Benchmarking: An International Journal

A conceptual framework for product service system design for machine tools: Issues in Indian context

Pankaj U. Zine Makarand S Kulkarni Arun K. Ray Rakesh Chawla

A conceptual framework for product service system design for machine tools

Issues in Indian context

Pankaj U. Zine and Makarand S. Kulkarni
Department of Mechanical Engineering, Indian Institute of Technology, New Delhi, India
Arun K. Ray
Endurance Technologies Private Limited, Aurangabad, India, and
Rakesh Chawla
Micromatic Machine Tools Private Limited, Gurgaon, India

Received 27 December 2014
Revised 31 August 2015
Accepted 5 September 2015

Abstract

Purpose – The purpose of this paper is to propose a conceptual framework for product service system (PSS) design for machine tools and discuss the PSS implementation issues focusing on the Indian machine tool business sector.

Design/methodology/approach – The paper opted for an exploratory survey conducted in the Indian machine tool sector including 39 in-depth interviews with employees of different organizations representing middle and senior management having decision-making authority. It also involves proposing a framework to address the stakeholder's requirements for services that offers foundation for PSS designers.

Findings – The paper helps get an insights about key issues for PSS implementation by the Indian machine tool sector. The hybrid PSS model proposed in the paper can address the stakeholder's requirements for flexibility in business models through different business phases.

Practical implications – The paper offers suggestions for the development of PSS for machine tools for designers and identify issues to be considered particularly in Indian machine tools business context.

Originality/value – This paper provides an insight to judge the feasibility of PSS concept for machine tools in Indian context and offers framework for PSS designers.

Keywords Product service system, Machine tools, Hybrid PSS business models, PSS design, PSS implementation issues

Paper type Research paper

1. Introduction

For catering the needs of the ever demanding customers, industries have to adopt new strategies to create innovative products and services. In the current age of service economy, increasing global competition has been putting steady pressure on manufacturing companies to find new business strategies and market differentiators beyond "cost-quality-time" (Tan *et al.*, 2007). Servitization (Baines *et al.*, 2009) is the key for success for such businesses. The term "servitization of business" focuses on offering packages of customer focused combinations of goods, services, support, self-service and knowledge with service domination. Accordingly, many manufacturing companies around the world are adding service dimension to their

Authors gratefully acknowledge the financial assistance provided by Council for Scientific and Industrial Research (CSIR), India for this research under scheme No. 22(0553)/EMR-II.

Benchmarking: An International Journal
Vol. 23 No. 5, 2016
pp. 1227-1248

1463-5771
DOI 10.1108/BIJ-12-2014-0116

business and transitioning the business model from products to services through servitization (Kim and Yoon, 2012). For doing so, one of the most promising service-oriented business models is the product service system (PSS) model (Roy, 2000; Baines *et al.*, 2007). It has received significant attention due to its potential as an alternative way of doing business that is more efficient and effective.

A PSS is an innovation strategy where instead of focusing on the value of selling physical products, one focuses on the value of the utility of products and services throughout the product's life period (Tan *et al.*, 2007). The PSS concept basically says that given a choice, the customer would want to just buy functionality (along with its service support) and not the product itself. The existing PSS business models include product-oriented PSS, use-oriented PSS, result-oriented PSS (Mont, 2002; Manzini and Vezzoli, 2003; Tukker, 2004; Wang *et al.*, 2011), integrated PSS and service-oriented PSS (Neely, 2008). In the context of machine tools, PSS can be regarded as kind of machining capability outsourcing services (Zhu *et al.*, 2011). It means that the PSS provider has to take responsibility for managing production, maintenance, quality control and produce using the machine. The customer would typically provide space and electricity and pay on cost per piece basis to the PSS provider. A machine tool PSS stakeholders include the machine tool manufacturer, the enterprise user, module suppliers and other service providers. It is expected that by opting for PSS, all the involved stakeholders will have certain benefits.

However, with limited available literature on PSS for machine tools (Zhu *et al.*, 2011; Meier *et al.*, 2010; Isaksson *et al.*, 2009; Mei *et al.*, 2014; Doualle *et al.*, 2015; Mert *et al.*, 2014; Copani and Rosa, 2015), it would be interesting to explore whether the existing PSS models meet the demands of all types of machine tool manufacturers and customers in the market? Are customers satisfied and happy with existing kind of business offerings? Are there any other concerns of the PSS business stakeholders, particularly in Indian context? To find satisfactory answers to all such questions and explore the feasibility of PSS business concept in the Indian machine tool sector, this paper attempt to propose a conceptual framework for PSS design for machine tools and discuss the PSS implementation issues focusing on the Indian machine tool business sector. For this purpose, an industrial survey was conducted in association with a leading machine tool manufacturing group, having a large industrial customer base in India, and a selected machine tool user industries. Based on the observations made during the survey, the modified structures of PSS have been proposed by generating different scenarios based on the participation of various stakeholders. To meet the stakeholders' expectations, the existing PSS models are appropriately modified to develop a hybrid PSS model that satisfy the stakeholder's concerns through different business phases. Possibility of few context-specific PSS structures is discussed through relevant examples. The key issues for PSS implementation by the Indian machine tool sector are identified and discussed along with favourable situations for PSS. The proposed framework is expected to guide the PSS designers on how to incorporate the flexibility in business models and service offerings to meet the varied customers' requirements.

Rest of the paper is organized as follows. In Section 2, literature related to PSS is briefly reviewed and summarized. Section 3 briefs about an industrial survey conducted in the Indian machine tools sector. Proposed conceptual framework for PSS design for machine tools is discussed in Section 4. Different PSS scenarios and hybrid PSS structure are discussed in Section 5. The important issues in PSS implementation in Indian context are discussed in Section 6; followed by conclusion in Section 7.

2. Literature review

The objective of this section is to present and summarize the methodologies and approaches for PSS design available in the existing literature and capture the related gaps in machine tools PSS context.

With ever increasing competition and varied customer's demands, industries are finding difficulties in differentiating their products in the global markets with respect to price, functions and design (Tan *et al.*, 2007). To overcome this issue, manufacturing companies have started inclination towards "servitization" (Baines *et al.*, 2009) of their businesses. The servitization aims at offering value added services along with the basic products by the manufacturers. The increasing trend towards servitization by manufacturing organizations can be because of the fact that the services exhibit higher potential for revenue generation and can help the providers to have an edge over their competitors. Therefore, the manufacturers can enhance the utility of their products by offering value added services moving with the servitization trend. The manufacturing industries are realizing that to improve profitability, it is not enough to sell just a product as the real impact on profitability comes from exploiting downstream opportunities, by providing the customers with products such as financing, maintenance, spare parts, consumables and other after sale-services (Wise and Baumgartner, 1999; Biege *et al.*, 2009; Schuh *et al.*, 2011; Eggert *et al.*, 2014). Thus, the traditional boundary between manufacturing and services is becoming increasingly blurred (Mont, 2002) and most manufacturing companies are looking to increase service revenues by offering bundled services with products (Gebauer *et al.*, 2006).

For designing a PSS, many approaches have been proposed by researchers to highlight the potential of the PSSs focusing on competency and capability requirement for an organization. The PSS approach enables companies to provide customers with offerings that continuously deliver value and create a strong competitive advantage by offering integrated products and services (Tan *et al.*, 2007; Durugbo *et al.*, 2010; Vasantha *et al.*, 2012; Durugbo, 2013). Morelli (2006) emphasized the designers' role in developing innovative PSS and developed methodological tools to support designers for generating systemic solutions including products and services. A general framework for service design and a strategic evolution concept towards PSSs was provided by Aurich *et al.* (2004). Isaksson *et al.* (2009) and Alonso-Rasgado *et al.* (2004) emphasized the functional product design which involves the design of a service support system integrated with hardware. Aurich *et al.* (2006a, b) proposed a systematic design process for product-related technical services based on modularization that links with the corresponding product design process. Tan *et al.* (2007) presented a theoretical framework of the expected managerial and organizational implications of PSS approaches.

