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CUSTOMER AND FIRM TECHNICAL KNOWLEDGE INTEGRATION IN PRODUCT SERVICE SYSTEM DEVELOPMENT

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Abstract: *This research provides a conceptual view about knowledge creation in PSS development. This research has threefolds: first, the research compares several methodologies of PSS development in the current literature and propose a new one; second, the research describes the integration of customer knowledge and firm technical knowledge during PSS development; and third, the research illustrates knowledge creation process during the development of PSS. The comparison of several PSS development methodologies has led us to several crucial phases that includes planning, concept and design, production, use-phase and dematerialization. The PSS development phase requires customer experience to create novelty ideas especially from the use-phase to incorporate customer needs into new product design and development.*

Keyword: Knowledge creation, PSS, customer knowledge, firm technical knowledge.

1. INTRODUCTION

Product-Service System (PSS), product-related services or full-services are interchangeably used to designate the integrated product and s service offerings for selling functions (Velamuri *et al.*, 2011). Functionality describes the ability of integrated product-services (Durugbo and Riedel, 2013) to provide a function, usability, or purpose rather than the physical artefact. PSS has a long-term business relationship with customers, as the provider involves directly with customer during the use-phase (Alonso-Rasgado *et al.*, 2004). They refer functional products as total care products, the integration of hard and soft element. Similarly (Reim *et al.*, 2014) also highlight, one of the two tactics to succeed in PSS business, is the functionality created to serve the customer. Thus after-sales service such as maintenance, repair, reuse, and recycling are approaches used to achieve the objectives (Barquet *et al.*, 2013).

A new PSS is developed through specific activities by capturing, understanding

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and integrating customer demand into integrated products and services (Ueda *et al.*, 2009) to improve existing core product concept and manufacturing capabilities (Goedkoop *et al.*, 1999). In addition, PSS focus on the durability of a product-service that in turn reduce resources usage but at the same time maintain the quality (Mont, 2002) and enhance existing customers' value (Kang and Snell, 2007), generate more profit (Husted and Allen, 2009; Zhang and Wang, 2010) and reduce environmental effect (Goedkoop *et al.*, 1999; Kimita and Shimomura, 2014). Integrating customer knowledge in each phase of new PSS development is crucial for the sake of product functionality and its services offering. The provider that continues to explore for new knowledge from customers' experiences and exploit internal knowledge for upgrading an existing system may have opportunities to succeed (Prahalad and Ramaswamy, 2004) However, integration of customer knowledge in PSS is not a straightforward task due to its systemic characteristics, actors' involvement and related components (Kimita *et al.*, 2009; Pezzotta *et al.*, 2012).

Services have traditionally treated as add-on to the product offering. Product is created at different time where the involvement of customer is not compulsory. Unlike product, service is produced and consumed simultaneously that requires the existence of customer (Morelli, 2002, 2003). As such, service design is introduced separately into product design (Clayton *et al.*, 2012). Furthermore, they claim that product development approach is not suitable for service development approach and vice versa (Clayton *et al.*, 2012). In fact, when develop an integrated product and service, either product development or service development is depending on the prevailing characteristics but may not be designed at the same time. However, when products and services are closelay related, they need to be developed simultaneously (Alonso-Rasgado *et al.*, 2004; Clayton *et al.*, 2012; Kimita *et al.*, 2009). Currently, less research emphasize on the development of integrated product and service, as it is different in terms of product or service dominance (Clayton *et al.*, 2012). Whereas, in KM practices, many have highlighted the success of firms may be characterized by the ability of the firm to create new knowledge during new product development (Chen *et al.*, 2008; Nonaka and Takeuchi, 1995; Rauniar, 2005). For example, study by Kimita *et al.* (2009) findings that firm may estimate customer satisfaction through their design solution in the conceptual stage. However, according to Morelli (2003), the PSS development signifies a new experiment as the emphasis of the design solution moves from offering new products to re-structuring of existing elements or existing knowledge to suit new requirements and values. This represents a knowledge gap within the product-service literature in terms enhancing integrated product-service (new knowledge creation) based on existing firm technical knowledge but at the same time require new requirement from the users of the product-service. As Nonaka and Takeuchi (1995) highlight that new product development itself is a mechanism for new knowledge creation

(Björklund, 2010; Söderquist, 2006). Hence, in order to fill the gap, customer knowledge and firm technical knowledge are analyzed together; whether it create new knowledge for PSS advancement or innovation, in turn lead to PSS success. Based on these arguments, we propose the main research question of this article: How the interplay of existing firm technical knowledge and new customer-use knowledge assist new knowledge creation in order for simultaneous development of product and service in an integrated product-service context?

