A FRAMEWORK FOR DESIGNING PRODUCT-SERVICE SYSTEMS

Gokula Vijaykumar Annamalai Vasantha[1], Romana Hussain[1], Rajkumar Roy[1], Ashutosh Tiwari[1], and Stephen Evans[1]
(1) Cranfield University, UK

ABSTRACT
In this competitive globalizing scenario, manufacturers are adopting a strategy of bundling products and services into an integrated solution to create sustainable competitive advantage. Servitizing manufacturers are increasingly transforming their processes and practices to build product-service systems (PSS). During this transformation they require substantial support to face stringent challenges. Research in the PSS domain is heading towards the development of a design theory and methodology that facilitates the systematic creation of viable PSS conceptual designs. In this paper, various proposed design methods are reviewed and research gaps are summarized. Primarily, it has been observed that the importance of the capabilities of the stakeholders involved in designing PSS has not been noted in the proposed methods. Regarding this capability view point, a framework for designing PSS has been proposed. This framework highlights the important features required in designing PSS such as co-creation, responsibilities and competences. Every step in the framework has been explained with a case study involving laser systems used for manufacturing cutting operation.

Keywords: Product-Service System, design, capability, co-creation

1 INTRODUCTION
Manufacturers are feeling the strain of the recent recession and need alternate strategies to cope with globalization, reducing profit margins and for retaining and attracting customers. Servitization is a promising approach to help manufacturers to achieve these objectives. Servitization emphasizes the importance of service and aids in integrating products and services to satisfy customer needs better. It is a strategy of bundling products and services into an integrated solution to create sustainable competitive advantage. It aims to provide required customer value through reduce cost, optimized resources which can be sustained for both consumption and production. The term servitization is also referred as the service economy or Product-Service Systems (PSS). These concepts intend to emphasise a use or outcome to the customer. Many definitions for PSS are proposed in literature. Commonly PSS is defined as a “system of products, services, networks of “players” and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models” [1]. The major merits for the manufacturer of this approach are increased revenue, prolonged and strategic relationships with the customer and product/service improvements based on improved understanding of customer requirements.
Based on the spectrum of product and service mixtures in the offerings, PSS has been commonly classified into three types: Product Oriented, Use Oriented and Result Oriented [2]. This classification is based on product ownership and functionality, business models and product and service substitution. The emphasis in all types is on the ‘*sale of use*’ rather than the ‘*sale of product*’. A major perspective of this concept is to consider the system as a whole, rather than just physical products [3]. The partial substitution of product and service shares over the lifecycle and the dynamic adaptation to changing customer demands and provider abilities are with the details that defining PSS [4].
These points illustrate that the manufacturer’s core competences are moving away from manufacturing to systems design and integration. The primary element required to widen their core competences lies in the process of co-creation. This is because the design of a PSS is a co-creation process between manufacturers, suppliers and customers. PSS could be a win-win-win solution for all the stakeholders involved. The ability of the manufacturer to deliver a PSS very much depends on the capability of the available service network. It has been highlighted that the ability of a manufacturer to action a strategy of servitization is dependent on the capability of the available service network as over 75% of a

product is designed and sourced from the supply chain and they contribute to through life support through the design and delivery of services [5]. Design of a system along with products and services within a network context makes this process complex. Many factors are to be considered in designing PSS such as stakeholders (culture, relationships, role and communication), environment (B2B, B2G, B2C), business model, life cycle stages, support system, infrastructure, technology and risks. The focus of this work is on the business to business (B2B) environment.

PSS involves complex B2B relationships within a service network and has to consider the capability to deliver the service over a long timeframe across geographies. Currently the conceptual design in practice is ad-hoc and lacks a systematic approach to consider the service network and customer capabilities and issues in the PSS design process. The lack of systematic approach is also valid for take-back service operations such as product remanufacturing and recycling [6]. The research has also observed that service is often added after the product is designed, there is a lack of communication between after-sales and design teams, and the designers' mindset is still very product centric. The research has also identified current lack of knowledge to trade-off between physical (product) and non physical (service) functionalities to create required customer value or reduce cost and opportunities for resource optimisation during the PSS design process.

