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Towards Product-Service Systems modelling: a quest for dynamic behaviour and model parameters

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Abstract

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. PSS has various characteristics beyond the traditional product-selling businesses as a result from the 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

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1. Introduction

A Product Service System (PSS), according to Baines et al (2007), Mont (2002a) and Mantzini and Vezzoli (2003), 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 as 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. Alonso-Rasgado et al (2004), Baines et al (2007) and Mont (2002b)) are the Rolls-Royce's Power-by-the-Hour and Xerox's Document Management Solution business models. In the former, the Original Equipment Manufacturers (OEM), 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 see the integration of the products (photocopiers) and the services Xerox offers to support them (Baines et al, 2007).

[Insert Figure 1 here]

Figure 1: (a) Product selling; (b) PSS selling (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 the 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-

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4 per-usage or fix-term contract basis. For the customers, this is beneficial especially
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6 when the products are high in value and reliability critical. In PSS, the responsibility of
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8 maintaining the assets, provision of spare parts and even to take back and remove the
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10 assets at the end of their life, is within the manufacturers, leaving the customers to
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12 focus on their core business operations.
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16 Shifting from the traditional production-based model to PSS-based model means the
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18 manufacturers are required to add more value to the products they offer and at the
19
20 same time to design, and if necessary, diversify services around the products. Some
21
22 successful PSS cases have been documented in Baines et al (2007), Mont (2002b),
23
24 Tukker (2004) and Tukker & Tischner (2006), and interestingly, they have reported that
25
26 the PSS business model have improved the competitiveness of the companies
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28 adopting PSS. This is not surprising especially in the cases where more revenue is
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30 gained from services provision than from the products selling alone. Naturally in any
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32 service provision, PSS often necessitates companies to build stronger rapport with their
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34 customers as they no longer compete on the products they offer, but instead on the
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36 package (i.e. combination of products and services). It has also been reported that
37
38 those who succeeded will maintain their position in the market share (Roy and Cheruvu
39
40 2009; Neely, 2008). In addition to the commercial benefits, PSS literature also often
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42 links PSS with the environmental benefits. Furthermore, according to Tukker (2004),
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44 PSS could lead to decreased resource consumption, reduced waste and increased
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46 manufacturing sustainability.
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52 Despite the abovementioned benefits offered by PSS, the design of such PSS
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54 businesses remains challenging and risky. The shift from product-selling to PSS often
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56 raises several questions, for instance *what to offer in the 'package'?*, *how long is the*
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58 *contract?*, *how much to charge?*, *what resource required?* etc. In the traditional
59
60 production-based system design/redesign, system designers are typically faced with

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4 issues with no early visibility of the likely performance of the production system they
5 design. Not only are the design parameters often not well understood, but also the
6 interconnectedness amongst the design parameters, making it even more difficult to
7 predict the dynamic behaviour of the system. If designing a product-only system is
8 complicated, designing a PSS is even more challenging due to the service components
9 that also need to be accurately modelled.
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11
12
13 Rich amount of literature exists in the area of production-based system modelling and
14 simulation, and moreover the commercial tools are also widely available. However,
15 they usually do not consider the additional dynamic aspects of the service components.
16 As an example, the demand forecast in PSS should take into account the customers
17 interaction during the contract (De Coster, 2008) the multidimensional offers should
18 also be designed to be more creative and attractive than the technical function of the
19 product (Kang and Wimmer, 2008) which subsequently requires a tight cooperation
20 amongst the stakeholders in the supply network. In addition, the whole product lifecycle
21 and infrastructure must be considered during the design process (Azarenko et al,
22 2007). Without an appropriate tool, the designer could be in the risk of making poor
23 decision which could be detrimental to the whole business. For these reasons, such a
24 PSS modelling tool is desirable to deal with these complexities.
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29 The work described in this paper aims to capture the characteristics of PSS and to
30 better understand its dynamic behaviour. The structure of this paper is organised as
31 follows. Section 2 describes the research programme and methodology adopted in the
32 research. The findings of the research are summarised in Section 3. In this section, the
33 characteristics and dynamic behaviour of PSS are collated and the potential modelling
34 methods and tools are identified. The typical PSS model parameters are also
35 summarised in this section before the mapping of the current state of PSS models and
36 the capability of the existing tools/techniques with the characteristics and dynamic
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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 these can be used to effectively model PSS?
4. What are the commonly used parameters in PSS modelling?

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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.

[Insert Figure 2 here]

Figure 2: Contributions of the paper

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), Faria-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, manual search was conducted at the Winter Simulation Conference online proceedings (years 1999 to 2009) and 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

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4 papers were inspected. The whole process resulted in twenty two most relevant PSS
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6 models shown in Table 1.
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10 **Table 1: Classification of PSS techniques and tools**

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12 [Insert Table 1 here]
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14

15 16 **3. Findings**

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18 As part of the systematic literature review framework used in this research, the key
19
20 findings from each paper were thematically grouped. Each of these key findings is
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22 described below.
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25 26 **3.1 Characteristics of PSS**

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28 Companies or manufacturers who have shifted from the traditional product selling to
29
30 PSS typically exhibit a number of features that characterise their businesses. These
31
32 characteristics have been repeatedly mentioned and clearly highlighted in the literature,
33
34 for example Baines et al (2009b), Mont (2002a), Mantzini and Vezzoli (2003), and can
35
36 be grouped into three domains: *business and offering strategy, operations and*
37
38 *technology and supply/demand network* (see Table 2).
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42 **Table 2: Summary of characteristics exhibited in PSS models**

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44 [Insert Table 2 here]
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47 48 **3.1.1 Business and offering strategy**

