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Decision Engineering Report Series
Edited by Rajkumar Roy and Yuchun Xu

AN ONTOLOGY FOR PRODUCT-SERVICE SYSTEMS

By Gokula Annamalai, Romana Hussain, Mehmet Cakkol, Rajkumar Roy, Stephen Evans, Ashutosh Tiwari

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- Cost Engineering
- Product Engineering
- Applied soft computing

The intended audiences for this report are Product-Service Systems researchers and industrial practitioners.

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Preface

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Abstract

Industries are transforming their business strategy from a product-centric to a more service-centric nature by bundling products and services into integrated solutions. Such systems which offer value in use are commonly termed Product-Service Systems (PSS) and they tend to enhance the relationship between the provider and their customers. As the research related to Product-Service Systems is currently at a rudimentary stage, the development of a robust ontology for this area would be helpful. The purposes of developing a standardized ontology are that it could help researchers and practitioners to communicate and share their views without ambiguity and thus encourage the conception and implementation of useful methods and tools. In this report, an initial structure of a PSS ontology from the design perspective is proposed and evaluated. The primary objective of this ontology development is to aid clarity to the top-level concepts of PSS which would help to communicate these concepts better between researchers and practitioners. This development included the collection of PSS concepts, the definition of each concept, the grouping and structuring of the concepts hierarchically as well as the identification of the relationships between these concepts. This ontology has been developed from scratch from interviews with experts regarding current practices and challenges within the PSS domain. Some PSS concepts have been extracted from these interviews and structured whilst other concepts have been populated using the PSS literature. Subsequently, the proposed ontology was evaluated by thirty PSS researchers which resulted in revisions and established a common agreement for the structure. Reasoning based on the developed ontology is not within the scope of this work. This ontology could be expanded through multidisciplinary collaborative efforts and should mature as the PSS domain matures.

Keywords: *Ontology, Product-service systems, Methodology, Evaluation*

Table of Contents

Nomenclature

Abbreviation	Meaning
PSS	Product-Service Systems
GDO	General Domain Ontology
DSO	Domain Specific Ontology
ASO	Application Specific Ontology
TOVE	Toronto Virtual Enterprise
FR	Functional Representation
SBF	Structure, Behaviour and Function
EDIT	Engineering Design Integrated Taxonomy
STEP	Standard for the Exchange of Product Model Data
PSL	Process Specification Language
KIEF	Knowledge Intensive Engineering Framework
PS	Product-Service
IPS^2	Industrial Product Service Systems

1. Introduction

In this competitive globalizing economy, industries are changing their strategies from Product-centric to Service-centric approaches. An example of these approaches is Product-Service Systems (PSS) which is widely defined as an integrated product and service offering that delivers value in use. Goedkoop et al. [1] define a product-service system as "a system of products, services, networks of "players" and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models". There is an increasing interest towards PSS in order to develop theories, methodologies, tools and techniques to understand the concept as well as to support industries and designers in developing these offerings [2]. Nevertheless, this research is in its infancy and a review of literature reveals that the terminologies used to describe PSS vary considerably. This scenario necessitates the development of an ontology for the PSS domain.

Ontology is commonly defined as an explicit formal specification of the terms in the domain and the relations amongst them [3]. The core purpose of developing an ontology is to share the meaning of the terms in a domain. The shared understanding is accomplished by agreeing upon an appropriate way to conceptualize the domain. The result, an ontology, can be applied in a wide variety of contexts for various purposes [4]. Uschold [5] states that "an ontology may take a variety of forms, but necessarily it will include a vocabulary of terms, and some specification of their meaning. This includes definitions and an indication of how concepts are inter-related which collectively impose a structure on the domain and constrain the possible interpretations of terms." Although ontologies may be used for various purposes and applications, they are most commonly used for sharing, navigating, searching, indexing and retrieving domain knowledge. Furthermore, these purposes are used widely to validate the proposed ontology. The advantages in developing an ontology for a domain in its initial stage are:

- The effort required to develop an ontology is modest.
- There is an opportunity for progressive updating as the understanding evolves and
- The domain structure can be adapted and accommodated.

The importance and applications of ontologies have been widely discussed in literature and are emphasized in many domains. The immediate advantages of developing a PSS ontology are to:

- Provide a platform for stakeholders to communicate and share their concepts with each other effectively and without ambiguity.
- Help understand the uniqueness of research outcomes and
- Aid the validation of the research outcomes.

Schlenoff et al. [6] also stress that a domain ontology is helpful for unambiguous communication, standards-making and semantic-alignment efforts as well as future industrial information infrastructures. The challenge is not in building various information technologies but to develop common representation within the PSS community; without doubt, the terminologies proposed in the domain of PSS will increase exponentially in upcoming years. The aim of this work is for the ontology to be properly grounded with an appropriate structure to avoid cross-pollination of terminologies. The ultimate aim of this work is to develop a unique PSS ontology for the PSS community. This PSS ontology should help to define semantics for each terminology properly to avoid ambiguity between stakeholders (researchers and industries). This work seeks to develop and understand the fundamental structure of PSS i.e. to conceptualize the PSS domain. In this report, we intend to explain the structure developed for this PSS ontology from the design perspective as well as the methodology followed in this development process. The following sections comprehensively detail the literature on the methodology used in developing an ontology, a product ontology, a service ontology, a structure framed for PSS ontology, details of the terms involved in the structure and finally the validation process.

2. Methodologies to develop ontology

Many ontology development methodologies are proposed in the extant literature. This section reviews and summarizes these methodologies and elaborates the steps followed to develop a PSS ontology. Ahmed et al. [7] propose that a methodology for creating ontologies for a particular purpose consists of six stages. They combine a number of methods from social science and computer science to develop this methodology. The stages are: identifying the root concept of the taxonomies that form an engineering design ontology; identifying existing taxonomies for each of the root concepts from the previous stage; creating taxonomies if no existing taxonomy was found; testing the taxonomies for the particular application; building a thesaurus for the integrated taxonomy and; refinement of the integrated taxonomy. It is important to note that they stress methodological development through empirical analyses rather than from documentation. They also stress that it is often necessary to acquire domain knowledge from experts when building the ontology. Interviews, literature reviews, document analysis and map instances to taxonomy are proposed research methods for these steps.

Jayaram and Jayaram [8] suggest following steps for the process of developing the ontology: decide which domain the ontology will cover and refer to the related resources to determine what terms to use from the domain, define the classes hierarchically and define the associated properties for these classes, define constraints for the properties, create the instances of the classes and create the axiom definitions in ontology for reasoning purposes. They suggest a layered structure to build engineering ontologies for product design and analysis. The 3-tier ontology structure consists of: General Domain Ontology (GDO), Domain Specific Ontology (DSO) and Application Specific Ontology (ASO). Pinto and Martines [9] summarize five stages used for ontology building: specification, conceptualisation, formalisation, implementation, and maintenance. In the specification stage, the purpose and scope of the ontology are determined and subsequent conceptual descriptions of the ontology are made.

Eris et al. [10] propose a methodology for constructing the ontology which consists of: discussing the purpose and appropriateness of applying an ontological approach to product development projects in small teams, conducting a literature review of bases, purposes, and methods of identification and classification in other sciences, formulating tentative ontological frameworks, conducting internal validations, and making the frameworks accessible to researchers, discussing the frameworks with colleagues from related fields and developing criteria and evaluation systems for testing the validity, utility, and reliability of the proposed frameworks.

Uschold and King [11] outline a methodology for developing and evaluating ontologies considering informal techniques concerning issues such as scoping, handling ambiguity, reaching agreement and producing definitions as well as a formal approach. They propose a methodology for developing ontologies to include the following: identification of the purpose and scope, building the ontology (this encompasses ontology capture, ontology coding and the integration of existing ontologies), evaluation, documentation and the guidelines for each phase. They identify the following criteria to design ontologies: clarity, coherence, extensibility, minimal ontological commitment and minimal encoding bias.

Gruninger and Fox [12] propose an approach to develop engineering ontologies based on experiences in the development of TOVE (Toronto Virtual Enterprise). The approach consists of motivating scenarios, informal competency questions, terminology specification, formal competency questions, axiom specification and completeness theorems. Noy and McGuinness [13] propose a methodology for developing an ontology which includes: determination of the domain and the scope of the ontology, the consideration of reusing existing ontologies, the enumeration of important terms in the ontology, definition of the classes and the class hierarchy, definition of the properties of classes—slots, definition of the facets of the slots and the creation of instances. They argue that there is no one correct way to model a domain and that ontology development is necessarily an iterative process.

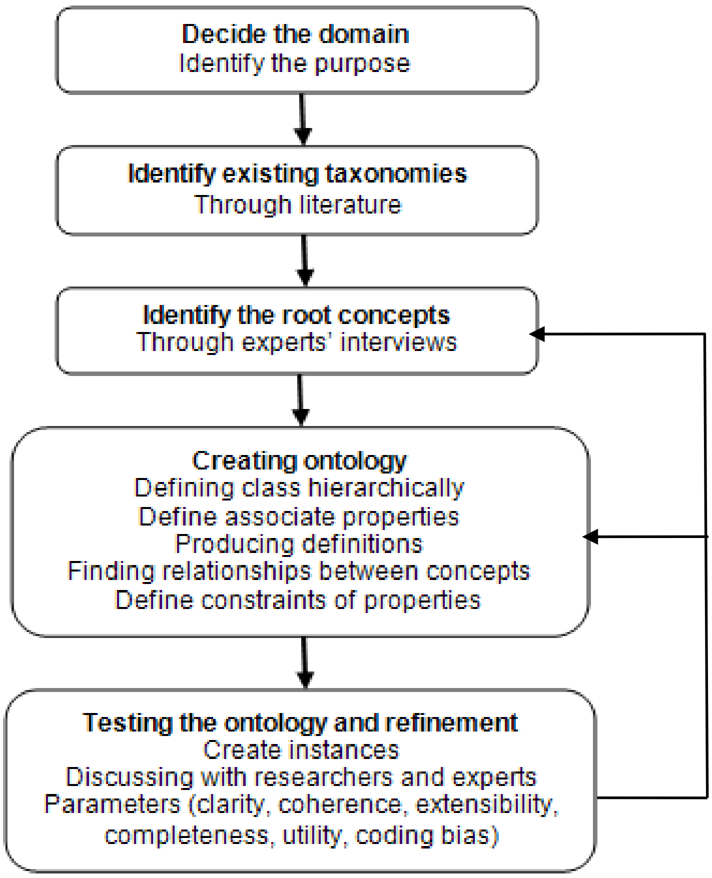

Figure 1: Steps in developing PSS ontology

Jones et al. [14] analyse various ontology development methods and conclude with the following suggestions: many of the methodologies take a task which is found useful as a starting point; if the purpose and requirements are clear at the outset, a stage based approach would seem more appropriate whereas if no clear purpose had been identified, an evolving prototype model may be more applicable.

