Product-service system design concept development based on product and service integration

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Abstract: Today's business environment puts pressure on many high-technology companies to continuously improve the value of their products and services to remain competitive. Product-service system (PSS) is an emerging paradigm that enables a tighter integration between product and service offering. The research described in this paper aims to propose a new PSS design methodology based on the integrated product and service design requirements. The process consists of three stages: the identification of design requirements, the determination of design requirements rating and the integration of product and service design requirement in order to develop a PSS design concept. A case study of mobile phones design has been chosen to validate the proposed PSS design methodology.

Keywords: product-service system; PSS; added values; design concept; design requirements; consumer needs; PSS design methodology; integration; mobile phone; product concept; service concept.

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1 Introduction

Consumer demands for products are becoming increasingly complex and customised (Morelli, 2002). Better consumer awareness of the quality and features of the product, tighter competition between the developed and developing countries and markets trend towards globalisation are some examples of the changes that exist in the global business environment (Lay et al., 2010). Product differentiation can be considered as a solution to this problem. However, advances in information and communication technology enable companies to compete globally, making it difficult for them to compete on the basis of the product differentiation alone (Tan et al., 2007).

Feinberg (2001) states, if the products in the market are not significantly differentiated then customer satisfaction will be a determining factor in the business competition. For that reason, in order to survive in the global competition, companies should increase their competitiveness by improving customer satisfaction. One possible way is to offer added value to the product, which can be done by shifting their paradigm from the product-oriented into the service-oriented economy (Geng et al., 2010). Shikata et al. (2013) argued that it is difficult for manufacturing companies nowadays to succeed by selling only product. The concept of product-service systems (PSSs) integrates products and services which can lead to a better value proposition, revenue generation opportunities and sustainable customer value (Roy and Cheruvu, 2009). Shifting from the production-based model to the PSS-based model also means that the manufacturers are required to diversify services around the products (Phumbua and Tjahjono, 2012).

Although PSS offers various benefits through increased added value, the analysis conducted by the sustainable product development network (SusProNet) showed that the PSS application is not always a win-win solution and sustainability is still questionable; in some cases it failed or simply gave a slight profit margin (Tukker, 2004). To avoid failure in the PSS implementation, the design process clearly needs to be improved. In this way, the implementation of PSS concept will be enhanced.

The research described in this paper aims to provide a new PSS design methodology based on the integrated product and service design requirements. Customer preferences will become the basis for the requirements. The integration process will focus on the product-oriented service. It is expected that the integration can facilitate the companies to shift from product-oriented enterprises to service-based enterprises and improve their competitiveness through the synergy between the product and services offered.

2 State of the art

2.1 Product-service systems

PSS can be defined as the integration between products and services to generate higher added value and fulfil the specific needs of consumers (Goedkoop et al., 1999; Mont, 2000; Erkoyuncu et al., 2009; Chirumalla et al., 2011; Wallin and Kihlander, 2012). In the context of PSS, a product is a tangible commodity manufactured to be sold, while a service is an activity with economic value often done on a commercial basis. A combination of products and services can expand the functionality offered to consumers, both in terms of improving the quality of products and services as well as reducing the total cost (Goedkoop et al., 1999).

Increased added value can be obtained by expanding the product utility and services during the period of use (Tan et al., 2007). Business strategies have often been purposely developed with a holistic approach to link economic, environmental and social aspects (Mateu et al., 2012). PSS is therefore closely related with sustainability and the relationship between products and services in the context of sustainability dimensions can be described as the 'triple bottom line (3BL)' as follows:

- *The economic dimension* means the integration of products and services will offer new functionality, open up opportunities for products and service customisation as well as improve product quality and customer satisfaction (Goedkoop et al., 1999). Furthermore, it will expand the market for producers, increase the company's reputation from the consumer point of view (Wimmer and Kang, 2006) and can reduce the cost of investment and production (Goedkoop et al., 1999; Wimmer and Kang, 2006).
- *The environment dimension* emphasises the integration of products and services that will reduce material waste by shifting the company's business from selling only products to providing functionality (Mont, 2002; Maussang et al., 2006). In addition, the combination of products and services that complement each other in providing the needs of the consumers can reduce energy consumption and use of aggregate materials.
- *The social dimension* shows the integration of service activities in manufacturing companies that will grow the employment. This integration will also affect the consumption patterns in the society so it can reduce the impact of the rebound effect. However, the relationship between the PSS concept with the social aspect is somewhat reciprocal. This is due to the effective implementation of PSS that also requires corresponding social structures (such as social infrastructure, community structure and organisational layout) (Mont, 2000).

2.2 Design approaches in PPS

Design aspect has a critical role in the efficiency, visibility and usability of PSS (Morelli, 2002). McAloone and Andreasen (2004) found that design in PSS ideally combines various disciplines by considering the product life cycle and consumer acceptance. The same opinion is expressed by Mont and Plepys (2003). They claimed that the PSS design should be able to connect the consumer perceptions and behaviour as well as the concept of sustainability development. Moreover, the collaboration between product (tangible) and services (intangible) in PSS design needs to be considered in order to increase the value. Therefore, the design process of products and services in PSS should be conducted jointly so as to maximise the potential profit of the resulting design. Design requirement is determined before the design process done and it is based on the perspective of products and services. Both perspective of requirements are then processed together to generate the optimal PSS design.

