the product level framework was subdivided into economic, environmental, and social aspects. Moreover, various related literatures were reviewed to construct the evaluation hierarchy. Then the fuzzy Delphi method (FDM) was applied through four experts and two rounds of questionnaires to confirm the evaluation hierarchy. The results of the evaluation hierarchy are shown in Fig. 2 and the criteria contents are shown in Table 1. The development of FDM and the calculation process are presented in "FAHP".

Table 1 Evaluating criteria contents

Criteria	Contents	Sources
Price of the product	Price greatly affects consumers' willingness to use PSS; expensive products may hinder PSS	White et al. (1999); Besch (2005); Mont (2006)
Use time or frequency	Products are used infrequently or have short use time by customers will affect PSS implementation	Besch (2005); Mont (2006)
Added value	Maintenance and reconditioning services may create competitive advantage for the producer, as well as increase customer retention. They can serve as an additional income source for manufacturers or retailers, and increase contact with customers	United Nations Environment Programme (UNEP) (1997); Mont (2002); Bartolomeo et al. (2003); Manzini and Vezzoli (2003); Tukker (2004); Besch (2005); Mont (2006)
Modularization	Modularity and standardization will tend to reduce time and cost	Mont (2006)
Maintenance system	The maintenance system includes management, inspection, disassembly and reconditioning; they will all affect time and cost	Bartolomeo et al. (2003); Besch (2005); Mont (2006)
Durability and longevity	A high durability and longevity allow products to be used by more customers, which reduces cost	Mont (2002); Bartolomeo et al. (2003); Manzini and Vezzoli (2003); Besch (2005); Mont (2006)
Energy consumption	Energy consumption during use stage	Manzini and Vezzoli (2003); Halme et al. (2006); Maxwell et al. (2006)
Ease of disassembly	Ease of disassembly can facilitate the separation of used parts and components for product recycling and remanufacturing	Besch (2005)
De-materialization and recyclability	To form a closed loop, the use of resources and ease of recyclability should be important attributes for PSS	Mont (2002); Manzini and Vezzoli (2003); Besch (2005); Halme et al. (2006); Maxwell et al. (2006); Mont (2006)
Hazardous material	Avoid the use of hazardous substances during the PSS life cycle	SusProNet (2004)
Emissions of pollutants	Minimize the emission of pollutants	Mont (2002); Manzini and Vezzoli (2003); Halme et al. (2006); Maxwell et al. (2006); Mont (2006)
Consumer acceptance	Since it is linked to the reuse of products, the careful preparation of a special marketing strategy and customer acceptance is required	Bartolomeo et al. (2003); Besch (2005); Mont (2006)
Improving life's quality	This is presumably due to the fact that in order to survive in the market, household services must first be socially beneficial to the users or can improve the quality of life of the consumers	SusProNet (2004); Halme et al. (2006)
Job creation	It is hoped that PSS can create new jobs, help secure existing ones, or help tackle long-term unemployment	SusProNet (2004); Halme et al. (2006)
Fairness and justice	Base on fairness and justice for labors rights and trade in supply chain	SusProNet (2004); Halme et al. (2006)
Healthy and safety	Improve stockholders' healthy and safety in full life cycle	SusProNet (2004); Halme et al. (2006)
Empowerment	Improve stockholders opportunities for participation, or the provision of new channels for residents toward decision-makers	Besch (2005); Halme et al. (2006)
Sustainable consumption	Promote customers' sustainable consciousness to make more responsibility consumer behavior	United Nations Environment Programme (UNEP) (1997); Halme et al. (2006); Maxwell et al. (2006)
Cash flow system	PSS is different from the traditional business model; it needs to have better management of cash flow	Mont (2006)
Reasonable contracts	PSS emphasizes on long-term profitability, and hence a reasonable contract between the producer and the consumer is necessary for both	Bartolomeo et al. (2003); Besch (2005); Mont (2006)
Education	To succeed in implementing PSS, education for employees, suppliers, and retailers is necessary	Mont (2006)

