NordDesign 2016
August 10 – 12, 2016
Trondheim, Norway

The framework of business model innovation for Smart Product-Service Ecosystem

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Abstract

The shift to service economy and rapid development of information technologies have greatly changed traditional business models based on commodities trading. In this work, a novel business paradigm of Smart Product-Service Ecosystem (SPSE) is proposed, integrating value co-creation network, service ecological thinking and Information &Communication Technologies (ICT), trying to offer possible guidelines and roadmaps for those transforming and emerging industries. New characters and business model innovation of SPSE are studied from three aspects, including interaction modes, resource allocation principles and cooperation mechanisms. First, smart interactions offer new approaches and opportunities for manifest customer demand acquiring and implicit demand reasoning. Supporting methods based on demand correlation matrix and fuzzy reasoning algorithm will be developed for customer demand mining and service scheme matching. Then, the dynamic sharing resource pool is first introduced for service resource allocation optimization. The integration of distributed layout and centralized management and scheduling of resources will significantly reduce operation costs, improve resource utilization efficiency, and accelerate service response speed. Last, cooperative mechanisms will be developed based on risk sharing, ecological diversification and node association multi-polarization, to achieve a win-win situation and improve the stability, reliability and competitiveness of SPSE.

Keywords: Business model innovation, Smart Product-Service Ecosystem (SPSE), smart interaction, resource allocation, value co-creation

1 Introduction

The shift to service economy and rapid development of information technologies have greatly changed traditional business models based on commodities trading. Information and communication technologies (ICT) are revolutionizing products. Once composed solely of mechanical and electrical parts, products have become complex systems that combine hardware, sensors, data storage, microprocessors, software, and connectivity in myriad ways. These "smart, connected products", made possible by vast improvements in processing power and device miniaturization and by the network benefits of ubiquitous wireless connectivity, have unleashed a new era of competition. The evolution of products into intelligent, connected devices, which are increasingly embedded in broader systems, is radically reshaping companies and competition (Porter & Heppelmann, 2014, 2015). Under this background, many companies are now changing their traditional manufacturing model to more globally integrated and customer-centric value creation. Companies are eagerly looking for ways to add more innovation to their products to deliver value-added services to their customers and expand their bottom line (Lee, 2010). Companies such as IBM, John Deere, and others are transforming into smart service business leaders. In a world where basic product competition is increasingly intense, a move into smart services can create opportunities that help ensure the future of the company. Society's transformation towards sustainability will only be successful if it is possible to launch ecologically smart product-service systems, and this is where the designer can make a crucial contribution (Liedtke et al., 2013). Arising new technologies and smart service based business models call for new theories to direct and support enterprise development and business model innovation. Based on current researches, and achievements of cooperation projects between industry, academia and education (noted as Nordic approach), a novel business paradigm of Smart Product-Service Ecosystem (SPSE) is proposed, integrating value co-creation network, service ecological thinking and ICT, trying to offer possible guidelines and roadmaps for those transforming and emerging industries.

2 Status review and problem statement

Smart product service ecosystem is developed from the concept of product service system and smart product systems. Product Service System (PSS) was first proposed for minimizing environmental impacts of both production and consumption to pursuit sustainable development through applying different methods of environmental policy (O. Mont, 2000). PSSs are defined as customer lifecycle-oriented combinations of products and services, realized in an extended value creation network(O. K. Mont, 2001), comprising a manufacturer as well as suppliers and service partners (Aurich et al., 2006). With the promotion in technological infrastructures, augmented networking, and vast connectivity options, products are becoming smarter with increased customer-oriented interactivity through effective combinations of a physical interface with a software interface. Such inherent technological capabilities in smart products are revealing hidden opportunities for business revenue that can be fulfilled through establishing a service framework around the core product. Innovation is not just about new product development; it increasingly refers to the creation of new value-added services to transform productivity and better meet customer needs (Lee, 2010). Smart PSSs integrate smart products and e-services into single solutions, bringing the potential to create innovative interactions between consumers and providers. By means of case studies, Valencia et al.(2013) spotted six defining characteristics of smart PSSs: consumer empowerment, individualization of services, community feeling, service involvement, product ownership and individual/shared experience. Then, continuous growth was added as the seventh character and the potential value of Smart PSSs both for consumers and companies, which was discussed in the further research of Valencia et al.(2015). Advances in information and communication technology have made it possible to combine products and services in innovative ways.