Vasantha et al. (2012) revealed that the design process to integrate products and services into primary goal is widely discussed in PSS literature. Some PSS design methodologies that appeared in the literature are summarised in Table 1.

From the review, it has become apparent that the main shortcoming of the abovementioned methodologies lays in the fact that they are not well grounded with respect to determining the design requirements. Owing to the fact that the primary goal of the design is to fulfil the needs of the consumers, this is a considerable weakness in the way that the PSS design should be developed based on the needs of consumers. Therefore, there is a clear need for a framework that can be used to determine the requirement lists for a development process.

Table 1 PSS design methodologies in literature

Reference	*Contribution*	*Strengths*	*Weaknesses*
Morelli (2002, 2006)	A set of methods to define a map of the actors involved in PSS, to define the requirements and structure a PSS and to represent and blueprint a PSS.	Methodical and operational tools to develop an innovative and multidisciplinary approach of PSS design.	Does not explain each of the stages in the design process.
Maussang et al. (2006, 2007, 2009)	An integrated product and service design methodology by using functional analysis and agent based model.	Enables designers to take into account the values and detailed costs provided by PSS while considering the functions that will fulfil the expected requirements.	Capable of generating several PSS scenarios, but the method has not explained the general procedures for the selection of the optimal scenario.
Hara et al. (2007, 2009)	A CAD system called 'service explorer' that can be used to design services.	Enables collaboration amongst managers, marketers, and engineers to improve existing services or design a new service.	Does not explain the feasibility assessment of the combination of products and services offered.
Thomas et al. (2008)	A PSS design methodology for determining the characteristics of the components of products and services based on a set of criteria developed from the consumer needs.	Allows consumer needs to be linked to product and service components.	Applied only for a specific case study, insufficient general conclusion.
Ericson et al. (2009)	TRIZ-based tools for PSS design methodology.	Reduces innovation risks through the use of TRIZ-based modules.	Does not have a mechanism for defining the problems in the early stages of design.
Kimita et al. (2010)	Axiomatic design and service engineering concept for PSS design methodology.	Allows PSS designers to detect and avoid conflicts amongst PSS elements.	Does not consider the constraints in the transition phase between design domains.
Chen and Li (2010)	Designers support to design PSS based on an eco-innovative design method and TRIZ method.	Able to bring a variety of eco-innovative possibilities by using TRIZ inventive principles without requiring contradiction analysis rules.	The solutions offered are considered only for reducing environmental impacts on eco-products or processes.

Table 1 PSS design methodologies in literature (continued)

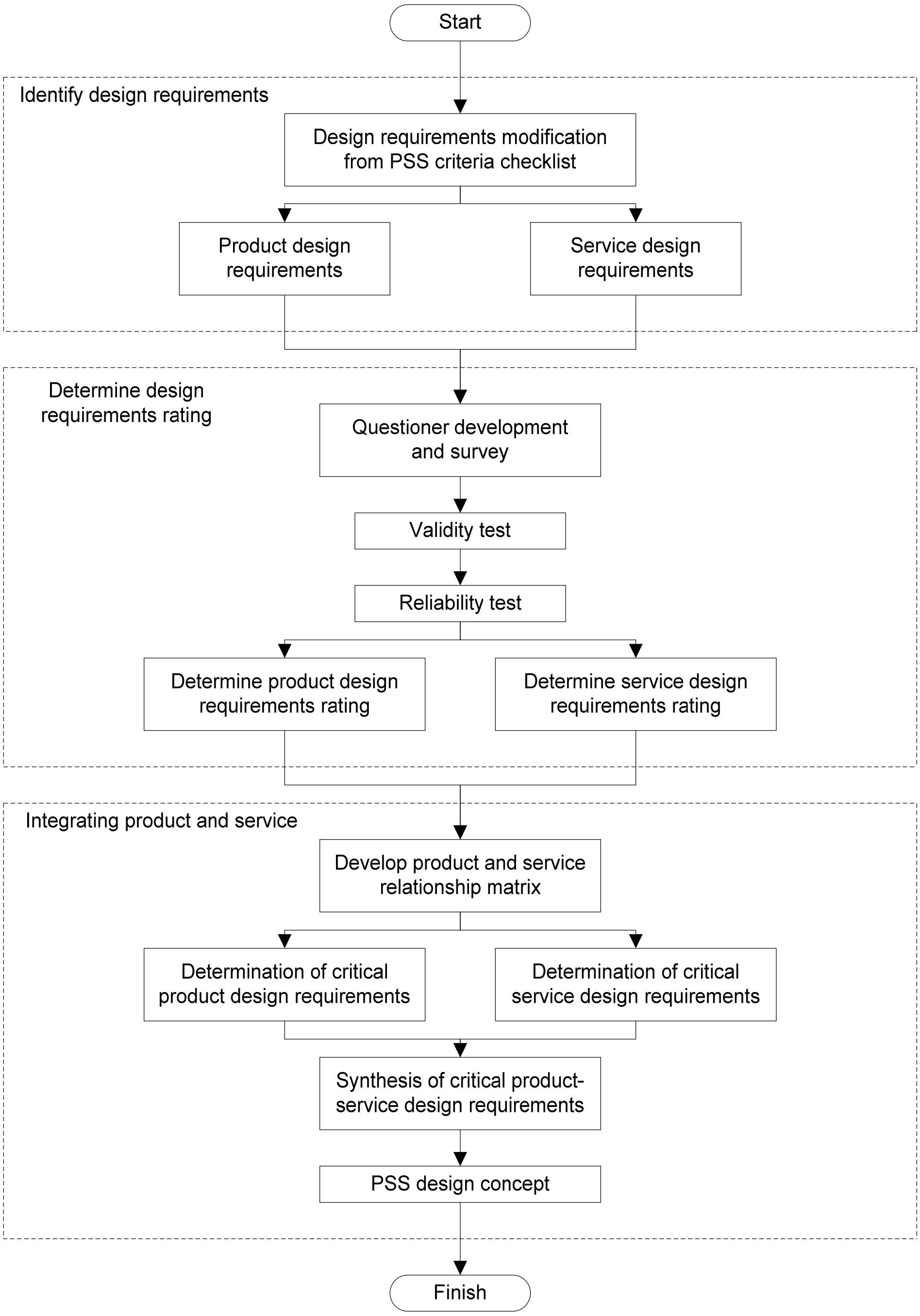
Reference	*Contribution*	*Strengths*	*Weaknesses*
Geng et al. (2010, 2011)	A methodology that translates customer requirements into product-and service-related engineering characteristics in order to determine critical PSS design parameter.	Capable of meeting consumer needs more thoroughly and increases accuracy in the selection of technical characteristics.	The decision making process becomes complicated along with the increased number of technical characteristics.
Kim et al. (2010)	A systematic methodology to generate the concepts for PSS.	The designer can generate PSS concepts easily and naturally while addressing a variety of customer needs in many different contexts.	The methodology treats a real problem as a general problem and then provides a general solution (but not necessarily a real solution).
Lee and Kim (2010)	A methodology for an effective PSS design concept using both functional modelling and service activities.	Enables a systematic mapping among various functions, service providers/receivers, service activities and product/service elements.	The methodology can produce several PSS design concepts but does not explain how to select the optimal PSS design concept.
Shikata et al. (2013)	A methodology to examine PSS characteristics that supports competitive advantages.	Improves PSS performance through product architecture analysis.	Only examines two specific case studies, insufficient general conclusion.