From the above statements, this research has threefolds. First, the research compares several methodologies of PSS development in the current literature and propose a new one. Second, the research describes the involvement of customers knowledge and firm technical knowledge during PSS development. Third, the research illustrates knowledge creation process during the development of PSS using Nonaka's knowledge creation model, known as SECI (Socialization, externalization, combination and internalization) for simultaneous development of an integrated product and service. Finally, we summarize the findings and the implications of the study for future research.

2. METHODOLOGY

The research was established on literature review involving publications on the PSS development, customer involvement or interaction, and firm technical knowledge. We focused on the customer involvement in new product development. The literature review was limited to the following scientific search engines: Science Direct, Ebscohost, Emerald, Springer and Google Scholar. For the first part of the study, we searched PSS development phase by entering the keywords title such as *PSS development, new product development, product-service development*. The search was narrow down to only eight authors and their findings were compared for our references. The rest of the literature review was based on searched results upon the keyword title such as *PSS developments and customer* to support our propositions.

3. EXISTING RESEARCH, AND THEORETICAL FRAMEWORK

3.1 PSS Development

The central theme of PSS is the integration of a products and services systems which drive to competitive strategy, environmental sustainability, and distinguished offering from competitors (Baines *et al.*, 2007; Beuren *et al.*, 2013; Park and Lee, 2009). This integrated product-service oriented demonstrate a new method of meeting customer needs that shift the emphasis of selling pure product (Isaksson *et al.*, 2009) to selling function (Hu *et al.*, 2012) through systemizing products-services, its networks and infrastructures (Cavalieri *et al.*, 2012). Different

approaches may be used to integrate product and service in single offering. Traditionally, product development is defined as the process of converting raw materials into finished good, sell and deliver it to customer (Aurich *et al.*, 2009). Conversely, a service development is a process or activity to provide services to customers. A PSS development integrates tangible product and intangible service to provide a solution to customers (Exner *et al.*, 2014) instead of providing a physical product or service separately. Several examples of PSS life cycle proposed by several scholars which focus on feedback loops PSS (Clayton *et al.*, 2012), design exploration process (Morelli, 2002, 2003), service-oriented approach (Alonso-Rasgado *et al.*, 2004), design and development (Pezzotta *et al.*, 2012), integrated product service (Marques *et al.*, 2013), functional product (Isaksson *et al.*, 2009), and sustainable PSS (Mcaloone and Andreasen, 2004; Shokohyar *et al.*, 2012) as shown in Table 1.

Table 1

After examining the eight different approaches in developing PSS, we adopt four main phases: plannning, BOL, MOL and EOL, as the basic of Product life Management and maintain the importance in the PSS life cycle. In addition, we add an additional factor which is planning as a separate element, although other researchers may include the initial stage in the BOL phase. During the planning phase, customer demands through idea generations, suggestions, and complaint, are gathered for feasibility analysis, which will become input to the new project. Another significant activity in this stage is analysis of its technical feasibility, the relationship between product and services. Next phase of a PSS development life cycle is BOL that includes concept development, detail design, prototyping and development. At this stage, two essential components of PSS services and environmental sustainability are incorporated in concept and design. Later, followed by product realization, which raw materials are transformed into end-product through a series of work processes. After completing the work processes, end-product is delivered to the customer. In MOL, training, is part of firm responsibility to enhance customer knowledge to more efficient handling of the purchased product. Finally upon reaching EOL stage, several options are available includes remanufacturing, recycle/reuse, and take-back for disposal to reduce environmental harmful.