Although PSS introduces new elements to the design process, it still requires a thorough rethinking of how designers should relate to this specific business model. Dewit et al.(2014) explored how existing service design tools, modified with a specific PSS focus, can be introduced in the early stages of PSS concept creation and definition. The number of smart products and services connected to the Internet grows exponentially, which will result in the emergence of numerous innovative, Web-based business models as well as new forms of social organisation both within and between the world of work and people's private lives. In future, Web-based and physical services will be combined in order to meet the needs of individual consumers. The trends will go a long way towards determining business models in the Smart Service Welt: digital industrial convergence and alliances, everything as a service, open innovation platforms and crowdsourcing, security and trustworthiness (Kagermann et al., 2014). New digital infrastructures need to be established, including networked physical platforms, software-defined platforms, service platforms. As designers' involvement in the design of these offerings is likely to increase, the understanding of the challenges emerging from the integration of product and service is of increasing relevance for the effective management of the design process (Valencia et al., 2014). It points out the need for new Smart Engineering approaches using the latest ICT innovation and smart features, which defines requirements for engineering processes, methods, and tools (Abramovici et al., 2015). With the thoughts of smart PSS, Peruzzini and Germani (2014) proposed a new User-Centred Design (UCD) based model to design assistive ICT-platform including smart products and services to support active aging for elderly and frail people.

Many studies about smart PSS have been conducted, but it is still an arising area with a short history since 2010. Current researches about Smart PSS mainly focus on developing of new intelligent extended services based on single core smart product. However, few researches have considered the interaction between smart PSSs. As more and more smart products and organizations are connected together by advanced ICTs, a new phenomenon of smart PSS network has emerged, like car networking, smart household appliance networking, etc. New theories are needed for developing new business models based on smart PSS network with ecological thinking, solving the problems of ecological architecture establishment and operation synergy mechanisms.

3 The proposed framework of smart product service ecosystem

Smart product service system (SPSE) is defined as a ICT based dynamic ecological smart PSS network, which integrates customers, smart product service systems, smart service platform and product service suppliers for value co-creation and customer experience improvement, by means of smart interaction, mutual cooperation, resource sharing and optimal configuration. The authors investigated more than 10 typical industries in China, including civil aircraft, elevator, construction machinery, household appliance, garment industry, etc., to summarize the characters of SPSEs. By comparison and analysis, it can be found that there are four different kinds of SPSEs, which are fore-end service chain model, back-end service chain model, back-end service ecological model and lifecycle service ecological model. Analysis results about specific characters, typical industrial areas and application cases of each kind of SPSE are listed in Table 1.

Table 1. Four types of smart product service ecosystems

Business Model	Characters	Typical areas	Applications
Fore-end service chain model	Personalized product customization services before product delivery	Fast consumer goods, consumables, decorative items,	Customization of clothes and furniture

Back-end service chain model	Offer accurate and fast response services for personalized customer needs based on smart approaches.	Industrial equipment with high single product value	Construction machinery, elevator, air compressor, civil aircraft, etc.
Back-end service ecological model	Build PSE platform based on core smart products, integrating supporting products and services	3C products with high level of integration and standardization	IPhone, TV set
Lifecycle service ecological model	Offer products and services for the whole customer lifecycle, including personalized product design, on-demand manufacturing and supporting ecological products and services.	Medium and small smart household appliances designed and manufactured in modular ways	Washing machine, air conditioner, air cleaner

