International Journal of Production Research
Vol. 50, No. 2, 15 January 2012, 425–442

Towards product-service systems modelling: a quest for dynamic behaviour and model parameters

Sarocha Phumbua and Benny Tjahjono*

Manufacturing Department, School of Applied Sciences, Cranfield University, Cranfield, Bedford MK43 0AL, UK

(*Received 8 June 2010; final version received 30 September 2010*)

The product-service system (PSS) is an emerging manufacturing paradigm embracing the increased value of offering through the integration of products and services as a basis of competitive strategy. The PSS has various characteristics beyond the traditional product-selling businesses as a result of intense customer interactions and increased service levels. These interactions can further trigger the dynamic behaviour of the system and consequently can cause uncertainties across the whole network of manufacturers and customers. The work described in this paper is part of a research project whose overall goal is to provide the manufacturing system designers with better decision making capabilities to effectively shift their manufacturing businesses from product selling to PSS offering. In particular, this paper aims to capture typical characteristics exhibited by manufacturers who have adopted PSS, to better understand their dynamic behaviour, to have appreciation of the existing techniques and tools for modelling PSS, and ultimately to search for PSS model parameters. The main contribution of this paper is the collation of key model parameters that should be considered for an effective PSS modelling. The paper also identifies strengths and weaknesses within the existing PSS modelling work, and highlights the opportunities for future research agenda.

Keywords: product-service model; dynamic behaviour; PSS modelling; PSS simulation

1. Introduction

A product service system (PSS), according to Mont (2002a), Manzini and Vezzoli (2003), and Baines *et al*. (2007) is defined as an integrated product and service that extends the traditional functionality of a product by incorporating additional services. The shift from offering the product alone to offering a PSS such that the product and services become inseparable is also known as 'servitization' of products (Almeida *et al*. 2008, Baines *et al*. 2009a). Typical examples found from the PSS literature (e.g., Mont 2002b, Alonso-Rasgado *et al*. 2004, Baines *et al*. 2007) are the Rolls-Royce's Power-by-the-Hour and Xerox's Document Management Solution business models. In the former, the original equipment manufacturers (OEMs), in this case Rolls-Royce, sell an aircraft engine along with the service and spare part support that are negotiated on the basis of the hours that the engine has actually flown (Baines *et al*. 2009a). Similarly, the Xerox PSS model described in the literature as the provision of a new, expanded and integrated business solution that sees the integration of the products (photocopiers) and the services Xerox offers to support them (Baines *et al*. 2007).

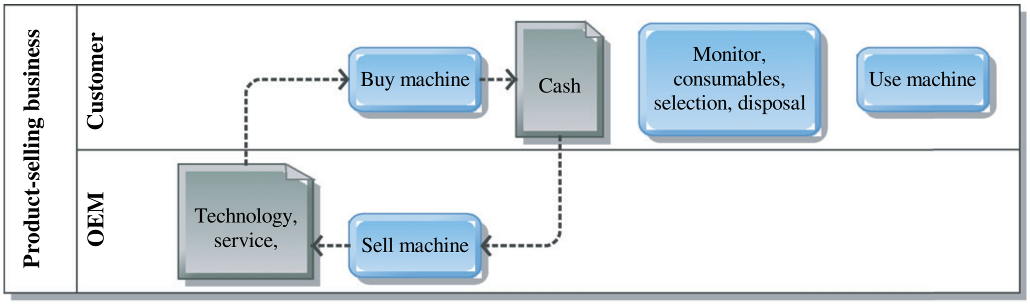
Figure 1 illustrates traditional product selling and the PSS selling. Unlike the traditional product selling, PSS businesses are not solely focusing on the products/assets selling and acquisition but rather focusing on selling the *usage* of the assets. The customers are said to buy the 'capability' of the assets rather than the actual assets themselves. This model to a certain extent is akin to that in product leasing where the customers do not normally own the products but pay to use the products either on pay-per-usage or fix-term contract basis. For the customers, this is beneficial especially when the products are high in value and reliability is critical. In PSS, the responsibility of maintaining the assets, provision of spare parts and even to take back and remove the assets at the end of their life, is within the manufacturers, leaving the customers to focus on their core business operations.

Shifting from the traditional production-based model to the PSS-based model means the manufacturers are required to add more value to the products they offer and at the same time to design, and if necessary, diversify services around the products. Some successful PSS cases have been documented in Mont (2002b), Tukker (2004),

*Corresponding author. Email: b.tjahjono@cranfield.ac.uk

ISSN 0020–7543 print/ISSN 1366–588X online

http://dx.doi.org/10.1080/00207543.2010.539279
http://www.tandfonline.com



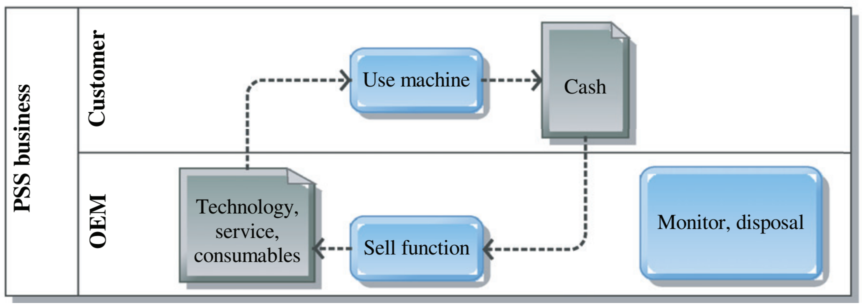


Figure 1. Product selling and PSS selling (adopted from Baines *et al*. 2007).

Tukker and Tischner (2006), and Baines *et al*. (2007), and interestingly, they have reported that the PSS business models have improved the competitiveness of the companies adopting PSS. This is not surprising especially in the cases where more revenue is gained from services provision than from the products selling alone. Naturally in any service provision, PSS often necessitates companies to build a stronger rapport with their customers as they no longer compete on the products they offer, but instead on the package (i.e., combination of products and services). It has also been reported that those who succeeded will maintain their position in the market share (Neely 2008, Roy and Cheruvu 2009). In addition to the commercial benefits, the PSS literature also often links PSS with the environmental benefits. Furthermore, according to Tukker (2004), a PSS could lead to decreased resource consumption, reduced waste and increased manufacturing sustainability.

Despite the abovementioned benefits offered by PSS, the design of such PSS businesses remains challenging and risky. The shift from product-selling to PSS often raises several questions, for instance *what to offer in the 'package'?*, *how long is the contract?*, *how much to charge?*, *what resource required?* etc. In the traditional production-based system design/redesign, system designers are typically faced with issues with no early visibility of the likely performance of the production system they design. Not only are the design parameters often not well understood, but also the interconnectedness amongst the design parameters is not well understood, making it even more difficult to predict the dynamic behaviour of the system. If designing a product-only system is complicated, designing a PSS is even more challenging due to the service components that also need to be accurately modelled.