Sakao and Shimomura (2007) and Sakao *et al.* (2009) developed a prototype system called "service explorer" and "service engineering" which focuses to design products with higher added value from enhanced services. Komoto and Tomiyama (2008, 2009) proposed service CAD for helping designers to generate a conceptual design of PSSs. It systematically supports designer in decision making regarding design problems by evaluating the design concepts and suggesting alternatives to improve them. A method for designing service activity and products concurrently and collaboratively during the early phase of product design has been proposed by Shimomura *et al.* (2008, 2009). They argued that by considering mutual effects of synergy, alternatives and complementarities, the design of services and products should be integrated for maximizing the customer value. Aurich *et al.* (2009) emphasized the need for systematic configuration of PSS to extract the potential of services with an appropriate

combination of products and services for achieving desired benefits for both, the manufacturers and their industrial customers.

Meier and Massberg (2004) proposed a model-based approach for integrating products and services to generate heterogeneous industrial PSS (IPSS) concept model in the early phase of IPSS development. Welp *et al.* (2008) argued that IPS2 concept considers combination of product and service for generating the principle solutions to meet specific customer requirements. Maussang *et al.* (2009) developed a methodology to provide engineering designers with technical engineering specifications precisely in relation to complete system requirements. McAloone (2007) and Tan *et al.* (2010) identified four dimensions: value proposition, product life cycle, activity modelling cycle and the actor network for proposing methodological steps for designing a PSS. They claimed that these elements cover the essential design elements of a PSS.

Other interesting contributions for developing PSS approaches cited in literature includes a methodology for PSS (MEPSS) structures presented by van Halen *et al.* (2005). It involves steps for designing PSS through strategic analysis, exploration of opportunities, PSS idea development, PSS concept design, and PSS project development and implementation. Weber *et al.* (2004) presented the concept of property-driven design to develop a MEPSSs. Rexfelt and Ornas (2009) identified characteristics of PSS solutions which may influence acceptance, and presented procedures for conceptual development of PSS based on methodology adapted from user-centred design. Muller *et al.* (2009) presented a PSS layer method for the development of PSS through nine classes: life cycle activities, needs, values, deliverables, actors, core products, peripheries, contracts and finance.

Manzini and Vezzoli (2003) suggested that the adoption of PSS provides insights about aspects considered relevant to businesses, such as: types of products, customer needs, product and service strategies, relationships with stakeholders and financial income options. Barquet *et al.* (2013) proposed a framework based on Canvas business model tool to support the adoption of PSS employing the business model concept. They demonstrated the framework through a case study (with a manufacturer) to show that it helped the company for analysing the business context, choosing the appropriate type of PSS and for defining their PSS characteristics.

However, the literature also points out that some specific features are required for service systems to ensure the desired benefits. One of the features is the "flexibility" in PSS offering. Long *et al.* (2013) presented an approach for PSS configuration in which the customer needs are first, divided as functional needs and perception needs and are further analysed to configure a PSS that meets the customers' requirements. In the context of designing IPSS, Richter *et al.* (2010) discussed the importance of flexibility as a solution to the uncertainties involved in long-term customer-provider relationship. Uhlmann *et al.* (2013) proposed an approach for flexible implementation of IPSS using service-oriented architecture. However, both Richter *et al.* (2010) and Uhlmann *et al.* (2013) have focused on product modularity aspects while designing and offering the IPSS but have not considered the flexibility requirements while offering services.

Focusing on the PSS for machine tools, few researchers attempted to design, develop and demonstrate the concept in manufacturing industries to highlight its potential. A machine tools PSS aims at selling the functionality (machining capability) of the machine tools or the end result rather than the machine tools by the manufacturer (Zhu *et al.*, 2011). The PSS has potential to derive significant sustainable benefits for its stakeholders by utilizing producer's knowledge of product design and volume production and cooperating closely with other stakeholders (Evans *et al.*, 2007).

Based on studies conducted in manufacturing firms, Isaksson *et al.* (2009) discussed the PSS requirements by a machine manufacturer (as service provider) especially in terms of required competencies and other capabilities. The competencies include requirement of knowledge of customer's complete business process and ability of service provider to design services innovatively to compliment the product's use focusing on value for the customer. They emphasized on challenges in terms of managing customers' involvement in the product and service development process, careful tailoring of intellectual property set-ups, and meeting customers' demands for flexibility but did not comment on how to address and manage those requirements.

In an attempt to develop a technical product service systems (t-PSS) for the an ultra precision free-form grinding machine, Azarenko *et al.* proposed business models for the machine product as product, use and result oriented. They discussed the stakeholders' responsibilities, cash flows, application sectors, the benefits and shortcomings of the three business approaches and the key implications of t-PSS on machine tool industry. Meier *et al.* (2010) discussed the potential for PSS applicability from industrial context through different case studies from industries offering integrated products and services. They highlighted on aspects to be considered while opting for PSS like new methods and tools for business models, sustainability contribution, risk management, knowledge management, design, development, delivery and use of IPSS. Zhu *et al.* (2011) proposed an IPSS for machine tools, which aims at transforming machine tool manufacturers from providing merely physical machine tools to providing machining capabilities. They proposed an architecture consisting hardware and software and discussed key techniques for implementing the architecture in the context of a CNC machine.

Recent studies related to servitization and PSS focusing on machine tools include an attempt by Mei *et al.* (2014) to study and identify the progress of manufacturing servitization in machine tool industry. Mert *et al.* (2014) presented a customer-oriented approach to assess the quality of PSS in the machine tool industry. It can help to ensure and continuously improve a long-term business relationship between a PSS provider and its customers. The need for operational methods and tools that can help companies to develop business models and support customer choices relating to PSS contracts has been emphasized in literature (Doualle *et al.*, 2015). Sheng *et al.* (2015) studied the configuration design of PSS for CNC machine tools.

Though existing literature presents evidences of research in the area of PSS along with service system design, PSS design approaches, models, methodologies, etc., there is limited work that address customers' requirements for flexibility in terms of business model as well as the service configurations. It is observed from the literature that there are limited studies on PSS for machine tools (like Zhu *et al.*, 2011; Meier *et al.*, 2010; Isaksson *et al.*, 2009). Also the stakeholders' concerns in terms of flexibility in business models over conventional business models, flexibility for service configuration and similar issues in the context of PSS for machine tools are not explicitly addressed. This paper attempt to bridge these gaps by proposing a conceptual PSS design framework focusing on business model flexibility and service configuration flexibility particularly in the context of machine tool PSS. It also discusses the various issues and concerns of PSS stakeholders particularly in the Indian context.