Table 1 continued

Criteria	Contents	Sources
Optimized transportation network	Since the ownership of the product belongs to the producer, the transfer or transportation of products among consumers, producers, and retailers is necessary. Hence, the transportation cost becomes important. A well-planned transportation system can minimize the cost of PSS	Manzini and Vezzoli (2003); Besch (2005); Mont (2006)
Independent PSS department	Since PSS is a different business model, a separate or independent department may need to be set up	Mont (2006)
Product development and design	For PSS to work efficiently and be economically attractive, product development and design capability need to be enhanced	Manzini and Vezzoli (2003); Besch (2005); Halme et al. (2006); Maxwell et al. (2006); Mont (2006)
Integrated service plan	PSS may offer additional services in combination with different products to draw the attention of clients. These additional services could stabilize the relationship with customers	Manzini and Vezzoli (2003); Besch (2005)
Brand advantage	The company has a strong brand name associated with high quality, safety, and durability of products, which will facilitate a successful PSS	Mont (2006)
Innovative marketing model	PSS is new to consumers, and hence it needs certain innovative marketing efforts, at least in the beginning when the whole concept is launched	Besch (2005); Mont (2006)
Product duplicability and immutability	The PSS provider should be able to create a unique system that cannot easily be copied or performed by other parties	Mont (2002); Tukker (2004)
Synergy of the supply chain	The producer collaborates with its suppliers, and this usually helps in the creation of the synergy effect in both financial and environmental aspects	Mont (2006)
Reverse logistics	In designing PSS, reverse logistics is needed because it can enhance the feedback among retailers, producers, and consumers	Mont (2006)
Cross-sector cooperation	In many instances, the creation of a successful PSS requires the involvement of multiple actors across sectors such as the government, the producer, and the consumers	Besch (2005); Halme et al. (2006)
Regulations	Regulations such as IPP, EPR, and others which are related to dematerialization may promote PSS	Mont (2002); Manzini and Bartolomeo et al. (2003); Manzini and Vezzoli (2003); Besch (2005); Maxwell et al. (2006); Mont (2006)

FDM and FAHP

FDM

Since Dalkey and Helmer in 1963 launched the Delphi Method at RAND Corporation, it has become a widely used and recognized instrument to aid prediction and decision making (Landeta 2006). The Delphi method was conceived as a group technique to obtain the most reliable consensus of a group of experts through a series of intensive questionnaires, using controlled opinion feedback (Dalkey and Helmer 1963). Despite the Delphi method being deemed a valuable tool, some drawbacks have always existed. The method requires a great deal of time and cost to converge results through repetitive surveys (Hwang and Lin 1986; Ishikawa et al. 1993; Hsu and Hu 2009; Shen et al. 2010). In addition, the problems of ambiguity and uncertainty still exist in the experts responses (Hwang and Lin 1986; Chang et al. 2000; Shen et al. 2010). In order to solve the above shortcomings, an early study of the FDM conducted by Murray et al. 1985 combined the concept of traditional Delphi method and the fuzzy set to improve the vagueness and ambiguity of the Delphi method (Kuo and Chen 2008). In addition, Kaufmann and Gupta 1988 proposed a more complete FDM procedure, utilizing the fuzzy set theory by asking the participants to give a three-point estimate (pessimistic, moderate, and optimistic values). Triangular fuzzy numbers (TFNs) were then formed, and their mean was computed.