Muller et al. (2010) developed a checklist of criteria to determine the needs of consumers in PSS design. The criteria can serve as a basis for developing a PSS design methodology. Using these criteria, the PSS design process which incorporating more systematic measures and structured should theoretically better reflect the consumer needs.

3 PSS design methodology

In this research, PSS categories are the main consideration in designing the PSS model. This is because the different groups of PSS categories will have different characteristics and thus they have different design needs. PSS design methodology in this research is, to a large extent, based on the Product-oriented PSS classification developed by Tukker (2004). The integration process is focused on the product-oriented services. This category can be considered as an early stage for a company to adopt PSS which traditionally adopts the product-oriented paradigm to service-based economy. The model will facilitate the adoption of the PSS concept for established companies which still apply the traditional approach.

Figure 1 PSS design methodology based on integrated requirements



A methodology for product and service integration suggested by this research (Figure 1) consists of three distinct stages as follows:

- *Stage 1* is to identify design requirements. This stage aims to determine the PSS core requirements for designing the products and services. This criterion is general in nature and can be further divided into product and service criteria. The PSS criteria checklist developed by Muller et al. (2010), especially technical artefacts and service criteria, are used as a basis for this stage.
- *Stage 2* is to determine design requirements rating. A survey is conducted to rate various design requirements for a product that reflects the customers' desires. As noted by Thomas et al. (2008), characteristics of product and service components can be systematically derived on the basis of customer requirements. For that reason the summated rating method (also known as Likert scale) developed by Likert (1932) is used to obtain ratings from the respondents on a symmetric important-not important scale for a series of design requirements. Compared to other methods such as the equal-appearing interval (also known as Thurstone scale), the summated rating method is relatively simpler and easier to apply.
- *Stage 3* is to integrate product and service design requirements. This stage aims to generate the PSS design concept from product and service requirements in order to fulfil customer's satisfaction. Product and service relationship matrix can be used for this purpose.

4 Case study

A case study of mobile phones design has been chosen for testing the developed methodology. This section describes the mobile phone design process, the product-service integrated design for mobile phones and the result analysis.

4.1 Mobile phone design

The design of mobile phones has numerous challenges that have to be considered to ensure the marketing success. These challenges may come from external as well as internal perspectives. The challenge from external marketing perspective has a slightly different technological mastery level from that of the competing manufacturers. This causes at least two problems namely the *lack of products variation* and the *shorter product life cycles*. From the perspective of the mobile phone design process other problems also emerged. The mobile phone design has evolved into a series of communication, knowledge and new innovative entertainment features (Ling et al., 2007; Ziefle et al., 2006). This makes the design process more complicated than ever before and reduces the usability of mobile phones (Ling et al., 2007).