By analysing these methodologies, the steps followed to develop PSS ontology are illustrated in Figure 1. Figure 1 stresses that the ontology development process is an iterative process and matures progressively with our understanding. Five steps followed in this PSS ontology development are detailed below:
Decide the domain and purpose: The purposes of developing a standardized PSS ontology are that it could help researchers and practitioners to communicate and share their views without ambiguity and thus encourage the conception and implementation of useful methods and tools.
Identify existing taxonomies: Since integration of products, services and business elements are core in developing PSS concepts; existing taxonomies in these research fields are reviewed and summarized. This summary helps to develop base for building PSS concepts.
Identify root concepts: PSS ontology development should be aligned to industrial PSS perspectives. To disclose these perspectives, interviews conducted with experts in three different industries in the UK who are heavily involved with developing PSS concepts were analysed to indentify root concepts. Details of these industries are provided in Section 4.
Creating ontology: Various concepts based on the summary from literature and industrial interviews were grouped within identified root concepts by maintaining consistency. Definitions of these concepts are noted from different sources. We have proposed new definitions on our understanding if definitions are not identified. During this process, relationships and properties of the concepts were also identified and structured.
Test the ontology and refinement: Testing the developed ontology was carried out by two rounds of evaluation with PSS researchers. The developed ontology is refined accordingly based on the received responses. The next step in ontology development will be creating instances to enhance this understanding gained.

The steps followed for developing PSS ontology are similar to other domains. But the complexity increases due to involvement of various subjects field. The subsequent sections elaborate these steps.

3. Identifying existing taxonomies

This section analyses various ontologies proposed in the product and service literature and also elements used in product-service systems. These analyses aim to identify the research gaps in order to develop an ontology for PSS. Each sub-section below addresses these topics individually.

3.1. Product Ontology

A number of representations have been proposed to characterize the artefact being designed. Chandrasekaran et al. [15] presented Functional Representation (FR). Goel [16] illustrates model representation through Structure, Behaviour and Function

(SBF) elements. Hubka and Eder [17] describe a technical system and the transformation process it creates in terms of process, function, organ and component structures. Andreasen [18] argues that design specifications and structures are linked by causal relations: the process determines the functions, which are created by the organs, which are materialized by the components. Chakrabarti et al. [19] proposed the SAPPhIRE model of causality with the following constructs: state, action, part, phenomenon, input, organ, effect and their relationships. The SAPPhIRE model of causality is explained in Figure 2.

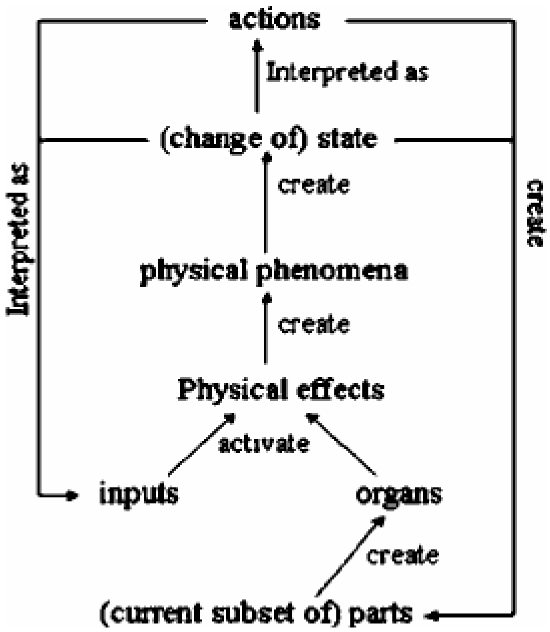

Figure 2: The SAPPhIRE model of causality [19]

Szykman et al. [20] represent product knowledge as requirements, specifications, artefacts (sub-artefacts, functions, forms and behaviours), design rationale, constraints and relationships. The taxonomy referred to as the functional basis with a set of functions (verbs) and flows (nouns) was developed by Hirtz et al. [21] and this integrates the efforts of Sykman et al. [20] with those of Stone and Wood [22]. Ahmed et al. [7] proposed an Engineering Design Integrated Taxonomy (EDIT) which consists of several taxonomies and their relations. They argue that it may not be possible to find an ontology for engineering design that suits all requirements. They postulated that a difficulty in identifying an engineering ontology that is generic to the product or system being designed is usually because it is specific to a particular company or project.

STEP (Standard for the Exchange of Product Model Data) [23] is an inter-lingua for defining and specifying products. The primary motivation for STEP is to achieve inter-operability and to enable product data to be exchanged amongst different computer systems and environments associated with the complete product lifecycle. Lin at al. [24] present an ontology for representing requirements that supports a generic requirements management process in the engineering design domain. Objects included in the ontology are parts, features, requirements, and constraints. Schlenoff et al. [6] analyse various ontologies (CYC, Enterprise Ontology, TOVE (Toronto Virtual Enterprise)) through typical manufacturing scenarios. They conclude that all three packages were approximately equal in their ability to represent manufacturing information based on the information which already existed and their ability to specialize this information to make it appropriate to the manufacturing field. But they noted that the inferencing capabilities in CYC proved to be a bit more mature than the other two packages.

Eris et al. [10] identified four categories under the product development project entry: project input and character, product development process, project output and character and project phases. They classified the product development process category into five overall dimensions: actors, activities, information, physical artefact, and environment. Li et al. [25] develop an engineering ontology to represent the established design and manufacturing knowledge for engineering information retrieval (Figure 3). Process Specification Language (PSL) developed by NIST [26] treats more general (discrete) 'processes' such as manufacturing process. It includes core-concepts such as activity, time point and objects as well as relations. Yoshioka et al. [27] explore ontological models of theories of engineering tools and their integration for KIEF (Knowledge Intensive Engineering Framework). KIEF consists of basic concepts which are categorized into entity, relation, attribute and physical phenomena and physical law.

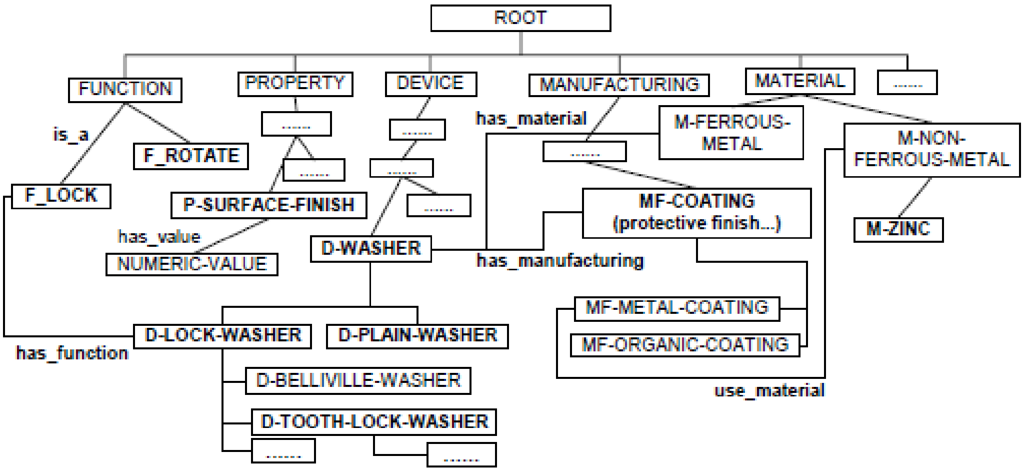

Figure 3: A portion of the engineering ontology (Li et al., 2007)

The development of a standard engineering language has been a widespread and major objective for decades throughout the engineering design community. Even though various ontologies are proposed in literature for representing artefacts, a standardized language has not emerged. It should be noted that it may not be possible to find an ontology for engineering design that suits all requirements. However, this leads to an interoperability issue which is a huge concern across all industries. In this context, developing an ontology for the new domain of PSS has added more complexity. The next section describes the ontologies proposed in the service domain.

3.2. Service Ontology

This section reviews various published service ontologies. Silvestro et al. [28] argue that although many service classification schemes have been proposed, no categorization has been either as pervasive or as useful as the process type classification provided in the production management literature. They have summarized six service dimensions from literature which are used in service operations management literature. These are: equipment/people focus, length of customer contact time, extent of customization, the extent to which customer contact personnel exercise judgment in meeting individual needs, the source of value added, front office or back office and product/process focus. Bullinger et al. [29] argue that a typical service can be characterized by three different dimensions: a structure dimension (the structure determines the ability and willingness to deliver the service in question), a process dimension (the service is performed on or with the external factors integrated in the processes) and an outcome dimension (the outcome of the service has certain material and immaterial consequences for the external factors). They show the integration and interaction of a product model, a process model and a resource concept within a basic service model (Figure 4). Boyt and Harvey [30] categorize services through characteristics: replacement rate, essentiality, complexity, personal delivery and credence properties.

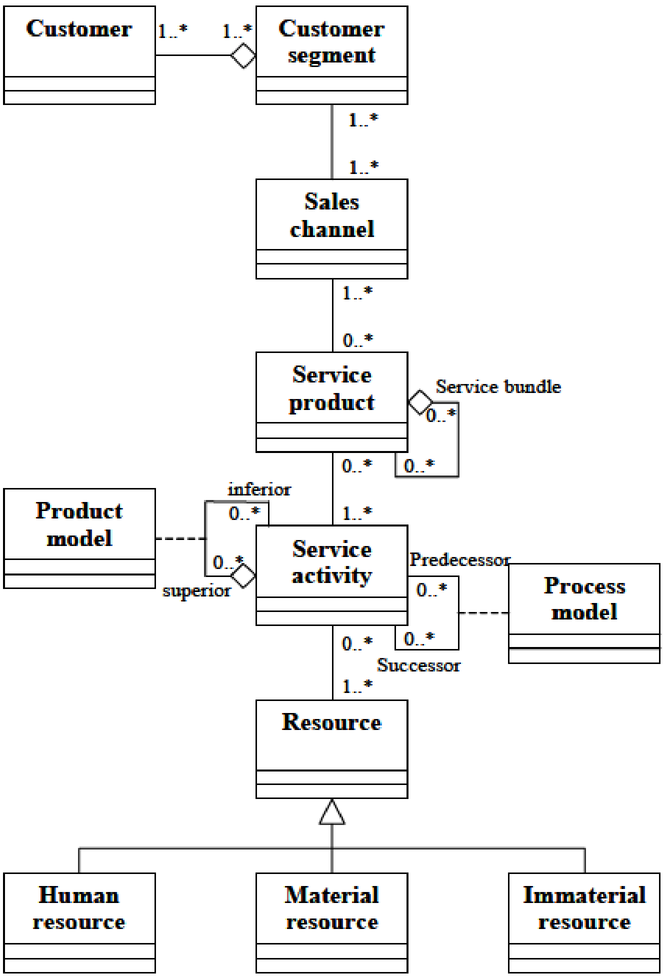

Figure 4: Basic service model (Bullinger et al., 2003)

Cho and Park [31] argue that factors frequently adopted for the classification of services from literature are tangibility or intangibility, interaction or customer contact, customization, and availability of service outlets at single or multiple sites. Bakrir [32] presents a typology of services founded upon a classification based upon the following criteria: the consumption of the service (internal or external), the association of the service to an object (to a product, to a service or none and the entity), and subject of the service (persons or companies). He used manufacturing production systems typologies to analyze the common characteristics between products and services from the view of a production system: the degree of uncertainty and the service relation to customers, the level of standardization of characterizing products, and the level of diversification. Wemmerlov [33] argues that one of the major problems in the study of service production is of a taxonomical nature and deals with the identification and classification of service systems in a meaningful way. He summarizes the following decision variables tied to the design and operation of service systems: strategic role, service facility, process design, goods, workforce, planning and control systems, marketing programme and relationship to other service processes. He argues that a taxonomy should be related to these decision variables in a meaningful way. The descriptive variables selected for the taxonomy are the nature of the customer/service system interaction, the degree of routinisation of the service process, and the objects towards which the service activities are directed. Figure 5 illustrates the service knowledge structure represented by Baxter et al. [34].