By incorporating TFNs to locate 3 points of the extent of importance with the scale of 0–10 points, in this study, a pair TFNs concepts adopted by Wei and Chang (Wei and Chang 2008) were applied to calculate and depict the "group average" values. The pair TFNs were categorized into two parts as the conservative TFN (C_L, C_M, C_U) and optimistic TFN (O_L, O_M, O_U). The intersection of fuzzy opinions of experts implies the convergence of consensus for expert-group opinion. The geometric means of conservative, moderate, and optimistic values (C^i, a^i, O^i) were computed to acquire the consensus values (G^i) of each item. In view of the advantages of FDM in evoking expert-group opinion, various studies (Saaty 1980; Wei and Chang 2008) have embraced FDM for constructing performance indicators or evaluation criteria. The essential steps are as follows (Wei and Chang 2008; Lee et al. 2010):

Step 1: Conducting the questionnaire and organizing an appropriate panel group of experts to express their most conservative (minimum) and optimistic (maximum) value of each item using a range of 1–10

Step 2: Gathering the most conservative (minimum) and optimistic (maximum) value of each expert for each item and computing the geometric mean of the group expert opinions, then calculating the conservative and optimistic value of each item i. When outside of the two standard deviations, i is eliminated. The rest of values are calculated for the minimum (C^i_L), geometric mean (C^i_M), and maximum (C^i_U) of the remaining conservative value, as well as the minimum (O^i_L), geometric mean (O^i_M) and maximum (O^i_U) of remaining optimistic value

Step 3: Determining the triangular fuzzy numbers (TFNs) of the most conservative and optimistic value by $C^i = \left(C^i_L, C^i_M, C^i_U\right)$ and $O^i = (O^i_L, O^i_M, O^i_U)$for each item

Step 4: Determining whether expert opinions are consistent and calculating the consensus significance value of G_i for each item,

1. If the pair-TFNs do not overlap (i.e., $C^i_U \leq O^i_L$), the expert opinions achieve consensus in item i, the consensus significance value is calculated as follows:

$$G_i = \frac{C^i_M + O^i_M}{2} \cdots\cdots\cdots (1)$$

2. If the pair-FTNs overlap (i.e. $C^i_U > O^i_L$) and the gray zone interval value $\left(Z^i = C^i_U - O^i_L\right)$ is less than the interval value of C^i and $O^i\left(M^i = O^i_U - C^i_M\right)(M^i = O^i_U - C^i_M)$, the consensus significance value of each item is calculated by Eq. (2):

$$G_i = \frac{\left[\left(C^i_U \times O^i_M\right) - \left(O^i_L \times C^i_M\right)\right]}{\left[\left(C^i_U - C^i_M\right) + \left(O^i_M - O^i_L\right)\right]} \cdots\cdots\cdots (2)$$

If the pair-TFNs overlap (i.e., $C^i_U > O^i_L$) and the gray zone interval value $\left(Z^i = C^i_U - O^i_L\right)$ is greater than the interval value of C^i and $O^i\left(M^i = O^i_U - C^i_M\right)$, implying that the experts opinions have discrepancies. Repeat Steps 1–4 until each item is a convergence and G_i is calculated.

FAHP

The analytic hierarchy process (AHP) method introduced by Saaty in 1980 shows the process of determining the priority of a set of alternatives, and the relative importance of attributes in a multi-criteria decision-making (MCDM) problem (Saaty 1980; Wei et al. 2005). The primary advantage of the AHP approach is the relative ease with which it handles multiple criteria and performs qualitative and quantitative data (Meade and Sarkis 1998; Kahraman et al. 2004). However, AHP is frequently criticized for its inability to adequately accommodate the inherent uncertainty and imprecision associated with mapping decision-maker perceptions to extract number (Kwong and Bai 2003; Chan and Kumar 2007; Lee et al. 2008). It is difficult to respond to the preference of decision makers by assigning precise numerical values. To improve the AHP method and to determine the relative weight of criteria for risk assessment, this study applies the fuzzy analytic hierarchy process (FAHP) and uses triangular fuzzy numbers to express the comparative judgments of decision makers. The essential calculation steps are as follows:

Step 1: Establishing the hierarchical structure
To construct the hierarchical structure with decision elements, decision makers are requested to make pair-wise comparisons between decision alternatives and criteria using a 9-point scale. All matrices are developed and all pair-wises comparisons are obtained from each n decision maker.