The mobile phones industry in Indonesia involves two main parties, the mobile phones manufacturers and network operators. In general, mobile phones in Indonesia are sold separately from the network operator. A consumer who buys a mobile phone can afterwards freely choose the network provider he/she wishes to use. This is somehow different from other countries around the world, where the mobile phones are sold to the consumers through contract and the payment is made essentially for the service offered by the network provider. The illustrations in this research will therefore focus only on mobile phones design and do not deliberately address the relationships between mobile phone manufacturers and network operators or the network operator as a service. Product-oriented service design will focus on producing a better product and product support service by mobile phones manufacturers. To test the applicability of the models that have been developed, an illustrative case study of a product-oriented service design for consumers in West Sumatra, Indonesia has been chosen.

4.2 Product-service integrated design for mobile phone product

As mentioned in Section 3, the development activity begins with the identification of the design requirements. This stage is done by using PSS checklist criteria developed by Muller et al. (2010), especially the technical artefact and service criteria. The technical artefact criteria are related to the physical form of a mobile phone which will be designed. Service criteria are related to the characteristics of the service support offered by the manufacturers. Checklist criteria from Muller et al. (2010) have been modified to suit the design requirements for mobile phones (Table 2).

Table 2 Product and service design requirements for mobile phone

Muller et al. (2010)	*Modified requirements for mobile phone*	*Code*
	Technical artefacts	
Main function	Telecommunication network support technology	P1
Related products/artefacts	Supporting device	P2
Interfaces	Mobile phone display	P3
Related activities	Camera feature	P4
Related service offers	Internet connectivity	P5
Availability	Battery durability	P6
Robustness	Mobile phone robustness	P7
Flexibility	Connectivity with other media	P8
Safety	Mobile phone safety	P9
Input, throughput, output	Type of keypad	P10
	Processing unit specification	P11
	Sound quality	P12
Required quantity	Single or multi-card hybrid phones	P13
Design for X requirements	Ease of assembly/disassembly	P14
Ownership and 'user ship'	Type of battery	P15
Qualification level of user	Ease of use	P16
Cost	Mobile phone price	P17
Location of product operation	Ease of handling	P18

Table 2 Product and service design requirements for mobile phone (continued)

Muller et al. (2010)	*Modified requirements for mobile phone*	*Code*
	Services	
Required resources	Ease of repair	S1
Related activities	Duration of product delivery	S2
Estimated result	Reliability of service result	S3
Required information	Early warning system	S4
Facultative services	Product upgrade	S5
Additional services	Diagnosis and repair	S6
Supplemental services	Product warranty	S7
Location of service applications	Availability of service centre	S8

The second stage is to determine the critical design requirement using the summated rating method developed by Likert (1932). This method employs respondents' assessments. In order to determine the importance for each requirement, the respondents are selected from the societies who are deemed to be 'savvy' and possess reasonable know-how about the object under study (in this case a mobile phone). Assessment is done through surveys, and respondents were selected using the following two criteria:

1 respondent's level of education is at least Bachelor

2 respondents have used mobile phones for at least five years.

Seventy-five respondents rated each of design requirements. Each design requirement was transformed into a question of the requirement function in order not to confuse the respondent. For example:

- *design requirement:* telecommunication network support technology
- *questionnaire item:* 'How important is the speed of internet access from your mobile phone?'
- *description:* type of telecommunication network support technology (2G, 3G and 4G) has a significant impact on internet speed.

Rating scales used are listed in Table 3.

Table 3 Rating scales used

Order	*Scale*	*Description*
S_1	1	Not important at all
S_2	2	Less important
S_3	3	Neutral
S_4	4	Important
S_5	5	Absolutely important

Product moment correlation is used to obtain the construct survey validity from each of the design requirement (coded as P1 to P18 for technical artefacts and S1 to S8 for services). The product moment correlation coefficient (r) can be calculated as follows (Bishop, 2008):

$$r = \frac{N\left(\sum XY\right) - \left(\sum X \sum Y\right)}{\sqrt{\left[N\sum X^2 - \left(\sum X\right)^2\right]\left[N\sum Y^2 - \left(\sum Y\right)^2\right]}} \quad (1)$$

where

N number of samples

X score of each design requirement

Y total score from all design requirements.

By using equation (1), the value of r_{count} for each of mobile phone design requirements can be calculated. This value was then compared to the value of r_{table}. If $r_{count} \geq r_{table}$, then the questionnaire item was deemed valid. The value of r_{table} for the number of sample of 75 can be obtained by using the Pearson Product Moment coefficient table (r_{table}) with the significance of 0.05 and 2 tailed. From the table (Bishop, 2008), the r_{table} value is 0.2272. The calculation of validity test is carried out using SPSS 20 software. The validity test result can be seen in Table 4. The result showed that only item P13 was deemed not valid.