A rich amount of literature exists in the area of production-based system modelling and simulation, and moreover the commercial tools are also widely available. However, they do not usually consider the additional dynamic aspects of the service components. As an example, the demand forecast in PSS should take into account the customers interaction during the contract (De Coster 2008) the multidimensional offers should also be designed to be more creative and attractive than the technical function of the product (Kang and Wimmer 2008) which subsequently requires a tight cooperation amongst the stakeholders in the supply network. In addition, the whole product lifecycle and infrastructure must be considered during the design process (Azarenko *et al*. 2007). Without an appropriate tool, the designer could be at risk of making a poor decision which could be detrimental to the whole business. For these reasons, such a PSS modelling tool is desirable to deal with these complexities.

The work described in this paper aims to capture the characteristics of PSS and to better understand its dynamic behaviour. The structure of this paper is organised as follows. Section 2 describes the research programme and methodology adopted in the research. The findings of the research are summarised in Section 3. In this section, the characteristics and dynamic behaviour of PSS are collated and the potential modelling methods and tools are identified. The typical PSS model parameters are also summarised in this section before the mapping of the current state of PSS models and the capability of the existing tools/techniques with the characteristics and dynamic behaviour in Section 4. The outcomes are used as a basis to identify the strengths and weaknesses within the PSS modelling research. The paper concludes with the detailed accounts on the research opportunities in PSS modelling and the future work.

2. Research programme

The work described in this paper is part of a research project that explores the feasibility of developing PSS modelling (and simulation) techniques. The intention is to provide system designers (and manufacturers) with better decision making capabilities to effectively and efficiently expand their businesses from product-only to product-service offering.

2.1 *Research questions*

As a precursor task to support the overall aim of the research, this paper explores and discusses the current state of the PSS modelling collated from the body of literature. For the purpose of the investigation, the literature survey is split into two areas: PSS in general and PSS modelling in particular. The relevant literature is then identified based on the following research questions:

(1) What are the typical characteristics exhibited by manufacturers who have adopted the PSS business model?
(2) What is the dynamic behaviour in PSS businesses that have specifically increased the complexity beyond the capability of existing production-based modelling methods?
(3) What are the existing techniques and tools for modelling PSS, and to what extent can these be used to effectively model PSS?
(4) What are the commonly used parameters in PSS modelling?
(5) What are the strengths, weaknesses and opportunities within the current PSS modelling research?

Consequently, this paper seeks to fill the gap in PSS modelling research by providing analysis based on the research questions. Figure 2 shows the contributions that will be used as a basis for PSS model building at the later stage of the research.

2.2 *Literature search strategy*

Following the research questions, a systematic literature review process was developed. The first step was to select the databases that include journal papers, conference proceedings, books and theses. SCOPUS, Google Scholar, Ingenta Connect and Emerald were initially chosen amongst dozens of electronic databases simply because of their easy access and entirety. The relevant keywords were then identified. These included *product-service model*, *after-sale model*, *servitization model* and *functional product model*. This search was also guided by a number of general PSS review papers such as Baines *et al*. (2007), Almeida *et al*. (2008), and Baines *et al*. (2009a), who reviewed 95 publications related to product-service systems. In addition to these journal publication databases, a manual search was conducted of the *Winter Simulation Conference* online proceedings (years 1999 to 2009) and the *CIRP Industrial Product-Service Systems (IPS2) Conference* proceedings (year 2009). The abstracts of those papers were first reviewed to filter from over 500 down to some 90 articles that are relevant to the work. The scope of this initial investigation covers any models with the presence of service consideration in production environment, and product consideration in service organisation. These papers were then skim-read to group similar papers and remove redundancy. Finally, cross-references of these papers were inspected. The whole process resulted in the 22 most relevant PSS models shown in Table 1.

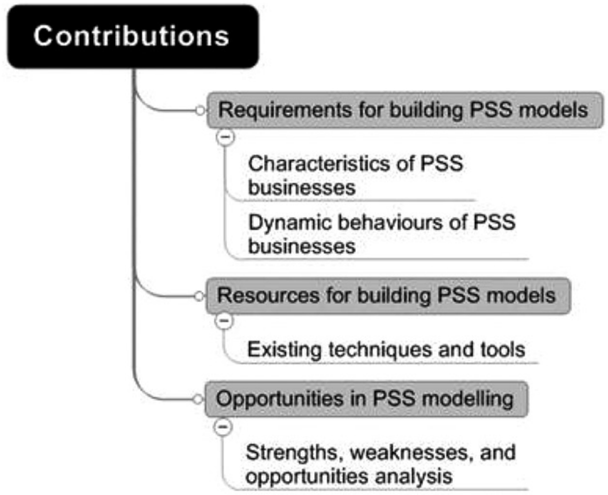


Figure 2. Contributions of the paper.

Table 1. Classification of PSS techniques and tools.

Reference	Technique	Tool
Fujimoto *et al*. (2003)	Discrete-event simulation	Life cycle simulator
Komoto *et al*. (2005)	Discrete-event simulation and genetic algorithm	Life cycle simulator
Aurich *et al*. (2006)	Lifecycle oriented method Process modularisation	UML 2.0 Integrated Production Process Model (IPMM)
Morelli (2006)	Scenarios and use case analysis Service blueprinting IDEF0	x
Buxton *et al*. (2006)	Agent-based simulation	AnyLogic
Sakao and Shimomura (2005)	Service Engineering Quality function deployment Analytical hierarchy process	Service Explorer JAVA2 SDK, Std Edition 1.4.1 XML 1.0
Maussang *et al*. (2007)	Functional analysis Agent-based value design Use case	x
Komoto and Tomiyama (2008)	Service modelling	Integrated Service CAD and life cycle simulator
Abramovici *et al*. (2009)	UML	x
Kim *et al*. (2009)	Ontological representation Activity modelling cycle UML OML	Protégé, with conversion to Jess
Hara *et al*. (2009b)	Service blueprinting	Business Process Modelling Notation
Bianchi *et al*. (2009)	System dynamics	x
Alonso-Rasgado *et al*. (2004)	Molecular modelling Service blueprinting Discrete-event simulation	General programming language
Hara *et al*. (2006)	Service Engineering Petri net simulation Quality function deployment Analytical hierarchy process DEMATEL Model for value & cost	Service Explorer CPN Tools

(*continued*)

Table 1. Continued.

Reference	Technique	Tool
Low *et al*. (2000)	TRIZ	x
Muller and Blessing (2007)	Process entities/V-model	x
Schuh *et al*. (2009)	Lifecycle cost-oriented models Activity-based costing	x
Morelli (2002)	Functional & use case analysis Blueprint	x
Weber *et al*. (2004)	Property-driven design/development	x
Evans *et al*. (2007)	Solution map Lifecycle costing	x
Shen and Wang (2008)	Fuzzy extended quality function deployment Analytical hierarchy process Optimisation model	x
Schuh and Gudergan (2009)	Service blueprinting Advance sequential incident Qualitative interdependence analysis Pairwise comparison Progressive abstraction	x

3. Findings

As part of the systematic literature review framework used in this research, the key findings from each paper were thematically grouped. Each of these key findings is described below.