Step 2: Calculating the consistency
To ensure that the priority of elements is consistent, the maximum eigenvector or relative weights and $\lambda_{\max}$ are calculated. Then, the consistency index (CI) for each matrix order n using Eq. 1 is computed. Based on CI and random index (RI), the consistency ratio (CR) is calculated using Eq. 2. The CI and CR are defined as follows (Saaty 1980)

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

Table 2 Random index (R.I.) (Saaty 1980)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

where n is the number of items being compared in the matrix, λ_{max} is the largest eigenvalue, and RI is a random consistency index obtained from a large number of simulation runs, which varies upon the order of the matrix (Table 2).

Step 3: Construct a fuzzy positive matrix

A decision maker transforms the score of pair-wise comparison into linguistic variables via the positive triangular fuzzy number (PTFN) listed in Table 3. The fuzzy positive reciprocal matrix can be defined as

$$\tilde{A}^k = \left[\tilde{A}_{ij}^k\right] \quad (3)$$

where $\tilde{A}^k$: a fuzzy position reciprocal matrix of decision maker k, $\tilde{A}_{ij}^k$: relative importance of i and j of decision elements

$$\tilde{A}_{ij}^k = 1, \quad \forall i = j, \quad \tilde{A}_{ij}^k = 1\Big/A_{ij}^k, \quad \forall i, j = 1, 2, \ldots, n$$

Step 4: Calculate fuzzy weights value

The fuzzy weights of the hierarchy can be calculated according to the Lambda-Max method proposed by Csutora and Buckley 2001. This process is described as follows:

- Let $\alpha = 1$ to obtain the positive matrix of the decision maker $\tilde{A}_m^k = \left[a_{ijm}\right]_{nxn}$. Then, AHP is applied to calculate the weight matrix W_m^k.

$$W_m^k = \left[w_{im}^k\right], \; i = 1, 2, \ldots, n \quad (4)$$

- Let $\alpha = 0$ to obtain the lower bound and upper bound of the positive matrix of the decision maker, $\tilde{A}_l^k = \left[a_{ijl}\right]_{nxn}$ and $\tilde{A}_u^k = \left[a_{iju}\right]_{nxn}$. Then, AHP is applied to calculate the weight matrix, W_l^k and W_u^k.

$$W_l^k = \left[w_{il}^k\right], \; i = 1, 2, \ldots, n \quad (5)$$

$$W_u^k = \left[w_{iu}^k\right], \; i = 1, 2, \ldots, n \quad (6)$$

- To ensure the fuzziness of weight, two constants, S_l^k and S_u^k, are calculated as follows:

$$S_l^k = \min\left\{\frac{w_{im}^k}{w_{il}^k} \,|\, 1 \le i \le n\right\} \quad (7)$$

$$S_u^k = \min\left\{\frac{w_{im}^k}{w_{iu}^k} \,|\, 1 \le i \le n\right\} \quad (8)$$

The lower bound ($W_l^{k^*}$) and upper bound ($W_u^{k^*}$) of the weight matrix are defined as

$$W_l^{k^*} = \left[w_{il}^{k^*}\right], \; w_{il}^{k^*} = S_l^k w_{il}^k, \; i = 1, 2, \ldots, n \quad (9)$$

$$W_i^{k*} = \left[w_{iu}^{K*}\right], \; w_{iu}^{k*} = S_u^k w_{iu}^k, \quad i = 1, 2, \ldots, n \quad (10)$$

- Aggregating $W_l^{k^*}$, $W_m^{k^*}$, and $W_u^{k^*}$, the fuzzy weight for decision maker k can be acquired as follows:

$$\tilde{W}_i^k = \left(w_{il}^{k*}, w_{im}^{k*}, w_{iu}^{k*}\right), \quad i = 1, 2, \ldots, n \quad (11)$$

- Applying the geometric average to incorporate the opinions of decision makers is defined as follows:

$$\tilde{\tilde{W}}_i = {}^1\!/_k\left(\tilde{W}_i^1 \otimes \tilde{W}_i^2 \otimes \ldots\ldots \otimes \tilde{W}_i^n\right) \quad (12)$$

where $\tilde{\tilde{W}}_i$: the fuzzy weight of decision makers i is incorporated with K decision makers, $\tilde{W}_i^k$: the fuzzy weight of decision element i of k decision maker, K: number of decision makers.