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50 Many of the PSS businesses feature a combination of the transactional-based
51
52 processes typically found in the product-selling (or manufacturing) and the relationship-
53
54 based in the service environment (Baines et al, 2009b). For those companies, the
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56 focus for improvement is no longer on the materials and energy, but in the efficiency of
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58 the services (Mont, 2002a). Human capital, as well as the reduction of transportation
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60 distance, is therefore deemed vital. These features, combined with the involvements of

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4 many parties, suggest the need of clear performance indicators, for example, the
5
6 measures that can reflect the lifespan of products (Mont, 2002a), life cycle cost (Baines
7
8 et al, 2009b), logistic cost (Omann, 2003), efficiency of resource consumption (Mont,
9
10 2002a) and closed cycle efficiency (Mont, 2002a). Furthermore, the value of product is
11
12 determined by its use. In other words, customers value the *availability, performance*
13
14 *and risk/reward sharing* in PSS (Baines et al, 2009b).
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18 The order winnings have now shifted from product/service features, cost, quality and
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20 delivery of product/service to features of the product-service bundles, the cost of
21
22 ownership, the availability of product and the capacity to deliver services (Baines et al,
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24 2009b). Products in PSS, typically co-developed with the customers, are designed for
25
26 reusability and recyclability (Mont, 2002a). It can also be observed that the variety of
27
28 product-service bundles in PSS is limited in comparison with product or service range
29
30 in the traditional product-selling businesses (Baines et al, 2009b).
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34 **3.1.2 Operations and technology**

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36 To support their business strategy, especially in maintaining a strong rapport with their
37
38 customer base, PSS businesses typically have proximity to their customers. As
39
40 highlighted by Baines et al (2009b), one of the PSS companies they investigated has
41
42 built their assembly and test facilities that are close to their market. In some cases,
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44 particularly with regards to the product-service development, the decision making
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46 process is decentralised due to the interactions with the different customers (Mont,
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48 2002a). The management of operations usually involves transformation of materials
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50 into tangible assets that are sold along with the support services to deliver functional
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52 capability to customers (Baines et al, 2009b). The planning and control mechanisms
53
54 therefore shift to the optimisation of the availability of the assets and responsiveness in
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56 providing this capability, rather than merely optimisation of the assets inventory. For
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4 that reason, the performance measures usually concern *product availability, response*
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6 *time and customer satisfaction.*
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10 Many of the PSS businesses adopt various enabling technologies at various levels
11 especially to continuously monitor the condition of their assets in use. The monitoring
12 of the assets allows a better visibility of what is required and when, so that the
13 downtime and subsequent losses can be minimised. Although in some cases the
14 technology itself is considered critical, in other cases (reported by Manzini and Verzolli
15 2003)), many PSS companies actually focus on the management of existing
16 technologies in order to maximise the efficiency in production and effectiveness in
17 delivery.
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28 **3.1.3 Supply/demand network**

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30 In terms of supply/demand network, PSS businesses typically adopt the vertical
31 integration strategy for product manufacture and the integrated partner approach
32 during the service provision (Baines et al, 2009b). The complex relationships amongst
33 the different actors are in fact governed by the product availability and performance.
34 Information flow between the companies and their customers becomes much more
35 crucial than that in the product selling businesses (Mont, 2002a). In addition to that,
36 PSS businesses typically have stronger cooperation with their suppliers. Having this
37 strong link allows PSS businesses to become more *responsive to market changes* and
38 will further *stimulate innovation* in their design and development.
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50 From several publications, it is apparent that many significant changes occur as the
51 business shifts towards PSS. It was observed in practice that technology and customer
52 relation are the major critical elements (Manzini and Verzolli, 2003), and therefore, the
53 new variables taken into account when designing PSS are *time dimension, interaction*
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4 *between people, cultural mind frame and social habits* (Morelli, 2006; Sakao and
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6
7 Lindahl, 2009).

8 9 10 **3.2 Dynamic behaviour**

11 Dynamic behaviour in this case is referred to as the disturbances, perturbations or
12 even reactions that may affect the performance of the PSS businesses and impose
13 risks on them (see Table 3).
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19 **Table 3: Summary of dynamic behaviour in PSS**

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22 [Insert Table 3 here]

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25 The dynamic behaviour in PSS is mostly triggered by the customer-manufacturer
26 interaction during the use of the assets. Unlike the product-selling businesses where
27 the responsibility of manufacturers ends after selling the product to customers, it is
28 crucial for PSS providers to understand the risks caused by dynamic behaviour, and be
29 capable of handling them. Otherwise, the PSS providers may not be able to deliver the
30 product-service contracts. Assets may stochastically fail and consequently be
31 unavailable (Baines et al, 2009b). Poor availability performance will ultimately affect the
32 customer loyalty and disloyal customers will subsequently results in inaccurate demand
33 forecasting at the manufacturers' end (De Coster, 2008). Prior to offering PSS,
34 feedback from customers, i.e. market analyses, can influence the design of the contract
35 (Mont, 2002a; Roy and Cheruvu, 2009). Design specification may also be affected
36 because of market change and customer complaints. As highlighted by Roy and
37 Cheruvu (2009) that contracts are typically agreed for 5-30 years and can be modified
38 to serve specific needs of customer, adaptation phase should therefore be structured
39 during the design phase. In defence and aerospace industries particularly, changes
40 during in-service phase are in the forms of spares, repairs, training services and
41 obsolescence (Erkoyuncu, 2009). In addition to that, customers can sign some service
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4 contracts in short period, for example, in the case of Fleet Management at MAN truck¹.
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6 This short term contract (i.e. pay-as-you use) can cause demand fluctuation and
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8 consequently the manufacturer needs to regularly fine tune their capacity plan.
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11 From the supply chain viewpoint, the PSS network has a complex relationship (Manzini
12 and Verzolli, 2003) with various decision rules that exist within different actors and
13 stakeholders. Nonetheless, PSS allows the manufacturers to be more responsive to
14 market parameter variations because the information, for example, asset condition,
15 design requirement, etc can be transmitted back to the manufacturers (Mont, 2002b).
16
17 This would also allow changes in the performance measures to be subsequently
18 modified during the delivery of a service contract, although profits as well as price
19 sensitivity and logistics cost, will be affected by the efficiency of this provision.
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30 **3.3 PSS modelling techniques**