3.1 *Characteristics of PSS*

Companies or manufacturers who have shifted from the traditional product selling to a PSS typically exhibit a number of features that characterise their businesses. These characteristics have been repeatedly mentioned and clearly highlighted in the literature, for example Baines *et al*. (2009b), Mont (2002a), Manzini and Vezzoli (2003), and can be grouped into three domains: *business and offering strategy*, *operations and technology* and *supply/demand network*. The characteristics exhibited in PSS models are summarised as follows:

- **Business and offering strategy**
  - Combination of transitional-based and relationship-based.
  - Improvement through efficiency of service.
  - Human capital and reduction of transportation are critical.
  - Top level performance indicators are product life, lifecycle cost, logistic cost, efficiency of resource consumption and closed cycle efficiency.
  - Values from availability, performance and risk/reward sharing.
  - Order winnings are features of product-service bundles, cost of ownership, availability of product and capability to deliver service.
  - Product designed for reusability and recyclability.
- **Operations and technology**
  - Facilities are close to customer/market.
  - Decentralised decision making process.
  - Planning and control availability and responsiveness.
  - Operational performance measures are product availability, response time, customer satisfaction.
  - Asset monitoring technology.
  - Management of technology.

- **Supply/demand network**
  - Vertical integration for product manufacture and integrated partner for services.
  - Information flow between actors.
  - Stronger cooperation with supplier.
  - Important factors are interaction between people, cultural mind frame and social habits.

3.1.1 *Business and offering strategy*

Many of the PSS businesses feature a combination of the transactional-based processes typically found in product-selling (or manufacturing) and the relationship-based in the service environment (Baines *et al*. 2009b). For those companies, the focus for improvement is no longer on the materials and energy, but in the efficiency of the services (Mont 2002a). Human capital, as well as the reduction of transportation distance, is therefore deemed vital. These features, combined with the involvement of many parties, suggest the need for clear performance indicators, for example, the measures that can reflect the lifespan of products (Mont 2002a), lifecycle cost (Baines *et al*. 2009b), logistic cost (Omann 2003), efficiency of resource consumption (Mont 2002a) and closed cycle efficiency (Mont 2002a). Furthermore, the value of a product is determined by its use. In other words, customers value the *availability*, *performance* and *risk/reward sharing* in PSS (Baines *et al*. 2009b).

The order winnings have now shifted from product/service features, cost, quality and delivery of product/service to features of the product-service bundles, the cost of ownership, the availability of product and the capacity to deliver services (Baines *et al*. 2009b). Products in PSS, typically co-developed with the customers, are designed for reusability and recyclability (Mont 2002a). It can also be observed that the variety of product-service bundles in PSS is limited in comparison with product or service range in the traditional product-selling businesses (Baines *et al*. 2009b).

3.1.2 *Operations and technology*

To support their business strategy, especially in maintaining a strong rapport with their customer base, PSS businesses typically have proximity to their customers. As highlighted by Baines *et al*. (2009b), one of the PSS companies they investigated has built their assembly and test facilities that are close to their market. In some cases, particularly with regards to the product-service development, the decision making process is decentralised due to the interactions with the different customers (Mont 2002a). The management of operations usually involves transformation of materials into tangible assets that are sold along with the support services to deliver functional capability to customers (Baines *et al*. 2009b). The planning and control mechanisms therefore shift to the optimisation of the availability of the assets and responsiveness in providing this capability, rather than merely optimisation of the assets inventory. For that reason, the performance measures usually concern *product availability*, *response time* and *customer satisfaction*.

Many of the PSS businesses adopt various enabling technologies at various levels especially to continuously monitor the condition of their assets in use. The monitoring of the assets allows a better visibility of what is required and when, so that the downtime and subsequent losses can be minimised. Although in some cases the technology itself is considered critical, in other cases (reported by Manzini and Vezzoli 2003), many PSS companies actually focus on the management of existing technologies in order to maximise the efficiency in production and effectiveness in delivery.

3.1.3 *Supply/demand network*

In terms of supply/demand network, PSS businesses typically adopt the vertical integration strategy for product manufacture and the integrated partner approach during the service provision (Baines *et al*. 2009b). The complex relationships amongst the different actors are in fact governed by the product availability and performance. Information flow between the companies and their customers becomes much more crucial than that in the product selling businesses (Mont 2002a). In addition to that, PSS businesses typically have stronger cooperation with their suppliers. Having this strong link allows PSS businesses to become more *responsive to market changes* and will further *stimulate innovation* in their design and development.

From several publications, it is apparent that many significant changes occur as the business shifts towards PSS. It was observed in practice that technology and customer relations are the major critical elements (Manzini and Vezzoli 2003), and therefore, the new variables taken into account when designing PSS are *time dimension*, *interaction between people*, *cultural mind frame* and *social habits* (Morelli 2006, Sakao and Lindahl 2009).

3.2 *Dynamic behaviour*

Dynamic behaviour in this case is referred to as the disturbances, perturbations or even reactions that may affect the performance of the PSS businesses and impose risks on them. Dynamic behaviour in PSS is summarised as follows:

- Asset failures during in-service phase.
- Customer's royalty to contract.
- Inputs from customers.
- Market changes.
- Short-term service contracts.
- Interactions between actors.
- Changes in actors' internal process.
- Performance measure changes.
- Price and logistic cost sensitivity.

The dynamic behaviour in PSS is mostly triggered by the customer-manufacturer interaction during the use of the assets. Unlike the product-selling businesses where the responsibility of manufacturers ends after selling the product to customers, it is crucial for PSS providers to understand the risks caused by dynamic behaviour, and be capable of handling them. Otherwise, the PSS providers may not be able to deliver the product-service contracts. Assets may stochastically fail and consequently be unavailable (Baines *et al.* 2009b). Poor availability performance will ultimately affect the customer loyalty and disloyal customers will subsequently result in inaccurate demand forecasting at the manufacturers' end (De Coster 2008). Prior to offering PSS, feedback from customers, i.e., market analyses, can influence the design of the contract (Mont 2002a, Roy and Cheruvu 2009). Design specification may also be affected because of market change and customer complaints. As highlighted by Roy and Cheruvu (2009) contracts that are typically agreed for 5–30 years and can be modified to serve the specific needs of a customer; the adaptation phase should therefore be structured during the design phase. In defence and aerospace industries particularly, changes during the in-service phase are in the form of spares, repairs, training services and obsolescence (Erkoyuncu *et al.* 2009). In addition to that, customers can sign some service contracts in the short period, for example, in the case of Fleet Management at MAN truck (MAN Truck & Bus UK 2010). This short term contract (i.e., pay-as-you use) can cause demand fluctuation and consequently the manufacturer needs to regularly fine tune their capacity plan.