3. Industry survey

For exploring the feasibility and applicability of PSS concept in Indian context and to capture various issues of involved stakeholders, an industrial survey was conducted in

association with a leading machine tool manufacturing group having a large industrial customer base in India, and a selected machine tool user companies. The group consists of four original equipment manufacturers (OEMs, referred as "principals" in this paper) and a service providing company (referred as main service provider "MSP") which supports the market base for all four principals in terms of offering value added services (annual maintenance contract (AMC), on-call service, training and other service support). Other service providers were also visited and interviewed that cater different service needs to their customers. Companies (machine tool users and manufacturers) from various regions of India were visited and key personnel (managers, higher management-level people and decision makers) representing these companies were interviewed in order to explore the feasibility of the PSS concept, the related issues and possible business models. The user companies visited included small and medium enterprises, large companies, corporates and OEMs. The OEMs were identified such that they cover major machine tool business sectors (conventional as well as non-conventional machine tools with special focus on CNC machine tools). A summary of visited companies is given in Table I.

Focus during the survey was on the "service aspect", which helped in capturing the possible service requirements of the machine tool users. The Delphi technique approach (Linstone and Turoff, 1975; Okoli and Pawlowski, 2004) was used to capture and validate the customers' service requirements. A questionnaire was developed in association with the MSP to capture various service requirements for machine tools. In the first round, it was piloted amongst the five machine tool users to capture their views about the PSS concept, their service requirements, etc., and these inputs were subsequently used to refine the questionnaire with the help of MSP.

Subsequently, 39 companies (machine tool manufacturers and users) were visited and appropriate personnel (mentioned earlier) were interviewed in the second round to know their views and perceptions about PSS, its feasibility in the Indian context, potential benefits and concerns about PSS. The customers' requirements in terms of services with respect to their competencies and business types were captured using Delphi technique which were further analysed and appropriate service components were identified along with their potential for value creation. This was done in association with MSP. The survey resulted in gathering customer's service requirements and identifying respective service components (Table II). It also helped to capture customer's needs for flexibility in business models, machine tool manufacturer's views about offering PSS for some initial period and their desire to

Table I.
Summary of companies visited during the industrial survey

Sr. no.	Type of organization	No. of companies	Designations of the personnel interviewed (nos)
1	Machine tool manufacturers	8	CEO (2), MD (2), VP (1), GM (1), AGM (1), marketing head (2), business head (2)
2	Service providing company	4	National service head (1), regional service head (3), service managers (5), service engineers (6)
3	Machine tool users: OEMs (2), corporate companies (3), large size companies (6), SMEs (10)	21	MD (8), AVP (2), GM (5), DGM (4), AGM (1), project manager (4), service manager (6), maintenance head (2), manager (6)
4	Module suppliers	4	MD (1), GM (1), manager (2)
5	Third party service providers	2	MD (1), GM (1)

Sr. no.	Service component	Value to customer
1	Operation	Solving customer qualification deficits
2	Corrective maintenance	Minimize downtime
3	Preventive maintenance	Minimizing breakdown risk at low cost
4	Predictive maintenance	Minimizing breakdown risk, maximizing component life utilization, JIT spare parts procurement
5	Spare parts and consumables	Genuine spares parts and consumables without delay
6	Tooling design & manufacture	Solving customer qualification deficits
7	Overhauling	Maintaining machine condition close to as good as new
8	Up-gradation	Functionality and capability enhancement
9	Buy back guarantee	Ensuring fair price for used equipment
10	Salvaging	Ensuring eco-friendly disposal of equipment

Table II.
Service components and value to customer

eventually sell the machines. These various needs of stakeholders are addressed in Section 5. The industrial survey also helped to capture PSS stakeholder's concerns and issues in its implementation, particularly in the Indian context which are discussed in detail in Section 6. The other findings of the survey are reported with appropriate examples in the paper.

4. Conceptual framework for PSS design for machine tools

In this section, a conceptual framework is proposed for PSS design for machine tools. The framework (Figure 1), begins with the generation of an idea for PSS between the customer and the service provider or manufacturer. They would first do the feasibility analysis of PSS concept by considering various factors such as manufacturers' willingness to offer newer business models, competency and compatibility requirement, sustainability of PSS model, IPR and confidentiality issues, etc. The details of the issues to be considered in feasibility analysis are discussed in Section 6.

Once the customer and provider find the PSS business model to be a feasible one, they would further identify the corresponding stakeholders and start the design of PSS by involving them appropriately. The various steps involved in PSS design and corresponding service delivery process development are further discussed in detail in the following subsections.

4.1 Design of PSS

Involvement and active participation of stakeholders is one of the most important activities in a PSS design. It needs a lot of information and data sharing between the stakeholders. Designing a PSS includes steps like capturing customer's requirement for products and associated services, designing a product to fulfil those needs, designing the services to support the product over its life cycle and life cycle costing of the services. The details of each step are discussed below.

4.1.1 Capture functional and service requirements. It is important to know and analyse the customer's requirements for designing a good product and services. The functional requirements are useful to decide the features of the product while the

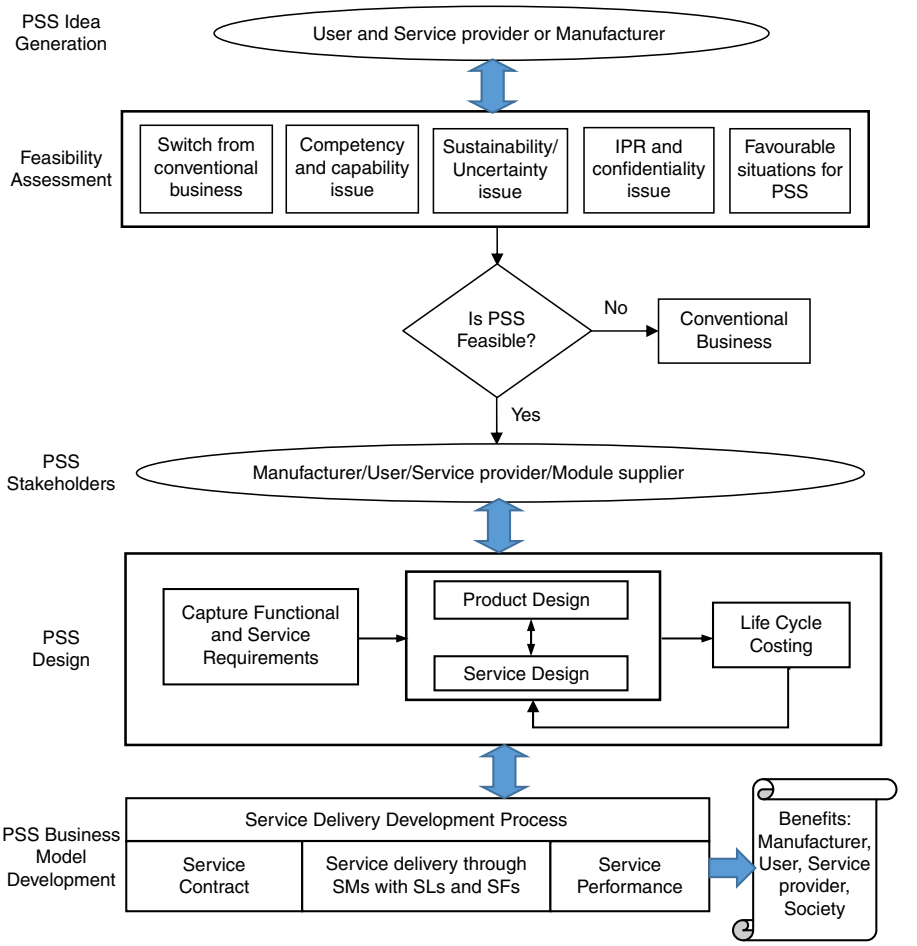

Figure 1.
Proposed conceptual framework for PSS design for machine tools

service requirements would be useful for designing the services for the product. The functional requirements can be captured through market surveys, questionnaires, etc. The service requirements for a product can be captured through surveys, interactions with the customers, customer feedbacks, etc. These requirements should further be analysed to identify the services that fulfil the requirements by adding value to customers.