Within our research group, PSS design is defined as a process to synthesise and create sustained functional behaviour through tangible products and intangible services. Sustained functional behaviour should represent how the system achieves its purpose continuously. PSS design involves design of business models, design of products and services, design of processes and the interactions between elements involved in the system. It has been emphasized that the requirement is to innovate the system, not just the business model. The aim of our research is to develop a formal approach to conceptual design of PSS considering existing and potential service network capability and past knowledge from the use of similar provisions. This PSS conceptual design framework for the manufacturer should address the capabilities and requirements of the service network and customer using a co-creation process.

In this paper, an initial framework for designing conceptual PSS has been proposed to emphasize the capabilities of the stakeholders. The rest of the paper is structured as follow: Section 2 summarizes various PSS design methodologies proposed in literature, Section 3 details the proposed framework explaining with a case study of laser system which is used for cutting operations and Section 4 concludes with a discussion and future work to be carried out.

2 LITERATURE SURVEY

In this section, PSS design methodologies proposed in literature are discussed and some of the research challenges are highlighted with respect to the focus of this paper. Komoto and Tomiyama [7] proposed Service CAD which supports designers to generate conceptual design of PSSs. They argue that for PSS design processes, designers define *activity* to meet specified *goal* and *quality*, and define *environment* as being the circumstance within which the *activity* is realized. The elements used in Service CAD are *service environment, provider, receiver, channel, contents, activity, aim of the service receiver's activity, target, promised goal, realised service, quality* and *value added*. They also developed ISCL (Integrating Service CAD with a life cycle simulator) which has functions to support quantitative and probabilistic PSS design using life cycle simulation.

Maussang et al. [8] consider the whole system and detail the physical objects and service units necessary to develop a successful PSS. They argue that this methodology can support the design of PSSs to start from the design of the architecture to go to the detail of physical objects (products) specifications. They used operational *scenarios* to go deeper into the system description once main elements of the system (physical objects and service units) have been identified. External *functional analysis* is used to list the external functions that the customer and actors involved in the product lifecycle expect from the 'product' without considering elements available to provide them. They argue that a specific external analysis must be carried out for each step of the product life cycle (use, manufacture, maintenance, recycling, etc.). They characterize each function or constraint by *criteria, level* and *allowance*. They argue that this characterisation leads to the detail of specifications and product performance expected by the customer.

Shimomura et al. [9] aim to propose a method for designing service activity and product concurrently and collaboratively during the early phase of product design. To enable this, a unified representation scheme of human process and physical process in service activity is proposed. They expressed a state change of a customer by parameters called *Receiver State Parameters* (RSPs), which represent customer value. They propose a *view model* which handles functions and attributes to represent RSPs. They include three phases in service design process: *identifying customer value, design of service contents* and *design of service activity*. They also developed a method to evaluate these processes with Quality Function Deployment. Sakao et al. [10] developed a service model consisting of four sub-models: *flow model, scope model, scenario model, and view model.* They emphasize that the critical concept is not the function of a product, but rather the state change of the receiver. The state change can be fulfilled either by products or by service activities. They have implemented these models in their prototype software tool which is named Service Explorer.

Aurich et al. [11] introduce a process for the systematic design of product related technical services based upon its *modularization* to link with corresponding product design processes. They propose an Object oriented technical service model to support the specification of technical services during their actual designing. The service components mentioned in the model are: the component *description* which provides a general overview of a technical service both verbally and graphically; the component *reference* covers the description of the products, product components or users' profiles addressed by the technical service along with the intended effects on them; the component *function* describes the measures for realizing the service functions; and the component *resources* covers both physical and nonphysical resources necessary for realizing a service. They developed a systematic service design process to specify technical services according to the presented service model. They suggest that adapting already existing product design processes to account for the special characteristics of technical services would lead to maximum acceptance for application within the enterprise.

Welp et al. [12] argue that an Industrial PSS (IPS^2) constitutes any combination of product and service shares and propose that the IPS^2 concept development is responsible for generating principle solutions that meet customer specific requirements. They present a model based approach to support an IPS^2 designer generating heterogeneous IPS^2 concept models in the early phase of IPS^2 development. They frame three planes for systematic conceptual development: IPS^2 function plane, IPS^2 object plane and IPS^2 process plane. Three different types of model elements are defined: *system elements, disturbance elements* and *context elements*. The combination of all types of model elements, planes and their respective relations constitutes a heterogeneous IPS^2 concept model.