From the supply chain viewpoint, the PSS network has a complex relationship (Manzini and Vezzoli 2003) with various decision rules that exist within different actors and stakeholders. Nonetheless, PSS allows the manufacturers to be more responsive to market parameter variations because the information, for example, asset condition, design requirement, etc. can be transmitted back to the manufacturers (Mont 2002b). This would also allow changes in the performance measures to be subsequently modified during the delivery of a service contract, although profits as well as price sensitivity and logistics cost, will be affected by the efficiency of this provision.

3.3 *PSS modelling techniques*

To help manufacturers shift towards PSS, several guidelines have been proposed in the literature. The **M**ethodology development and **E**valuation of **PSS** (MEPSS) and highly customised solution (HiCS) (Tukker and Tischner 2004) are examples of such guidelines. MEPSS was born from a project funded by the European Union, which provided a toolkit for successful implementation of new PSSes. The methodology is divided into phases: strategic analysis, exploring opportunity, PSS idea development, PSS development and preparing for implementation. HiCS introduced solution oriented partnership methodology framework (SOPMF) to initiate co-creating industrialised sustainable solutions. SOPMF brings together partnerships to create alliances and allows several concepts and tools to be inherent (Tukker and Tischner 2004). Although comprehensive, both MEPSS and HiCS do not specify quantitative evaluation techniques. Rather, they provide a bigger picture for ground understanding of the PSS transformation.

Some modelling techniques have been presented by Becker *et al.* (2009) to gain insights into the system, thus, are used for specific purposes. A model is defined as a simplification of the system that is of interest, and only incorporates the aspects that affect the problem of the study (Banks *et al.* 2009). PSS models are diverse as the PSS concept itself has been driven from different perspectives (Mont 2002a). Consequently, modelling methods are also numerous. Table 1 shows this diversity, and often, many modelling techniques are combined with other analytical methods such as scenarios and use case analysis, quality function deployment, model for value and cost, analytical hierarchy process, activity-based costing, etc.

In summary, PSS modelling techniques can be grouped into three main categories taking into account *the user*, *the system* and *the product-service perspectives*. The descriptions of these are given below.

3.3.1 *User focus*

This modelling technique focuses on the users, i.e., modelling how users as the recipient of services interact with each other. Within this category, service blueprinting (Shostack 1982) is the commonly cited modelling method in the literature. Service blueprinting illustrates the flow of service along with the time dimension and tolerances. It also incorporates the details of total standard execution time, total deviation tolerance and total acceptable execution. The line of visibility is used to separate activities which are essential for the performance of services but not directly concerned with the customer from other functions. The method can be seen as a symbolic snapshot of service processes. Service blueprinting was reported in the case of a telecentre to model a list of events generated by a use case (Morelli 2002). The blueprint was represented by a service cycle consisting of technical and maintenance services as well as tangible and intangible components. Additionally, service blueprinting can also be used to present the architecture of analytical methods and tools in developing new solutions, for example, pairwise comparison, progressive abstraction, advance sequential incident, etc. (Schuh and Gudergan 2009).

Also, within the service engineering paradigm, there exists a set of models comprising a *flow model*, a *scope model*, a *view model* and a *scenario model* (Hara *et al.* 2006, Sakao and Shimomura 2007). A flow model represents the stream of services, while both the scope model and the view model address a target area of service and their relationships, respectively. The designer typically identifies agents, demographic and psychological data, states parameters of the service receiver and the value characteristics. The realisation structure can then be generated to obtain the design solutions. In addition to the above models, a behaviour blueprint can be added to represent the interactions between the receiver and the products, and an activity blueprint can be combined to show the collaborations between the receiver and staff (Hara *et al.* 2009a). This combined model allows interactions between staff and equipment or facilities to be presented. Based on a view model and a scenarios model, a functional block diagram can be used to map the interaction of elements (Maussang *et al.* 2007). The system can be analysed in terms of customer's needs, people's involvement, external functions, technical functions and the elements of solutions. A detailed design is built once the specifications for each element are determined.

An ontological representation of a food assembly system was proposed by Kim *et al.* (2009) based on the Unified Modelling Language (UML) specifications. The system elements comprise values and relations. The value elements were described by their nature, constraints, category and realisation. The relations were defined by type, enable, enhance, and proxy, and paired up between product, service and value.

3.3.2 *System focus*

The majority of the existing work in this category typically includes the simulation techniques. The application of simulation allows the designers to carry out what-if analyses allowing them to assess the dynamic impacts of variation in input parameters to output parameters. This would consequently enable the designers to gain a deeper understanding of the likely performance of the system being designed. Depending on the levels of application, there are three commonly used simulation techniques: *discrete-event*, *system dynamics* and *agent-based*.

System dynamics (SD) is generally used for long-term decisions in a broad scope with high level of abstraction where 'structure determines behaviour' (Brailsford 2008). The system behaviour can be captured either quantitatively by using stock and flow diagrams with dependency graphs and mathematical formulation, or qualitatively via influence diagrams to enhance the relationships between variables. A quantitative SD allows the rate of change from one state (stock) to another state to be investigated. This rate is governed by a set of variables and parameters, and expressed in terms of mathematical formulation. In the context of PSS, SD was used by Bianchi *et al.* (2009) to study the transition from a product-oriented manufacturer to a PSS provider. Criteria for success and failure of PSS were first captured using qualitative SD and then modelled quantitatively. Product-oriented manufacturers and PSS providers were represented as stocks, whilst transition to PSS rate and fail rate were denoted as flows. From this, the rate of the transition could be investigated (Bianchi *et al.* 2009).

Discrete-event simulation (DES) is concerned with modelling a system where the state variables change only at a discrete set of points in time (Banks *et al.* 2009). A system indicates a flow of processes, denoted as queue and delay. Although DES has been traditionally used to model production-based and manufacturing systems, this technique has also been tried in a service support system to test its functionality (Alonso-Rasgado *et al.* 2004). Based on PSS, a lifecycle model was built upon three sub-models: lifecycle process, product and user (Fujimoto *et al.* 2003). The first sub-model indicated a network of processes such as manufacturing, operation, recycling and remanufacturing. The state changes of these processes were programmed. The second consisted of modules modelled by sets of attributes, and the third allocated customers according to types of packages and their behaviour. Another DES model was developed from a set of PSS objects and their subsequent transition/relationships (Komoto *et al.* 2005). The objects included service, service provider, service receiver, PSS events and the product. The PSS events were subdivided into generation and elimination, deterioration, and recovery, whereas the product was grouped according to the structure into the operation-critical modules and lifetime-critical modules. The changes in state description were defined. The resulting performance was the outcome of occurrences of PSS events and the individual performance. DES was also used in the integration with Service Engineering to evaluate lifecycle cost from the generated design solution (Komoto and Tomiyama 2008).

Unlike DES, agent-based simulation (ABS) models interactions between agents rather than flows of processes. The agents can have their own decision rules and autonomy which fundamentally differ from the objects and entities in DES. Within PSS, ABS has been used to study the dynamic behaviour of the market and investigate the agent's performance in the context of an aero-engine value chain business environment (Buxton *et al.* 2006). These agents included the OEM, the marketplace and the engines themselves. The model incorporated all activities throughout the whole lifecycle of the engines. The run time of 50 years provided sufficiently long term implication of the strategic decisions.