For example, a few service components (identified during the industrial survey), along with the value they would add to the customers can be seen in Table II.

4.1.2 Product design. After capturing, analysing and prioritizing the functional requirements of customers for a product, the designing team has to consider reliability, maintenance, quality requirements and usage pattern while designing the product with a focus on life cycle aspects. The early participation of the customers helps the designers to evaluate the alternatives at the product design stage so that the product is able to meet the customer's functional and operational requirements. Another way of improving the product design, in order to ensure system components compatibility for

service delivery, could be the involvement of the product designers in the service design process. Inputs to design improvements could be given based on knowledge resources like field records and customer complaints.

For example, during the industrial survey and discussion with service providers, in one case it was experienced by the service engineer that while offering the condition monitoring service, there were difficulties faced in installing the sensors at the right location on the spindle housing for collecting the vibration data for analysis. Based on the feedback of service engineers, the input was given to designers to make appropriate changes in design to make a proper provision for installing the sensors. Thus, the compatibility between the product design and service design needs to be ensured for the ease in serviceability while delivering services to customers.

4.1.3 Service design. Service design should go in parallel with the product design. It highlights the identification of service requirements and demand over the product life cycle based on the product use/consumption pattern. The service design has to be according to the customer expectations, which are different during various life cycle phases of a product. For example, a typical service expectation during the product purchasing phase can be the request for "detailed information" concerning the expected product performance. During product usage phase, a "maintenance" service is most desired by the customers, whereas, "take back" is a commonly expected service during product disposal phase. Services should be designed such that they support the utilization of the product with the required quality and specified performance to achieve customer satisfaction. The service design may call for basic restructuring of the organizational structure. New organizational capabilities may need to be established. It needs hiring new workforce and training them along with existing workforce to deliver the designed services.

4.1.4 Life cycle costing of services. Life cycle costing is one of the most crucial activities of a PSS, as it forms the basis for the economic viability of such a system and would decide the attractiveness of the product service offer to the customers. Life cycle costing includes the costing of all the associated activities including those related to the services offered with the product considering its life cycle, right from conceptual product design to the eco-disposal of the product after the end of its useful life. An accurate methodology should be used for life cycle costing to increase the effectiveness of the system. Life cycle costing would require a lot of cost data sharing between the stakeholders of the system which eventually makes the activity more important and sensible.

4.2 Service delivery development process

Delivery of the designed services is often called as "servicing" (Aurich *et al.*, 2004). It includes steps like designing service contracts, deciding service levels agreements, deciding alternative service delivery mechanisms, selecting the most economical alternative and measuring its service performance for effectiveness. These steps are further discussed in the following subsection.

4.2.1 Service contracts. A service contract is an exchange of promises between service provider and service user, regarding the use and delivery of one or more services (Gangadharan and Luttighuis, 2010). A service contract imposes bindings on the service provider (provider) and the receiver (user) to stick to their commitments for service transactions. It should be in a well-documented form and include terms and conditions pertaining to the service terminology, defined service processes, contract

duration and service delivery levels. It should also include the terms and conditions about the penalties and actions in the event of a breach of contract. The roles and responsibilities of each stakeholder should be clearly defined and illustrated to avoid any ambiguity in the service delivery process.

4.2.2 Service delivery mechanisms. A service mechanism is a structured way in which a particular service can be offered and delivered to a customer. There can be multiple service mechanisms to deliver a service component. For example, in the case of spare parts supply service, the possible mechanisms can be on-call service or stock-based service, i.e. the spare parts supply could be:

(1) On-call in which, based on user's requisition and information about the spare parts, the provider would arrange to supply the spare parts to user's premises.

(2) Stock-based supply in which the provider would keep the stock of the specific spares (frequently consumed by the user) at user's premises. The user would consume the spare parts as and when required and would pay as per consumption. The provider would monitor the stock or user may give a feedback to the provider about the quantity in stock. Accordingly, the provider would replenish the stock so as to avoid stock-outs.

As there can be multiple service mechanisms to deliver a service component, the most economical and convenient service mechanism, from the available options, should be selected considering customer's-specific requirements. Every service mechanism may have a different cost associated with it (cost to deliver that service). A number of possible service mechanisms can be identified for delivering the service components which may enable to offer flexibility to customers to choose an appropriate service mechanism as per their requirements.

4.2.3 Service levels. A service level, in most of the services, is a commitment of the service provider to respond to a customer's service demand within a certain time. Or it can be sometimes an agreeable payment term/mode or an agreeable quality level, as appropriate with respect to service component. For example, the service level in the case of corrective maintenance service can be the "response time" within which the provider attends the service call (service demand).

The various factors which can be considered for deciding the service levels to be offered are: type of customer business (i.e. type of manufacturing set up, whether continuous mass production or batch or job production), Operational need and urgency of the customer. For example, need and urgency for a breakdown maintenance service for a continuous operating plant could be more compared to a job shop production systems. In such a situation, the customer may expect shorter response time for service delivery than the later type business.

At the time of service component selection, the customers may expect the flexibility in terms of choice of service level (response time, cost of service, nature of service). Accordingly, customers should be offered with flexibility in terms of adequate choices to select an appropriate service level.

4.2.4 Service frequency. A "service frequency" refers to the number of times the service is demanded/fulfilled by the customer/service provider. For example, the service frequency in the case of preventive maintenance service can be once or twice or thrice a year. Thus, "service frequency" is based on the number of times the service can be consumed/delivered by the customer/service provider for a machine tool during the contract period. The factors that will affect the service

frequency include: production schedule at customer's end, time required to carry out the service, downtime of machine, cost associated with service, etc. An appropriate service frequency can be recommended and proposed to the customer by the service provider. The service frequency will have major influence on the cost of the service mechanisms and hence, its proper selection is very crucial. As the need for a service component and demand for its frequency by a customer depends largely upon factors like, customer's competency, buying capacity, type of business, etc., customers can expect the flexibility in terms of choice of service frequency. Accordingly, adequate choices in terms of service frequency should be offered such that the customers would be able to conveniently select an appropriate alternative as per their requirement considering the cost impact of service.

As an example, service mechanisms, service level and service frequency for a service component "corrective maintenance" is shown in Table III.

Sr. no.	Service (SC) component & its description	Value addition to user	Service mechanism (SM)	Service level (SL)	Service frequency (SF)
1	Corrective maintenance: breakdown service support with fault identification, diagnosis, repair/ replacement and testing and verification, i.e. bringing back the system to its operational state	Minimize downtime	SM1: technology enhanced web service User will be offered with access to the Provider's web support. From the available solutions of commonly observed failure modes and corrective actions, User may try to extract recommendations/guidelines/ corrective action about the repair/ replacement based on the failure symptoms of the machine	Not applicable (na)	SF1: as per requirement
			SM2: technology assisted web service On User's requisition (phone/mail/ web login query), the provider with user supplied information about the symptoms of the failure, using his expertise and/or web support, provides and communicates a solution to the user by mail/phone. Accordingly, user's workforce will carry out the corrective action	SL1: < 0.5 hrs SL2: < 1 hrs SL3: < 1.5 hrs SL4: < 2 hrs	SF1: as per requirement
			SM3: on-call service User calls the Provider for breakdown maintenance support and provides the primary details about failure symptoms & other relevant information of the machine. The Provider, based on user supplied information, arranges to send expert to User's premises to diagnose/rectify fault and carry out repair/ replacement action to restore the machine in operational state	SL1: < 8 hrs SL2: < 16 hrs SL3: < 24 hrs SL4: < 48 hrs	SF1: as per requirement

Table III.
Service components with service mechanism, service level and service frequency

Thus, the flexibility in terms of service mechanisms, service level and service frequency would enable the customer to create value by customizing the service offering as per their specific requirements.