Alonso-Rasgado et al. [13] described a design process for Total Care Product (TCP) creation that integrates hardware and service support by providing a robust design methodology. Five stages identified in the design of service support systems for a functional product are: concept creation for the service support system, identification of subsystems required, integration of the subsystems that together will provide the service, modeling of the proposed service system and testing and implementation. The fast-track design process consists of a methodology that breaks down the iterative process between customer and supplier into a number of distinct stages necessary for the creation of the TCP. Fast-track design process is framed as: business ambitions of the client, potential business solutions, enhanced definition of the potential TCP, business case risk analysis of options, business case validation and evaluation of alternatives and contract. They consider two main variables of the system to consider in simulations: time taken to perform the service and the quality and flow of information within the system.

Muller et al. [14] have proposed a method for the development of PSS called PSS Layer method. This method is intended to apply to the early development phases which comprise of the clarification of the design task and the conceptual design phase. It defines a metamodel of nine main element classes for a PSS. The classes are: n*eeds, values, deliverables, actors, lifecycle activities, core products, periphery, contract and finance*. All classes are graphically layered to simplify the representation. They argue that this model provides the user with a structured outline and an overall picture of PSS idea or concept. Tan et al. [15] proposed four dimensions of PSS that had to be considered: *value proposition, product life cycle, activity modelling cycle* and the *actor network*. They argue that these elements cover the essential design elements of a PSS. They suggest that a change in one dimension influences the others and the designer has to ensure that each of the dimensions of a new PSS concept support each other in order to be consistent.

Some of the observations from the various methodologies discussed in literature are as follow:

Integrating products and services seems to be the major objective for most of the proposed methodologies.

- The driving factors (risks and uncertainties) of PSS are not properly modelled.

- Most of the approaches are based upon a systems perspective.
- Only a few methodologies stress the importance of co-creation between stakeholders and feedback loops between the steps involved in the process.
- The roles of the stakeholders involved in designing PSS offerings are not clearly defined in the methodologies. In particular, the capabilities of the stakeholders are not considered during design stage.
- The influences of business models on product and service offers are not studied in detail.

These issues stress the enormous amount of research still required in developing PSS design methodology. To stress the importance of co-creation and the capabilities of the stakeholders in designing PSS, the following framework has been developed. It should be noted that PSS design involves offerings to the customers and also the system development which delivers the offerings for the contractual period. The next section details the framework structure and elaborates the steps through a laser system case study applied to manufacturing cutting operation.

3 FRAMEWORK FOR DESIGNING PSS

From literature it has been identified that a framework is required to emphasise the importance of co-creation process and capabilities of the stakeholders involved in designing PSS. A framework has been developed from our understanding through industrial case studies. This framework intends to facilitate:

- Structuring the purposes of interactions between the customer, manufacturer and suppliers,
- An understanding of the value of PSS offerings as appreciated by the customer,
- An understanding of the competences of the stakeholders and
- Assist in implementing developed PSS offerings.

Figure 1 illustrates this initial framework for the PSS co-creation design process. The subsequent sub-sections detail each step in the framework using a case study example of a laser system which is used for cutting operations for manufacturing purposes.

3.1 Customer Needs

Identifying and understanding the customer needs are the primary steps in the design process. Apart from identifying the value needed by the customers, in PSS design prime importance has to be stressed in the added value to be received by the customer in long term. The value addition needs to be emphasized in all the dimensions of economic, social and environmental sectors. In literature, Shimomura et al. [9] details this stage through a state change of a customer. Alonso-Rasgado et al. [13] specified this stage through understanding the business ambitions of the client. Technical PSS considers how to make the best use of capital-intensive assets so more value can be released and more revenue generated per cost unit of the asset throughout its lifecycle. PSS design should focus on integrating business models, products and services together considering throughout the lifecycle stages which create innovative value addition to the system. Influences of the business models on the products and services requirements specification need to be highlighted. As mentioned in [2], the business focus has to be shifted from the actual goods or services sold to the “need behind the need” that has to be fulfilled. Figure 1 represents that it would be ideal if all the stakeholders involved in every step of the framework. This involvement will provide wider visibility and aids to build a robust network to offer PSS. Aurich et al. [11] stress the importance of information procurement which is defined as “providing the manufacturer with customer information from product usage such as experiences, expectations or suggestions.” This helps to develop the complete list of customer requirements.