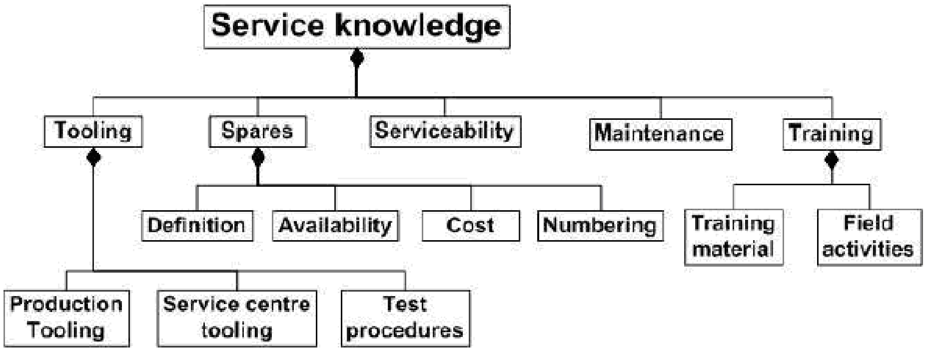

Figure 5: Service knowledge structure (Baxter et al., 2009)

The number of service ontologies is less than the number of product ontologies proposed in literature. Even though few ontologies are proposed in the service sector, standardization is again a major challenge. Many applications need to be generated around these ontologies to validate and prove their usefulness. The next section summarizes the terminologies commonly used in the PSS domain.

3.3. Elements used in Product-Service Systems

Various definitions for PSS are proposed in literature. Commonly agreed PSS definition is yet to be developed within the PSS community. Van Ostaeyen and Duflou [35] argue that product-service (PS) is a specific type of value proposition and a PSS is a specific type of business model. They state that throughout PSS-literature, the terms PS and PSS are not always used consistently. This underlines the need for the terminologies which are used in the PSS domain to be consistently defined across literature. The prevalent terminologies within the PSS domain are reviewed in this section and the business models used are also discussed at length here. Tucker and Tischner [36] propose three models: function-, availability-, and result-oriented models based on the customer-supplier relation. Meier and Massberg [37] differentiate business models by: production responsibilities, supply of operating personnel, service initiative, ownership, supply of maintenance personnel and service turn model. Roy and Cheruvu [38] identified different IPS² (Industrial Product Service Systems) contract types from the literature and various industries. Datta and Roy [39] noted that main parameters considered in the contracts are responsibility, cost of performance and incentives. They classify the key cost elements into recurring cost, non-recurring cost, overheads and hidden costs. Others support this by stating that understanding and estimating the true whole life cost of an IPS² contract is required [40]. Risks and uncertainties are other important parameters which are very much referred in association with the PSS solutions [41]. Issues of obsolescence in PSS are detailed and discussed by Romero Rojo et al. [42].

Apart from business issues, other elements that are important in the design of PSS elements are reviewed. Factors distinguishing products and services such as intangibility, inseparability, heterogeneity, perishability, simultaneous production and consumption as well as ownership are discussed [43]. Authors have also noted that the development of PSS is influenced by several factors such as partners, organization, benefits for the IPS² provider, benefits for the IPS² customer, the environment, social considerations as well as the intention to use IPS², interactions of system/users and system life-cycle phases. It has been commonly noted that integrating the business model, technical artefacts, service activities, the IPS² lifecycle, aspects of the system‘s context and resources to deliver added value is a major challenge. Baxter et al. [34] depict an upper level PSS structure that enables the description of a combined product- and business- system (Figure 6). The central class 'life cycle system' is comprised of three classes: product, process and resource.

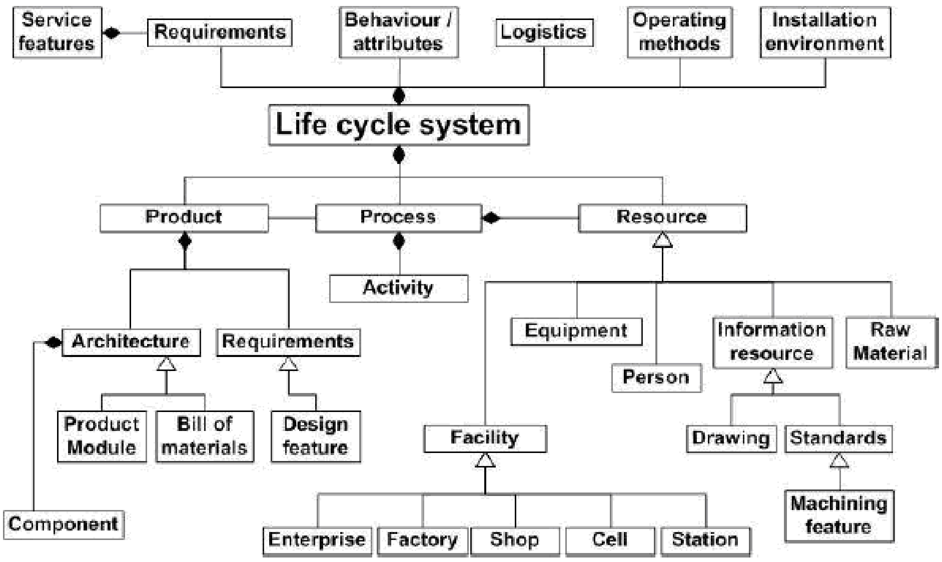

Figure 6: Integrated knowledge framework structure (Baxter et al., 2009)

Doultsinou et al. [44] argue that product design processes are well-structured, whereas the service design process is highly intuitive. They identified important variables which impact the difference in service issues were size, location, budget, number of projects in parallel, and personnel availability. Mahnel [45] stresses the quality of the service as an essential factor for customer retention. Brunner and Wagner [46] have identified quality criteria for services: presentation and ambiance, reliability, accuracy, correctness, competence, politeness, friendliness, cooperativeness, understanding, authenticity, security, accessibility and availability and ability to communicate and sociableness. Kim et al. [47] propose graph and ontological representations of PSS, consisting of values, product and service elements, and their relations. Shen and Wang [48] define product service ontology as the conceptualization of the product service. The proposed basic ontological representation of product service is shown in Figure 7. Jagtap [49] found that the in-service information required by designers mainly consists of deterioration information, i.e. deterioration mechanisms, deterioration effects, deterioration causes, etc. Also factors such as component failure, operating conditions, maintenance, life cycle cost and reliability are stressed.

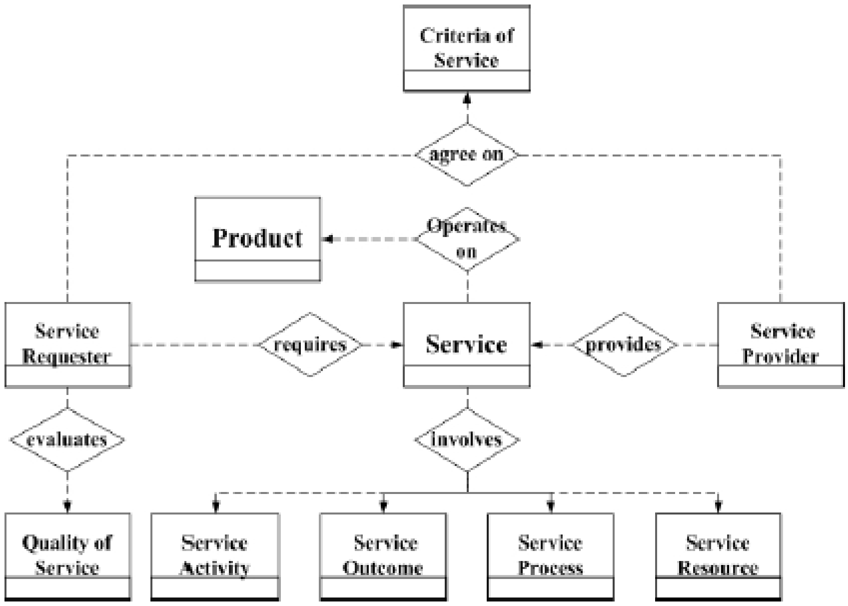

Figure 7: Product Service Ontology (Shen and Wang, 2007)

From the aforesaid it can be said that the ontology development for PSS is in its infancy. The various ontologies proposed are to be evaluated in-depth in terms of inclusiveness and exhaustiveness. Due to the involvement of many stakeholders within PSS, the semantics for each term should be defined accordingly. The challenge is not in building various information technologies but to develop a common representation across domains. This will subsequently expedite knowledge retrieval, discovery, editing, sorting and also automate reasoning with minimal implementation and maintenance effort. The next section describes the process of identifying the root concepts of PSS, their details and the evaluation process.

4. Identifying root concepts and creating PSS Ontology

Reviewing the PSS literature provides an initial overview of the concepts discussed. Since PSS is very industry driven, the concepts used in current industrial practices need to be captured to align the root concepts appropriately. In order to identify the root concepts of PSS from industrial practices, thirteen explorative interviews which were conducted with various experts to elicit the definitive processes and challenges within PSS were analysed (please refer to the acknowledgement regarding the research team which conducted these interviews). This research team furnished us with transcribed interviews which were conducted with three different industries in the UK who are heavily involved with developing

PSS concepts. Due to confidentiality, identity of the companies is not disclosed in this report. The industries are leading global manufacturer and suppliers of systems and services to the Aerospace and Defense industry. These transcribed interviews were shared equally to each of three researchers to extract the concepts uttered by the interviewees which were then consolidated, discussed, filtered and refined to develop the root concepts. These identified root concepts were compared with concepts proposed within literature and then further refined. This lent itself to an industry as well as academic perspective for this PSS ontology. The afore-mentioned root concepts aim to describe PSS comprehensively from the design perspective (Figure 8). These are: *customer needs, stakeholders, PSS-Design, product life cycle, use phase, infrastructure, business elements, business models, supply network and benefits*.