4.3 Service performance measurement

Performance assessment or evaluation of the delivered services should be done to know what values it has added to the customers. Basically, the services are designed to address the pain areas of the customers. The services delivered should be able to satisfy customers and generate a pleasant experience for them. Quantitative analysis of performance evaluation can be on the basis of the time in which a service call has been responded and completed by service personnel while delivering services to the a customer. The customer satisfaction can be evaluated on the basis of customer retention rate and number of new customers added, alternatively it can also make use of a feedback system to rate the services on a scale. An importance-performance analysis can be used as an effective customer satisfaction evaluation tool (Geng and Chu, 2012).

4.4 PSS benefits

The PSS benefits are manifold. All the involved stakeholders are expected to be benefited in one or other way and the system would bring in a win-win situation for all the stakeholders. For a customer, the pain areas like risks and operational responsibilities, traditionally associated with ownership would get eliminated and they would be benefited in terms of enhanced productivity and increased utilization of equipment. For a machine tool manufacturer, with ownership and direct access to the asset, he can collect data on product performance and use, which can then enable the improvement of performance parameters (e.g. maintenance schedules) to improve machine efficiency, improve asset utilization, reduce total costs and the environmental impact (Baines *et al.*, 2007). It also helps in gaining a positive impact on profitability by exploiting the downstream opportunities through offerings of additional services like financing, maintenance, spare parts and consumables supply, take back, disposal, etc. The other stakeholders like, the module suppliers and auxiliary service providers are also expected to be benefited through a guaranteed business in terms of tangible goods as well as a greater revenue generation through service provisions. It is also expected that the society will get benefited through ecologically safe businesses with PSS for environment protection due to the reduction in resources consumption, and less waste generation.

5. PSS scenario generation and hybrid PSS structures

In this section, the industry survey findings are discussed. It is observed from the customer survey that the machine tool users want flexibility to choose a business model and accordingly adequate role in PSS as per their core competencies. The machine tool manufacturers want that their machines be sold eventually while the PSS type business model can be offered by them for some initial period of time. To address various such requirements of PSS stakeholders, this section attempts to propose various possible alternatives. For this purpose, some new modified structures of PSS have been proposed by generating different scenarios based on the participation of various stakeholders in the modified PSS structures. The hybrid contract structure for PSS are also proposed and discussed along with the key issues for PSS implementation by the Indian machine tool sector.

5.1 Possible scenario generation for PSS

Based on the meetings and discussion held with machine tool manufacturers, users and service providers during the industrial survey, the following possible PSS scenarios (Table IV) are revealed. These are based on machine tool user's and manufacturer's requirement and their PSS perspectives resulting in willingness to opt for PSS.

In case of scenario 1, when two main stakeholders (user and provider), agrees for the PSS, then the PSS conceptualization may take place and negotiations about the other details of the PSS model contract may be initiated. In scenarios 2 and 3, when any of the two main stakeholders (user and provider) does not agree for the PSS, it will not be resulting into a PSS business contract. In scenario 4, the PSS business model contract may get resulted as PSS for the first year, followed by the conventional business model thereafter. Whereas, in case of scenario 5, the PSS model contract would be resulting with the involvement of a third party (leasing bank as a financer) in which, the manufacturer sells machines to third party who offers PSS to the user; after completion of contract period, third party may re-offer PSS with existing user or search for other user as PSS partner.

5.2 Modified PSS structures

Depending on core competencies and mutual understanding, there can be different levels of involvement of machine tool user (user) and manufacturer or service provider (provider) while participating in a PSS. For example, in a full PSS, the user has to provide space and power (mandatory in all forms of PSS) whereas rest all manufacturing requirements will be taken care of by the service provider. Likewise, in some other form of PSS:

- user owns machine, operations and tooling, while maintenance is done by the provider;
- user owns machine and tooling, while the operations and maintenance is through the provider; and
- provider owns machine and offers maintenance, while user takes care of operations and tooling, and so on.

There can be number of such combinations with varying level of stakeholders' participation. Few of such combinations for selected artefacts and activities (machine, tooling solution, process design, operations and quality control, preventive and breakdown maintenance, etc.) with respect to ownership are shown in Table V.

5.3 Hybrid PSS structures

During the industrial survey, it was observed that most of the machine tool manufacturers were not very much in favour of PSS concept as it requires a shift from

Sr. no.	PSS type	User	Provider
1	Pure PSS	Yes	Yes
2	Pure PSS	Yes	No
3	Pure PSS	No	Yes
4	One year PSS offer and eventually after one year user buys the machines	Yes	Yes
5	PSS offer with a third party involvement (e.g. leasing bank)	Yes	Yes

Table IV. PSS scenarios

PSS alternative	Machine	Tooling solution	Process design	Ownership Operations & quality control	Maintenance Preventive	Maintenance Breakdown
1 (full PSS)	P	P	P	P	P	P
2	U	P	P	P	P	P
3	P	U	P	P	P	P
4	P	P	U	P	P	P
5	P	P	P	U	P	P
6	P	P	P	P	U	P
7	P	P	P	P	P	U
8	U	U	P	P	P	P
9	P	U	U	P	P	P
10	P	P	U	U	P	P
11	P	P	P	U	U	P
12	P	P	P	P	U	U
13	U	P	P	P	P	U
14	U	U	U	P	P	P
15	P	U	U	U	P	P
16	P	P	U	U	U	P
17	P	P	P	U	U	U
18	U	P	P	P	U	U
19	U	U	P	P	P	U
20	U	U	U	U	P	P
21	P	U	U	U	U	P
22	P	P	U	U	U	U
23	U	P	P	U	U	U
24	U	U	P	P	U	U
25	U	U	U	P	P	U
26	U	U	U	U	U	P
27	P	U	U	U	U	U
28	U	P	U	U	U	U
29	U	U	P	U	U	U
30	U	U	U	P	U	U
–						
–						
–						
64 (conventional business)	U	U	U	U	U	U

Table V.
PSS structures

Notes: U, user; P, provider

the conventional machine selling business model. They were interested in business models which eventually would lead to selling of their machines. To address this need and to enhance the flexibility of PSS business model offerings, a hybrid PSS model comprising the three phases is proposed and elaborated as follows.

In the hybrid PSS model the usage and other service responsibilities can be shared by the system stakeholders in a phased manner as per their competencies and requirements. A hybrid PSS model consisting three phases, namely, PSS operation phase, PSS transition phase and the system handover phase is shown in Figure 2.

The first phase represents a result-oriented PSS, i.e. PSS operation phase. In this phase, the activities related to usage, maintenance of the machine tool, quality

control, spares supply, warehousing, etc., are taken care of by the PSS provider. The customer would be responsible to make provision for space and the electricity and would pay to the provider on cost per piece basis. This would be done for a specific period, say one year during which the provider may develop and establish the process.

After one year, second phase, i.e. transition period will start. This phase represents a usage or use oriented PSS. During this phase, the machine ownership will remain with the provider but the production activities, quality control and warehousing activities would be taken care of by the customer. The provider would be responsible only for offering services to ensure the availability of the machines for production, and all the activities related to production would have to be taken care of the customer. During transition period the customer will be in learning stage and the provider would have to train the customer's workforce for activities and skills required for production and other services. Gradually, activities can be taken over by the customer and thus partially may share the responsibility depending upon the competency. This would be done for some duration, say one year.