We argue that every case study report in PSS should specify three parameters to indicate the applicability of their work to different types of PSS. The three factors which would differentiate each case study are: maturity of considered products, customer’s intelligence and industrial domains (B2B, B2C and B2G). Such contextual information for the laser system case study in this work is outlined below:

- The laser systems under consideration are mature products as are the laser processes which are structured and mostly in-built to the system.
- The customers are laser job-shop owners who procure laser systems from the original equipment manufacturer and supply semi-finished goods to the end product manufacturer. The

laser job-shops have many years experience in this field. They could explicitly specify their requirements precisely.

- The context is business to business environments, as illustrated in the above point.

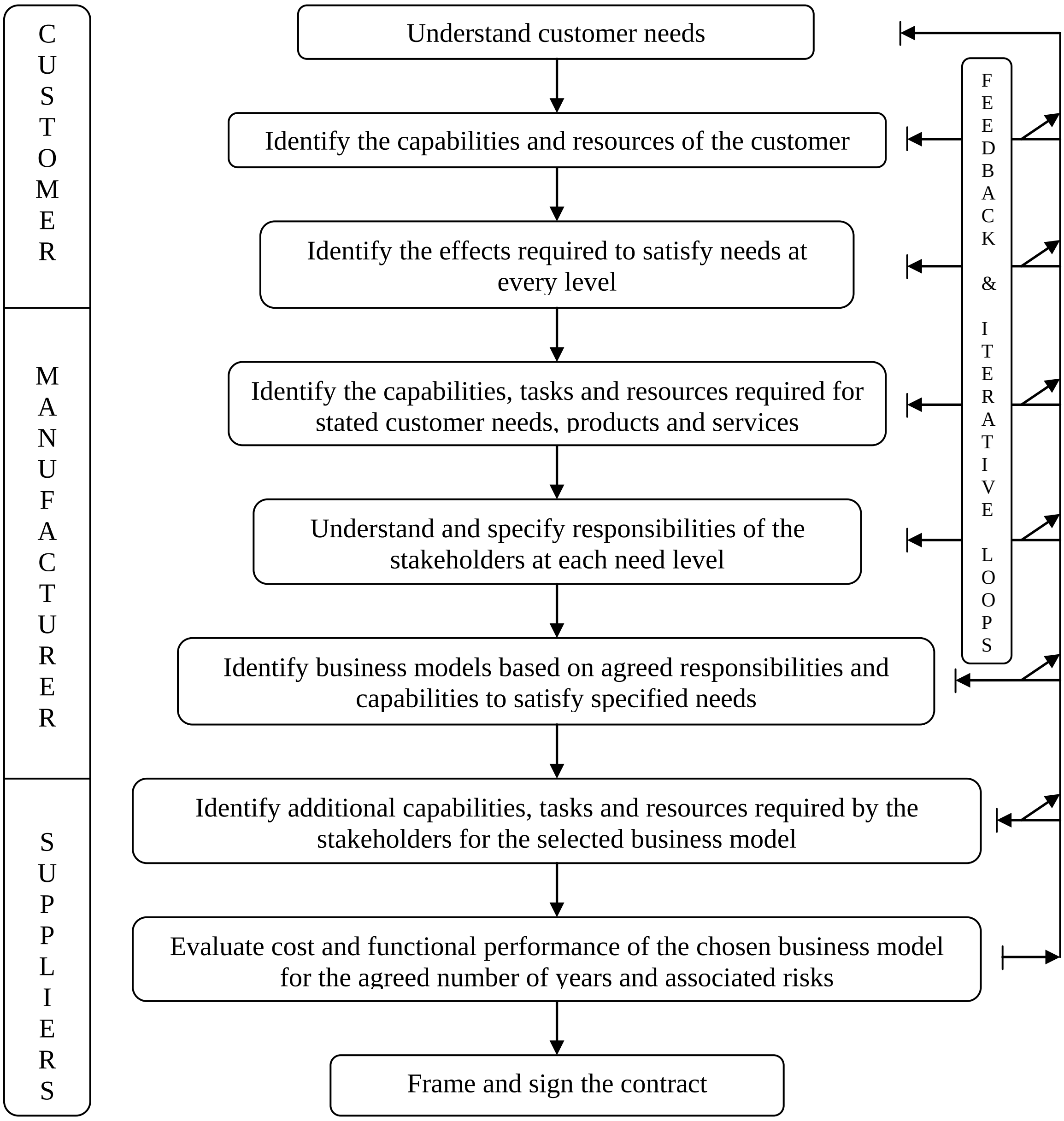

Figure 1. Initial framework for PSS co-creation design process

The specification of laser systems requirements is an important step towards defining PSSs which could be suitable for the customer and provider. Within industry, laser systems are commonly specified by following parameters:

- Power range
- Maximum sheet thickness
- Repeatability
- Working range
- Maximum work piece weight
- Maximum speed
- Precision (depends on work piece, pre-treatment, sheet size and position)
- Maximum axis acceleration
- Laser gas used
- Wavelength and Focal length
- Occupied volume and
- Environmental temperature to be maintained (at specified degrees).

Importantly it has to be emphasised that in addition to these parameters, following parameters are most required in order to develop PSS requirements. These are:

- Reliability
- Flexibility/modularity
- Robustness
- Interchangeable

- Updatability
- Component age
- Portability
- Energy/ consumables/ wastages
- Maintainable/repairable
- Amount of usage/cycles of usage
- Use context details (temperature, humidity etc) and
- Knowledge transfer from the manufacturer.

These parameters need to be explicitly specified by the manufacturer and should be negotiated with the customer to satisfy their operational needs. The operational needs should depict the variation of usage levels across the intended period. For higher PSS offerings, the defects to the end product through laser processes should also be specified. The parameters could be:

- Porosity
- Cracking
- Spatter
- Excess metal
- Sagging
- Undercut
- Humping and
- Distortion (residual stresses).

Even though specifying these parameters could help the manufacturer to develop better laser systems, the real value for customers would lie in meeting the following parameters:

- High productivity
- Less expertise required
- Less set-up and operating time
- Less space required
- Quality outcomes
- Operating versatility
- Less energy consumption
- Less consumables
- Latest technology
- Protection and safety
- Process stability
- Preventive defect faults
- Cost transparency
- Service scheduling certainty

These parameters represent the *functionalities* to be achieved by the PSS that need to be explicitly stated at this stage. Satisfying some of these needs could lead to a conflict of interest between the customer and provider. Therefore, the careful structuring of needs and careful negotiation would be required for PSS development. It should be noted that in PSS, specification characteristics should be for mass customization rather than mass production. Some of the features involved in mass customization have been highlighted in [16].

3.2 Existing capabilities of the customer

After identifying the customer's needs, the next step is to understand the existing customer's capabilities. This understanding will help to develop products and services aligned to their capabilities. Capability is defined as the continuing ability to generate a desired operational outcome. The capabilities could be realised through people, processes, tools, and technology. It should be noted that these parameters are highly coupled and should be visualized together. This integration is possible if the list of tasks to be carried out is identified and the efficiency of each task is measured. This analysis will highlight the gaps within the customer capabilities that need to be filled by the PSS offering. This stage will highlight the customer's life cycle activities along with the product. When analyzing the life cycle activities it is important to improve the PSS on an overall system level and avoid sub-optimizing towards any of the single activities e.g. production. The main difficulty at this stage is the division of competence available to perform each task based on resource availability. A more open environment between the customer and the manufacturer will help to understand this competence better. The factors to be considered for each task could be performance, technicality, human resources, financial and quality.

A laser system is an assemblage of a laser generator unit, beam delivery system, beam manipulation system, motion system, process monitoring system and a control system. Some of the tasks to map the customer's capabilities in the laser system case study are detailed in Table 1. Developing the complete list of tasks and their respective status will help in understand the capability gaps of the customer. This status will inform the next phase to develop better combination of products and services. It should be noted that the steps mentioned in this framework are highly dependent on each other. For simplicity and clarity, these steps are subdivided and illustrated. Therefore feedback loops exist between every step in the proposed framework.

Table 1. Example tasks to understand customer's capabilities

Tasks	Status
The development of a laser process for specific applications	Such processes are standardized.
Preparation of the work piece for laser cutting.	The necessary equipment is available and operators are well-trained to make work pieces ready for laser machining.
Work piece loading	Automated loading tools are available to fix the work piece with intended precision.
Work piece alignment	Manual alignment is performed and this can be a problematic area.
Cleaning and adjusting the optical parts	This is an error prone zone: the risks of damaging the optics are high.