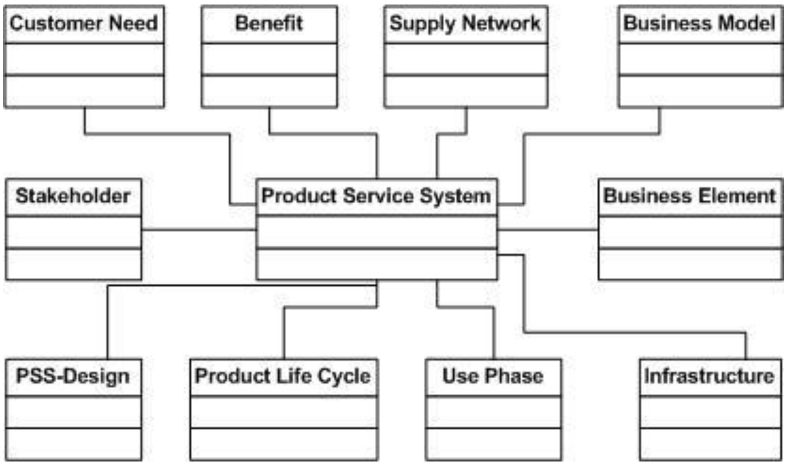

Figure 8: Root concepts to describe ontology of PSS

The rationale to choose these root concepts will be expounded upon here. As customers are playing a vital role in structuring and developing PSS, their needs are taken as a starting point in these root concepts which begin with *customer needs* and end with *benefits* realized through PSS. As developing a PSS is a co-design activity, inclusion of *stakeholders* in the root concepts is mandatory. Whilst the importance of stakeholders is adequately stressed in literature, an extensive list of members involved in PSS has not been identified. To emphasize this, the concept of *stakeholder* was added to the root concepts. The various PSS related processes are very diverse and often used interchangeably within literature. To avoid this ambiguity, three processes are considered: to describe the design of PSS (*PSS-Design*), stages of products (*product life cycle*) and customer activities revolving around the products (*use phase*). It has been commonly argued in literature that PSS consists of product-service, value network, infrastructure and business models. To emphasize this statement, these concepts are included in the PSS ontology. Although *business models* are often discussed within PSS literature, *business elements* are not sufficiently addressed. *Business elements* describe the processes and issues involved in businesses which influence PSS. Since a viable PSS is not possible without appropriate *infrastructure* and *supply network*, these concepts were also included in the model. In view of the fact that a variety of *business models* in PSS depend upon the inclusion of products and services in the offerings, the product and service ontologies discussed in literature have been incorporated under the root concept *business model*.

Whilst generating these root concepts, sub-concepts associated with each concept were also simultaneously identified and then hierarchically categorized along with their respective properties. In total, 214 sub-concepts and properties have been identified. We used Protégé™ software to develop these concepts and sub-concepts (Figure 9). Protégé™ software is used because it is a free, open-source platform that provides a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats. It aids to develop a computerized specification of the meaning of terms used in the vocabulary. It is commonly used software for developing ontologies. As the definitions for many concepts were not fully articulated in the interviews, these concepts were then framed by referring to the literature and discussion amongst the researchers. Upon analyzing the interview transcripts, various relationships between the concepts and sub-concepts were identified. The identified relationships statements were re-written by incorporating structured root concepts and sub-concepts. For example the modified statements look like,

'Shared business vision' between *'customer', 'provider'* and *'supplier'* is crucial in *PSS*.

'Provider' needs new *'infrastructure'* to *'support'* emerging *'business models'*.

The complete list of definitions and relationship statements generated are provided in Appendix – II and Appendix – III of this report respectively. These modified relationships statements were incorporated into Protégé™ software either through slots (properties) of the sub-concepts or through the super class to link between the concepts. We have observed that Protégé™ software is limited in the scope of representing the relationships identified in the re-written statements. The standard relationships such as 'is-a', 'part-of' are not sufficient to represent these statements. Since computational representation and application development are not within the scope of this work, the text based relationships statements were kept as they are. Representing these relationships appropriately will be the next subsequent activity to be carried out in expanding this PSS ontology. Also these relationships should be populated through the current understandings and findings from the PSS literature.

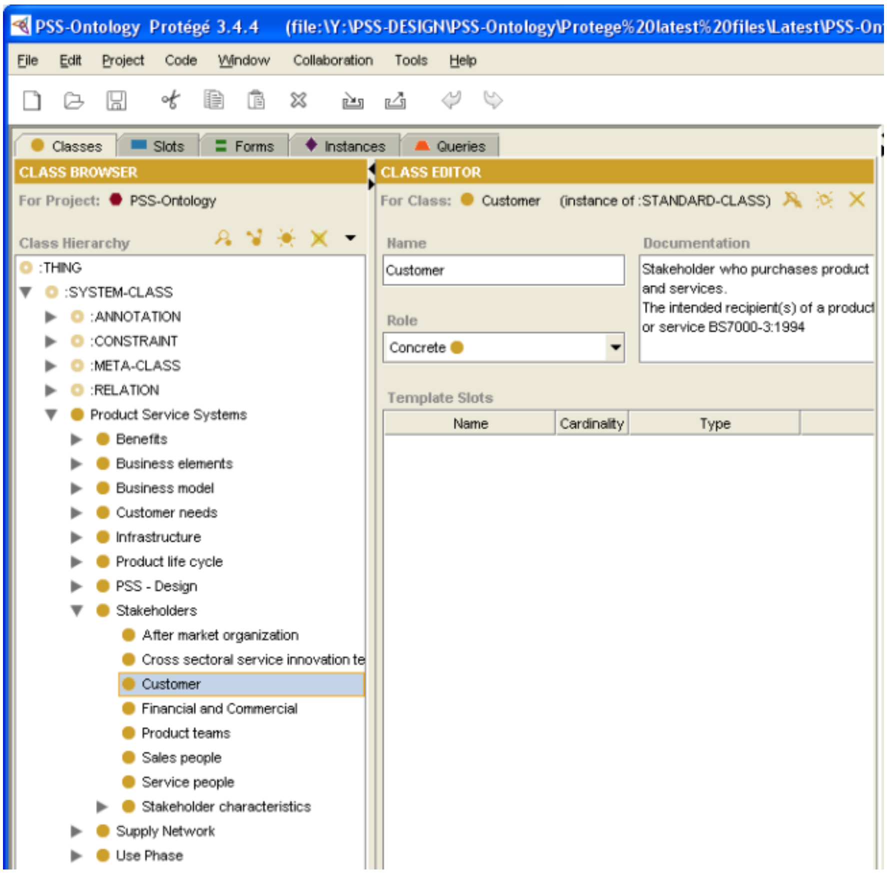

Figure 9: PSS ontology developed in Protégé™ software

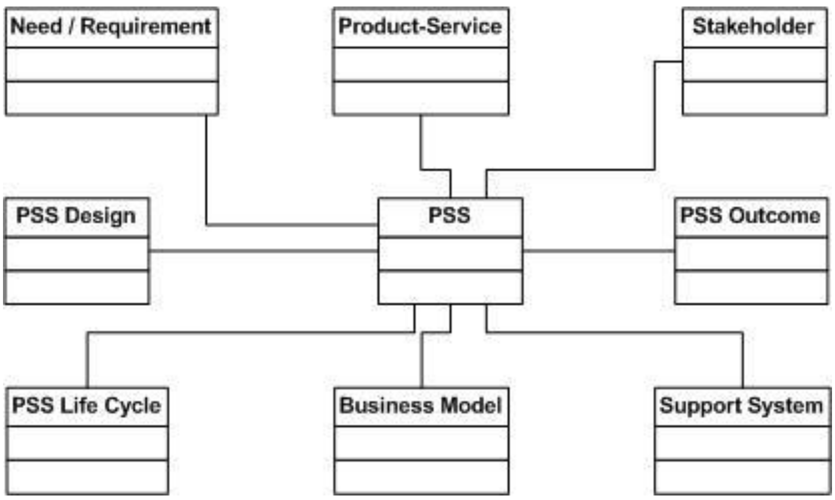

Figure 10: Revised root concepts to describe ontology of PSS

This formulated PSS ontology has been validated by inviting PSS researchers across the globe for their input: the complete list of concepts, sub-concepts, definitions and relationships were sent to PSS researchers for validation. The comprehensive process of validation and feedback received are detailed in the next section. The modifications for the top concepts from the validation are represented in Figure 10. The rationale for these modifications is explained in the next section. Since the sub-concepts are modified significantly in the validation process, the detailed descriptions for these concepts are explained in the validation step. The next section describes important observations from the validation of the proposed ontology.

5. Validation

Figure 11 illustrates the steps followed to validate the proposed ontology. The first step for validation was to find a common agreement between the three researchers who extensively worked in developing this ontology. It was an arduous process to arrive at a common agreement because each researcher had different perspectives from different domains (product design, information usage and supply chain). Nevertheless, this encouraged the development of a comprehensive ontology. For the second step, exhaustive, individual discussions were conducted with four experts (academic researchers) who are engaged in PSS research. From this, we received valuable comments and suggestions to improve the developed ontology. It is interesting to note that all these researchers have provided positive feedback about the structure of the ontology. Their comments and suggestions were noted and incorporated into the ontology. The chief comments received from them were as follows:

- The need for clarification in classifying *processes*.
- Not to use *properties* and *characteristics* interchangeably.
- To describe *process* characteristics in terms of *quality*, *cost*, *time* and *risk*.
- The sub-concept *risk* missed in the business model and
- To include *risk reduction* in the *'benefit'* concept.

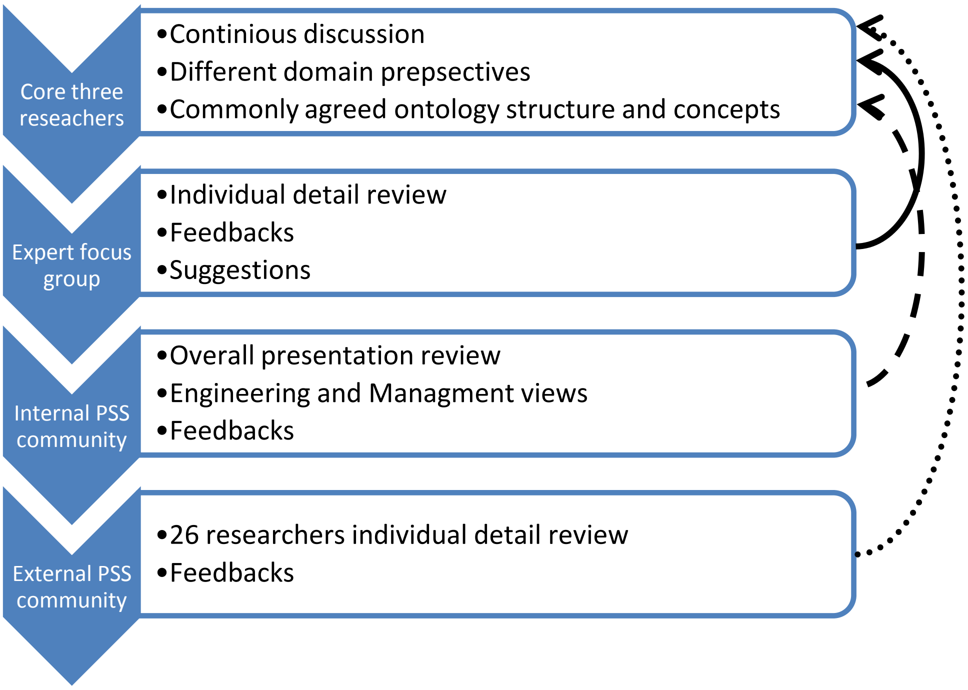

Figure 11: Steps involved in validating PSS ontology

Such positive responses begged for a demonstration presentation to which a group of PSS academic researchers from Cranfield University were invited. This provided more positive feedback to this ontology and also generated an opportunity for more researchers to participate in its development. An invitation was then sent to PSS researchers globally to validate this ontology from which we have received feedback and comments from 26 researchers from various universities in different countries (UK, Japan, Belgium, Sweden, France, Germany, Italy, Netherlands and US). PSS researchers participated in this ontology evaluation process is given in Appendix – I. The purposes of this validation process are,

To confirm whether:

- This top level ontology is an appropriate structure for PSS from design perspective.
- All necessary concepts have been included at these top levels.
- These concepts are consistent with each other and
- These definitions and relationships are correct.