31 To help manufacturers shift towards PSS, several guidelines have been proposed in
32 the literature. The Methodology Development and Evaluation of PSS (MEPSS) and
33 Highly Customised Solution (HiCS) (Tukker & Tischner, 2004) are example of such
34 guidelines. MEPSS was born from a project funded by the European Union, which
35 provided a toolkit for successful implementation of new PSS. The methodology is
36 divided into phases: strategic analysis, exploring opportunity, PSS idea development,
37 PSS development and preparing for implementation. HiCS introduced Solution
38 Oriented Partnership Methodology Framework (SOPMF) to initiate co-creating
39 industrialised sustainable solutions. SOPMF brings together partnerships to create
40 alliances and allows several concepts and tools to be inherent (Tukker & Tischner,
41 2004). Although comprehensive, both MEPSS and HiCS do not specify quantitative
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60 ¹ <http://www.man-mn.co.uk/en/Services/Services.jsp> last accessed 1 June 2010

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4 evaluation techniques. Rather, they provide a big picture for ground understanding of
5 the PSS transformation.
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9 Some modelling techniques have been presented by Becker et al (2009) to gain
10 insights into the system, thus, are used for specific purposes. A model is defined as a
11 simplification of the system that is of interest, and only incorporates the aspects that
12 affect the problem of the study (Banks, 2009). PSS models are diverse as the PSS
13 concept itself has been driven from different perspectives (Mont, 2002a).
14 Consequently, modelling methods are also numerous. Table 1 shows this diversity, and
15 often, many modelling techniques are combined with other analytical methods such as
16 scenarios and use case analysis, quality function deployment, model for value and
17 cost, analytical hierarchy process, activity-based costing, etc.
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20 In summary, PSS modelling techniques can be grouped into 3 main categories taking
21 into account *the user*, *the system* and *the product-service perspectives*. The
22 descriptions of these are given below.
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30 **3.3.1 User focus**

31 This modelling technique focuses on the users, i.e. modelling how users as the
32 recipient of services interact to each other. Within this category, service blueprinting
33 (Shostack, 1982) is the commonly cited modelling method in the literature. Service
34 blueprinting illustrates the flow of service along with the time dimension and tolerances.
35 It also incorporates the details of total standard execution time, total deviation tolerance
36 and total acceptable execution. The line of visibility is used to separates activities which
37 are essential for the performance of services but not directly concerned with customer
38 from other functions. The method can be seen as a symbolic snapshot of service
39 processes. Service blueprinting was reported in the case of tele-centre to model a list
40 of events generated by a use case (Morelli, 2002). The blueprint was represented by a
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4 service cycle consisting of technical and maintenance services as well as tangible and
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6 intangible components. Additionally, service blueprinting can also be used to present
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8 architecture of analytical methods and tools in developing new solutions, for example,
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10 pair wise comparison, progressive abstraction, advance sequential incident etc (Schuh
11
12 & Gudergan, 2009).

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15 Also, within the service engineering paradigm, there exists a set of models comprising
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17 a *flow model*, a *scope model*, a *view model* and a *scenario model* (Sakao &
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19 Shimomura, 2007; Hara et al, 2006). A flow model represents the stream of services,
20
21 while both the scope model and the view model address a target area of service and
22
23 their relationships respectively. The designer typically identifies agents, demographic
24
25 and psychological data, states parameters of the service receiver and the value
26
27 characteristics. The realisation structure can then be generated to obtain the design
28
29 solutions. In addition to the above models, a behaviour blueprint can be added to
30
31 represent the interactions between the receiver and the products, and an activity
32
33 blueprint can be combined to show the collaborations between the receiver and staff
34
35 (Hara et al, 2009a). This combined model allows interactions between staff and
36
37 equipment or facilities to be presented. Based on a view model and a scenarios model,
38
39 a functional block diagram can be used to map the interaction of elements (Maussang
40
41 et al, 2007). The system can be analysed in terms of customer's needs, people's
42
43 involvement, external functions, technical functions and the elements of solutions. A
44
45 detailed design was built once the specifications for each element were determined.
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51 An ontological representation of a food assembly system was proposed by Kim et al
52
53 (2009) based on the Unified Modelling Language (UML) specifications. The system
54
55 elements comprise values and relations. The value elements were described by their
56
57 nature, constraints, category and realisation. The relations were defined by type,
58
59 enable, enhance, and proxy, and paired up between product, service and value.
60

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 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) concerns with modelling a system where the state variables change only at a discrete set of points in time (Banks, 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