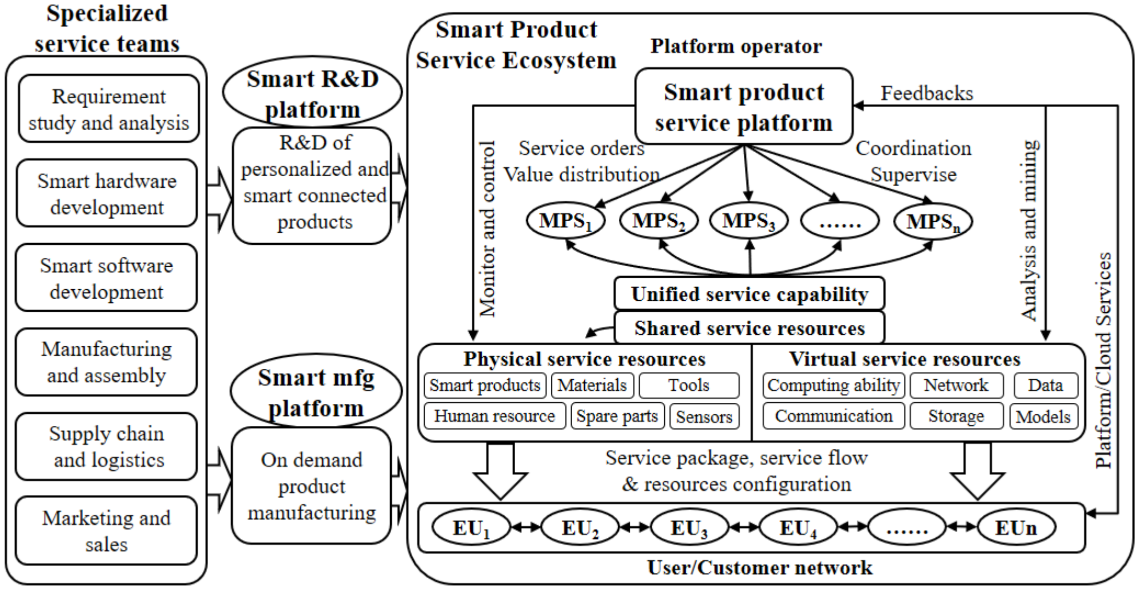

Figure 1. The proposed framework of Smart Product Service System

Though different kinds of SPSE have different characters, they share a basic common system structure, while they may lay different emphasis on different aspects or layers. Considering various possible scenarios, a unified SPSE framework is proposed as depicted in Figure 1. Apart from common infrastructures, a systematic SPSE may have supports of specialized service teams of R&D, manufacturing, supply chain management, sales and marketing, etc. Those personalized smart connected products in SPSE calls for new requirements for both R&D and manufacturing processes. In the R&D procedure, customers could be included to provide their creativity and intelligence to propose their unique demands and make some contributions. In the manufacturing procedure, the development of smart flexible manufacturing technologies offers the possibility of on-demand manufacturing for customized single or small batch products. The fore-end service chain model mainly lays emphasis on the intellectualization of these two procedures. Back-end service chain model mainly emphasizes the intellectualization of products for automation, self-adaption and self-diagnosis to enhance customer experience and reduce use-costs. Back-end service ecological model integrates related product and service suppliers and connect them to a core smart product service platform to provide customers with comprehensive solutions, more stable and uniform user experience. Lifecycle service ecological model synthesizes the entire process and all the elements of the concept framework when constructing the SPSE, introducing intelligence to every possible module and step. By unified management and scheduling of products, service flows and resources through smart R&D platform, smart manufacturing platform and smart product service platform, it will improve system operation efficiency significantly and new niche space for value co-creation can be created. But so far, lifecycle service ecological model can only be applied within a few typical industrial areas, which is characterized by medium single product value, flexible module configuration and large numbers of user group, such as smart household appliances.