1.1 Product Functionality

A functional economy focus on the level of material or resource usage to offer function or service to customers but at the same time maintain the quality (Mont, 2002) rather than the physical product (Park *et al.*, 2012). Several approaches suggested by (Mont, 2002) to achieve sustainability based on functional business are by reducing the usage of materials via different ways of product use, increase

Table 1
Summary of PSS development phase

PSS development phase	*Planning*			*Beginning of life (BOL)*			*Middle of life (MOL)*			*End of life (EOL)*		
Author	*Idea generation*	*Feasibility analysis*	*Product Concept*	*Product Detail design*	*Prototyping & testing*	*Development*	*Training*	*Maintenance*	*Feedback*	*Remanufacturing*	*Recycling/ reuse*	*Take-back*
(Clayton *et al.*, 2012)	/	/	/	/	/		/	/	/			
(Morelli, 2002) (Morelli, 2003)	/	/	/	/	/	/	/	/				
(Alonso-Rasgado *et al.*, 2004)			/	/	/	/	/	/	/			
(Pezzotta *et al.*, 2012)						/	/		/	/	/	/
(Marques *et al.*, 2013)	/	/	/	/	/	/	/					
(Isaksson *et al.*, 2009)		/	/	/	/	/	/					
(Shokohyar *et al.*, 2012) (Mcaloone & Andreasen, 2004)										/	/	/

productivity and dematerialization of product-service and offer integrated solution that reduce material used and increase functional efficiency. Meanwhile, often unaffordable or expensive items used as an alternative approach to sell product by offering their functionalities to customers. The provider controls over the use-phase of the product, shall reuse or remanufacture the collected used product (OECD, 2012; Parida *et al.*, 2014). It is a long-term business relationship with customer, as the provider shall involve directly during use-phase with customer (Alonso-Rasgado *et al.*, 2004). Functionality describe the ability of a PSS to functions based on integrated products and services (Durugbo and Riedel, 2013), the integration of hard and soft element (Alonso-Rasgado *et al.*, 2004), product related services or full service are interchangeably used to designate product-service offerings (Velamuri *et al.*, 2011). Functionality can be measured based on the fit of function in solving existing problems, enable interoperability with partners, compatible designed, modularity for product families/solutions, provide value in-use to customers, usability, and manufacturability according to pay-per unit (Durugbo and Riedel, 2013). The more providers shift to services side of this spectrum, the provider selling more functional results' than products, and result to having more share of services in their total revenue (Van Ostaeyen *et al.*, 2013).

1.2 Customer and Firm Technical Knowledge and Their Integration Process

1.2.1 Customer knowledge exploration and firm technical knowledge exploitation

Two types of knowledge are required to develop the service: customer knowledge and firm technological knowledge (Akgün *et al*, 2008; Söderquist, 2006). Customer knowledge is crucial resources for all businesses (Rowley, 2002). However, the customer knowledge integrated in service development is depending on whether customer ideas are captured during the use-phase or outside the use-phase (Alonso-Rasgado *et al.*, 2004). Although unique value and experienced are created based on the knowledge and skills applied during consumption (Edvardsson *et al.*, 2011), customer knowledge should be captured from each phase of product development stage (Dongmin *et al.*, 2012). Customer knowledge are captured from future and existing customers with regards to their needs, information on context, as industry experts, option for production material, and financial matters (Aarikka-Stenroos and Jaakkola, 2012).

Providers own knowledge with regards to technical systems such as expert knowledge, diagnosis skills, facilities, experience, objectivity and integrity, ethical codes; relational capital (Aarikka-Stenroos and Jaakkola, 2012); and professional equipment utilization are required to enable service creation(Aarikka-Stenroos and Jaakkola, 2012; Alonso-Rasgado *et al.*, 2004). The ability of the provider to create

new and utilize current knowledge is depending on how the providers interprets existing knowledge, new knowledge and integrate them (Claycomb *et al.*, 2005; Isaksson *et al.*, 2009). The provider may customize knowledge by utilizing its resources to recognize particular patterns and rules regarding domain-specific knowledge about customer needs through relationship invested for their knowledge exchange (Sun, 2007). The integration of both sources may lead to firm product flexibility, timely response and build long term relationship with customers (Claycomb *et al.*, 2005).