Based on the feedback and comments received the ontology is revised and modified. Figure 10 details the revised root concepts to describe ontology of PSS. Apart from renaming some of the concepts, major modifications are: the addition of *PSS life cycle* (both *product life cycle* and *use phase* are included within this); *infrastructure* and *supply network* are now grouped to form a single concept *'support system'*; and *business element* is incorporated into *business model*. New *Product-Service* root concept is added to emphasize these combinations. The details about the sub-concepts and responses given to the reviewers for their feedbacks are summarized in the following sections.

5.1. Root Concepts and Sub-concepts

This section details the sub-concepts within the root concepts and elaborates the rationale of grouping these concepts. The following sub-sections detail the eight root concepts (*Need/Requirement, Stakeholder,* Product-Service, *Business Model, PSS Life Cycle, PSS-Design, Support System* and *Outcome*).

5.1.1. Need/Requirement

Based on the comments received from the evaluators, the root concept *Customer Need* is changed to *PSS Need/Requirement*. The reason for this change is needs/requirements for the PSS are not only driven from the customers but also from the other stakeholders involved. Even though it could be primarily from the customers, others' requirements should also be emphasized. To differentiate between the needs and requirements, both of these terms are included in the root concept. This joint inclusion avoids repetition of terms within needs and requirements. The standard definitions of need and requirement are noted. Need is defined as problems that customers intend to solve with the purchase of goods and/or services. Requirement is defined as particular characteristics and specifications of goods and/or services. Figure 12 illustrates the sub-concepts included in this root. The *requirement* concept is primarily classified into *stakeholder, product-service* and *support system* requirements. These requirements are aligned with the elements involved in PSS. The requirement from the business perspective is incorporated in the *stakeholder* requirement. The definitions for all of the terms have been listed in Appendix – II.

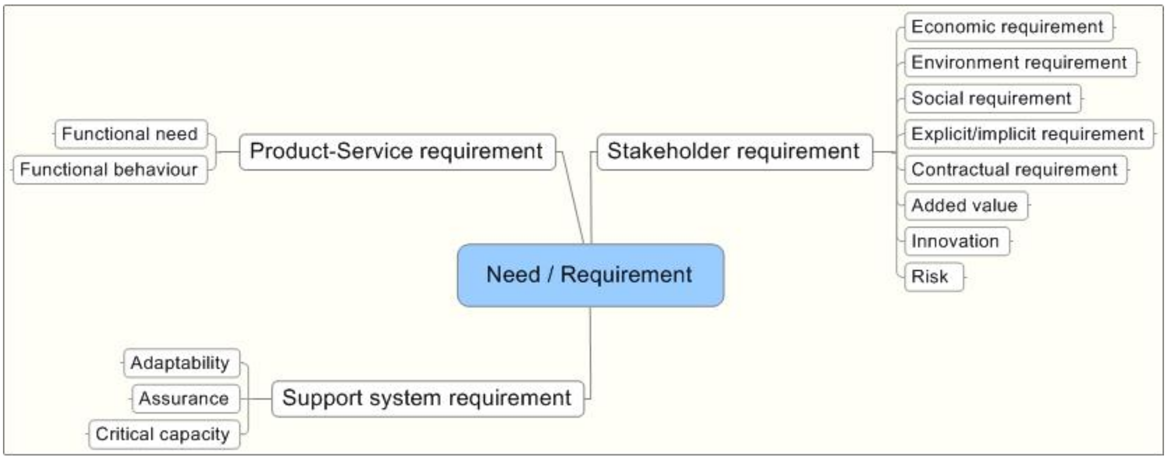

Figure 12: Sub-concepts included in Need / Requirement concept

5.1.2. Stakeholder

Many stakeholders are involved in designing PSS. These stakeholders need to be properly considered for sustained PSS. It is necessary to understand their various viewpoints and any inconsistencies and conflicts should be properly managed. To emphasize this point, various stakeholders are appropriately considered in the proposed ontology. The proposed ontology stressed the importance of person (employee), group (value network), organization (receiver, provider, and supplier) and society. Comprehensive properties of these stakeholders are also summarized and represented within the ontology. Figure 13 illustrates these sub-concepts and their structure. It has been noted that, in reality, the receiver varies between end operator and decision maker. This variation is highlighted in the *receiver* sub-concept.

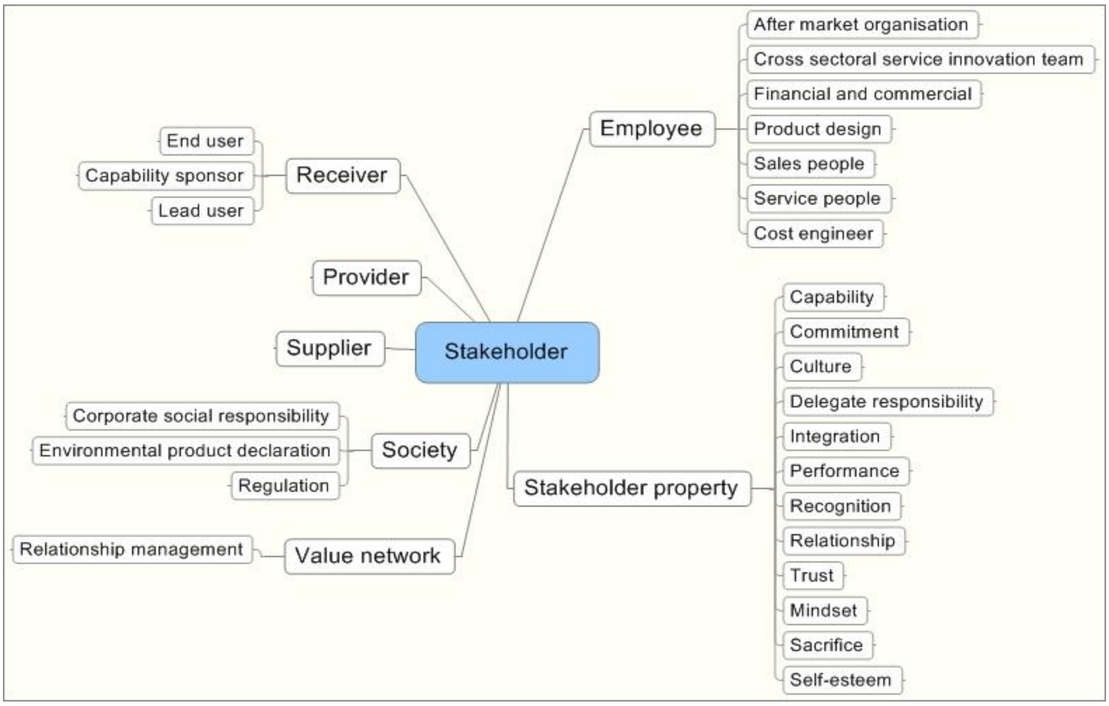

Figure 13: Sub-concepts included in Stakeholder concept

5.1.3. Product-Service

According to Tukker and Tischner [36], a *product-service* is a mix of tangible products and intangible service, designed and combined so that they are jointly capable of satisfying final customer needs. A *product-service* plays a vital role in PSS for framing business models and the necessary support system. To emphasize this role, *product-service* is added as a separate root concept. The concept is described through *product*, *service* and *product-service* property sub-concepts. To represent a product, *SAPPhIRE representation* [19] is used because using these constructs and relationships, function, behaviour and structure of product could be linked to each other. The *product properties* relevant for PSS are chosen and presented. For service, *types of services* and their *properties* are grouped. *Product-service properties* are represented through *alteration*, *substitution* and *integration*. These properties emphasize the importance of linkages between the products and services in developing and delivering PSS (Figure 14).

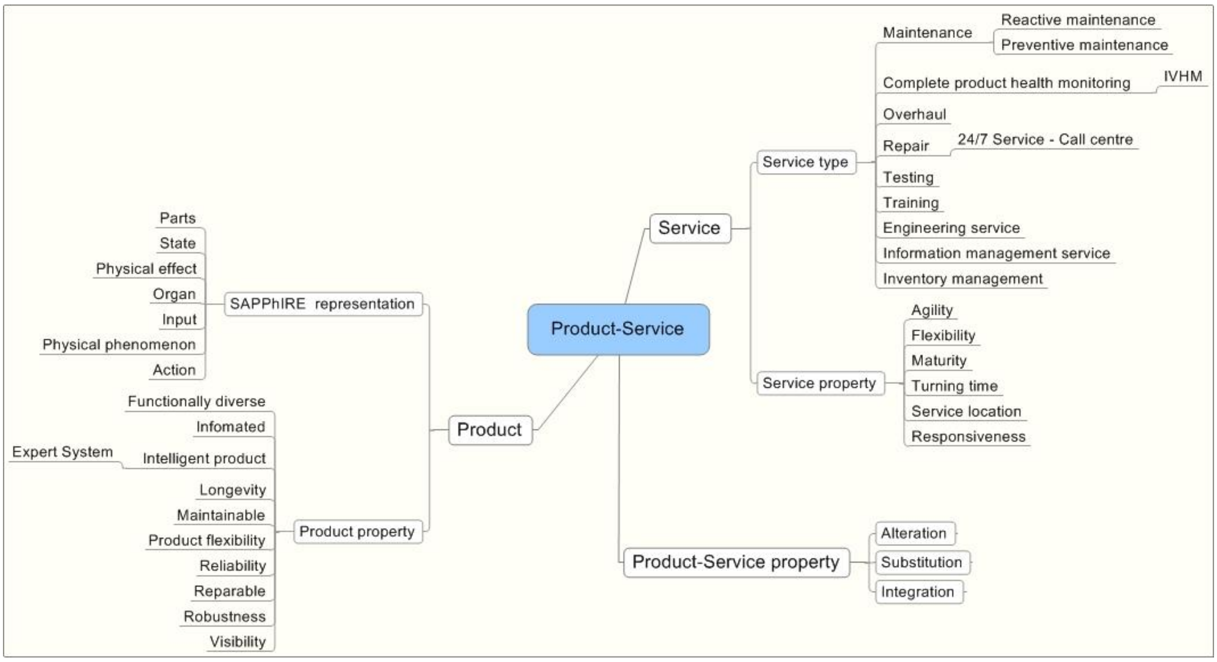

Figure 14: Sub-concepts included in Product-Service concept

5.1.4. Business Model

Business models play a central role in defining PSS. A *business model* describes the rationale of how an organization creates, delivers, and captures value– economic, social, or other forms of value [50]. Commonly used *business models* in PSS domain are included in types: *Product-*, *Use-* and *Result*-oriented. The frequently cited examples within these business models from literature and industrial practice are presented within these models. The properties which differentiate these business models are grouped in the *business model property* sub-concept. Emphasis is upon *cost*, *ownership* and *customization* elements. Apart from these sub-concepts, *business element* is used to describe the parameters influencing the business process, issues and solutions. Figure 15 details the sub-concepts included in the *business model* concept.