3.3 Identify products and services

From the steps 1 and 2, customer needs and their capabilities will be stated and specified. The next step is to identify the products and services which will satisfy their needs and fill the gaps identified in the required capabilities. The important point in this step is to identify the trade-off between the products and services because the capability shifts as this boundary shifts. Figures 2 and 3 illustrate these capability shifts using a laser system and it's supporting maintenance activities. Although maintenance can increase asset availability, when maintenance is being administered, it can also contribute to the assets unavailability. In scenario 1, the customer finds the amount of maintenance unacceptable as there is too much disturbance to business operations. Scenario 2 shows how the capability for a certain level of availability has shifted from the maintenance service to the asset: here, the asset is redesigned to require less maintenance. The overall outcomes of the laser system have not changed between these scenarios but some of it has been redistributed from service to asset.

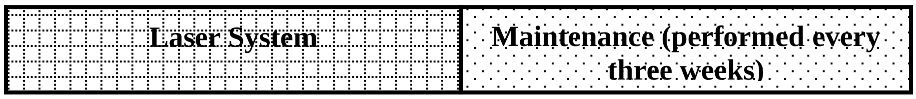

Figure 2. Scenario 1: The capability for asset availability division between product and service

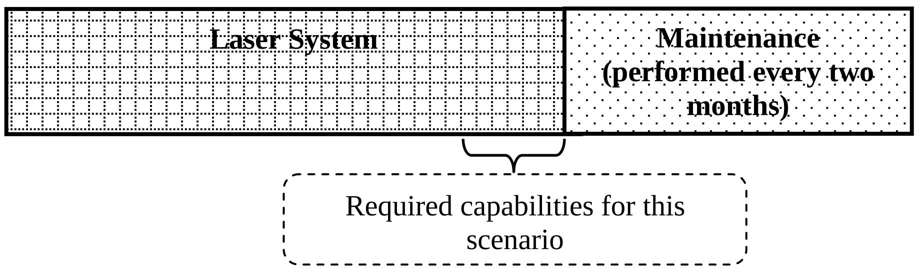

Figure 3. Scenario 2: Laser system and maintenance schedule

The above scenarios represent that the current level of products and services needs to be investigated and future scope should be envisioned. This will help in the design of the right product and service mix which should enable superior designs which increase the availability of laser systems and satisfy the needs of customers. Various services are specified in the laser market such as:

- Software support
- Tools and spare parts supply Installation
- Technical services
- Remote services
- Upgrading
- Customer training
- Consult to fine tune the machine's parameters to optimize speed etc.
- Maintenance types
- Remanufacturing
- Recycling

Asset performance and service activities are highly coupled. Therefore questions such as how maintenance (and calibration and servicing) affect availability and performance should be carefully addressed. There are various issues highlighted in current practice due to invisibility of product knowledge to the customer. For example, currently if a laser system breaks down, the manufacturer will often replace a whole module instead of just an individual component which increases the repair cost to the customer. The manufacturer has argued that this replacement reduces the downtime as otherwise there could be difficulty in diagnosing the problem and the repair cost could be more than the replacement cost because of testing and so forth. Additionally, there is an argument which states that the more reliable a product is, the more costly it is to repair. These arguments need to be negotiated between the customer and the manufacturer to find the right mix between products and services. Apart from identifying the products and services, this stage should make out the key performance indicators for the products and services. These indicators should act as a benchmark for throughout the life cycle stages.

3.4 Identify capabilities of the manufacturer and the suppliers

Identifying products and services that need to be delivered given the understanding of the customer's capabilities will help the manufacturer to develop their own capabilities along with that of the supply network. As over 75% of a product is designed and sourced from the supply chain, this contributes to through life support through the design and delivery of services [5]. The supply network needs to be developed by sharing the required capabilities from the manufacturer. The commonalities and differences between the capabilities of the manufacturer, customer and suppliers need to be explicitly shared and understood between them. This network formulation of stakeholders at this stage plays a vital role in developing sustained PSS offerings. As in Table 1, a detailed list of tasks to deliver products and services needs to be created and the status of each of task should be identified. This would lead to an understanding of the available resources between the stakeholders. Table 2 provides examples of the manufacturer's and suppliers' resources and their respective status using the laser system case study.