1.2.2 The integration of customer knowledge exploration and firm technical knowledge exploitation

The essential process in new PSS development is how new customer knowledge is converted into new knowledge by combining with existing firm technical knowledge. Therefore, this section discusses how this process takes place in the context of PSS development by applying Lam's organization knowledge (Lam, 2000) and Nonaka's SECI model. Lam proposes knowledge representation based on epistemological dimension (tacit vs. explicit) and ontological dimension (individual *vs.* collective) as shown in Figure 1. The four types of firm knowledge are embrained, embodied, encoded and embedded knowledge. Embrained knowledge is a formal and theoretical knowledge, which depends on the individual's abilities on conceptual skills and cognitive capabilities. Embodied knowledge is an individual type of tacit knowledge based on action oriented and practical gather upon practical experience in context specific. Encoded knowledge is collective explicit knowledge carried by sign and symbols, stored and organized in the form of written rules, blueprints and procedures. Collective tacit knowledge exists in the form of firm routines and shared norm.

Nonaka and Takeuchi's knowledge creation model is a dynamic model by assuming human knowledge interplay between tacit knowledge and explicit

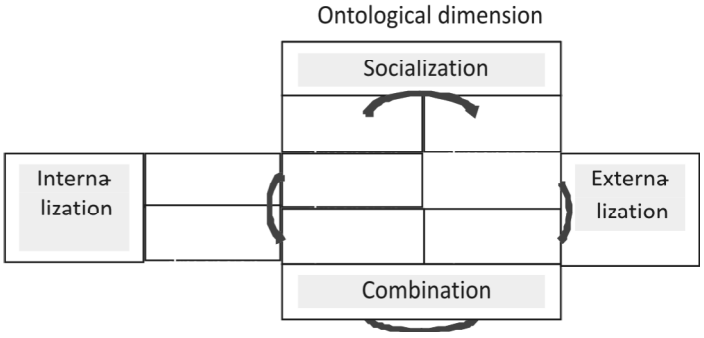

Figure 1: Four types of knowledge (Lam, 2000) and SECI model (Nonaka and Takeuchi, 1995)

knowledge through human interaction between persons (*i.e.* dialogue). This customer interaction for co-creation of knowledge develops insight, skills and relationship by combining new customer knowledge and firm existing one through a SECI approach. SECI requires dialogue, the mechanism to engage with the customer, encourage and share information, create new behavior, innovation and capabilities for the firm's existence (Hoivik, 2011). In socialization, a transformation process of experience embodied in a person can be achieved through endless interaction between the firm and its customers. This process is called "experiential sharing" or defined as social interactions between two entities such as employee and customer involving the exchange of specialized skills and knowledge of employees (tacit technical knowledge) with customer experience (tacit knowledge) (Argote and Ingram, 2000).

During socialization process, embodied knowledge reside in customer is transferred to individual employee tacit knowledge (embodied knowledge) or transferred a group of employees tacit knowledge (embrained knowledge). In the externalization stage, collective tacit knowledge *(embedded)* is articulated in common terms and explicit concepts *(encoded)* such as metaphors, analogies, hypotheses and models (Nonaka and Takeuchi, 1995) images, symbols, and language including design and product concepts (Schulte, 2008). The conversion of collective tacit knowledge (*embedded*) to explicit collective knowledge *(encoded)* can be done easier through IT application system (Varra *et al.*, 2012). The previous collective experience, mental models, and thoughts *(encoded)* and the new collective explicit knowledge gathered from customers *(encoded)* are combined into more complex and systematic, explicit knowledge (Nonaka and Toyama, 2003). The combination process involves reconfigure current explicit knowledge through sorting, adding, reorganizing, and combining processes which yield to new explicit knowledge (Chatti, 2012) using IT system such as electronic communication, formal documents, database, and shared management (Hosseini, 2011). Next, collective explicit knowledge (encoded) are dispersed to employees and internalized into new individual tacit knowledge (embodied) through learning by doing.

3.4 Knowledge Creation in PSS Development Process

3.4.1 Planning

During the planning phase, two sub-processes are identified:

a) idea generation phase,

b) feasibility analysis.

Idea generation encourages customer and employee to contribute their ideas to PSS development through socialization process. The socialization between

customers and employees or informal communication between customer and the firm create opportunity. In the planning stage of PSS, it is difficult for the provider to start the process without customer's requirement, financial and schedule plan (Aarikka-Stenroos and Jaakkola, 2012; Ramly and Omar, 2016). In idea generation, to solve the current problem requires defining problems appropriately that lead to specifying the requirement that meet product-services characteristics. Problems can be solved by focusing on lead users of a product or processes as they represent strong influence of a future product or process (Hippel, 1986). The lead users share personalized experience (*embodied* knowledge) regarding to their experiential learning on the firm's product offering for product quality standards, design of products, production plans and costs (Claycomb *et al.*, 2005).