3.3.3 *Product-service focus*

The methods within this group were rooted from the design paradigm. For example, the theory of inventive problem solving (TRIZ) was applied by Low *et al.* (2000) to generate a list of product and service infrastructures by specifying the need for service and subsequent functions and technology. Another example is the V-model (Muller and Blessing 2007) which can be used to show the activities in the contract development. quality function deployment (QFD), integrated with a mathematical model, was applied by Shen and Wang (2008) to design services that maximise customer satisfaction under implementation cost and technical feasible range constraints.

Another technique stemmed from the product design area is the property-driven development/design (PDD). According to Weber *et al.* (2004), in PSS, service elements were considered as non-material in the product model although practically both material and non-material characteristics were determined from a customer's needs, which lead to their related properties. Within the PDD method, particularly in the development phase, the actual properties, in comparison with the targeted requirements, were assessed to indicate the area of improvement.

In addition to the aforementioned techniques, a simple rich picture was used by Evans *et al.* (2007) to present actors in service networks and their associated relationships. The solution map illustrated the material movement and information flow for a food production system to achieve sustainability.

A lifecycle oriented design based on object-oriented modelling was proposed by Aurich *et al.* (2006). Process objects, structures, relations, functions, and subsequent properties were defined. The lifecycle oriented approach can also be used in conjunction with activity-based costing to provide a better assessment of the lifecycle cost (Schuh *et al.* 2009).

Metadata models, typically used to describe a product and its properties throughout its lifecycle, are the core of the traditional product lifecycle management (PLM) system (Abramovici *et al.* 2009). The reference model was used as the domain knowledge whereas the modelling language determined the structure of the conceptual model. Interfaces that allowed information flows between manufacturing and services were examined to enable the integration between them.

3.4 *PSS modelling tools*

Supporting tools to design PSS offers can be in the form of the so called front-end tools or software packages offering a platform for model building. Life cycle simulators (LCSs), Service Explorer, Business Process Modelling Notation (BPMN) and Integrated Production Process Model (IPPM) are examples from the first group, whereas AnyLogic and Protégé are examples from the second group.

LCS, developed from DES, simulates the stochastic behaviour of component lifetime distribution and dynamic changes of behaviour of actors (Komoto *et al*. 2005, Komoto and Tomiyama 2008). Actions performed by actors were described as events and triggered in the product lifecycle and allowed for economical and environmental impacts to be calculated based on the occurrence of these events.

Service Explorer, based on the Service Engineering concept and the Java computer language, shows the needs of customers and the relations between those needs, and simulated the flow of service (Hara *et al*. 2006). The tool provides a design workspace to build a model using drag and drop operations. A model consists of a set of connected nodes which represent receiver state parameters, functions and agents. Behaviour of services can be simulated. BPMN was developed as a blueprint editor for the Service Explorer to ensure consistent semantics, which aims to enhance understanding by all business users (Hara *et al*. 2009a). The result obtained from BPMN is a diagram that represents the flow of process.

IPPM, based on object oriented modelling, defines process objects by their structures, relations, required functions and related properties (Aurich *et al*. 2006). Process modularisation was incorporated to enhance lifecycle oriented design. These process modules were assigned to the network partners for the compilation.

The software packages usually provide drag and drop operations and allow a user to define or customise an object by using the Java language. AnyLogic is capable of modelling SD, DES and ABS and provides numerical evaluation of the impact of input changes to the outputs. Protégé is an ontology editor for the purpose of knowledge management, which produces graphical representation rather than numerical evaluation.

3.5 *Design of PSS offering*

The majority of the methods mentioned in the previous section were developed for the purpose of designing the PSS offering. A spectrum of offering category was proposed by Tukker (2004), ranged from a pure product to a pure service. This section investigates the current state of model developments with respect to offering design to address the gap between the concepts and the supporting tools.

With regards to the offering decision, there are two distinct levels of issue involved. The first is when the company *has little idea/knowledge what product-service bundles should be offered to customers* (Morelli 2002, Tukker and Tischner 2004). At this stage, a product-service focused modelling approach can be used to *generate the options*, for example as discussed in Low *et al*. (2000), Weber *et al*. (2004), Muller and Blessing (2007), and Shen and Wang (2008). Additionally, Service Explorer can guide the feature of service activities and the corresponding product (Sakao and Shimomura 2005). The procedure of product-service design is similar to product design and service design (Alonso-Rasgado *et al*. 2004). In fact, the service design is also developed from the product design procedure. In the product design domain, a bill of material is generated to show the structure of a product. The technology, in this case is a computer-aided design (CAD) tool, helps keep track of the product structure when changes to the design occurs. In the service design domain, instead of satisfying the customer by delivering the product functionality, the provider needs to consider physical and psychological benefits. Nonetheless, at the moment, the product items and service activities are mostly designed separately. The strategy has moved away from speed, cost and quality, to cost of ownership, availability of product and functional result.

The second is when the *company has some alternative offerings and prefers to evaluate each option* (Fujimoto *et al*. 2003, Komoto *et al*. 2005, Komoto and Tomiyama 2008). Here, simulation is typically used to *evaluate the options*.

3.6 *Range of PSS offering*

A wide range of products and services were introduced in PSS modelling. Examples include electronic equipment (Fujimoto *et al*. 2003, Komoto *et al*. 2005), production machines (Komoto and Tomiyama 2008, Schuh *et al*. 2009), transportation (Morelli 2006, Hara *et al*. 2009a, 2009b), aero-engines (Alonso-Rasgado *et al*. 2004, Buxton *et al*. 2006), food production (Evans *et al*. 2007, Kim *et al*. 2009), and heavy road construction (Aurich *et al*. 2006).

In the model scenarios, often the traditional production-based system was used as a baseline for different PSSes. The manufacturer only sells products with no further contact with the customers (Fujimoto *et al.* 2003, Komoto *et al.* 2005, Buxton *et al.* 2006, Evans *et al.* 2007). However, some services can be included to support product selling, for example, sales counselling (Aurich *et al.* 2006) and parts production (Schuh *et al.* 2009). Services at the end of product life such as material recycling and module reuse (Fujimoto *et al.* 2003), and product disposal (Aurich *et al.* 2006, Evans *et al.* 2007, Schuh *et al.* 2009) also add further interactions with the customers.

The majority of PSS modelling work (e.g., Fujimoto *et al.* 2003, Alonso-Rasgado *et al.* 2004, Komoto *et al.* 2005, Buxton *et al.* 2006, Maussang *et al.* 2007) suggest that the functional products operate in a similar way to product renting and sharing. Supported services during the use phase involve upgrading, maintenance and troubleshooting (Alonso-Rasgado *et al.* 2004, Aurich *et al.* 2006, Schuh *et al.* 2009). A manufacturer or an organisation can also assign third party service providers. For instance, a hospital can associate a catering provider to take care of patients' food (Evans *et al.* 2007) and a washing machine manufacturer can be incorporated within a launderette business (Komoto *et al.* 2005). Another detailed factor can also be added to differentiate offerings. A good illustration is when particular product modules are produced for a specific product type, thus, the flexibility of module reuse is limited (Fujimoto *et al.* 2003). Likewise, a sudden demand slump can be added in the scenarios to investigate the impact on each alternative (Buxton *et al.* 2006). Towards the pure service spectrum, a company can evaluate different service levels and test the alternatives affecting customer satisfaction (Sakao and Shimomura 2007, Hara *et al.* 2009b).