Table 2. Examples of the manufacturer's and suppliers' resources

Resources	Status
Labour Experience in developing laser systems Knowledge possession in creating advanced technology	The manufacturer has vast experience in developing laser generator unit. Knowledge regarding the beam guidance unit and motion system is advanced in the supply network.
Infrastructure IT support system	IT support is weak between the manufacturer and supply network.
Laser system Reliability and Consumables	Laser systems are extremely reliable (90% - 99.5%). Consumables are readily available.
Location Mobility	The customer's location may be remote. Mobility is an issue to transfer resources.

Identifying a complete list of tasks and resources as well as the respective status of each will aid the development of a more substantial network between the manufacturer and suppliers to satisfy customer needs. This will also help to assess the *service network capability*. It should be noted that the resource status mapping should consider past, present and future scenarios.

3.5 Specify responsibilities

The capability assessment of all the stakeholders by developing complete lists of the tasks and resources required would subsequently help to align the roles and responsibilities between them. This alignment of responsibilities take place over the life span of the PSS offering and will precisely define the network relationships. Various soft elements play vital roles in relationship development such as trust, confidence, commitment, culture and self-esteem. The development of an open network will be more valuable as the responsibilities map should be visible to all in the network even though, ultimately, all responsibilities are the concern of all in the network.

3.6 Identify business models

The framing of business models should be based on the responsibilities alignment between the stakeholders. Business models play a central role in defining PSS as they describe the rationale of how an organization creates, delivers, and captures value: economic, social, or other forms of value. Commonly used business models within the PSS domain are: Product-, Use- and Result-oriented which emphasise cost, ownership and customization elements. In these business models, the business elements should contain parameters which will influence business processes, issues and solutions. In laser systems, various important parameters which influence buying behaviour are purchase cost, running costs, efficiency, consumables (e.g. gases, flash lamps, diodes, optics) and delivery options. Predictable costs, cost transparency and maximal security are the other important factors considered during business model selection. Thus, the framing of business models should considering all of these parameters as well as the demarcation of capabilities and responsibilities.

3.7 Identify additional capabilities required

To fulfil the requirements of the selected business model, additional capabilities would need to be acquired amongst the stakeholders. Existing and new capabilities and resources from each stakeholder should be carefully aligned and integrated. Shifts in the capabilities between stakeholders which lead to acquire additional resources to match the activities needs should be noted. Difficulties for the stakeholders to quickly expand to meet increasing capabilities demands should be handled with possible resource variations and time constraints.

3.8 Evaluation and contract finalization

Evaluation should be part of every step in the proposed framework. To emphasise this evaluation process, it is dealt with separately in the framework. The evaluation should focus on three dimensions: economic, social and environmental. From a business perspective, the major evaluation criteria will be profit, revenue, customer satisfaction, quality of products and services, value-in-use and risk reduction. Both tangible and intangible merits and demerits should be evaluated. In the laser system case study some of the evaluation questions could be:

- What are the risks in the manufacturer in retaining the asset?
- What is the frequency of mainetanance and servicing and the associated costs? What other lifecycle costs should be considered?
- Does the manufacturer`s supply base have the capability to support possible PSS solutions?
- What are the issues in achieving the stated availability of the laser system?

The final step would be to frame the contract using terms and conditions that are relevant to all of the stakeholders involved. These terms would also stipulate all of the legal obligations to be met by the stakeholders. All of the terms have to be very carefully noted and defined. The contract should be concise, unambiguous, consistent, simple, complete, easy to interpret and easy to maintain.

4 DISCUSSION AND FUTURE WORK

In this paper, various proposed PSS design methods have been reviewed and the research gaps have been summarized. Primarily, it has been observed that the importance of capabilities of the stakeholders involved in designing PSSs have not been noted in the proposed methods. Emphasising this capability view point, a framework for designing PSSs has been proposed. This framework highlights the important features required in designing PSSs such as co-creation, responsibilities and capabilities. Importance of the feedback is stressed by the iterative loops between every step in the proposed framework. Every step in the framework has been illustrated with a case study involving laser systems used for cutting operations in manufacturing. We believe that this framework would facilitate and structure the interactions between the customer, manufacturer and supplier. It also helps to understand the capabilities of the stakeholders and aids an understanding of the value of PSS offerings as appreciated by the customer. This initial framework will be developed iteratively by applying it to various case studies involving various other companies who are in the process of refining the development of their PSS offerings. A computer assisted design tool will be developed to help stakeholders to use this framework for developing PSSs. The design tool is intended to facilitate a novel representation of PSS modelling.