At the same time, provider knowledge resources required for co-creation are expert knowledge, diagnosis skills, facilities and professional equipment, experience, objectivity and integrity, ethical codes; and relational capital (Aarikka-Stenroos and Jaakkola, 2012). Employee's diagnosis skills assist new ideas captured from customer and externalized based on the provider evaluation system and vision/mission (Song *et al.*, 2011) are created (embrained knowledge). Using the KM tools, the new embrained knowledge are combined with other existing provider expert knowledge (Marques *et al.*, 2013) which becomes collective knowledge. The encoded knowledge is shared with the entire firm using IT system. Both provider and customer embrained knowledge co-create service and product functionality (Mukhtar *et al.*, 2012). Customer knowledge resources can be captured in various ways either virtual channel or face to face (Romero and Molina, 2011). Different providers may have various approaches how new knowledge is acquired such as customer visits (Schaarschmidt and Kilian, 2014), brainstorming with customer (Alam, 2013), dialogues (Pezzotta *et al.*, 2012), in-depth interviews (Baxter *et al.*, 2009; Kindström and Kowalkowski, 2009), observations of social networking sites, blog, online communities, and forum.

Later, new ideas either incremental or radical must be analyzed for its feasibility such as business viability, customer satisfaction and environmental safety. It can be achieved by identifying target customer, and cost-benefit analysis with regards to human resources, machine and tools for service realization (Aurich *et al.*, 2006). Value proposition is internalized in the detailed planning, through firm routines or shared norms and becomes input for future phases. The new knowledge creation process repeats until end of PSS development phases.

3.4.2 Beginning of life-cycle: Concept development, design and prototyping

Concept and design phase composes three sub-systems:

a) Product concept development, b) Product detail design,

c) prototyping and testing.

During concept development of customer value proposition, budget and actors involved in designing product and service project are the first step needs specification (Aurich *et al.*, 2006). In PSS, service concept play important role for other phases in developing PSS (Meyer *et al.*, 2002). The authors highlight how service concept affect the design of the services, the use of operational level while integrating service strategy into the service delivery system and service recovery to enhance service encounter interactions. Hence, to meet the customer requirement, potential solutions are drawn from dialogue with customers (Aurich *et al.*, 2006) in the previous phase or include customer during this phase to ensure the concept and design for the new functionality meets its requirements (Kimita and Shimomura, 2014). Thus, employees utilize their analyzing skills to explore new tacit insight from customers and convert them to understandable embrained knowledge.

In PSS design, both product and service are equally important; thus the designing of both aspects must take place concurrently in the beginning of the new PSS development (Yang, 2005). The service modeling provides a detailed of all activities to realizing a technical service model of a product which denotes the most ideal interactions between employees and customers. But in many cases, , the level of involvement from other function during the design phase may be little or not occur as the design phase involves engineering activities (Cavalieri and Pezzotta, 2012). The combination of the firm technical knowledge (for example material used) and newly created knowledge (enhancement of existing product or service concept), hence new product and service concept are developed. Significant amount of service function and product design knowledge, either newly captured from customers or existing knowledge are highly needed during concept and design phase as compare to other phases such as development, use and services, and end-of-life phase (Geng, Chu, and Zhang, 2011). Another essential point to highlight is the product concept that requires integration during product design such as sustainability issue, waste and material deduction, recyclable and re-use material and easy to disassemble for disposal (Khor and Udin, 2013).

Firm technical knowledge and new written and codified knowledge explored from customer are combined into more complex and systematic new diagram, chart and document; new knowledge *embedded* into products and enhance manuals, patents, and legal documents (Schulte, 2008). This detail design of concept may include new product and service concept characteristic such as functionality, cost, durability, and environmental safe; target markets and competitive positioning (Schulze and Hoegl, 2005). For example the use of product design tools such as CAD/CAE assists drawing in the design of the product (Durmuþoðlu and Barczak, 2011). These tools may be used to manage and access huge amount of knowledge

(Silcher *et al.*, 2010). A model or a prototype is built to validate and verify the product design appear as it is planned and demanded by customer, especially its unique function (Kindström and Kowalkowski, 2009). The prototype is tested and must satisfy both product and service elements (Exner *et al.*, 2014). Once the detail design is defined and internalized by employees from various departments, a model or a prototype is built to validate and verify the product design appear as it is planned and demanded by customer, especially its unique function (Kindström and Kowalkowski, 2009). Otherwise, the design process repeat until the built prototype works very well as desired.