Table 4 Validity test results for each of mobile phone design requirements

Technical artefacts				
No.	*Design requirements*	r_{count}	r_{table}	*Decision*
P1	Telecommunication network support technology	0.353	0.2272	Valid
P2	Supporting device	0.272	0.2272	Valid
P3	Mobile phone display	0.585	0.2272	Valid
P4	Camera feature	0.448	0.2272	Valid
P5	Internet connectivity	0.578	0.2272	Valid
P6	Battery durability	0.256	0.2272	Valid
P7	Mobile phone robustness	0.655	0.2272	Valid
P8	Connectivity with other media	0.695	0.2272	Valid
P9	Mobile phone safety	0.616	0.2272	Valid
P10	Type of keypad	0.485	0.2272	Valid
P11	Processing unit specification	0.655	0.2272	Valid
P12	Sound quality	0.577	0.2272	Valid
P13	Single or multi-card hybrid phones	0.084	0.2272	Not valid
P14	Ease of assembly/disassembly	0.360	0.2272	Valid
P15	Type of battery	0.523	0.2272	Valid
P16	Ease of use	0.713	0.2272	Valid
P17	Mobile phone price	0.572	0.2272	Valid
P18	Ease of handling	0.474	0.2272	Valid

Table 4 Validity test results for each of mobile phone design requirements (continued)

Technical artefacts				
Services				
No.	*Design requirements*	r_{count}	r_{table}	*Decision*
S1	Ease of repair	0.713	0.2272	Valid
S2	Duration of product delivery	0.764	0.2272	Valid
S3	Reliability of service result	0.789	0.2272	Valid
S4	Early warning system	0.705	0.2272	Valid
S5	Product upgrade	0.603	0.2272	Valid
S6	Diagnosis and repair	0.776	0.2272	Valid
S7	Product warranty	0.662	0.2272	Valid
S8	Availability of service centre	0.571	0.2272	Valid

Reliability test was conducted only to validate the questionnaire items. The value of Cronbach's alpha, a coefficient to measure the internal consistency, is determined to estimate the reliability of a test. The value of Cronbach's alpha is obtained using (Bishop, 2008):

$$\alpha = \left(\frac{K}{K-1}\right)\left(\frac{s_x^2 - \sum s_i^2}{s_x^2}\right) \tag{2}$$

where

K number of design requirement

s_x^2 the variance of the observed total design requirement scores

s_i^2 the variance of design factor i for the current sample.

The result is acceptable if the value of $\alpha > 0.70$ (Tavakol and Dennick, 2011). Computation of the reliability test was also done using SPSS 20 software. The reliability test results can be seen in Table 5. The reliability results showed that the alpha value of both design requirements >0.70. This suggests that all questionnaire items are reliable and internally consistent.

Table 5 Reliability test results

Design requirements	*Cronbach's alpha*	*Decision*
Technical artefacts	0.883	Reliable
Service	0.904	Reliable

The design requirement rating was determined by using the summated ratings method developed by Likert (1932). The results of summated ratings are then transformed into T-scores by using the equation (Kreyszig, 2011):

$$T = 50 + 10\left(\frac{X - \bar{X}}{s}\right) \tag{3}$$

where

X the total value of the scale that would be converted into T-score

$\bar{X}$ the average of the group scale total value

s the standard deviation of the group scale total value.

Design requirements rating and T-score can be seen in Table 6.

Table 6 Mobile phone design requirements rating and T-score

	Technical artefacts				
No.	*Design requirements*	*Total*	$\bar{X}$	*s*	*T-score*
P1	Telecommunication network support technology	328	311.94	22.37	57.18
P2	Supporting device	308			48.24
P3	Mobile phone display	313			50.47
P4	Camera feature	307			47.79
P5	Internet connectivity	310			49.13
P6	Battery durability	354			68.80
P7	Mobile phone robustness	303			46.00
P8	Connectivity with other media	315			51.37
P9	Mobile phone safety	331			58.52
P10	Type of keypad	296			42.87
P11	Processing unit specification	324			55.39
P12	Sound quality	335			60.31
P14	Ease of assembly/disassembly	262			27.68
P15	Type of battery	279			35.27
P16	Ease of use	290			40.19
P17	Mobile phone price	334			59.86
P18	Ease of handling	314			50.92
	Services				
No.	*Design requirements*	*Total*	$\bar{X}$	*S*	*T-score*
S1	Ease of repair	321	315.13	10.89	55.39
S2	Duration of product delivery	312			47.13
S3	Reliability of service result	325			59.06
S4	Early warning system	301			37.04
S5	Product upgrade	304			39.79
S6	Diagnosis and repair	307			42.54
S7	Product warranty	332			65.49
S8	Availability of service centre	319			53.56

The third stage is to integrate the product and service design requirements. This can be achieved by investigating the correlation between the product and service design requirements. A product and service relationship matrix (Figure 2) was constructed based on product and service requirements and their T-scores obtained in the second stage.