In the third phase, i.e. handover phase, the ownership of the machine tool and responsibilities for activities like usage, maintenance and quality control would be transferred to the customer. Depending upon the requirements, the customer can seek provider's support in some of the activities in terms of services for which the provider would be paid by the customer. This would continue on mutual understanding between the customer and provider for the period of contractual agreement. After that, the customer may or may not take the support services from the provider, thus resulting into a conventional business. Such a business arrangement is also termed as product-oriented PSS.

The advantage of such contracts is that the risk of the service provider as well as the customer is reduced to a large extent. The service provider does not have to hold on to the machines for long durations thereby avoiding future risks of contract termination and profitability loss. The customer does not have to worry about initial operation of the machines, training of operators and the risk of buying the machines during uncertain stages of product development.

5.4 Context-specific PSS structures

There could be situations where a context-specific form of PSS structure may be beneficial. During the industrial survey, some modified versions of a PSS appeared relatively more attractive to the machine tool manufacturer. For example, the customer agrees for a specified period of contract, where the manufacturing system would be owned, maintained and operated by the PSS provider. At the end of the contract period, the customer would buy the manufacturing system. Any modifications required for the manufacturing system and tooling during this period would be done by the PSS provider. Subsequently, the tooling will always be purchased from the machine tool

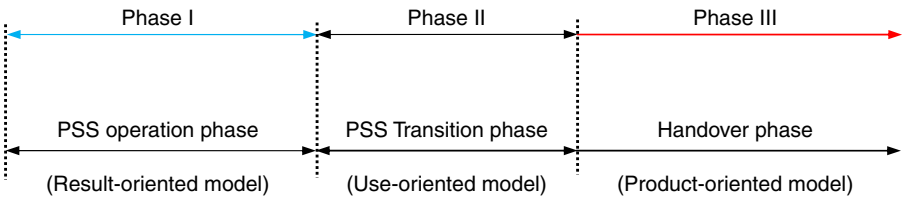

Figure 2.
Hybrid PSS business model

manufacturer for an additional time period. Eventually, as the machines would be purchased by the customer, the machine tool manufacturer will continue to offer PSS for the tooling.

In another situation, the end customer (e.g. an OEM) would identify a supplier who has component manufacturing experience and is ready to invest only if the product demand and mix are reasonably stable. For products under development stage, the demand and the product mix are uncertain for an initial period. So the OEM can host the manufacturing system which is being offered as a PSS by a machine tool manufacturer during this period. Once the product designs, demand and product mix are fairly stable, the manufacturing system will be purchased by the supplier if the OEM agrees for a minimum duration and quantity contract.

Some machine tool manufacturers have their own component manufacturing set-ups. Here, the concept is that the component can be manufactured with the purpose of demonstrating the process capability, cycle times, along with helping the customer in process development. Once the manufacturing system is proven, it is sold to the customer. The duration of such contracts could be very short.

Few machine tool manufacturers were of the opinion that in case a PSS is offered, the sustainability is better if during lean periods, the manufacturing system can be used to produce components for other customers. However, since it is expected that the manufacturing system will be hosted at customer's premises, it appears unlikely that such an arrangement will be acceptable to the customer.

6. Important issues related to PSS design, implementation and management

In this section, the key issues for PSS implementation by the Indian machine tool sector are elaborated along with various stakeholders' concerns. Some favourable situations for the PSS are also discussed.

6.1 Issues related to PSS feasibility, sustainability and implementation

There are some business issues concerned to PSS as observed during the industrial survey. The stakeholders of PSS were found suspicious about the feasibility of PSS and were interested in knowing elucidations regarding issues like, by going for a PSS which of the customer's pain areas would get eliminated? Is PSS model sustainable with sufficient profitability? Does it help in having a better understanding of how machines are performing? Will it help in improving the machines, thereby helping in increasing the regular business? Taking into consideration these issues, following important inferences were made based on observations through meetings and interviews with machine tool manufacturers, users and service providers.

6.1.1 Machine tool manufacturer's desire to continue with the conventional business. Machine tool manufacturers wanted to stick to the conventional business of selling machines and hesitate to get into a different line of business. Offering of functionality (PSS) rather than selling tangible products does not fit into their strategy. They wanted to be in the business of making and selling machining solutions. Any business activity that does not contribute to their machine selling business did not get a favourable consideration.

This may be due to lack of awareness about the potential benefits of the PSS concept and local laws and regulations of the country. The mind-sets of the people and business stakeholders may be another reason for the hesitation.

6.1.2 Competency and capability issue. Machine tool manufacturers believed that component production is all-together a different domain, and expertise in machine building does not automatically lead to an expertise in component manufacturing, leading to competency issue. Also, they do not wanted to appear as competitors to their customers who are in the business of component manufacturing. Manufacturers think that the additional production and services provision activity would need extra skilled manpower and supporting staff. The existing workforce would not be sufficient and capable to meet such business demand leading to capability issue, and additional manpower needs to be hired. This may also call for basic restructuring of the organization.

6.1.3 Sustainability and uncertainty issue. For non-critical components, customer would find it cheaper to outsource the production to a supplier who is specialized in component manufacturing. Space within OEM's factories is generally very costly. The cost to the PSS provider to setup the manufacturing system in such location may prove to be very high. Machine tool manufacturers believe that the profit margins may not be enough to sustain such an activity on a larger scale. In addition to this, uncertainties like demand change, technological changes, market fluctuations over the period of time, are amongst few factors which also influence the business profitability and sustainability in market and needs due considerations.

6.1.4 Intellectual property rights (IPR) and confidentiality issue. Suitability of this business (PSS) model is an issue. OEMs generally retain in-house manufacturing of only critical components. For such components, the fear remains that the process information may get divulged to their competitors if the machine tool manufacturer does a similar business with them. On the other hand, machine tool manufacturers do not want to restrict their business to any one customer. One of the requisites of PSS is sharing of data and information amongst the stakeholders. Users and manufacturers of machine tool were found reluctant to share any confidential information related to product/process design, service design, maintenance, quality and other business secrets because of divulge fear leading to IPRs issue.

Along with above mentioned issues, the general concerns of stakeholders includes, possibility of getting another PSS contract, if the first one gets terminated, was of high concern. Even if a customer was available, modifications would be needed for the manufacturing systems, which mean additional investment. If the returns on investments are not high, such models (PSS) do not appear attractive in the Indian business environment.

6.2 Favourable situations for PSS

Even though some issues related to PSS concept do exists, there observed some situations where the PSS concept was found to be attractive to the machine tool users and manufacturers. Some of such situations are discussed as below.

6.2.1 Possibility of low-cost per piece. Almost all the user industries visited and interviewed during survey, have shown their concerns about the cost per piece if the PSS business model is implemented. The users found PSS concept attractive when the possibility of a much lower cost per piece was considered.

6.2.2 User has plan to venture into new business segment. In cases where the user has plans of venturing into new market segments, the PSS concept appeared to be more attractive, as the entire burden of system design, process development, operations and maintenance was to be taken care of by the service provider (machine tool manufacturer).

PSS was also found attractive to the users in situations where high frequencies of design modifications were expected and the burden of modifying the manufacturing system and the tooling could be transferred to the PSS provider.