3.4.3 Beginning of life-cycle: Production and delivery

The firm experience, capabilities and business objectives are utilized to articulate new explicit knowledge, to speed up the development or manufacturing process and improve the quality of design and its cost simultaneously. In another words, once customer tacit knowledge is externalized into explicit knowledge, new ideas related to product's functionality, design and its service function are developed.

Hence, customer knowledge and firm technical knowledge has significant effect on enhanced value realization, technical processes, knowledge intensive service, improved business processes, management decision making and IT infrastructure for enhancement of system response rate and overall efficiency of the development process (Wu and Haasis, 2011). Existing *technical* knowledge in the production process is important player that may strategize production process to develop a particular function for the product and the embedded knowledge in the process yield to faster learning cycles (Paiva *et al.*, 2008). Example of related production is best practices processed, tools, machines, scrap rates and generic manufacturing approach for estimated scrap rates (Baxter *et al.*, 2009) that lead to production flexibility and timely response. With this knowledge, provider may arrange innovative production processes with specialization of labor for customization product with low price offered to customers (Baden-Fuller and Morgan, 2010). In addition, by ''know-what'' customer wants and ''know-how'' to run operations are considered essential components in the production process (Paiva *et al.*, 2008). Hence, existing and new knowledge has significant effect on value realization, technical processes, knowledge intensive service, business processes and management decision making (Wu and Haasis, 2011).

However, firm technical knowledge embedded in the production process is more important to strategize development process in a particular function for the product yield to faster learning cycles (Paiva *et al.*, 2008). With this knowledge firm may arrange innovative development processes with specialization of labor for customization product with low price offered to customers (Baden-Fuller and

Morgan, 2010). The combined of new product knowledge and existing explicit knowledge guides provider for implementation, support and management to reduce the needs to provide more services during the use-phase and take back (Dongmin *et al.*, 2012). New explicit knowledge is disseminated throughout the organization and internalized by employees for future application. The ease of knowledge navigation, organization and retrieval may facilitate PSS to increase long term benefit through the quality of product offers as such may lessen operational cost for greater efficiency, better service (Dongmin *et al.*, 2012) and finally adapt business environment changes (Kazemi and Allahyari, 2010).

Both existing and new knowledge affect system response rate and overall efficiency of the production process (Wu and Haasis, 2011). In the production phase, customer and provider may evaluate cost, quality, durability, production speed and delivery speed (Trentin *et al.*, 2011). Production speed can be differentiated based prompt performance: production lead-times that lead to delivery lead-time (run time, set-up time, move time and queue time; and external time), delivery speed (elapse time between order time and receive time) and delivery reliability (delivered product as promised) (Trentin *et al.*, 2011). At the same time, they may assess the reliability, responsive, flexiblility and ability of the product to control cost and resources (Yeung *et al.*, 2008). Whereas, from the viewpoint of sustainability, the provider may enhance the product-service by including safety and health protection, environmental pollution control through waste recycling and waste disposal during the production process (Sezen and Çankaya, 2013) which may reduce production cost (Chen *et al.*, 2012).

3.4.4 Middle of life-cycle

The provider has the responsibility to provide training to customer for proper guidelines and increase the quality of product offering as specified in the service modeling. User training services create benefit to the customer by enhancing product application and increase cost effectiveness (Aurich *et al.*, 2009) and reduce customer carelessness while using the product. Beside training, service maintenance is required to provide scheduled services, repairing to malfunction of product-offering, or upgrading to increase the lifespan of products (Gelbmann and Hammerl, 2014; Tukker, 2004). During use-phase, value for customer is created not only by provider through their embedded knowledge in the product, but customer also co-creates value when they apply their own knowledge and skills to use the product (Vargo *et al.*, 2008). In fact, a combination of customer personalized idea create different value and solve various problems (Isaksson *et al.*, 2009). Thus, in use-phase, interaction between provider and customer is crucial (Cavalieri and Pezzotta, 2012; Marques *et al.*, 2013; Morelli, 2003) shared customer knowledge or feedbacks of these experiences with the provider. Customer

feedbacks of tacit knowledge are collected through direct contact person-to-person (or socialization). Examples of customer experience during use-phase are knowledge about product quality, reliability, time to market and product innovativeness. For service, knowledge from customer may include maintenance of products, product upgrades, training quality, repairs and spare-part. Customer embodied knowledge is easier to understand when it is explicitly written in a formal, stored and organized formed by provider's employee.