As is analysed above, the introduction of ICTs in the lifecycle of the products and customers, has changed traditional business models greatly. However, for those arising or transforming enterprises or industries, they still don't have systematic theories to follow. So, in order to make it clear how ICTs integrating with new business models, and help operators design and construct their own smart product service ecosystems based on the proposed reference framework, three basic innovation aspects are summarized as follows:

(1) The innovation of customer interactions
- Customer participated personalized product design.
- On demand and flexible manufacturing based on customer options.
- Optimized product service configuration for best customer experience.

(2) The innovation of service resource configuration approaches
- Customer needs acquiring based on intelligent terminals.
- Stakeholder data sharing and analysis based on smart service platform.
- Physical resources sharing and uniform allocation.

(3) Innovation of cooperation mechanisms
- Structure layer: Increase ecological diversity and connection nodes, improve stability.
- Mechanism layer: Risk sharing, reduce individual risks by introducing socialized sharing mechanism.
- Function layer: Complementary Ecological functions and mutual cooperation, to reduce conflict cross and independent operation costs.
- Relationship layer：upgrade to cooperative and value co-creation connections.

Details about these rules and supporting methods and tools are presented in section 4.

4 Proposed approaches to business model innovation for SPSE

4.1 Innovation of customer interactions

The development and applications of ICTs have greatly changed how customers, machines and suppliers interact with each other. According to the reference concept framework, all the roles in an SPSE are clustered into four categories, namely smart products, smart service platform, customers and suppliers (for products and services). Typical interaction contents of the four key roles are identified as presented in Table 2. The table can be further developed as a tool for interaction analysis by introducing directed acyclic graphical model, which is not the emphasis of this work. Actually, all the new interactions generated based on smart approaches have the same purpose, that is to improve material and information transfer efficiency by eliminating island effect and mining more value in implicit information and knowledge.

Table 2. Interaction matrix of four key roles in an SPSE

Roles	Smart Products	Smart service platform	Customers	Suppliers

Smart Products	Data exchange Communication Functions	——	——	——
Smart service platform	Data exchange Monitoring Controlling Upgrading	Platform maintaining Function extension Storage and analysis Strategy adjustment	——	——
Customers	ID authentication Man-machine interaction (vision, auditory, tactile) Autonomous service	Service requests Resource matching QoS assurance Trading center Customer data storage	Experience exchange PSS assessment Material/data sharing and exchange C2C service	——
Suppliers	Data exchange Monitoring Controlling Service push	Resource allocation Service order Service flow manage Supplier assessment Trading management	CR acquiring and reasoning Scheme configuration Service data acquiring Automatic feedbacks	Virtual/physical resources sharing Cooperation Capability complementary

Here, this work mainly focuses on the interactions of customers with other roles in SPSE. As interaction interface, smart terminals/products bridge customers with suppliers and smart service platforms. Smart interactions offer new approaches and opportunities for manifest customer demand acquiring and implicit demand reasoning. Customers can submit their subjective thoughts and needs to product service suppliers directly, or generate service orders and assign service tasks through the service platform. In the meantime, by monitoring the conditions of products remotely, suppliers can offer preventive maintenance for those appliance being used by customers, which could let customers avoid lots of troubles and costs caused by major failures and machine halt. Moreover, customers' habits and historical service orders acquired can be used as a data base for mining of customer implicit demands. Supporting methods based on demand correlation matrix and fuzzy reasoning algorithm are developed for customer demand mining and service scheme matching.