Table 3 Triangular fuzzy numbers (Lee et al. 2008)

Linguistic variables	Positive triangular number	Positive reciprocal triangular fuzzy number
Extremely strong	(9,9,9)	(1/9,1/9,1/9)
Intermediate	(7,8,9)	(1/9,1/8,1/7)
Very strong	(6,7,8)	(1/8,1/7,1/6)
Intermediate	(5,6,7)	(1/7,1/6,1/5)
Strong	(4,5,6)	(1/6,1/5,1/4)
Intermediate	(3,4,5)	(1/5,1/4,1/3)
Moderately strong	(2,3,4)	(1/4,1/3,1/2)
Intermediate	(1,2,3)	(1/3,1/2,1)
Equally strong	(1,1,1)	(1,1,1)

Results and Discussion

Through literature review and FDM, an evaluation hierarchy was built for businesses implementing PSS. The PSS evaluation hierarchy is shown in "FDM". The FAHP method was applied to determine the each criterion's weight and ranking. The results are shown in Table 4.

The results of FAHP show that economics is the most important sub-aspect in product aspect (weight = 0.678), and has a much higher value in each aspect's weight. This is understandable; profitability is certainly the most

Table 4 Local and global weights of each aspect and criterion

Dimension	Aspect and Criteria	Local weights	Global weights	Ranking
Product	*Economic aspect*	*0.678*		*1*
	Price of the product	0.194	0.132	3
	Use time or frequency	0.214	0.145	2
	Added value	0.144	0.098	4
	Modularization	0.071	0.048	7
	Maintenance system	0.254	0.172	1
	Durability and longevity	0.122	0.083	6
	Environmental aspect	*0.201*		*2*
	Energy consumption	0.429	0.086	5
	Ease of disassembly	0.123	0.025	11
	De-materialization and recyclability	0.11	0.022	13
	Hazardous material	0.146	0.029	9
	Emissions of pollutants	0.192	0.039	8
	Social aspect	*0.121*		*3*
	Consumer acceptance	0.199	0.024	12
	Fairness and justice	0.084	0.010	17
	Healthy and safety	0.226	0.027	10
	Empowerment	0.085	0.010	18
	Sustainable consumption	0.17	0.021	14
	Improving life's quality	0.136	0.016	15
	Job creation	0.099	0.012	16
Organization	*Management capability*	*0.660*		*1*
	Cash flow system	0.127	0.084	4
	Reasonable contracts	0.068	0.045	10
	Education	0.087	0.057	7
	Optimized transportation network	0.135	0.089	3
	Independent PSS department	0.067	0.044	12
	Product development and design	0.218	0.144	2
	Integrated service plan	0.298	0.197	1
	External factors	*0.340*		*2*
	Brand advantage	0.190	0.065	6
	Innovative marketing model	0.166	0.056	8
	Product duplicability and immutability	0.138	0.047	9
	Synergy of the supply chain	0.133	0.045	11
	Reverse logistics	0.100	0.034	13
	Cross-sector cooperation	0.078	0.027	14
	Regulations	0.195	0.066	5

important consideration for businesses. The environmental sub-aspect is the second most important in this aspect (weight = 0.201), representing the close attention paid by businesses to the environmental impact of the product or service. This also indicates public agreement on the importance of environmental protection for sustainable development. The social sub-aspect is the least important in product aspect (weight = 0.121); however, some of its criteria ranking are in the lead, such as "healthy and safety" (ranking 10th in 18 criteria), and "consumer acceptance" (ranking 12th in 18 criteria). This shows that although social sub-aspect ranks least, businesses should still pay attention to some high-profile issues when evaluating the implementation of PSS. In the social sub-aspect, the factors for all of the stakeholders were considered; therefore, it is suggested that businesses consider this aspect in order to incorporate the views of different stakeholders.