The embedded knowledge resulting from externalization process assist provider to identify the strengths and weaknesses of their product offering to search for new solution to current problem, and as such the firm usually adopts a problem-solving system based on a technology such as groupware and other collaboration tools for learning. The service's processes may also allow more emphasis on use-phase and high freedom of combination and connection of different components (Hara, Shimada, and Arai, 2013). During combination process, new tacit knowledge related to product-service performance captured from customer is combined with prior firm experience in delivering services and create innovation related to customer service or product durability. New knowledge for technical know-how or mental model (Chatti, 2012) are internalized or embedded in the product or service offering via application or participation (L. and Gudergan, 2006) simulation or experiment (Nonaka and Toyama, 2003).

3.4.5 End of life-cycle

In product dematerialization phase, several activities are included such as reuse, remanufacture, recycle, take-back and disposal. During interaction with customer, the firm may explore customer tacit point of view in terms of repair, recycle, and disposal. These inputs are transformed into more logical and clear picture before they are combined with the firm technical knowledge strategies such as funding collecting, disposal activities, eco-design initiatives and economic benefits, which may create new strategy to how risks of environmental problems can be minimized, save space, reduce cost of disposal etc. New strategy knowledge to dispose product are internalized, shared and implemented in the firm.

The summary of PSS development phase and the interplay of customer knowledge and firm technical knowledge resources to produce specific outcome is shown in Table 2.

4. IMPLICATION AND CONCLUSIONS

This study has significant two theoretical contributions to the evolution of knowledge creation in developing integrated product-service. First, the research emphasizes on the interplay of customer knowledge exploration and firm technical knowledge exploitation contribution towards new knowledge creation in each

Table 2
Summary of PSS development and knowledge creation process

Integrated service and product development	*Customer knowledge/Firm technical knowledge resources*	*Crucial knowledge creation process*	*Outcome*
Planning a) Idea generation phase b) Feasibility analysis	*Firm technical knowledge:* • Expert knowledge, diagnosis skills, facilities, experience, objectivity and integrity, relational capitial (Aarikka-Stenroos & Jaakkola, 2012). • Planning on service quality such as maintenance of products, product upgrades, training in using the products, repairs and make spare-parts available (He *et al*., 2014) *Customer knowledge (from potential and existing customer)* • Customer needs, information on context, production material, effort and time and costing (Aarikka-Stenroos & Jaakkola, 2012).	Socialization within or outside firm (customer experiential learning and firm expertise) ↓ Externalization (Diagnose results) ↓ Combination (Product and service function-value proposition) ↓ Internalization (embrained)	Enhance functional product either incremental/ radical
BOL a) Concept development, b) Detail design, c) Prototyping & testing	*Firm technical knowledge:* • Product quality levels, design of products, production plans, production costs (Claycomb *et al.*, 2005). • Specification material (Marques *et al.*, 2013), • Specification equipment (Kang *et al.*, 2013) • Service quality such as maintenance of products, product upgrades, and make spare-parts available (He *et al.*, 2014) *Customer knowledge (from existing customer)* • Extract customer knowledge from MOL	Combination (material use, product concept) ↓ Internalization (product manuals, pattern, documentation)	Functional product and design cost