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4 (Alonso-Rasgado et al, 2004). Based on PSS, a lifecycle model was built upon three
5 sub-model; lifecycle process, product and user (Fujimoto et al, 2003). The first sub-
6 model indicated a network of process such as manufacturing, operation, recycling and
7 remanufacturing. The state changes of these processes were programmed. The
8 second consisted of modules modelled by sets of attributes, the other allocated
9 customers according to types of packages and their behaviours. Another DES model
10 was developed from a set of PSS objects and their subsequent transition/relationships
11 (Komoto et al, 2005). The objects included service, service provider, service receiver,
12 PSS events and the product. The PSS events were subdivided into generation and
13 elimination, deterioration, and recovery, whereas the product was grouped according to
14 the structure into the operation-critical modules and lifetime-critical modules. The
15 changes in state description were defined. The resulting performance was the outcome
16 of occurrences of PSS events and the individual performance. DES was also used in
17 the integration with Service Engineering to evaluate lifecycle cost from the generated
18 design solution (Komoto & Tomiyama, 2008).
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38 Unlike DES, Agent-Based Simulation (ABS) models interactions between agents rather
39 than flows of processes. The agents can have their own decision rules and autonomy
40 which fundamentally differ from the objects and entities in DES. Within PSS, ABS has
41 been used to study the dynamic behaviour of the market and investigate the agent's
42 performance in the context of an aero engine value chain business environment
43 (Buxton et al, 2006). These agents included the OEM, the marketplace and the engines
44 themselves. The model incorporated all activities throughout the whole lifecycle of the
45 engines. The run time of fifty years provided sufficiently long term implication of the
46 strategic decisions.
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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 of service and subsequent functions and technology. Another example is the V-model (Muller & 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 Shin & 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 Weiber 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 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 food production system to achieve sustainability.

A life cycle oriented design based on the object-oriented modelling was proposed by Aurich et al (2006). Process objects, structures, relations, functions, and subsequent properties were defined. The life-cycle 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).

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4 Metadata models, typically used to describe a product and its properties throughout its
5 lifecycle, are the core of the traditional Product Lifecycle Management system
6 (Abramovici et al, 2009). The reference model was used as the domain knowledge
7 whereas modelling language determined the structure of the conceptual model.
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9 Interfaces that allowed information flows between manufacturing and services were
10 examined to enable the integration between them.
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18 **3.4 PSS modelling tools**

19 Supporting tools to design PSS offers can be in the form of the so called front-end tools
20 or software packages offering a platform for model building. Life Cycle Simulators
21 (LCS), Service Explorer, Business Process Modelling Notation (BPMN) and Integrated
22 Production Process Model (IPPM) are examples from the first group, whereas
23 AnyLogic and Protégé are examples from the second group. Figures 3 to 6 show
24 examples of some PSS models developed using the aforementioned tools.
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34 LCS, developed from DES, simulated stochastic behaviour of component lifetime
35 distribution and dynamic changes of behaviour of actors (Komoto et al, 2005; Komoto
36 & Tomiyama, 2008). Actions performed by actors were described as events and
37 triggered in the product lifecycle and allowed for economical and environmental
38 impacts to be calculated based on the occurrence of these event.
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45 Service Explorer, based on the Service Engineering concept and the Java computer
46 language, shows the needs of customers and the relations between those needs, and
47 simulated the flow of service (Hara et al, 2006). The tool provides a design workspace
48 to build a model using drag and drop operations. A model consists of a set of
49 connected nodes which represent receiver state parameters, functions and agents.
50 Behaviour of services can be simulated. BPMN was developed as a blueprint editor for
51 the Service Explorer to ensure consistent semantics, which aims to enhance
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4 understandings by all business users (Hara et al, 2009a). The result obtained from
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6 BPMN is a diagram that represents the flow of process.
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10 [Insert Figure 3 here]
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13 **Figure 3: Integrated lifecycle simulator with service explorer (Komoto and**
14 **Tomiyama, 2008)**
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18 IPPM, based on object oriented modelling, defined process objects by their structures,
19 relations, required functions and related properties (Aurich et al, 2006). Process
20 modularisation was incorporated to enhance life cycle oriented design. These process
21 modules were assigned to the network partners for the compilation.
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28 [Insert Figure 4 here]
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31 **Figure 4: Integrated Production Process Model (Aurich et al, 2006)**
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35 The software packages usually provide drag and drop operations and allow a user to
36 define or customise an object by using Java language. AnyLogic is capable of
37 modelling SD, DES and ABS and provides numerical evaluation of the impact of input
38 changes to the outputs. Protégé is an ontology editor for the purpose of knowledge
39 management, which produces graphical representation rather than numerical
40 evaluation.
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50 [Insert Figure 5 here]
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53 **Figure 5: Agent-based model (Buxton et al, 2006)**
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[Insert Figure 6 here]

Figure 6: Protégé (Kim et al, 2009)

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* (Tukker & Tischner, 2004; Morelli, 2002). 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), Muller & Blessing (2007), Weiber et al (2004), Shin & Wang (2008). Additionally, Service Explorer can guide the feature of service activities and the corresponding product (Sakao & 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 product design procedure. In product design domain, a bill of material is generated to show the structure of a product. The technology, in this case is Computer-Aided Design (CAD) tool, helps keep track of the product structure when changes to the design occurs. In 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

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4 mostly designed separately. The strategy has moved away from speed, cost and
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6 quality, to cost of ownership, availability of product and functional result.
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10 The second is when the *company has some alternative offerings and prefers to*
11 *evaluate each option* (Fujimoto et al, 2003; Komoto et al, 2005; Komoto & Tomiyama,
12 2008). Here, simulation is typically used to *evaluate the options*.
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15 16 17 **3.6 Range of PSS offering**