REFERENCES

[1] Goedkoop M. van Haler C. te Riele H. and Rommers P. Product Service-Systems, ecological and economic basics. *Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ)*, 1999.

[2] Tucker A. and Tischner U. *New Business for Old Europe - Product-Service Development, Competiveness and Sustainability*, 2006, Greanleaf Publishing, Sheffield, UK.

[3] Shehab E.M. and Roy R. Product-Service Systems: Issues and Challenges, *Proc. of the 4th International Conference on Manufacturing Research (ICMR 2006)*, Liverpool John Moores University, 2006, pp.17 – 22, ISBN 0-9553215-0-6.

[4] Meier H. Roy R. and Seliger G. Industrial Product-Service Systems - IPS², *CIRP Annals Manufacturing Technology*, 2010, 59(2), pp. 607-627.

[5] Cohen M.A. Agrawal N. and Agrawal V. Winning in the Aftermarket, *Harvard Business Review* 84 (5), pp.129-138, 2006.

[6] Sundin E. Lindahl M. and Ijomah W. Product design for product/service systems - design experiences from Swedish industry, *Journal of Manufacturing Technology Management*, 2009, 20 (5), pp. 723-753.

[7] Komoto H. Computer Aided Product Service Systems Design (Service CAD and its integration with Life Cycle Simulation), *PhD Thesis*, Delft University of Technology, Delft, the Netherlands 2009.

[8] Maussang N. Peggy Z. and Brissaud D. Product-service system design methodology: from the PSS architecture design to the products specifications. *Journal of Engineering Design*, 2009, 20(4), pp.349 – 366.

[9] Shimomura Y. Hara T. and Arai T. A unified representation scheme for effective PSS development. *CIRP Annals - Manufacturing Technology*, 2009, 58, pp.379–382.

[10] Sakao T. Shimomura Y. Sundin E. and Comstock M. Modeling design objects in CAD system for Service/Product Engineering, *Computer-Aided Design*, 2009, 41, pp.197-213.

[11] Aurich J. Fuchs C. and Wagenknecht C. Life cycle oriented design of technical Product-Service Systems, *Journal of Cleaner Production*, 2006, 14(17), pp.1480-1494.

[12] Welp E.G. Meier H. Sadek T. and Sadek K. Modelling approach for the integrated development of industrial Product-Service Systems. *Proceedings of 41st CIRP Conference on Manufacturing Systems*, Tokyo, Japan, 2008.

[13] Alonso-Rasgado T. Thompson G. and Elfstrom B-O. The design of functional (total care) products. *Journal of Engineering Design*, 2004, 15 (6), pp.515-540.

[14] Müller P. Kebir N. Stark R. and Blessing L. PSS Layer Method – Application to Microenergy Systems, book title *Introduction to Product/Service-System Design*, 2009, Springer Publisher.

[15] Tan A. McAloone T.C. and Hagelskjær L.E. Reflections on product/service-system (PSS) conceptualisation in a course setting, *International Journal of Design Engineering*, 2009.

[16] Sundin E. Lindahl M. Comstock M. Shimomura Y. and Sakao T. Integrated Product and Service Engineering Enabling Mass Customization, on CD-ROM of *19th International Conference on Production Research (ICPR-19)*, 2009, Valparaiso, Chile.

Contact: Professor Rajkumar Roy
Cranfield University
Head of Manufacturing Department
Cranfield, MK43 0AL
UK
Tel: Int +44 1234 758335
Fax: Int +44 1234 758292
Email: r.roy@cranfield.ac.uk
URL: http://www.cranfield.ac.uk/sas/aboutus/staff/royr.html

Professor Rajkumar Roy is leading the Manufacturing Department and Director of the EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services. He is interested in developing whole life cost models for products and services, real life application of soft computing techniques for modeling and optimization and innovating product-service systems business models.