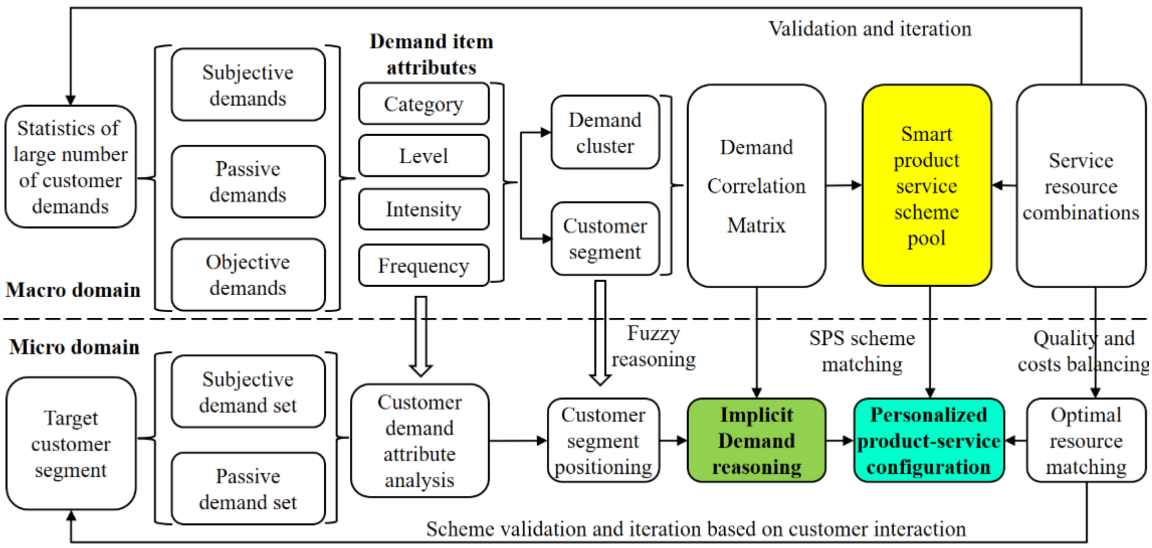

Figure 2. Process of general customer demand acquisition

The process of general customer demand acquisition based on smart interaction in SPSE is given in Figure 2. Implicit demands are related to complex customer subjective factors and psychological activities, with the character of vagueness and uncertainty. But as an important part of customer needs, implicit customer demands are usually difficult to identify, discover and acquire. Here, customer demand domain is defined as a demand set *CR* and customer manifest demand set $D'=\{D'_1, D'_2, \cdots, D'_{m'}\}$ is a subset of *CR*, in which m is the number of manifest demand items. Set $K(k)=\{K_1, K_2, \cdots K_m\}$ represents those attribute elements of customer's perceptual cognition. Set $A=\{A_1, A_2, \cdots A_n\}$ is the collection of product service attribute elements. The two sets also reflect their own characters, states and quantity. *K* and *A* have specific mapping relations according to different customers and product services. The differences or similarities of customer perceptual cognition are important source for product and service innovation. Then, we define the cognition degree and similarity of different customers as follows:

$$\tilde{R}(p,k)=N(K(k)\cap\tilde{G}(p))/N(\tilde{G}(p))\geq\delta_{\min} \quad (1)$$

$$S(i,j)=\alpha f(\tilde{I}\cap\tilde{J})-\beta f(\tilde{I}-\tilde{J})-\gamma f(\tilde{J}-\tilde{I}) \quad (2)$$

where, $K(k)$ is attribute set of customer perceptual cognition element k, $\tilde{G}(p)$ is the set of perceptual element set of customer p, $N(a)$ is the number of set elements. If customer p has perceptual cognition of k, then the minimum $\tilde{R}(p,k)=\delta_{\min}$ in equation (1) represents the minimum possibility of customer p perceptually cognizing k. I and J are the attribute sets of customer *i* and *j*. If α=1, β=0 and γ=0, then *i* and *j* have the maximum similarity $S(i,j)$. If α=0, β=1 and γ=1, then *i* and *j* have the minimum similarity $S(i,j)$.