3.7 *Model parameters*

This section captures the information required in the model. By considering a system that consists of product, service and actor elements, the input parameters can be recognised as properties attached to those elements. Some factors that cannot be segmented as product, service or user-related are categorised as system-related. The combination of these parameters results in the model's outputs. It can be seen from Table 2 that some studies consider product and service elements individually while the others do not segregate the elements. There appears to be some cost accounting parameters, e.g., cash flow, net present value, introduced by one author only, i.e., Buxton *et al.* (2006), whereas economic measures (costs, profit), environment measures (waste amount, resource consumption), and operation measures (resource level, product specification) were included repetitively in several models, e.g., Fujimoto *et al.* (2003), Maussang *et al.* (2007), Sakao and Shimomura (2007), and Abramovici *et al.* (2009).

4. Analysis of the findings

This section presents the mapping of the current state of PSS models and the capability of the existing tools/techniques with the characteristics and dynamic behaviour of PSS businesses.

4.1 *Relationships between model parameters and PSS characteristics*

The first analysis is the mapping of the PSS model parameters and range of PSS offering with the PSS characteristics.

In relation to the *business and offering* characteristics, parameters, such as lifetime, reusability, product use and cost of ownership, indicate that the extended responsibility of the manufacturer from design and manufacture to services during the lifecycle was considered in several papers. *Value* parameters, qualitatively derived from customer needs were often incorporated in many models but indicators of service efficiency, such as overall *product availability, operating times* and *functional reliability*, were not commonly found. No model specifically illustrates the mix between transactional-based and customer relationship in the PSS business model as well as the associated risks. Despite the wide range of product-service offering, the choices of product types and service activities remain limited.

In terms of *operations and technology*, the decentralised decision making feature was not emphasised in any model, although the autonomy of each actor in the supply chain appeared in one model. This can be seen from the fact that no model incorporates variation within the decision making across service staff and the majority of existing

Table 2. Summary of PSS model parameters.

	Parameters				
Reference	Product	Service	System	User	Output
Komoto *et al.* (2005)	Module cost Process cost Lifetime Capacity Wear out time Failure rate Price Reparability Reusability	Activity costs Service fee	Number of operations Usage rate		Total cost Occurrence of PSS event
Morelli (2006)			Time dimension Interaction between people Cultural mind frames and social habit		Network configuration PSS blueprint
Aurich *et al.* (2006)	Specifications	Service process	Resource Information exchange		Servicing process specification
Sakao and Shimomura (2007)	Choices			Name/age/gender Family/career Excitement Security Being well respected Self fulfilment Sense of accomplishment Warm relationship Fun and enjoyment Self respect Sense of belonging Personality	Cost Energy saving Aesthetics Amount of light Temperature condition
Buxton *et al.* (2006)			Sales frequency Volumes Engine flight hours Engine flight cycles Usage characteristics	Customer characteristics	Break even point Net present value Cash flow

Maussang *et al.* (2007)	Quality/condition Cost Time for making design specifications Time for delivery of new product	Available time Cost of activities	Cost of infrastructure Security	Cost of ownership Convenience	Specification of element
Komoto and Tomiyama (2008)	Lifetime Rate of failure occurrence Market size Interval of function release Newness Functionality		Duration	Preference of user to service type	Life cycle cost
Abramovici *et al.* (2009)			Product use information (sensor data, environment parameters, maintenance events, failure)		Costs Values Energy efficient factor
Kim *et al.* (2009)	Product design Availability	Service roles	Element relation Relation type	User characteristics	Product-service specification
Hara *et al.* (2009b)	Visibility to receiver Interactivity with receiver	Visibility to receiver Interactivity with receiver		Degree of receiver participation	Product availability Ease of use Comfort ability Functionality Punctuality
Bianchi *et al.* (2009)			Initial members Aptitude to PSS transition Dissatisfaction to PSS Barriers to PSS Intensity and duration of incentives First time of activation		Number of product-oriented manufacturers Number of PSS providers.
Alonso-Rasgado *et al.* (2004)		Time taken to perform the service	The quality and flow of information		Performance level (functional reliability) Resource level
Hara *et al.* (2006)				Demographic data Psychological data Sense of fulfilment Being well respected Self respect Fun and enjoyment in life	Value

techniques, in fact, use a top-down approach meaning that the model is built from the system perspective rather than the individual's viewpoint. In addition, many of the models showed the link between the transformation of tangible assets and support services to deliver the capability of PSS. Assessments of availability which dictate the control parameters were also considered in some papers. Also, it was observed that there was no proposition for new technologies, which in fact supports the study by Manzini and Vezzoli (2003). In addition, both response times and service levels were not explicitly taken into account.

On the contrary, the interactions with the customers in the *supply/demand* network were clearly illustrated in the majority of the PSS models. The relationships triggered by the product availability and performance, similar to the information feedback from customers, however, were not shown. Government influence which can be a dominant player in public sectors such as water was hardly considered. The degree of interactions between suppliers and manufacturers, market responsiveness and the influences between customers were also not explicitly included in any model. However, although the cultural mind sets and social habits were mentioned in some models, no model took into account the fact that profit and satisfaction level could be improved by efficiency provision and the staff's skills developed throughout the contract.

4.2 *Capability of modelling tools and techniques*

The second analysis is the mapping between the capability of existing PSS modelling techniques (and tools) with the dynamic behaviour of PSS.

First of all, there is a wealth of research that integrates several analytical techniques with modelling techniques which in turn allows numerical assessments of the PSS offering options. Nevertheless, supporting tools have not yet been fully matured (Komoto *et al*. 2005, Hara *et al*. 2006). The majority of the existing tools do not incorporate the time varying variables and so they did not allow the dynamic behaviour to be investigated over time. As mentioned earlier, customer involvement can cause input changes but the tools and techniques that allow these variations to be captured are generally lacking, with the exception of those found in the applied simulation techniques and lifecycle concepts. Although the time varying variable was suggested by Morelli (2006), the tool implementation was not presented. Only one paper considered the autonomy of an organisation in a complex relationship, a decentralised decision making and an economic sensitivity (Buxton *et al*. 2006). Likewise, none of the tools allow different levels of performance measures to be included in the model. Only the paper by Komoto and Tomiyama (2008) integrated the tool to enhance the capability of PSS modelling using a mixed approach, i.e., between life cycle simulator and Service Explorer. The former is used to generate an alternative PSS whereas the latter analyses the subsequent lifecycle cost. However, there was also no evidence of environmental measure in the simulation.