5.1.5. PSS Life Cycle

PSS Life Cycle is an integration and connection of the life cycles of services and products to a common life cycle. The integrated PSS life cycle takes into account the service characteristics, while the requirements for the life cycle of the product are considered as well. The life cycle can be applied regardless of how distinctive the service part or the product part is in the PSS [51]. Apart from the product life cycle and service life cycle, customer's activity cycle and total life cycle management are considered in the PSS life cycle. Since the customer's activity cycle forms a core in developing PSS, it has been specially emphasized. Herrmann et al. [52] argue that "the aims of a Total Life Cycle Management are to integrate all relevant disciplines with both economical and ecological target criteria." It incorporates *life cycle design process, process management, knowledge management* and *environment management system*. It has been argued that these elements comprehensively map the PSS life cycle. Figure 16 details the sub-concepts included in the *PSS Life Cycle* concept.

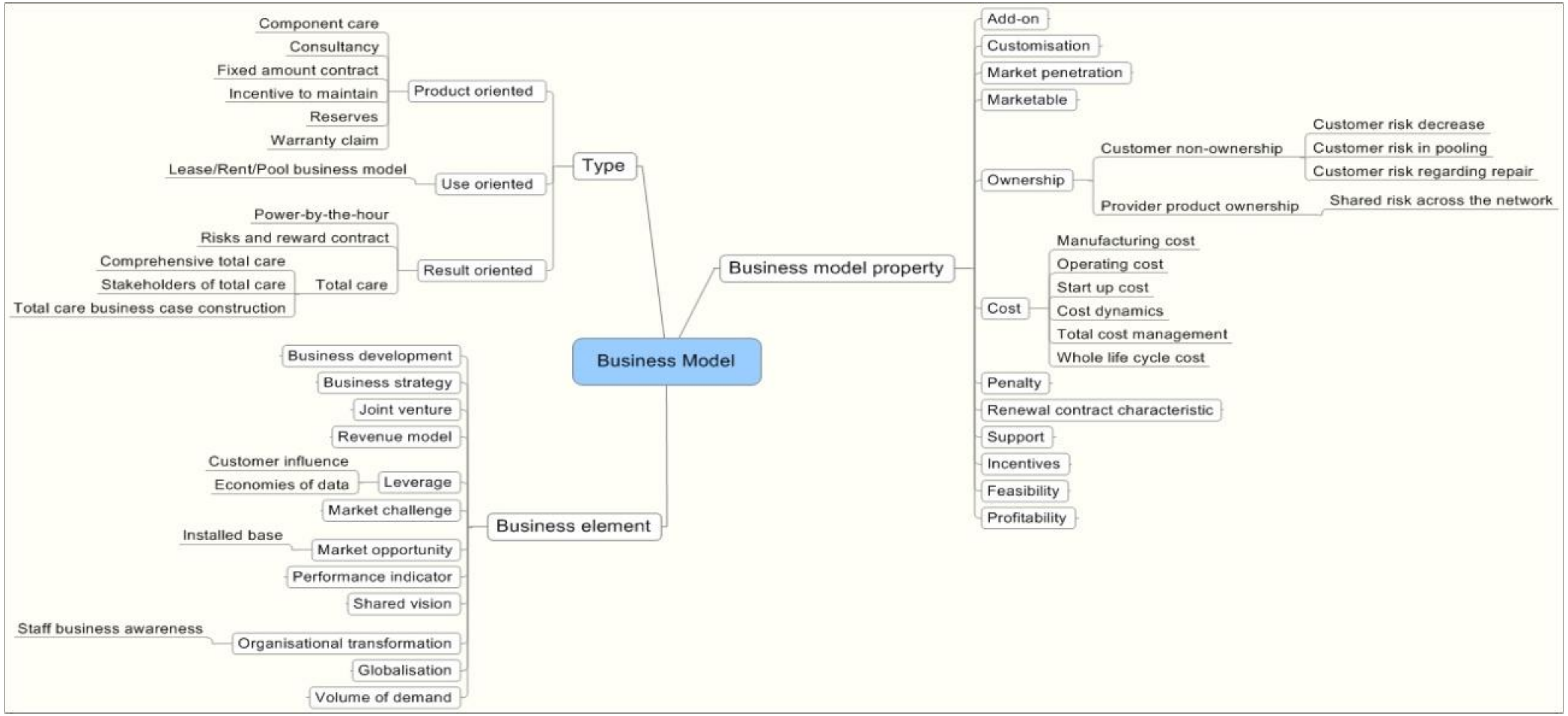

Figure 15: Sub-concepts included in Business Model concept

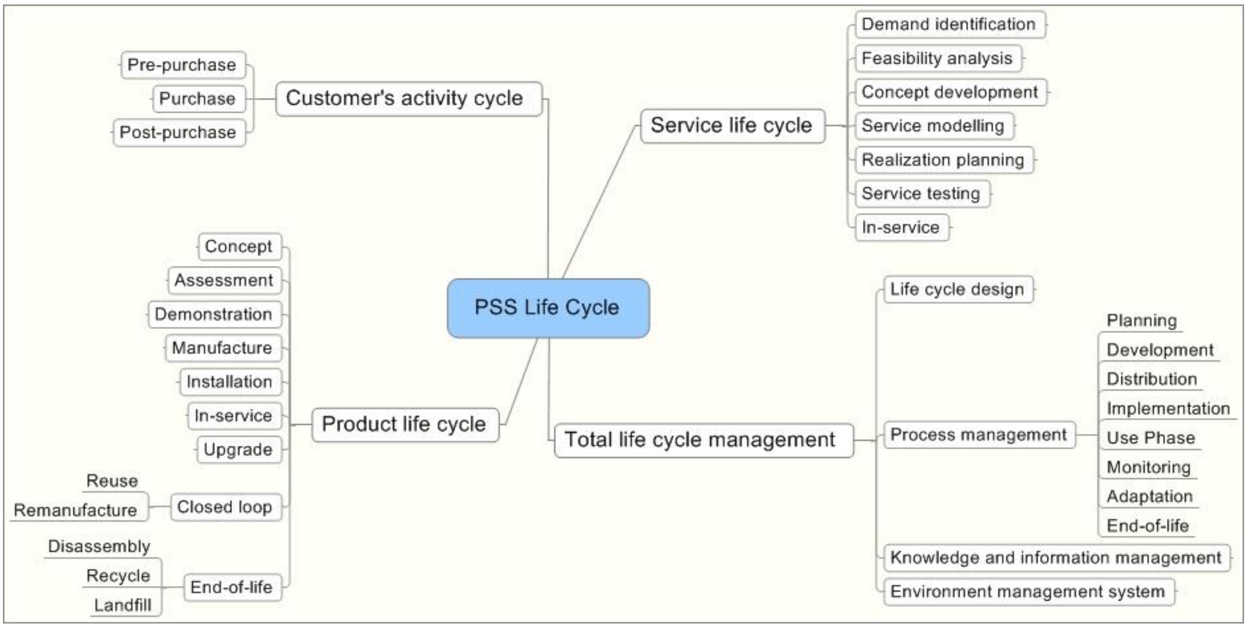

Figure 16: Sub-concepts included in PSS Life Cycle concept

5.1.6. PSS Design

PSS design is a process to synthesise and create sustained functional behaviour through tangible products and intangible services [53]. This process is sub-divided into *design strategy* and *design process*. A d*esign strategy* provides direction for the stakeholders to determine what to make and do, why do it and how to do it, both immediately and over the long term. The d*esign process* intends to structure the sequence of activities to be carried out to develop a PSS. The d*esign process* is primarily classified into *system*, *product* and *service* design. *Process property* is incorporated to distinguish the quality of the activities involved in developing a PSS. This structure for PSS design maps a broad level of the details involved. This structure needs to be detailed corresponding to the maturity in developing PSS.

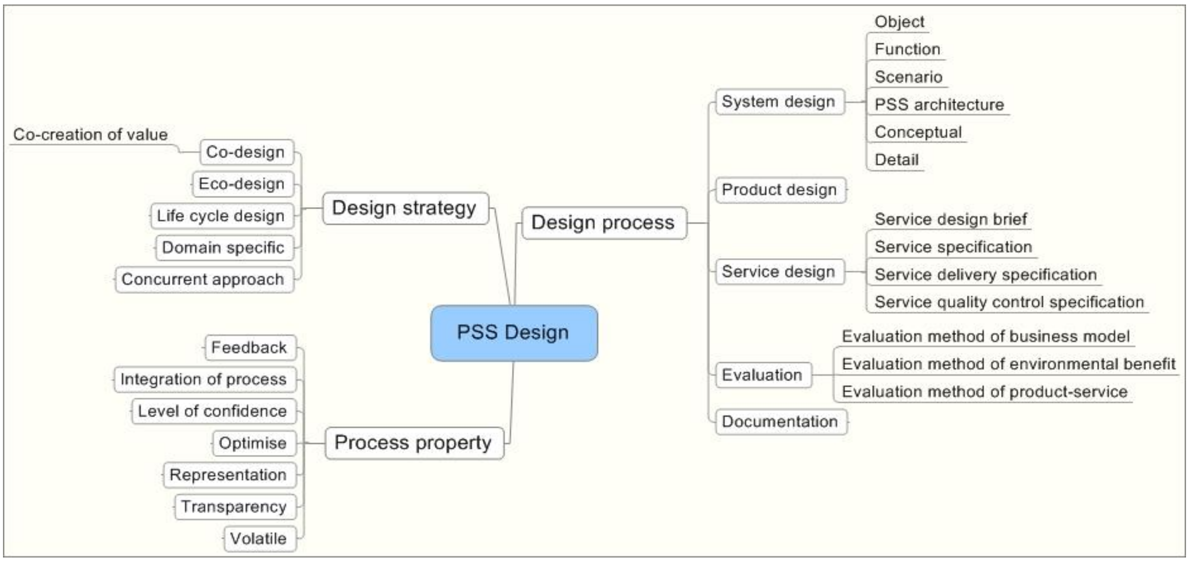

Figure 17: Sub-concepts included in PSS Design concept

5.1.7. Support System

Support system plays vital role in sustaining the PSS model. *Support system* is composed of elements which are used to assist in delivering PSS offerings. It has been sub-divided into *infrastructure* and *supply network*. *Hard* and *soft infrastructures* are used to classify the tangible and intangible elements involved in developing PSS. The elements that characterize the *supply network* are *design, provider-supplier relationship* and *types of supply network*. Various *properties* of the *supply network* are summarized and represented. The *relationship* is emphasized because, as expounded in the literature, it plays an important role in constructing the *supply network*. The factors mentioned in *infrastructure* and *supply network* need to be expanded to help assist firms in developing sustained PSSs. Figure 18 details the sub-concepts included in the *Support System* concept.