Figure 2 Product and service relationship matrix (see online version for colours)

Product Design Requirements		Ease of repair	Duration of product delivery	**Reliability of service result**	Early warning system	**Product upgrade**	Diagnosis and repair	**Product warranty**	Availability of service center	Total
		55,39	47,13	59,06	37,04	39,79	42,54	65,49	53,56	
Telecommunication network support technology	57,18	0	0	0	1	1	0	0	0	**114**
Supporting device	48,24	0	0	0	0	0	0	0	1	48
Mobile phone display	50,47	0	0	0	0	0	0	0	0	0
Camera feature	47,79	0	0	0	0	0	0	0	0	0
Internet connectivity	49,13	0	0	0	1	1	0	0	0	98
Battery durability	68,80	0	0	0	0	0	0	0	0	0
Mobile phone robustness	46,00	0	0	1	0	0	0	1	0	92
Connectivity with other media	51,37	0	0	0	0	1	0	0	0	51
Mobile phone safety	58,52	0	0	0	0	0	0	0	0	0
Type of keypad	42,87	1	0	0	0	0	1	0	0	86
Processing unit specification	55,39	0	0	0	1	1	0	0	0	**111**
Sound quality	60,31	0	0	0	0	0	0	0	0	0
Ease of assembly/ disassembly	27,68	1	0	1	0	0	1	1	0	**111**
Type of battery	35,27	0	0	0	0	0	0	1	1	71
Ease of use	40,19	0	0	0	0	1	0	0	0	40
Mobile phone price	59,86	0	0	0	0	0	0	1	0	60
Ease of handling	50,92	0	1	0	0	0	0	0	0	51
	Total	111	47	**118**	111	**199**	85	**262**	107	

Notes: 1 – relationship between product and service design requirement exist,
0 – no relationship between product and service design requirement.

The total score of each product and service design requirement was calculated by multiplying the design requirement score and the existence of the relationship between product and service design requirements (the value is 1, if the relationship exists and 0, if no relationship). For example, the score of 'supporting device' can be calculated as:

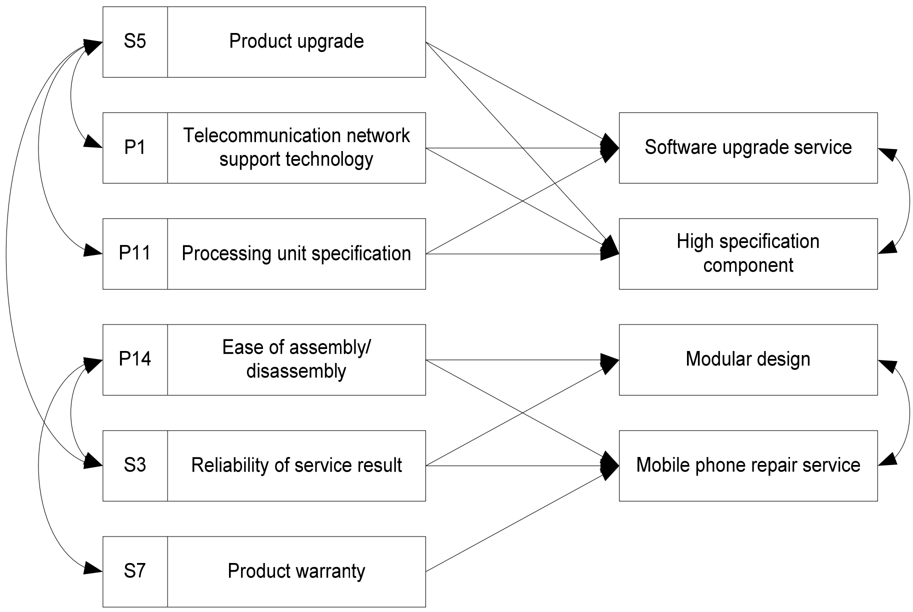
$$\begin{aligned}\text{'Supporting device' score} &= (48.24\times 0)+(48.24\times 0)+(48.24\times 0)\\ &\quad +(48.24\times 0)+(48.24\times 0)+(48.24\times 0)\\ &\quad +(48.24\times 0)+(48.24\times 1)\\ &= 48.24\\ &\approx 48\end{aligned}$$

Three product design requirements with the total highest values will be nominated as the critical product design requirements. A similar method was also applied for the service design requirements. Product and service design requirement in ‘yellow’ (namely ‘telecommunication network support technology’, ‘processing unit specification’, ‘ease of assembly/disassembly’ for product design requirement and ‘reliability of service result’, ‘product upgrade’, ‘product warranty’ for service design requirement) are the critical design requirements. These will then become the basis for PSS design concept development.

Table 7 Developed product-service design concept

Critical design requirements	*Product design concept*	*Service design concept*
Telecommunication network support technology	Mobile phone with high specification component	Software upgrade service
Processing unit specification	Mobile phone with high specification component	Software upgrade service
Ease of assembly/disassembly	Modular design	Mobile phone repair service
Product warranty	Mobile phone with high specification component	Mobile phone repair service
Product upgrade	Mobile phone with high specification component	Software upgrade service
Reliability of service result	Modular design	Mobile phone repair service
PSS design concept	Modular mobile phone with high specification component	Software upgrade and mobile phone repair service provision

Figure 3 PSS design concept for a mobile phone



According to Sundin et al. (2007), the integrated product and service engineering can be achieved by developing the functional design which then breaks down into product functions and service functions. Based on this approach, a set of critical design requirements which reflect the PSS concept was then synthesised into a set of product and service design concepts (Table 7). Finally, PSS design concepts were elaborated from both product and service design concepts.

Figure 3 shows the approach to elaborate the PSS design concept from a set of critical design requirements and the product and service design concept. The PSS design concept suggested by product and service integration is a modular mobile phone featuring high specification components. This product design concept is supported by mobile phones repair and software upgrade services.