Cont. table 2

Integrated service and product development	*Customer knowledge/Firm technical knowledge resources*	*Crucial knowledge creation process*	*Outcome*
d) Production and delivery	*Firm technical knowledge* • Product customization and innovation ability, volume flexibility, mix flexibility, delivery speed and delivery reliability (He *et al.*, 2014). • Best practices processed, tools, machines, scrap rates and manufacturing approach (Baxter *et al.*, 2009) • Equipment utilization (Alonso-Rasgado *et al.*, 2004) (Aarikka-Stenroos & Jaakkola, 2012) *Customer knowledge (from existing customer)* • Extract customer knowledge from MOL	Combination (know-what and know-how) ↓ Internalization (specialization of labor, best practices)	Production flexibility and enhance response time, reduce cost and need less service during use-phase
MOL a) Training b) Use-phase c) Maintenance d) Feedbacks	*Firm technical knowledge* • Product quality and reliability, time to market (He *et al.*, 2014); • Service quality such as maintenance of products, product upgrades, training in using the products, repairs and make spare-parts available (He *et al.*, 2014) *Customer knowledge* • Customer experience, feedbacks on • Flexibility, timely response, quality and product innovativeness.	Socialization with customer (experiential learning) ↓ Externalization (strength and weaknesses product offering) ↓ Combination (combine customer knowledge and firm experience to improve service delivery. ↓ Internalization	Innovation, long term customer relationship and durability of product

Cont. table 2

Integrated service and product development	*Customer knowledge/Firm technical knowledge resources*	*Crucial knowledge creation process*	*Outcome*
EOL a) Remanufacture, b) Recycle / reuse c) Take-back	*Firm technical knowledge* Disposable activities, eco-design initiatives and economic benefits (Khor & Udin, 2013), *Customer knowledge* Recycling/repair/disposal	Socialization with customers (new ideas on dematerialization) ↓ Externalization (new logical ideas on dispose product) ↓ Combination (New ideas + firm technical knowledge strategies) ↓ Internalization (New strategy to dematerialize)	Environmental safety and competitive position

PSS development phase using the combination of Nonaka and Lam's model. Second, the services accompanied the traditional product offering have drawbacks due to unplanned required services by customers. It happens because of services is designed after product is developed but not during the new product is developed. Hence, the services meant for product must be designed simultaneously to allow compatible action between product design and services provided during customer use-phase. This can be done by integrating customer knowledge such as flexibility, timely response, quality and product innovativeness at each product development phase and firm technical knowledge. In turn, enhance the functionality of the product and later usage after end of life. Besides that, firm must be ready with spare part availability, predict the best time for maintenance, ready for relevant spare parts, the suitable materials use for later recycle or reuse product.

5. LIMITATION AND FUTURE RESEARCH

The comparison of several PSS development methodologies has lead us to several crucial phases which includes planning, concept and design, production, use-phase and dematerialization. During the PSS planning, close interaction between customers and the provider is crucial as value created with customers is incorporated into the functional product. During concept creation, in functional product, the customer involvement is essential, although the information is not necessary gathered during that stage. Knowledge can be gathered by other functional units such as during idea generation, use phase, prototype testing and after product development.

The knowledge is transferred between the firm and customer in relation to the development of PSS models, and complete when both satisfy with the attributes concept, function and its cost during the testing phase. The use-phase is the overlapping process between product consumption and service delivery, hence the *customer knowledge* is crucial, for example new ideas, user behavior and emotions and suggestions. While at the same time, during the PSS development, firm develops and enhances *technological knowledge* through experience. The outcome of PSS product is not about the product artefacts or services independently, but both are seen as complementary rather than replacement, because the service is attached with the product to provide the functions and the services. The PSS development phase shows that customer knowledge is crucial in each stage of PSS development phase and becomes input for PSS especially in the early part of the product development. Based on SECI approach, each stage experience the conversion of tacit knowledge into explicit knowledge; finally firm utilize the new knowledge created and the process repeats in each PSS development phase.

However, this study has limitation. Exploring customer knowledge may generate more benefits include increased firm's performance in terms of productivity, incremental innovation and dynamic capacity through efficiency of

technical knowledge search, absorption and combination. However, it will incur more costs and high risk. Furthermore, too much explorative learning may give higher benefits but will usually block a firm from achieving the actual return from its knowledge. As a result of continuous exploratory learning, less utilizing the firm existing experience may lead a firm to run with inefficiencies. As such in many cases or business context, balance of both exploratory and exploitative learning is crucial to maintain firm's current capacity. The provider's success is depending on the ability to co-create new knowledge with customers based on these resources. However, customer and firm technical knowledge create tension to develop PSS. Hence, this research opens for further research, whether balance of both customer knowledge exploration and firm technical knowledge exploitation in PSS context provides better results.

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