4.3 *Analogy between design of PSS offering and product-only offering*

With respect to the PSS offering design, an analogy could be made with the product offering especially when a *company provides many different product-service bundles*. The mix of bundles brings the question of volume and price with the objective to maximise the profits and at the same time to minimise the total cost (because they share the same resource). In the traditional production system, the decision making process can be assisted by using linear programming (LP). Nonetheless, the stochastic occurrences of service activities could influence the cost and the product-service bundle mix could also change dynamically at different time periods.

Simulation can be advantageous to assess and select the most realistic/feasible solution from a number of possible solutions given by LP (Al-Aomar 2000). This is because simulation can take into account variability and randomness and can be used to test the different scenarios under which the LP mix option of the product-service bundle can be achieved. As each bundle has a different production/delivery rate and capacity requirement (resource type, utilisation, availability, etc.), the constraints are often in the form of technological capacity and other types of resource. As a result, the selection is usually based on the organisation's goals, environment and the production, marketing and financing strategies. In addition to LP and simulation, decision of the product mix method could include genetic algorithm, (heuristics) theory of constraints, extended methods of LP and activity-based costing. Nevertheless, there are no PSS models developed using these methods.

4.4 *Strengths, weaknesses and opportunities within PSS modelling research*

Based on the findings and the analyses in previous sections, an analysis of strengths, weaknesses and opportunities within PSS modelling research has been developed and summarised in Figure 3.

It can be seen that there are several strengths within the existing PSS modelling work since many characteristics of PSS models have been repeatedly discussed in several models. Nonetheless, there are also some PSS characteristics that were rarely mentioned, if not at all reflected by parameters in any models. These were grouped into the weaknesses of existing PSS modelling research.

From the strengths and weaknesses mentioned above, a number of opportunities within the PSS modelling research can be identified as follows. To better describe PSS businesses, the model should allow tracking of products' movement between the OEM and customers during their use; the parameters, e.g., product lifetime, time to fail, etc. should be based on the operating time rather than a fixed number of years/months, and finally, the model should also take into account parameters that reflect problems in all domains (business, operations, and network). With regard to the business and offering a technique that can enhance the analysis of product-service bundle offering is required. This technique should allow companies to offer the right proportion of each product-service bundle to maximise the profit at the most feasible scenario. From the operational viewpoint, the model should also consider the impact of technology on the companies' capability towards PSS.

Based on the above techniques, computer-based simulation tools incorporating the dynamic behaviour of PSS can be developed. Possible usage of these tools, for instance, is to investigate the dynamic behaviour caused by the improved service efficiency using the knowledge gathered over the contract period. Finally, the developed techniques and tools should be validated through case studies and industry implementation.

Although there have been several propositions for adopting the PSS concept to a wide range of products, especially for high value and reliability critical, the cost of building the infrastructure to support such a system may not be worthwhile in some products. The evaluation through the risks and rewards is therefore crucial.

Strengths

- Variety of technique stemmed from product perspective and service perspective.
- Rich combination between analytical methods and simulation techniques.
- Lifecycle perspective in an extension to product selling.
- Various value proposition from the use
- Explicit interactions between parties in supply chain and customer interaction.
- Wealth economic and environmental measures evaluation.
- Clear link between asset transformation and service supports.

Weaknesses

- Lack of service efficiency measure (availability, service response time, customer satisfaction level)
- Weak link between transactional and relationship aspects, product performance and customer-manufacturer interaction, and information feedback and customer involvements.
- Insufficient representation of decentralised decision making process, supplier-manufacturer interaction, cultural mind frame, and social habits.
- Absence of influences between customer, effect of technology on the company's capability, impacts from government.

Opportunities

- New definition and customisation of performance measures in PSS
- New techniques/approaches that can support the design of product-service bundle mix offering
- Development of operational level, computer-based simulation tools that incorporate the dynamic behaviour of PSS
- Better illustration of PSS modelling techniques and tools through case studies and industry implementation

Figure 3. Strengths, weaknesses and opportunities.

5. Conclusion

This paper has aimed to capture the characteristics of PSS and to better understand its dynamic behaviour. The main contribution of this paper is the collation of key model parameters that should be included into the PSS modelling capabilities. The relevant literature has been identified and the key findings were generated. The findings are grouped into several thematic areas: *the characteristics and dynamic behaviour of PSS*, *existing modelling tools and techniques*, *PSS offering scenarios* and *the modelling parameters*. Following the generation of key findings is the analysis of the models and tools' capabilities, which allow the strengths and weaknesses of the current research to be examined, and the opportunities for future research in PSS modelling to be identified.

The outcomes of the analysis suggest the following. First, tools and techniques that can effectively and comprehensively capture the dynamic behaviour of PSS are lacking. Secondly, even if they are available, the underlying performance measures of PSS are not obvious and difficult to quantify. Furthermore, PSS modelling and simulation techniques should ideally consider the supplier capability prior to the model development. The models should also take into account the monitoring of service level throughout the lifecycle of the product offering (contract) due to the continuous interaction between the customers and the manufacturers (PSS providers) which typically occurs in PSS businesses.

This paper therefore highlighted the need for future research which will focus towards the development of simulation modelling tools and techniques incorporating the modelling parameters formulated in this paper to reflect PSS business and offering, operation and technology, and supply/demand network domains. Is it envisaged that the tool will also include simulation component templates (customised to different PSS scenarios), and an input/output data interface as the front-end to discrete-event and agent-based simulation engines.

References

Abramovici, M., *et al*., 2009. Metadata reference model for IPS2 lifecycle management. *In*: *Proceedings of the CIRP IPS2 conference 2009*, 1-2 April, Cranfield, UK, 268.

Al-Aomar, R., 2000. Product-mix analysis with discrete event simulation. *In*: *Proceedings of the 32nd winter simulation conference*, 10–13 December, Orlando,1385–1392.

Almeida, F.L., Miguel, P.A.C. and Silva, M.T.D., 2008. A literature review of servitisation: a preliminary analysis. *In*: *Proceedings of the POMS 19th annual conference*, 9–12 May, California, USA.

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

Aurich, J.C., Fuchs, C., and Wagenknecht, C., 2006. Life cycle oriented design of technical product-service systems. *Journal of Cleaner Production*, 14 (17), 1480–1494.

Azarenko, A., *et al*., 2007. Technical product-service systems: business models for high precision machine tool manufacturers. *In*: *Proceedings of the 5th international conference on manufacturing research (ICMR2007)*, 11–13 September, Leicester, UK.

Baines, T.S., *et al*., 2007. State-of-the-art in the product-service systems. *Journal of Engineering Manufacture*, 221 (10), 1543–1552.

Baines, T.S., *et al*., 2009a. The servitisation of manufacturing: a review of literature and reflection on future challenges. *Journal of Manufacturing Technology Management*, 20 (5), 547–567.

Baines, T., *et al*., 2009b. Towards an operations strategy for product-centric servitisation. *International Journal of Operations and Production Management*, 29 (5), 494–519.