For the other aspect, the organization was separated into two sub-aspects: management capability and external factors. The results indicate that management capability is more important (weight = 0.660). In this sub-aspect, there are four criteria with rankings in the lead: “Integrated service plan” (ranking 1st in 14 criteria), “Product development and design” (ranking 2nd in 14 criteria), “Optimized transportation network” (ranking 3rd in 14 criteria), and “Cash flow system” (ranking 4th in 14 criteria). This shows that to have a complete service plan is an important factor that will affect the implementation of PSS. The product design and development should also be carefully considered. In this study, the high ranking of optimized transportation network is a rather surprising result. Transportation is very important since it directly impacts costs such as manpower, material, and time. However, an optimized transportation network is ranked third in the organization aspect of the management ability sub-aspect, showing that the importance of transport network for PSS is much higher than other business models. This result shows that businesses should pay attention to this aspect when considering PSS implementation. The fourth ranking is the cash flow system, implying that applying PSS may need a more robust financial support system. PSS is a new business model. PSS may result in fewer short-term gains, but will have greater long-term gains; thus, a better financial structure should be required.

The external factors dimension, the criteria “regulations” (ranking 5th in 14 criteria) and “brand advantage” (ranking 6th in 14 criteria) have degrees of importance. Implementing PSS may produce a new kind of service model; therefore, providing a proper service contract will be important for both supply and demand side. For brand advantage, basic PSS can reduce the capital cost on the demand side; however, will not decrease supplier’s overall profits. Therefore, the demand side should access to more resources for a better service, and also can choice the better brand in same kinds of product.

PSS is a new business model that could bring more profits in the saturated market. This kind of business model is different from the traditional model since consumers do not buy a physical product; rather, they purchase a service. Therefore, in implementing this new business model many factors need to be considered. This paper constructed an evaluation hierarchy as a tool for implementing PSS.

Conclusion

A new business based-PSS is created to improve profits in a saturated market. An evaluation model was constructed to estimate whether a product or service is suitable under PSS. PSS can be a tool for businesses to assess a product or service. The FDM was applied to confirm the evaluation hierarchy. Through FAHP, each criterion’s weights and ranking were determined. The evaluation structure was divided into two aspects: product and organization. The top three criteria in product aspect are maintenance system, use time or frequency, and price of the product. These are the main issues that should be given attention when assessing the feasibility of implementing PSS. For organization, the top three criteria are integrated service plan, product development and design, and optimized transportation network. As mentioned above, the requirements for implementing PSS are very different from traditional sale of goods. Businesses should consider the sustainability of PSS and focus on long-term gains instead of immediate profits.

The proposed method has the following contributions. First, a new model for evaluating PSS with emphasis on sustainable issues has been developed. Such a framework has not been discussed in previous literature. This evaluation tool can help businesses assess the feasibility of implementing PSS. Second, this study incorporates literature review and FDM to build a more effective evaluation hierarchy. The light was also shed on the organization aspect, which makes this evaluation tool more complete when applied by businesses. It is expected that this evaluation tool will not only reduce manpower and time to assess the implementation of PSS, but also mitigate uncertainty in risks associated with PSS.

The evaluation model incorporates most of the evaluation criteria; however, there maybe be some factors required for special products or services that were not included. This research paper’s main aim is to construct an evaluation model for the initial implementation of PSS. After using this evaluation model, a more in-depth assessment of implementing PSS is suggested. This evaluation hierarchy is unable to consider different characteristics; therefore, when using this evaluation model to assess implementing PSS, it must also consider the specific characteristics of a product or service. In addition, the FAHP results can be used by businesses to adjust each criterion’s weight for different products or services. Finally, future studies should develop a PSS implementation strategy and consider conducting case studies to verify the evaluation model. This evaluation model may not be fully applicable to all products, nor to the development of a strategy; however, this evaluation model still have value as an initial evaluation tool to implement PSS.

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