6.2.3 Raw material purchase and inventory management as a part of PSS. Users have shown more inclinations if the raw material purchase from a user specified supplier and the inventory holding is also done as a part of the PSS. In such cases, the burden of ensuring availability of raw material, ensuring its quality and maintaining appropriate inventory is on the part of PSS provider.

6.2.4 Manufacturer intends to prove newly developed machine's performance. Some machine tool manufacturers have shown interest in the PSS concept in cases where high end new machines are designed. The benefit to the PSS provider is that the performance of the new machines can be evaluated and issues related to reliability, accuracy, repeatability could be addressed in subsequent designs. In such cases, generally, profit earning is not the objective of service provider (machine tool manufacturer).

7. Conclusions

The PSS is an emerging concept in the manufacturing sector. The "selling functionality" model (PSS) in the machine tool context is not explored and addressed explicitly in the existing literature. To address this gap, an attempt has been made through this paper to propose a conceptual framework for PSS design for machine tools. It would help the concerned stakeholders to understand the PSS concept and serve as a primary foundation for further developing different PSS business models in order to motivate the stakeholders towards this emerging business alternative.

It was observed from the literature review and the discussion with relevant stakeholders during the industrial survey that offering service configuration flexibility is not practiced currently in the Indian machine tool sector. Therefore, many times, the customer has no choice other than availing the standard service packages like AMCs from the service provider. With the proposed framework, the service provider would be able to design the services with adequate flexibility (for service specifications like choices for opting service mechanism, service level and service frequency) to the customers so that they can choose the services as per their specific requirements. With such a flexibility, the customers would also be able to customize the service packages offered by providers.

The framework would guide the PSS designers on how to incorporate the flexibility in business models and service offerings to meet the varied customers' requirements. While the customer's flexibility requirements about service configuration is addressed through the framework, the business model flexibility is addressed through the proposed hybrid PSS model which was evolved as an outcome of industrial survey.

The industrial survey contributes towards providing an insight about the PSS design and implementation issues in the context of the Indian machine tool business sector. It is also revealed from industry survey that the concept of PSS and its benefits for the industries are not known to and explored by the machine tool industries. There seems some hesitation in the machine tool manufacturers' minds for its adaptation thinking that with PSS, there would be two conflicting business streams, one wanting to sell machines, other wanting to own the machines and offer functionality as a service. It is also noticed that the "selling functionality" approach (PSS) would be considered by the industries if it comes as a customer's demand or as an

alternative being offered by the machine tool manufacturer to the customer in order to explore innovative business ideas. Moreover, it is found that PSS approach can be attractive to a machine tool manufacturer in those cases where new machines are to be promoted in the market, and when the machine tool manufacturer is new and therefore wants to build confidence in the minds of customers in order to establish its credibility in the new market segment.

Despite the need for more structured guidelines and standardised methods to develop the PSS for machine tools and motivate the industries to consider it as an alternative business model, the proposed framework attempts to offer a ground to further develop the innovative practices for newer business models. Apart from the existing business models of PSS, a potential for hybrid PSS models and context-based PSS models can also be seen in the future machine tool market. As a future scope, it would be interesting to develop a service system design using the proposed framework and apply it in a real life manufacturing scenario. It may require identification of appropriate tools and techniques that would help in developing such a system and evaluating its performance.

References

Alonso-Rasgado, T., Thompson, G. and Elfström, B. (2004), "The design of functional (total care) products", *Journal of Engineering Design*, Vol. 15 No. 6, pp. 515-540.

Aurich, J.C., Fuchs, C. and DeVries, M.F. (2004), "An approach to life cycle oriented technical service design", *CIRP Annals-Manufacturing Technology*, Vol. 53 No. 1, pp. 151-154.

Aurich, J.C., Fuchs, C. and Wagenknecht, C. (2006a), "Life cycle oriented design of technical product-service systems", *Journal of Cleaner Production*, Vol. 14 No. 17, pp. 1480-1494.

Aurich, J.C., Fuchs, C. and Wagenknecht, C. (2006b), "Modular design of technical product-service systems", in Brissaud, D., Tichkiewitch, S. and Zwolinski, P. (Eds), *Innovation in Life Cycle Engineering and Sustainable Development*, Springer, Berlin, pp. 303-320.

Aurich, J.C., Wolf, N., Siener, M. and Schweitzer, E. (2009), "Configuration of product-service systems", *Journal of Manufacturing Technology Management*, Vol. 20 No. 5, pp. 591-605.

Baines, T.S., Lightfoot, H.W., Benedettini, O. and Kay, J.M. (2009), "The servitization of manufacturing – a review of literature and reflection on future challenges", *Journal of Manufacturing Technology Management*, Vol. 20 No. 5, pp. 547-567.

Baines, T.S., Howard, W., Lightfoot, S.E., Neely, A., Greenough, R., Joe, P. and Roy, R. (2007), "State-of-the-art in product-service systems", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, Vol. 221 No. 10, pp. 1543-1552.

Barquet, A.P.B., de Oliveira, M.G., Amigo, C.R., Cunha, V.P. and Rozenfeld, H. (2013), "Employing the business model concept to support the adoption of product-service systems (PSS)", *Industrial Marketing Management*, Vol. 42 No. 5, pp. 693-704.

Biege, S., Copani, G., Lay, G., Marvulli, S. and Schroeter, M. (2009), "Innovative service-based business concepts for the machine tool building industry", *Proceedings of the 1st CIRP Industrial Product-Service Systems (IPS2) Conference, Cranfield University, London*, p. 173.

Copani, G. and Rosa, P. (2015), "DEMAT: sustainability assessment of new flexibility-oriented business models in the machine tools industry", *International Journal of Computer Integrated Manufacturing*, Vol. 28 No. 4, pp. 408-417.

Doualle, B., Medini, K., Boucher, X. and Laforest, V. (2015), "Investigating sustainability assessment methods of product-service systems", *Procedia CIRP*, Vol. 30, pp. 161-166.

Durugbo, C. (2013), "Competitive product-service systems: lessons from a multicase study", *International Journal of Production Research*, Vol. 51 No. 19, pp. 5671-5682.

Durugbo, C., Bankole, O., Erkoyuncu, J.A., Tiwari, A., Alcock, J.R., Roy, R. and Shehab, E. (2010), "Product-service systems across industry sectors: future research needs and challenges", *Proceedings of the 2nd CIRP IPSS Conference*, *Linköping*, *14-15 April*, pp. 535-542.

Eggert, A., Hogreve, J., Ulaga, W. and Muenkhoff, E. (2014), "Revenue and profit implications of industrial service strategies", *Journal of Service Research*, Vol. 17 No. 1, pp. 23-39.

Evans, S., Partidario, P.J. and Lambert, J. (2007), "Industrialization as a key element of sustainable product-service solutions", *International Journal of Production Research*, Vol. 45 Nos 18-19, pp. 4225-4246.

Gangadharan, G.R. and Luttighuis, P.O. (2010), "BHive: a reference framework for business-driven service design and management", *Journal of Service Science*, Vol. 2 No. 1, pp. 81-110.

Gebauer, H., Friedli, T. and Fleisch, E. (2006), "Success factors for achieving high service revenues in manufacturing companies", *Benchmarking: An International Journal*, Vol. 13 No. 3, pp. 374-386.

Geng, X. and Chu, X. (2012), "A new importance-performance analysis approach for customer satisfaction evaluation supporting PSS design", *Expert System & Applications*, Vol. 39 No. 1, pp. 1492-1502.

Isaksson, O., Larsson, T.C. and Rönnbäck, A.O. (2009), "Development of product-service systems: challenges and opportunities for the manufacturing firm", *Journal of Engineering Design*, Vol. 20 No. 4, pp. 329-348.