Define $K(k)$ as a fuzzy state set, which has m1 elements. Suppose customer’s cognition assessment is *v* and the fuzzy membership function is $\mu_{K_i}(v)$, then $\sum_{i=1}^{m1}\mu_{K_i}(v)=1$. Set A of product service attribute elements can be rewrote as:

$$A=\{\{A_{j1}, A_{j2}, \cdots, A_{jk}\} \mid j=1,2,\cdots,n1; k=i_1, i_2, \cdots, i_\sigma\} \quad (3)$$

in which, n1 represents attribute number of product services, $\{A_{jk} \mid k=i_1, i_2, \cdots, i_\sigma\}$ is the attribute set of the *j*th product or service.

Then a method of Fuzzy Cognitive Map (FCM) is implemented for acquisition of implicit customer demands. In the FCM model, correlation coefficient of product service attribute A_j and customer perceptual cognition K_j can be represented by a fuzzy number of μ_{ij}, which could be degenerated to symmetric ternary logic of $\{-1,0,1\}$. The correlation matrix of customer perceptual cognition attributes and product service attributes can be acquired as follows:

$$[K,A]=\begin{bmatrix} \mu_{1,1} & \mu_{1,2} & \mu_{1,3} & \cdots & \mu_{1,m1} \\ \mu_{2,1} & \mu_{2,1} & \mu_{2,1} & \cdots & \mu_{2,m1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \mu_{n1,1} & \mu_{n1,2} & \mu_{n1,3} & \cdots & \mu_{n1,m1} \end{bmatrix} \quad (4)$$

By calculating the correlation matrix with genetic algorithm, the implicit customer demand set can be presented as $D''(d'')=\{D''_1, D''_2, \cdots, D''_{m''}\}$. The preliminary general customer demand set will be $D^0=D'\cup D''=\{D_1^0, D_2^0, \cdots, D_m^0\}$. By repeating the process of self-correlation adjacent matrix calculation with FCM for D^0, those highly correlated demand items can be merged and reduced to get the final general customer demand set D.

4.2 Innovation of service resource allocation approaches

Resources of smart product service system can be classified into two categories, physical service resources and virtual service resources. Physical service resources mainly include products, materials, tools, human resources, etc., which are characterized as real existing objects. Virtual service resources are the virtualized forms of the physical resources in the parallel space, structured data or knowledge generated in the process of system operation, and potential capability formed by physical resources. Based on the classification of service resources, the concept of dynamic sharing resource pool is first introduced. It is defined as a loose mesh collection of physical and virtual resources from multiple stakeholders, which can be shared and configured under unified management of the smart service platform. The integration of distributed layout and centralized management and scheduling will significantly eliminate wastes, reduce operation costs, improve resource utilization efficiency, and accelerate service response speed. Four salient features of dynamic sharing resource pool are identified as follows:

(1) Centralization: Integrated and unified management of the underlying hardware equipment, human resources and other physical resources, can provide common supports for the upper business system.
(2) Abstraction: The physical resources are abstracted through virtualization and clustering, which makes the scheduling of resources more flexible, dynamic and elastic.
(3) Customization: Combined with actual demand of the upper application and customers, those service modules and service packages are able to be customized to fulfill personalized needs, while further reduce costs and improve operation efficiency.
(4) Standardization: Standard technical architecture of service processes and infrastructures offers supports for good interoperability and interface standardization.

Resource aggregation based on dynamic shared resource pool is a new approach for service resource allocation. The dynamic resource pool can be described as follows:

$$RP = < Pool\ Id, Resource\ Description, Size, Node - Info, State, Constrains > \quad (5)$$

Pool Id is the unique identification of resource pool. *size* is the scale of nodes. *Node-info* is a hash table recording all the node information, which every node can be described as *Node* = <*Address, QoS value, Load* >. *State* is the status information of resource pool. Constrains are those conditions of customer needs and resource inherent attributes.