Banks, J., *et al*., 2009. *Discrete-event system simulation*. Upper Saddle River, NJ: Pearson Prentice Hall.

Becker, J., Beverungen, D.F., and Knackstedt, R., 2009. The challenge of conceptual modelling for product-service systems: status-quo and perspectives for reference models and modelling languages. *Information Systems e-Business Management*, 8 (1), 33–66.

Bianchi, N.P., *et al*., 2009. Influencing factors of successful transitions towards product-service systems: a simulation approach. *International Journal of Mathematics and Computers in Simulation*, 3 (1), 30–43.

Brasilford, S.C., 2008. System dynamics: what's in it for healthcare simulation modelers. *In*: *Proceedings of the 2008 winter simulation conference*, 7–10 December, Miami, Florida, 1478–1483.

Buxton, D., Farr, R. and McCarthy, B., 2006. The aero-engine value chain under future business environments: using agent-based simulation to understand dynamic behaviour. *In*: *Proceedings of the MITIP2006*, 11–12 September, Budapest, Hungary.

De Coster, R., 2008. Differences in forecasting approaches between product firms and product-service systems (PSS). *In*: *Proceedings of the 6th international conference on manufacturing research (ICMR08)*, 9-10 September, Brunel, 539–547.

Erkoyuncu, J.A., *et al.*, 2009. Uncertainty challenges in service cost estimation for product-service systems in the aerospace and defence industries. *In*: *Proceedings of the 1st CIRP industrial product-service systems (IPS2) conference*, 1-2 April, Cranfield, UK, 200.

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

Fujimoto, J., *et al.*, 2003. Development of service-oriented products based on the inverse manufacturing concept. *Environmental Sciences & Technology*, 37 (23), 5398–5406.

Hara, T., Arai, T. and Shimomura, Y., 2006. A concept of service engineering: a modeling method and a tool for service design. *In*: *Proceedings of the international conference on service systems and service management*, 25–27 October, Troyes, France, 13–18.

Hara, T., Arai, T. and Shimomura, T., 2009a. A method to analyse PSS from the viewpoints of function, service activity, and product behaviour. *In*: *Proceedings of the CIRP IPS2 conference 2009*, 1-2 April, Cranfield, UK, 180.

Hara, T., *et al.*, 2009b. Service CAD system to integrate product and human activity for total value. *CIRP Journal of Manufacturing Science and Technology*, 1 (4), 262–271.

Kang, M.J. and Wimmer, R., 2008. Product service systems as systemic cures for obese consumption and production. *Journal of Cleaner Production*, 16 (11), 1146–1152.

Kim, Y.S., *et al.*, 2009. A product-service system representation and its application in a concept design scenario. *In*: *Proceedings of the CIRP IPS2 conference 2009*, 1-2 April, Cranfield, UK, 32.

Komoto, H., *et al.*, 2005. Life cycle simulation for analyzing product service systems. *In*: *Proceedings of the fourth international symposium on environmentally conscious design and inverse manufacturing*, 12–14 December, Tokyo, 386–393.

Komoto, H. and Tomiyama, T., 2008. Integration of a service CAD and a life cycle simulator. *CIRP Annals – Manufacturing Technology*, 57 (1), 9–12.

Low, M.K., *et al.*, 2000. Product to service eco-innovation: the TRIZ model of creativity explored. *In*: *Proceedings of the IEEE international symposium on electronics and the environment*, 8–10 May, California, 209–214.

MAN Truck & Bus UK, 2010. MAN Truck & Bus UK services [online]. Available from: http://www.man-mn.co.uk/en/Services/Services.jsp [Accessed 1 June 2010].

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*, 11 (8), 851–857.

Maussang, N., *et al.*, 2007. A model for designing product-service systems using functional analysis and agent based model. *In*: *Proceedings of the international conference on engineering design*, ICED'07, 28–31 August, Paris, France.

Mont, O., 2002a. Clarifying the concept of product-service system. *Journal of Cleaner Production*, 10 (3), 237–245.

Mont, O., 2002b. Drivers and barriers for shifting toward more service-oriented businesses: analysis of PSS field and contributions from Sweden. *The Journal of Sustainable Product Design*, 2 (3-4), 89–93.

Morelli, N., 2002. Product-service systems, a perspective shift for designers: a case study: the design of a telecentre. *Design Studies*, 24 (1), 73–99.

Morelli, N., 2006. Developing new product service systems (PSS): methodologies and operational tools. *Journal of Cleaner Production*, 14 (17), 1495–1501.

Muller, P. and Blessing, L., 2007. Development of product-service-systems –comparison of product and service development process models. *In*: *Proceedings of the international conference on engineering design ICED'07*, 28–31 August, Paris, France.

Neely, A., 2008. Exploring the financial consequences of the servitization of manufacturing. *Operations Management Research*, 1 (2), 103–108.

Oman, I., 2003. Product service-system and their impacts on sustainable development—a multi-criteria evaluation for Austrian companies. *Frontiers*.

Roy, R. and Cheruvu, K.S., 2009. A competitive framework for industrial product-service systems. *International Journal of Internet Manufacturing and Services*, 2 (1), 4–29.

Sakao, T. and Shimomura, Y., 2005. A novel design methodology for services to increase value combining service and product based on service engineering. *In*: *Proceedings of the 4th international symposium on environmentally conscious design and inverse manufacturing*, 12–14 December, Tokyo, 402–409.

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*, 15 (6), 390–604.

Sakao, T. and Lindahl, M., 2009. *Introduction to product/service-system design*. London: Springer.

Schuh, G., Boos, W. and Kozielski, S., 2009. Life cycle cost-oriented service models for tool and die companies. *In*: *Proceedings of the CIRP IPS2 conference 2009*, 1–2 April, Cranfield, UK, 249.

Schuh, G. and Gudergan, G., 2009. Service engineering as an approach to designing industrial product service system. *In*: *Proceedings of the CIRP IPS2 conference 2009*, 1–2 April, UK.

Shen, J. and Wang, L., 2008. A methodology based on fuzzy extended quality function deployment for determining optimal engineering characteristics in product-service system design. *In*: *Proceedings of 2008 IEEE international conference on service operations and logistics and informatics*, 2–15 October, Beijing, 331–336.

Shostack, G.L., 1982. How to design a service. *European Journal of Marketing*, 16 (1), 49–63.

Tukker, A., 2004. Eight types of product-service system: eight ways to sustainability? Experiences from SusProNet. *Business Strategy and the Environment*, 13 (4), 246–260.

Tukker, A. and Tischner, U., 2004. *New business for old Europe*. Final report of SusProNet. TNO-STB, Delft, the Netherlands.

Tukker, A. and Tischner, U., 2006. Product-services as a research field: past, present and future. Reflections from a decade of research. *Journal of Cleaner Production*, 14 (17), 1552–1556.

Weber, C., *et al*., 2004. Modelling of product-service systems (PSS) based on the PDD approach. *In*: *Proceedings of the international design conference - Design 2004*, 18–21 May, Dubrovnik, Croatia, 547–554.