Kim, S. and Yoon, B. (2012), "Developing a process of concept generation for new product-service systems: a QFD and TRIZ-based approach", *Service Business*, Vol. 6 No. 3, pp. 323-348.

Komoto, H. and Tomiyama, T. (2008), "Integration of a service CAD and a life cycle simulator", *CIRP Annals-Manufacturing Technology*, Vol. 57 No. 1, pp. 9-12.

Komoto, H. and Tomiyama, T. (2009), "Design of competitive maintenance service for durable and capital goods using life cycle simulation", *International Journal of Automation Technology*, Vol. 3 No. 1, pp. 63-70.

Linstone, H.A. and Turoff, M. (1975), *The Delphi Method: Techniques and Applications*, Vol. 29, Addison-Wesley, Boston, MA.

Long, H.J., Wang, L.Y., Shen, J., Wu, M.X. and Jiang, Z.B. (2013), "Product service system configuration based on support vector machine considering customer perception", *International Journal of Production Research*, Vol. 51 No. 18, pp. 5450-5468.

McAloone, T.C. (2007), "A competence-based approach to sustainable innovation teaching, experiences within a new engineering program", *Journal of Mechanical Design*, Vol. 129 No. 7, pp. 769-778.

Manzini, E. and Vezzoli, C. (2003), "A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize", *Journal of Cleaner Production*, Vol. 11 No. 8, pp. 851-857.

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.

Mei, H.C., Sher, P.J., Chen, C.W. and Lo, S. (2014), "A preliminary study on manufacturing servitization in machine tool industry", *Management of Engineering & Technology (PICMET) 2014 Portland International Conference, IEEE*, pp. 2343-2353.

Meier, H. and Massberg, W. (2004), "Life cycle-based service design for innovative business models", *CIRP Annals-Manufacturing Technology*, Vol. 53 No. 1, pp. 393-396.

Meier, H., Roy, R. and Seliger, G. (2010), "Industrial product-service systems-IPS2", *CIRP Annals-Manufacturing Technology*, Vol. 59 No. 2, pp. 607-627.

Mert, G., Waltemode, S. and Aurich, J.C. (2014), "Quality assessment of technical product-service systems in the machine tool industry", *Procedia CIRP*, Vol. 16, pp. 253-258.

Mont, O.K. (2002), "Clarifying the concept of product-service system", *Journal of Cleaner Production*, Vol. 10 No. 3, pp. 237-245.

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., Kebir, N., Stark, R. and Blessing, L. (2009), "PSS layer method-application to microenergy systems", *Introduction to Product/Service-System Design*, Springer, London, pp. 3-30.

Neely, A. (2008), "Exploring the financial consequences of the servitization of manufacturing", *Operations Management Research*, Vol. 1 No. 2, pp. 103-118.

Okoli, C. and Pawlowski, S.D. (2004), "The Delphi method as a research tool: an example, design considerations and applications", *Information & Management*, Vol. 42 No. 1, pp. 15-29.

Rexfelt, O. and Ornas, V.H. (2009), "Consumer acceptance of product-service systems. Designing for relative advantages and uncertainty reductions", *Journal of Manufacturing Technology Management*, Vol. 20 No. 5, pp. 674-699.

Richter, A., Sadek, T. and Steven, M. (2010), "Flexibility in industrial product-service systems and use-oriented business models", *CIRP Journal of Manufacturing Science & Technology*, Vol. 3 No. 2, pp. 128-134.

Roy, R. (2000), "Sustainable product-service systems", *Futures*, Vol. 32 No. 3, pp. 289-299.

Sakao, T. and Shimomura, Y. (2007), "Service engineering: a novel engineering discipline for producers to increase value combining service and product", *Journal of Cleaner Production*, Vol. 15 No. 6, pp. 590-604.

Sakao, T., Shimomura, Y., Sundin, E. and Comstock, M. (2009), "Modeling design objects in CAD system for service/product engineering", *Computer-Aided Design*, Vol. 41 No. 3, pp. 197-213.

Schuh, G., Potente, T., Schittny, B. and Wittek, A. (2011), "Industrial product-service-systems for the tooling industry", *Proceedings of the 17th International Conference on Concurrent Enterprising (ICE 2011), Vols 20-22*, pp. 1-8.

Sheng, Z., Xu, T. and Song, J. (2015), "Configuration design of product service system for CNC machine tools", *Advances in Mechanical Engineering*, Vol. 7 No. 2, p. 971720.

Shimomura, Y., Hara, T. and Arai, T. (2008), "A service evaluation method using mathematical methodologies", *CIRP Annals-Manufacturing Technology*, Vol. 57 No. 1, pp. 437-440.

Shimomura, Y., Hara, T. and Arai, T. (2009), "A unified representation scheme for effective PSS development", *CIRP Annals-Manufacturing Technology*, Vol. 58 No. 1, pp. 379-382.

Tan, A.R., McAloone, T.C. and Gall, C. (2007), "Product/service-system development – an explorative case study in a manufacturing company", *Proceedings of the International Conference on Engineering Design ICED'07, 28-31 August*.

Tan, A.R., Matzen, D., McAloone, T.C. and Evans, S. (2010), "Strategies for designing and developing services for manufacturing firms", *CIRP Journal of Manufacturing Science & Technology*, Vol. 3 No. 2, pp. 90-97.

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

Uhlmann, E., Raue, N. and Gabriel, C. (2013), "Flexible implementation of IPS2 through a service-based automation approach", *Procedia CIRP*, Vol. 11, pp. 108-113.

van Halen, C., Vezzoli, C. and Wimmer, R. (2005), *Methodology for Product Service System Innovation, How to Implement Clean, Clever and Competitive Strategies in European Industries*, ISBN: 90-232-4143-6, Royal Van Gorcum, Assen.

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.

Wang, P.P., Ming, X.G., Li, D., Kong, F.B., Wang, L. and Wu, Z.Y. (2011), "Status review and research strategies on product-service systems", *International Journal of Production Research*, Vol. 49 No. 22, pp. 6863-6883.

Weber, C., Steinbach, M., Botta, C. and Deubel, T. (2004), "Modelling of product-service systems (PSS) based on the PDD approach", *Proceedings of the 8th International Design Conference, Dubrovnik, 18-21 May*.

Welp, E.G., Meier, H., Sadek, T. and Sadek, K. (2008), "Modelling approach for the integrated development of industrial product-service systems", *Manufacturing Systems and Technologies for the New Frontier*, Springer, London, pp. 525-530.

Wise, R. and Baumgartner, P. (1999), "Go downstream – the new profit imperative in manufacturing", *Harvard Business Review*, Vol. 77 No. 5, pp. 133-141.

Zhu, Q.Q., Jiang, P.Y., Huang, G.Q. and Qu, T. (2011), "Implementing an industrial product-service system for CNC machine tool", *International Journal of Advanced Manufacturing Technology*, Vol. 52 Nos 9-12, pp. 1133-1147.

Further reading

Azarenko, A., Roy, R., Shehab, E. and Tiwari, A. (2009), "Technical product-service systems: some implications for the machine tool industry", *Journal of Manufacturing Technology Management*, Vol. 20 No. 5, pp. 700-722.

Morelli, N. (2003), "Product-service systems, a perspective shift for designers: a case study: the design of a telecentre", *Design Studies*, Vol. 24 No. 1, pp. 73-99.

Corresponding author

Pankaj U. Zine can be contacted at: zinepu@mech.iitd.ac.in