5.1.8. PSS Outcome

The *outcomes* of PSSs differentiate this domain from others; a *PSS outcome* should lead to substantial benefits for the whole system. To stress this argument, *PSS outcome* is sub-divided into *economic, social* and *environment*. Many of the reviewers who participated in this PSS ontology development favoured this classification. To describe the classification of benefits in quantitative and qualitative form, *tangible* and *intangible* elements are added. The list of benefits mentioned in Figure 19 is comprehensive. At the moment, there is an absence in the literature to fully explain the benefits offered by PSSs. Furthermore, more elements could be added based on the real-time evaluation of benefits of by PSSs.

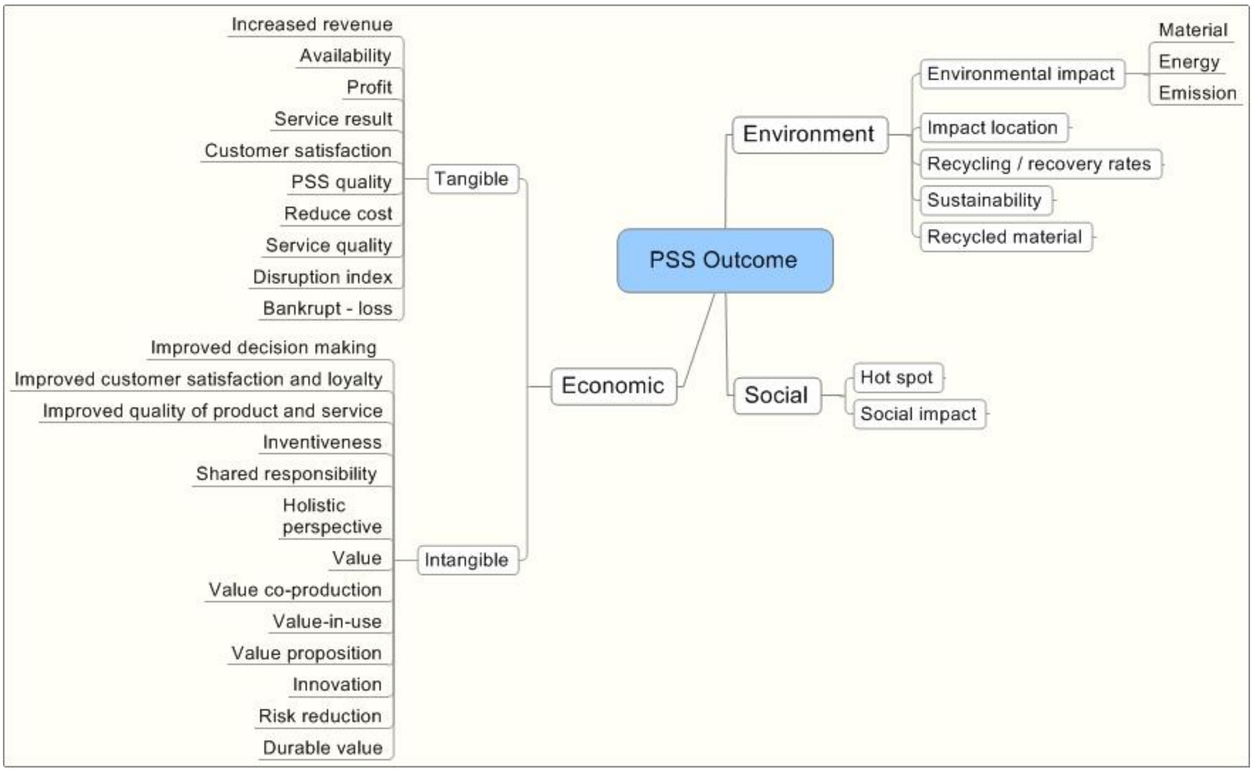

Figure 19: Sub-concepts included in PSS Outcome concept

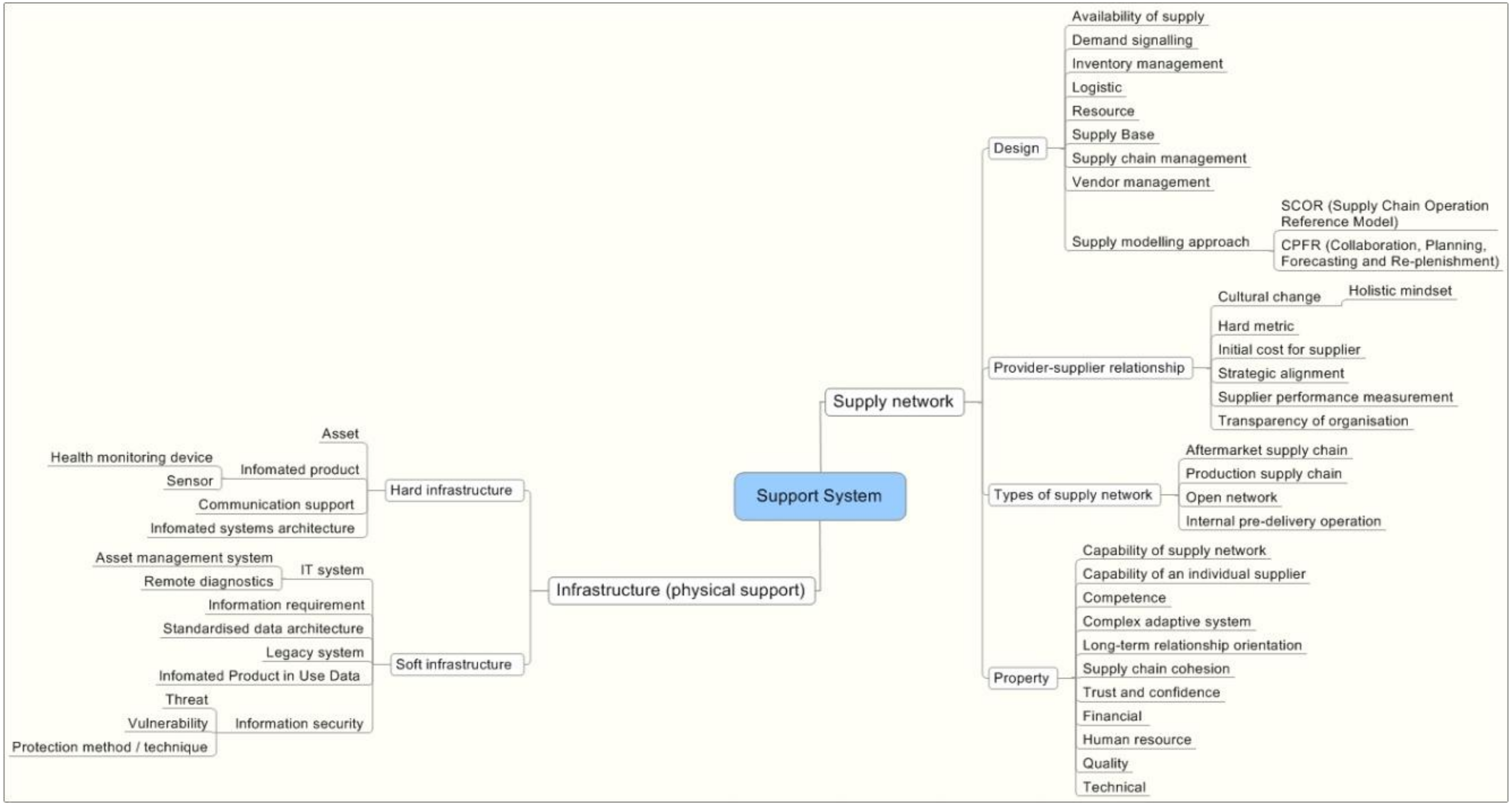

Figure 18: Sub-concepts included in Support System concept

5.2. Responses to the first round of received reviewers' feedback

The foremost query regards the objective of the PSS ontology development. The primary objective of this ontology development is to aid clarity to the top-level concepts of PSS which will aid the communication between researchers and practitioners. This development includes,

- A collection of PSS concepts.
- The definition of each concept.
- The hierarchical grouping and structuring of these concepts and
- Identification of the relationships between these concepts.

As the purpose is to represent the top-level concepts, only three levels of classes are defined in the proposed ontology. We believe that the level of concepts included and the hierarchy described are important to describe top-level PSS ontology. Our approach is top down i.e. the development of the top level structure of PSS and then refining this from roots to leaves. For example, *'service quality'* in *'outcome'* could be further extended and structured. Alternatively, defining all of the leaves and merging these together to define the root could be another possible approach. These approaches could be mixed based on how our understanding unfolds.

Suggestions for corrections and additions to these concepts have been incorporated in the proposed and revised ontology. An improvement in representation rigor is expected from the researchers who had previously worked on the development of this ontology. As many researchers may not be comfortable with using Protégé™ software, a single MindMap™ diagram representing the ontology levels in a hierarchical tree structure had been provided to engage as many people as possible in this evaluation process. For the revision, a high level concept representation diagram has been used to illustrate the top-level ontology (Figure 9) along with an updated MindMap™ diagram. Protégé files will be available on request for those who are interested in exploring this ontology using Protégé.

Only detailed and defined concepts are included within this ontology development. All concepts included in the PSS ontology have been defined. The definitions are from literature, web sources, interviews with industry experts and from our understanding. The representation of abstract descriptions is not within the scope of this ontology development. It has been iterated that reasoning based on the developed ontology is not within the scope of this work. As previously mentioned, issues involved in representing the relationships are highlighted. A much better representation to show the relationships has yet to be identified and/or developed.