5 Conclusions

This research proposes a new way of developing the PSS design concept based on the integrated product and service requirements. There are three stages involved namely: identification of design requirements, determination of design requirements rating and integration of product-service into the PSS design concepts for a product. A mobile phones design case has been used to test the proposed model. Results suggest the development of modular mobile phones featuring high specification components supported by mobile phones repair and software upgrade services. This research solely attempted to develop the design concept for PSS without necessarily developing a detailed specification for the design. Future research needs to be focused on the development model for transforming a PSS design concept into a PSS design specification.

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References

Bishop, A.P. (2008) *Measurement and Evaluation: Calculating and Evaluating Validity*, Holcomb Hathaway, Publisher, Inc., New York.

Chen, J.L. and Li, H-C. (2010) 'Innovative design method of product service system by using case study and TRIZ method', *Proceedings of the 2nd CIRP IPS2 Conference*, Linköping, Sweden, pp.299–305.

Chirumalla, K., Larsson, A., Bertoni, M. and Larsson, T. (2011) 'Knowledge sharing across boundaries: Web 2.0 and product-service system development', Paper presented at *International Conference on Research into Design (IcoRD)* '*11*, 10–12 January, Indian Institute of Science, Bangalore, India.

Ericson, Å., Bertoni, M. and Larsson, T. (2009) 'Needs and requirements – how TRIZ may be applied in product-service development', Paper presented at *2nd Nordic Conference on Product Lifecycle Management – NordPLM '09*, 28–29 January, Göteborg, Sweden.

Erkoyuncu, J.A., Roy, R., Shehab, E. and Wardle, P. (2009) 'Uncertainty challenges in service cost estimation for product-service systems in the aerospace and defence industries' *Proceeding of the 1st CIRP Industrial Product-Service Systems (IPS2) Conference*, Cranfield University, Bedford, England, pp.200–206.

Feinberg, R.A. (2001) 'Customer service and service quality', in Salvendy, G. (Ed.): *Handbook of Industrial Engineering*, 3rd ed., pp.651–664, John Wiley & Sons, Inc., New York.

Geng, X., Chu, X., Xue, D. and Zhang, Z. (2010) 'An integrated approach for rating engineering characteristics' final importance in product-service system development', *Computers & Industrial Engineering*, Vol. 59, No. 4, pp.585–594.

Geng, X., Chu, X., Xue, D. and Zhang, Z. (2011) 'A systematic decision-making approach for the optimal product-service system planning', *Expert Systems with Applications*, Vol. 38, No. 9, pp.11849–11858.

Goedkoop, M.J., van Halen, C.J., te Riele, H.R.M. and Rommens, P.J.M. (1999) *Product Service Systems*, *Ecological and Economic Basics*, Dutch Ministries of Environment (VROM) and Economic Affairs (EZ), Report, No. 1999/36.

Hara, T., Arai, T. and Shimomura, Y. (2009) 'A CAD system for service innovation: integrated representation of function, service activity, and product behaviour', *Journal of Engineering Design*, Vol. 20, No. 4, pp.367–388.

Hara, T., Arai, T., Shimomura, Y. and Sakao, T. (2007) 'Service/product engineering: a new discipline for value production', Paper presented at the *19th International Conference on Production Research*, 29 July–2 August, Valparaiso, Chile.

Kim, K., Proctor, R.W. and Salvendy, G. (2012) 'The relation between usability and product success in cell phones', *Behaviour & Information Technology*, Vol. 31, No. 10, pp.969–982.

Kim, K-J., Lim, C-H., Lee, J., Lee, D-H., Hong, Y.S. and Park, K-T. (2010) 'Generation of concept for product-service system', in *Proceedings of the 2nd CIRP IPS2 Conference*, Linköping, Sweden, pp.203–209.

Kimita, K., Akasaka, F., Hosono, S. and Shimomura, Y. (2010) 'Design method for concurrent PSS development' in *Proceedings of the 2nd CIRP IPS2 Conference*, Linköping, Sweden, pp.283–290.

Kreyszig, E. (2011) *Advanced Engineering Mathematics*, 10th ed., Wiley, London.

Lay, G., Copani, G., Jager, A. and Biege, S. (2010) 'The relevance of service in European manufacturing industries', *Journal of Service Management*, Vol. 21, No. 5, pp.715–726.

Lee, S.W. and Kim, Y.S. (2010) 'A product-service systems design method integrating service function and service activity and case study', in *Proceedings of the 2nd CIRP IPS2 Conference*, Linköping, Sweden, pp.275–282.

Likert, R. (1932) 'A technique for the measurement of attitudes', *Archives of Psychology*, Vol. 22, No. 140, pp.5–55.

Ling, C., Hwang, W. and Salvendy, G. (2007) 'A survey of what customers want in a cell phone design', *Behaviour & Information Technology*, Vol. 26, No. 2, pp.149–163.

Mateu, A.G.I., Li, Z. and Tyson, P. (2012) *Cocreating a Sustainability Strategy in a Product/Service-System Value-Based Network of Stakeholders*, Unpublished master thesis, School of Engineering, Blekinge Institute of Technology, Karlskrona, Sweden.