When customers submit requests, the smart service platform will abstract away resource lists in the virtual space for different service requests. The clear description for service request would help fast resource querying and resource pool establishing. A service request is defined as follows:

$$Pool\ Request\ Event = < RequestEvent, ServiceMode, QoSRestriction, PRI, constraints > \quad (6)$$

where *Request Event* is the service order identification, *Service Mode* is an option for service patterns (backup or concurrent), *QoS Restrictions* are those requirements for service quality, *PRI* is the priority sequence, *LB-parameters* is load balancing parameters. The service platform will return a suitable set of nodes according to customer request event and push service based on *PRI*. A resource node can be shared by different resource node sets. Service platform integrates two kinds of service patterns (backup mode and concurrent mode) to improve service efficiency. Based on these top-level rules, the resource allocation problem then can be solved by transforming and decomposing to M/M/n queuing questions.

4.3 Innovation of cooperation patterns

In this section, cooperative mechanisms of SPSE are developed based on risk sharing, ecological diversification and node association multi-polarization, to achieve a win-win situation and improve the stability, reliability and competitiveness of SPSE. As is mentioned in section 3, the innovations of cooperation mechanisms are performed on four layers, namely structure layer, mechanism layer, function layer and relationship layer. Each layer represents a specific aspect of SPSE.

First, the structure layer mainly focuses on the physical element constitution of SPSEs. Same to the ecological thinking of a nature ecosystem, the coordination of group size and species diversity is decisive to the stability of the SPSE. Specifically, in order to create continuous and steady service network and customer experience, ecological diversity and connection stability should be increased by gradual richness of product categories, service combinations and alternative service supplier.

The mechanism layer solves the problem of unbalanced risk distribution. On the one hand, traditional transaction based business chain is vulnerable, because some nodes take too much risks. On the other hand, anti-risk capability of an individual node is limited, which will lead to high wastage rage of key stakeholders, like customers or service suppliers. So the mechanism of Eco-fund or Eco-insurance should be set up, to balance the risk distribution in the smart product service network and guarantee node viability. Meanwhile, smart sensing and real-time analytics based on ICT will reduce risk treatment costs by forecasting potential risks and eliminate them before causing huge loss.

The function layer emphasizes competitive differentiation among service suppliers in SPSE. The unified smart service platform can suggest clear positions for those stakeholders to avoid overlapping of functional roles. Service suppliers can be more specialized by outsourcing non-core business or unnecessary investments to other suppliers in the cooperation network. In the meantime, with the centralized order assignment and resource allocation, operational efficiency can be improved significantly and independent costs can be cut down.

On the relationship layer, links between stakeholders should be designed for convergence of value proposition. Onetime transactions will be replaced by long term cooperation and the links between nodes will be more stable and continuous. The establishment of win-win cooperation or coopetition relationships will also eliminate those internal frictions caused by interest confliction. So, value co-creation based product service network can be more competitive than traditional simple business chains.

5 Discussions and conclusions

The SPSE framework and three aspects for business model innovation are research achievements derived from some undergoing cooperation research projects with several companies from different industries in China, including elevator, household appliances, civil aircraft, construction machinery, etc. The introduction of ICTs in these industries has changed their traditional business models, bringing not only opportunities for their development, but also new problems and challenges. Enterprises feel confused on the road of transformation, urging for theoretical directions.

The framework of SPSE proposed in this work is an integration of value co-creation network, service ecological thinking and ICTs, providing future perspectives and possible guidelines for industry transformation and further development of new service based business models. Main contributions of this work are the studies about three aspects of SPSE business model innovation. The methodologies have been applied by the research team to help those industries mentioned above to establish their own smart service ecosystems to enhance their integrated competitiveness and offer better customer experience. The approach still needs more practical testing and validations in more industrial areas and a longer time period. More quantitative analysis, refinement of specific algorithms and development of supporting information systems will be conducted in future work.

Acknowledgement

The author would like to thank Shanghai Institute of Producer Service Development (SIPSD) and Shanghai Research Centre for industrial Informatics (SRCI2) for the funding support to this research.

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