18 Wide range of products and services were introduced in PSS modelling. Examples
19 include electronic equipments (Fujimoto et al, 2003; Komoto et al, 2005), production
20 machines (Komoto & Tomiyama, 2008; Schuh et al, 2009), transportation (Morelli,
21 2006; Hara et al, 2009a; Hara et al, 2009b), aero engines (Alonso-Rasgado, et al,
22 2004; Buxton et al, 2006), food production (Evans et al, 2007; Kim et al, 2009) and
23 heavy road construction (Aurich et al, 2006).
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32 In the model scenarios, often that traditional production-based system was used as a
33 baseline for different PSS. The manufacturer only sells product with no further contact
34 with the customers (Fujimoto et al, 2003; Komoto et al, 2005; Buxton et al, 2006; Evans
35 et al, 2007). However, some services can be included to support product selling, for
36 example, sales counselling (Aurich et al, 2006) and parts production (Schuh et al,
37 2009). Services at the end of product life such as material recycling and module reuse
38 (Fujimoto et al, 2003) and product disposal (Aurich et al, 2006; Schuh et al, 2009;
39 Evans et al, 2007) also add further interactions with the customers.
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50 The majority of PSS modelling work (e.g. Alonso-Rasgado et al, 2004; Komoto et al,
51 2005; Buxton et al, 2006; Maussang et al, 2007; Fujimoto et al, 2003) suggest the
52 functional products to operate in similar way to product renting and sharing. Supported
53 services during the use phase involve upgrading, maintenance and troubleshooting
54 (Alonso-Rasgado et al, 2004; Aurich et al, 2006; Schuh et al, 2009). A manufacturer or
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4 an organisation can also assign third party service providers. For instance, a hospital
5 can associate a catering provider to take care of patients' food (Evans et al, 2007) and
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7 a washing machine manufacturer can be incorporated within a launderette business
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9 (Komoto et al, 2005). Another detailed factor can also be added to differentiate
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11 offerings. A good illustration is when particular product modules are produced for a
12
13 specific product type, thus, the flexibility of module reuse is limited (Fujimoto et al,
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15 2003). Likewise, a sudden demand slump can be added in the scenarios to investigate
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17 the impact on each alternative (Buxton et al, 2006). Towards the pure service
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19 spectrum, a company can evaluate different service levels and test the alternatives
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21 affecting the customer satisfaction (Sakao & Shimomura, 2007; Hara et al, 2009b).
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27 **3.7 Model parameters**

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29 This section captures the information required in the model. By considering a system
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31 that consists of product, service and actor elements, the input parameters can be
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33 recognised as properties attached to those elements. Some factors that cannot be
34
35 segmented as a product, a service or a user-related are categorised as system-related.
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37 The combination of these parameters results in the model's outputs. It can be seen
38
39 from Table 4 that some studies consider product and service elements individually
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41 while the others do not segregate the elements. There appears to be some cost
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43 accounting parameters, e.g. cash flow, net present value, introduced by one author
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45 only, i.e. Buxton et al (2006), whereas economic measures (costs, profit), environment
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47 measures (waste amount, resource consumption), and operation measures (resource
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49 level, product specification) were included repetitively in several models, e.g. Sakao &
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51 Shimomura (2007), Maussang et al (2007), Fujimoto et al (2003) and Abramovici et al
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53 (2009).
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58 **Table 4: Summary of PSS model parameters**

[Insert Table 4 here]

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 mixed 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 techniques, in fact, use 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

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4 services to deliver the capability of PSS. Assessments of availability which dictate the
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6 control parameters were also considered in some papers. Also, it was observed that
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8 there was no proposition for new technologies, which in fact supports the study by
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10 Manzini & Verzolli (2003). In addition, both response times and service levels were not
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12 explicitly taken into account.
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16 In contrary, the interactions with the customers in the *supply/demand* network were
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18 clearly illustrated in the majority of the PSS models. The relationships triggered by the
19
20 product availability and performance, similar to the information feedback from
21
22 customers, however, were not shown. Government influence which can be a dominant
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24 player in public sectors such as water was hardly considered. The degree of
25
26 interactions between suppliers and manufacturers, market responsiveness and the
27
28 influences between customers were also not explicitly included in any model. However,
29
30 although the cultural mind sets and social habits were mentioned in some models, no
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32 model took into account the fact that profit and satisfaction level could be improved by
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34 efficiency provision and the staff's skills developed throughout the contract.
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38 **4.2 Capability of modelling tools and techniques**

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40 The second analysis is the mapping between the capability of existing PSS modelling
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42 techniques (and tools) with the dynamic behaviour of PSS.
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46 First of all, there is a wealth of research that integrates several analytical techniques
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48 with modelling techniques which in turn allows numerical assessments of the PSS
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50 offering options. Nevertheless, supporting tools have not yet been fully mature (Hara et
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52 al, 2006; Komoto et al, 2005). The majority of the existing tools do not incorporate the
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54 time varying variables and so they did not allow the dynamic behaviour to be
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56 investigated over time. As mentioned earlier, customer involvements can cause input
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58 changes but the tools and techniques that allow these variations to be captured are
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4 generally lacking, with the exceptions of those found in the applied simulation
5 techniques and lifecycle concepts. Although the time varying variable was suggested
6 by Morelli (2006), the tool implementation was not presented. Only one paper
7 considered the autonomy of an organisation in a complex relationship, a decentralised
8 decision making and an economic sensitivity (Buxton et al, 2006). Likewise, none of the
9 tools allow different levels of performance measures to be included into the model.
10 Only the paper by Komoto & Tomiyama (2008) integrated the tool to enhance the
11 capability of PSS modelling using a mixed approach, i.e. between life-cycle simulator
12 and service explorer. The former is used to generate alternative PSS whereas the latter
13 analyses the subsequent life cycle cost. However, there was also no evident of
14 environmental measure in the simulation.
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29 **4.3 Analogy between design of PSS offering and Product-only offering**