Maussang, N., Sakao, T., Zwolinski, P. and Brissaud, D. (2007) 'A model for designing product-service systems using functional analysis and agent based model', Paper presented at *International Conference on Engineering Design*, *ICED '07*, 28–31 August, Cite des Sciences et de L'industrie, Paris, France.

Maussang, N., Zwolinski, P. and Brissaud, D. (2006) 'A representation of a product-service system during its design phase – a case study of a Helium liquefier', in *Proceedings of the 13th CIRP International Conference on Life Cycle Engineering*, International Institution for Production Engineering Research (CIRP), Leuven, Belgium, pp.555–562.

Maussang, N., Zwolinski, P. and Brissaud, D. (2009) 'Product-service system design methodology: from the PSS architecture design to the products specifications', *Journal of Engineering Design*, Vol. 20, No. 4, pp.349–366.

McAloone, T.C. and Andreasen, M.M. (2004) 'Design for utility, sustainability and societal virtues: developing product service systems', in *Design 2004: Proceeding of the International Design Conference*, Cavtat, Croatia, pp.1–8.

Mont, O. (2000) *Product-Service Systems*, The International Institute of Industrial Environmental Economics (IIIEE), AFR-Report 288.

Mont, O. (2002) *Functional Thinking – The Role of Functional Sales and Product Service Systems for a Function-Based Society*, The International Institute of Industrial Environmental Economics (IIIEE), Rapport 5233.

Mont, O. and Plepys, A. (2003) *Customer Satisfaction: Review of Literature and Application to the Product-Service Systems*, Final Report to the Society for Non-traditional Technology, The International Institute of Industrial Environmental Economics (IIIEE), Japan.

Morelli, N. (2002) 'Designing product/service systems: a methodological exploration', *Design Issues*, Vol. 18, No. 3, pp.3–17.

Morelli, N. (2006) 'Developing new product service systems (PSS): methodologies and operational tools', *Journal of Cleaner Production*, Vol. 14, No. 17, pp.1495–1501.

Muller, P., Schutz, F. and Stark, R. (2010) 'Guideline to elicit requirements on industrial product-service systems', in *Proceeding of the CRIP IPS2 Conference*, *CRIP*, Linköping, Sweden, pp.109–116.

Phumbua, S. and Tjahjono, B. (2012) 'Towards product-service systems modelling: a quest for dynamic behaviour and model parameters', *International Journal of Production Research*, Vol. 50, No. 2, pp.425–442.

Roy, R. and Cheruvu, K.S. (2009) 'A competitive framework for industrial product-service systems', *International Journal of Internet Manufacturing and Services*, Vol. 2, No. 1, pp.4–29.

Shikata, N., Gemba, K. and Uenishi, K. (2013) 'A competitive product development strategy using modular architecture for product and service systems', *International Journal of Business and Systems Research*, Vol. 7, No. 4, pp.375–394.

Shikata, N., Gemba, K. and Uenishi, K. (2013) 'A competitive product development strategy using modular architecture for product and service systems', *International Journal of Business and Systems Research*, Vol. 7, No. 4, pp.375–394.

Sundin, E., Lindahl, M., Comstock, M., Shimomura, Y. and Sakao, T. (2007) 'Integrated product and service engineering enabling mass customization', Paper presented at the *19th International Conference on Production Research*, 29 July–2 August, Valparaiso, Chile.

Tan, A.R., McAloone, T.C. and Gall, C. (2007) 'Product/service-system development – an explorative case study in a manufacturing company', Paper presented at *International Conference ON Engineering Design*, *ICED* '*07*, 28–31 August, Cite des Sciences et de L'industrie, Paris, France.

Tavakol, M. and Dennick, R. (2011) 'Making sense of Cronbach's alpha', *International Journal of Medical Education*, Vol. 2, pp.53–55 [online] http://www.ijme.net/archive/2/.

Thomas, O., Walter, P. and Loos, P. (2008) 'Design and usage of an engineering methodology for product-service systems', *Journal of Design Research*, Vol. 7, No. 2, pp.177–195.

Tukker, A. (2004) 'Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet', *Business Strategy and the Environment*, Vol. 13, No. 4, pp.246–260.

Vasantha, G.V.A., Roy, R., Lelah, A. and Brissaud, D. (2012) 'A review of product–service systems design methodologies', *Journal of Engineering Design*, Vol. 23, No. 9, pp.635–659.

Wallin, J. and Kihlander, I. (2012) 'Enabling product-service system development using creative workshops: experiences from industry cases', in *DESIGN 2012: Proceeding of the International Design Conference*, The Design Society, Dubrovnik, Croatia, pp.321–330.

Wimmer, R. and Kang, M.J. (2006) 'Product service systems as a holistic cure for obese consumption and production', in *Workshop of the Sustainable Consumption Research Exchange (SCORE!) Network: Proceeding of Perspectives on Radical Changes to Sustainable Consumption and Production (SCP)*, SCORE!, Copenhagen, Denmark, pp.401–410.

Ziefle, M., Bay, S. and Schwade, A. (2006) 'On keys' meanings and modes: the impact of different key solutions on children's efficiency using a mobile phone', *Behaviour & Information Technology*, Vol. 25, No. 5, pp.413–431.