30 With respect to the PSS offering design, an analogy could be made with the Product
31 offering especially when a *company provides many different product-service bundles*.
32 The mix of bundles brings the question of volume and price with the objective to
33 maximise the profits and at the same time to minimise the total cost (because they
34 share the same resource). In the traditional production system, the decision making
35 process can be assisted by using Linear Programming (LP). Nonetheless, the
36 stochastic occurrences of service activities could influence the cost and the product-
37 service bundle mix could also change dynamically at different time periods.
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49 Simulation can be advantageous to assess and select the most realistic/feasible
50 solution from a number of possible solutions given by LP (Al-Aomar, 2000). This is
51 because simulation can take into account variability and randomness and can be used
52 to test the different scenarios under which LP mix option of the product-service bundle
53 can be achieved. As each bundle have different production/delivery rate and capacity
54 requirement (resource type, utilisation, availability, etc.), the constraints are often in the
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4 form of technological capacity and other types of resource. As a result, the selection is
5 usually based on the organisation's goals, environment and the production, marketing
6 and financing strategies. In addition to LP and simulation, decision of product mix
7 method could include genetic algorithm, (heuristics) theory of constraint, extended
8 methods of LP and activity-based costing. Nevertheless, there are no PSS models
9 developed using these methods.
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17 18 **4.4 Strengths, weaknesses and opportunities within PSS modelling research**

19 Based on the findings and the analyses in previous sections, an analysis of strengths,
20 weaknesses and opportunities within PSS modelling research has been developed and
21 summarised in Figure 7.
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27 [Insert Figure 7 here]
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30 **Figure 7: Strengths, weaknesses and opportunities**

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35 It can be seen that there are several strengths within the existing PSS modelling work
36 since many characteristics of PSS models have been repeatedly discussed in several
37 models. Nonetheless, there are also some PSS characteristics that were rarely
38 mentioned, if not at all reflected by parameters in any models. These were grouped into
39 the weaknesses of existing PSS modelling research.
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47 From the strengths and weaknesses mentioned above, a number of opportunities
48 within the PSS modelling research can be identified as follows. To better describe PSS
49 businesses, the model should allow tracking of products movement between the OEM
50 and customers during the use, the parameters e.g. product lifetime, time to fail etc
51 should be based on the operating time rather than a fixed number of years/months, and
52 finally, the model should also take into account parameters that reflect problems in all
53 domains (business, operations, and network). With regard to the business and offering,
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4 a technique that can enhance the analysis of product-service bundle offering is
5 required. This technique should allow companies to offer the right proportion of each
6 product-service bundle to maximise the profit at the most feasible scenario. From the
7 operational viewpoint, the model should also consider the impact of technology on the
8 companies' capability towards PSS.
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16 Based on the above techniques, computer-based simulation tools incorporating the
17 dynamic behaviour of PSS can be developed. Possible usage of these tools, for
18 instance, is to investigate the dynamic behaviour caused by the improved service
19 efficiency using the knowledge gathered over the contract period. Finally, the
20 developed techniques and tools should be validated through case studies and industry
21 implementation.
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30 Although there have been several propositions for adopting PSS concept to a wide
31 range of products, especially for high value and reliability critical, the cost of building
32 infrastructure to support such system may not be worthwhile in some products. The
33 evaluation through the risks and rewards is therefore crucial.
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39 **5. Conclusion**

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41 This paper aims to capture the characteristics of PSS and to better understand its
42 dynamic behaviour. The main contribution of this paper is the collation of key model
43 parameters that should be included into the PSS modelling capabilities. The relevant
44 literature has been identified and the key findings were generated. The findings are
45 grouped into several thematic areas: *the characteristics and dynamic behaviour of*
46 *PSS, existing modelling tools and techniques, PSS offering scenarios and the*
47 *modelling parameters*. Following the generation of key findings is the analysis of the
48 models and tools' capabilities, which allow strengths and weaknesses of current
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4 research to be examined, and the opportunities for future research in PSS modelling to
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6 be identified.
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10 The outcomes of the analysis suggest the following. First, tools and techniques that
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12 can effectively and comprehensively capture the dynamic behaviours of PSS are
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14 lacking. Secondly, even if they are available, the underlying performance measures of
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16 PSS are not obvious and difficult to quantify. Furthermore, PSS modelling and
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18 simulation techniques should ideally consider the supplier capability prior to the model
19
20 development. The models should also take into account the monitoring of service level
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22 throughout the life-cycle of the product offering (contract) due to the continuous
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24 interaction between the customers and the manufacturers (PSS providers) typically
25
26 occurs in PSS businesses.
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30 This paper therefore highlights the needs for future research which will focus towards
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32 the development of simulation modelling tools and techniques incorporating the
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34 modelling parameters formulated in this paper to reflect PSS business and offering,
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36 operation and technology, and supply/demand network domains. Is it envisaged that
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38 the tool will also include simulation component templates (customised to different PSS
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40 scenarios), and an input/output data interface as the front-end to a discrete-event and
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42 agent-based simulation engines.
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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)	Life cycle oriented method Process modularization	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 & 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 & 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
Low et al (2000)	TRIZ	x
Muller and Blessing (2007)	Process entities/ V-Model	x

Schuh et al (2009)	Life Cycle 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 Life Cycle Costing	x
Shin & Wang (2008)	Fuzzy Extended Quality Function Deployment Analytical Hierarchy Process Optimisation model	x
Schuh & Gudergan (2009)	Service blueprinting Advance sequential incident Qualitative interdependence analysis Pair Wise comparison Progressive abstraction	x

Table 1

Characteristics	
Business and offering strategy	<ul style="list-style-type: none"> • 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, life cycle 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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

Table 2

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Dynamic behaviours
<ul style="list-style-type: none">• 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

Table 3

Peer Review Only

Reference	Parameters				
	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 & Shimomura (2007)	Choices			Name/Age/Gender Family/Career Excitement Security Being well respect Self fulfilment Sense of accomplishment Warm relationship Fun and enjoyment Self respect	Cost Energy saving Aesthetics Amount of light Temperature condition

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				Sense of belonging Personality	
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 new product	Available time Cost of activities	Cost of infrastructure Security	Cost of ownership Convenience	Specification of element
Komoto & 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		Degree of receiver participation	Product availability Ease of use Comfort ability

		receiver			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

Table 4

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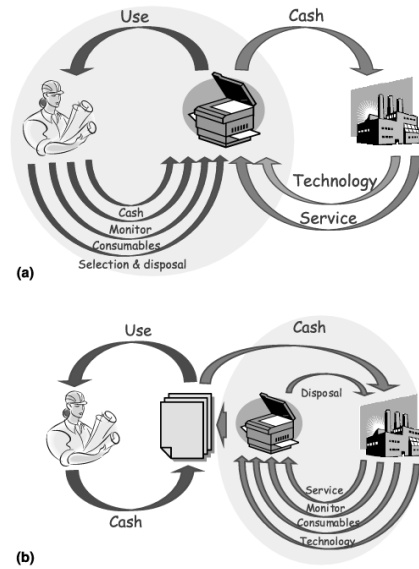


Figure 1: (a) Product selling; (b) PSS selling (Baines et al, 2007)

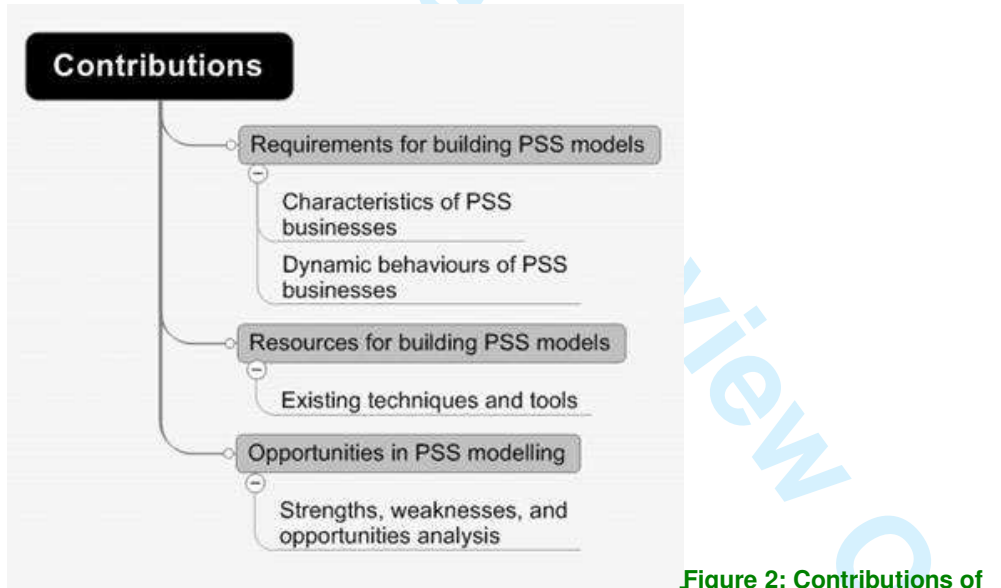


Figure 2: Contributions of the paper

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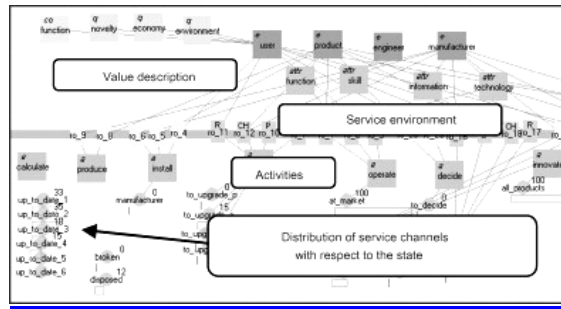


Figure 3: Integrated lifecycle simulator with service explorer (Komoto and Tomiyama, 2008)

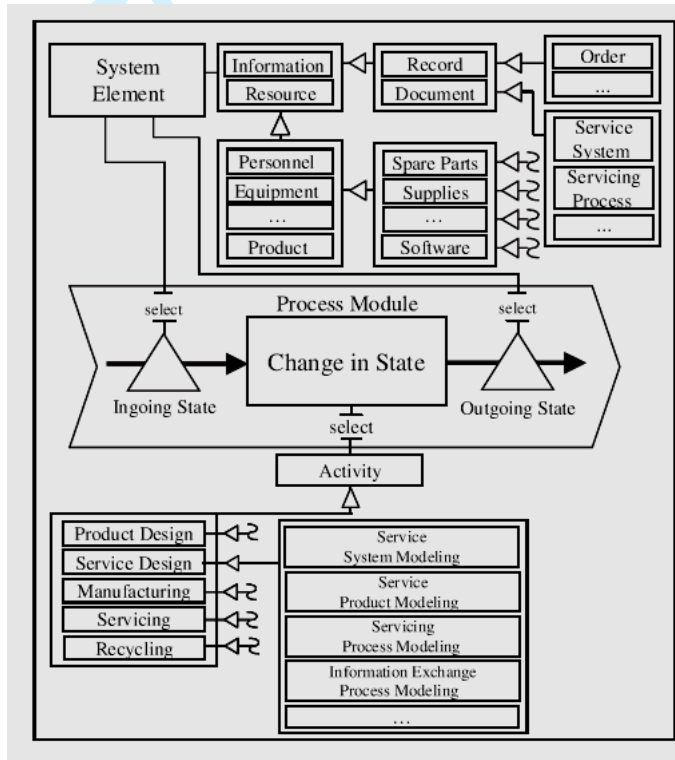


Figure 4: IPPM (Aurich et al, 2006)

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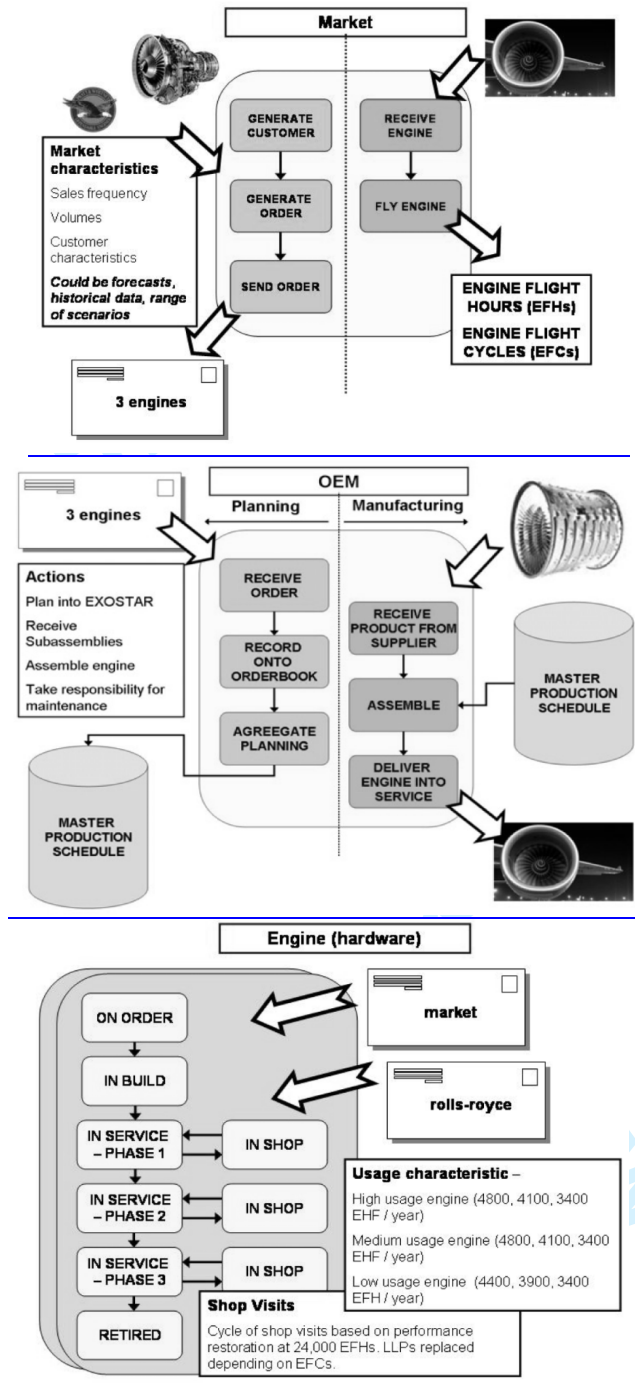


Figure 5: Agents model (Buxton et al, 2006)

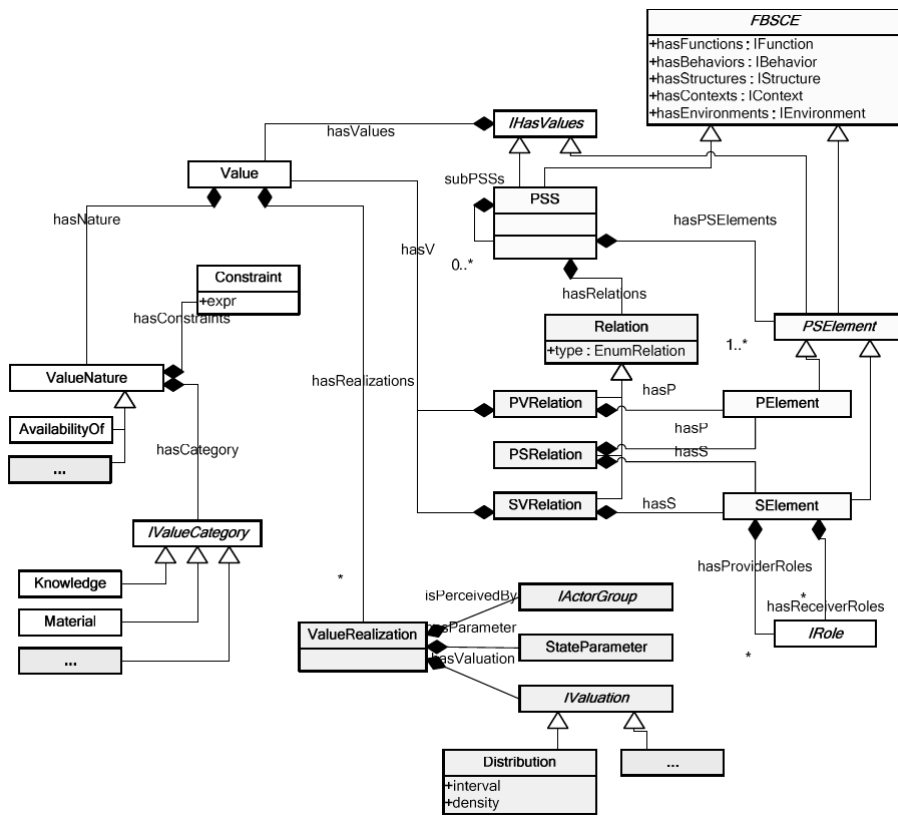


Figure 6: Ontology representation (Kim et al, 2009)

Strengths	Weaknesses
<ul style="list-style-type: none"> • 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. 	<ul style="list-style-type: none"> • 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.
<p style="text-align: center;">Opportunities</p> <ul style="list-style-type: none"> • 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 7