Besides fostering better communication amongst researchers and PSS practitioners, we believe that the ontology will also facilitate the development of improved applications in PSS design domain. As the purpose of this ontology development is to represent top-level PSS concepts from the design perspective, illustration of this ontology through an application map has been developed and demonstrated in Figure 20. Figure 20 represents only the links between various concepts to be considered during PSS design. Since researchers involved in this PSS ontology development and evaluation process had primarily come from engineering backgrounds, this ontology could be expanded through multidisciplinary collaborative effort by inviting researchers from other disciplines. Importance and implications of PSS to other fields have to be established and spread across for researchers from other disciplines to participate in this ontology development

5.3. Responses to second round of received reviewers' feedbacks

To check for corrections and consistency in the revised ontology based on responses provided by the reviewers, it was sent again to the PSS researchers to make sure that their comments had been incorporated in the revised ontology. In the second round, apart from a few minor corrections and suggestions received from the reviewers, the overall feedback was favourable. This suggests that the proposed and evaluated PSS ontology is converging and there is merit in debating the understanding and structure of a PSS ontology as a common agreement is emerging between the PSS researchers. The ontology development is an iterative process which will evolve as our understanding unfolds. To foster this iterative development, a web based ontology development portal will be created to propagate and sustain the discussion between the researchers and practitioners. Therefore, the next step in the evaluation process will be to develop a web forum through web protégé™ to allow international researchers to participate and further develop the globally elaborated, comprehensive ontology.

6. Conclusions and future work

In this report, the first and foremost ontology for the PSS domain has been developed from interviews with experts and from literature. A widespread demonstration and evaluation of the proposed ontology was positively responded to by twenty six researchers. The identified root concepts were found to be almost complete. The current stage to enhance this ontology is to populate the relationships between concepts, to define constraints of properties and to test this ontology by creating instances for different applications. The ontology needs to be evaluated for its completeness, consistency and intuitive appeal to users with focus on the following,

- The PSS ontology should be intuitive so that it can be easily and appropriately implemented within industry.
- For the exclusivity and exhaustiveness of the PSS ontology to evolve over time and
- Many applications need to be generated around this ontology to validate and prove its usefulness.

This could be achieved by involving many researchers to expand and debate this ontology as well as develop many applications from this ontology. The collaborative approach adopted should encourage diverse viewpoints to be offered which will strengthen this ontology. ProtégéTM software was used to develop this ontology as this provides a well established platform for collaboration; Web Protégé is in development which will support users in creating and discussing the ontologies collaboratively over the Internet. Importantly, longitudinal studies are required to develop an exhaustive ontology because retrospective interviews may not provide a complete picture.

Since enhancing communication between the stakeholders is a primary objective of this ontology development, the proposed ontology needs to be evaluated for its capability for common representation. Various evaluations need to be carried out to measure common interpretation between stakeholders. The maturity of common representation could be measured by using a software platform to develop PSS which is agreed upon by the stakeholders. That software platform should be based on this ontology developed. The next level in ontology maturity is the development of a machine interoperable language which would aid in developing PSS by understanding these terminologies. The ultimate goal of this work is to develop a single PSS ontology which aims to understand the commonalities and differences between research groups and between industries as well as help industry to develop viable PSSs by providing good communication between the stakeholders.

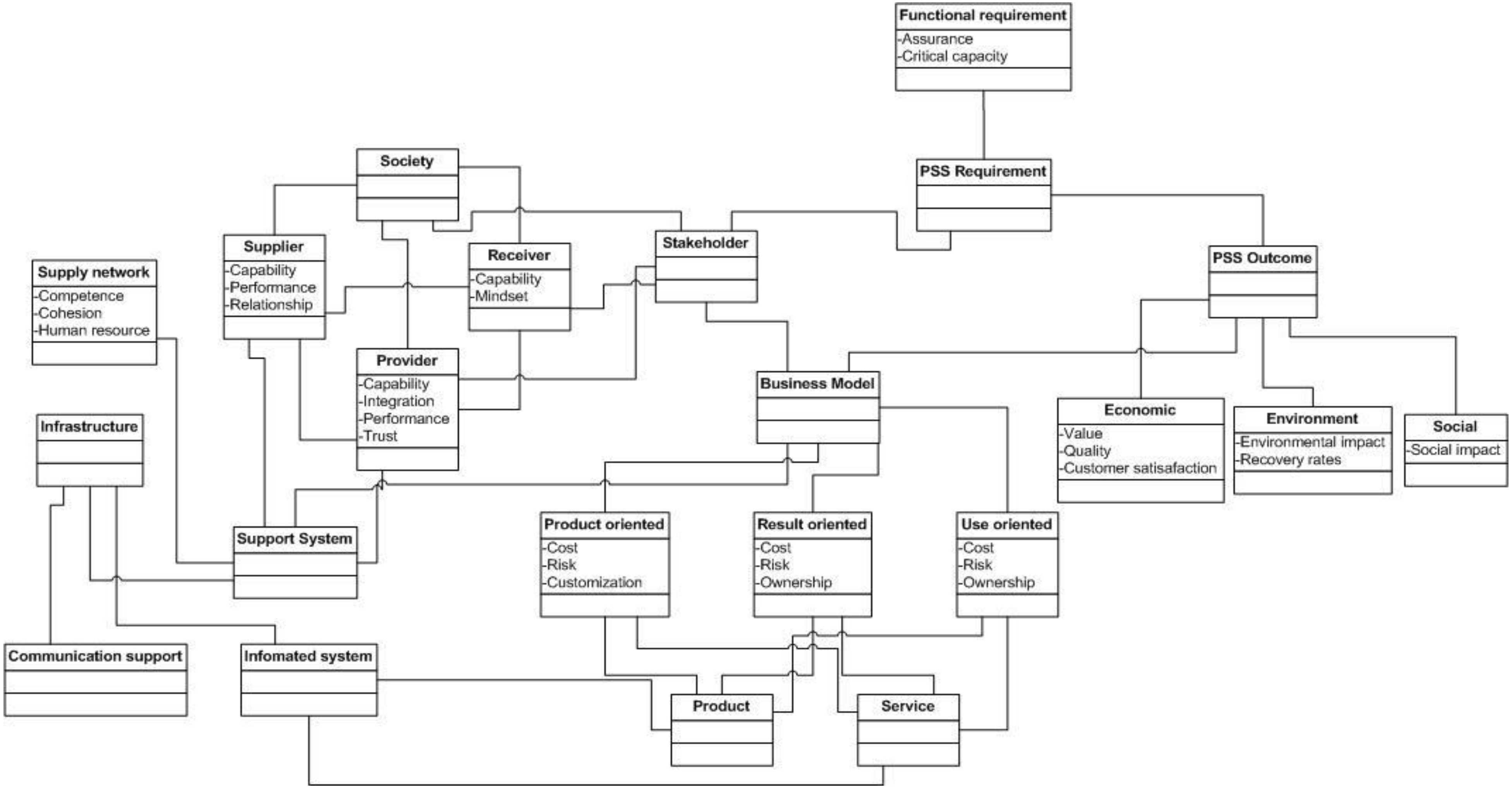

Figure 20: An application of top level ontology to designing PSS

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Appendix – I

List of PSS ontology evaluators

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Appendix – II

Root and sub-concepts definitions

Terms	Definitions
Product Service System	A product service-system is a system of products, services, networks of "players" and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models'. (Goedkoop et al., 99) An innovation strategy, shifting the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly capable of fulfilling specific client demands Manzini, 03)
Need / Requirement	Customer needs is often used to represent something that is necessary for life or the reasons for the actions (Maslow., 1987). Requirements are represented to define specified characteristics or specifications, which are more formalized into a precise description of the product (Ericson et al., 2009).
Product-Service requirement	Specific functionality that defines what product-service is supposed to accomplish.
Functional need	"…the needs behind the need". A value proposition concerns something that fulfils specific, integrated client needs. Tukker, A. and Tischner, U. (2006) "New Business for Old Europe", Greenleaf Publishing (UK).
Functional behaviour	Sustained Functional Behaviour – How does the system achieve its purpose continuously? Sustained functional behaviour is the property of the system's structure which influences the transforming elements within the system.
Support system requirement	Necessary elements and properties which are used to assist in delivering the PSS offerings.
Adaptability	Variability in respect to, or under the influence of, external conditions
Assurance	A statement or indication that inspires confidence; a guarantee or pledge
Critical capacity	System and resources required to deliver intended outcomes
Stakeholder requirement	The needs and expectations of all involved stakeholders. It is necessary to understand their various viewpoints and manage any inconsistencies and conflicts. (Darke and Shanks, 1998)
Economic requirement	Specification of economic benefits of business e.g. Revenue.
Environmnet requirement	Specification of environment benefits due to the effects of PSS. e.g. Reduction in pollution
Social requirement	Specification of social outcomes due to PSS. e.g. Employment, utility
Contractual requirement	The requirements that are agreed between customer, provider and other stakeholders.
Explicit / Implicit requirement	Requirement that is properly communicated as envisaged by the stakeholder. Requirement that is envisaged but not communicated to other stakeholders but will be reflected during use phase.
Added value	Specification of the enhancement added to a product or service by a provider before the product is offered to customers or during the use stage of the product.

Innovation	Specify the required novelty of products, services and business models. Apart from aesthetics, design can contribute significantly to utility value, and is often a decisive factor when choosing between different options. …. Europe must capitalise on its proven ability to handle complexity, and ensure continuing access to developments in enabling technologies such as holistic user-centred design, innovative materials, nanotechnologies, ICT and mechatronics. These will give almost limitless possibilities to develop new products, achieve faster manufacturing, or add functionality to existing product concepts (ManuFuture ETP Strategic Research Agenda, 2006, pag.14)
Risk	The reduction of risk concerns the reduction of the deviation of one or more results of one or more future events from their expected value. http://en.wikipedia.org/wiki/Risk
Stakeholder	Person, group, or organization that has direct or indirect stake in designing and delivering PSS because it can affect or be affected by the actions, objectives, and policies. http://www.businessdictionary.com/definition/stakeholder.html#ixzz18kSd5HZj
Receiver	The entity who is receiving the provided offering. Stakeholder who purchases product and services. The intended recipient(s) of a product or service BS7000-3:1994
End user	People who operate and interact with the product.
Capability sponsor	People looking at capability requirements and following those capability needs.
Lead users	"[lead users]….are ahead of the majority of users in their populations with respect to an important market trend, and they expect to gain relatively high benefits from a solution to the needs they have encountered there." von Hippel, E. (2005). Democratizing Innovation. MIT Press: Cambridge, MA (Free download by Creative Commons), http://web.mit.edu/evhippel/www/democ1.htm, accessed 2008-06-12.
Provider	A person, organization or business that offers a good or service. (http://www.businessdictionary.com/definition/provider.html)
Supplier	The company which supports the OEM (Original Equipment Manufacturer) whether by providing product/service/solution for PSS.
Employee	Person involved within provider or in the network to design or deliver PSS.
After market organization	Stakeholder who supports the OEM during product usage.
Cross sectoral service innovation team	A team works alongside each of the sectors business development teams to identify numerous opportunities that could have applications in more than one sector.
Financial and Commercial	Teams which monitors and assess offerings and business growth.
Product team	People involved in designing new or modify artefacts.
Sales people	People who sell products and services to customers.
Service people	People who carry out activities to keep product functional.
Cost engineer	People who estimates cost for the products and services.
Society	Stakeholder regrouping government, local community and citizens.
Corporate social responsibility	A form of corporate self-regulation integrated into a business model.
Environmental product declaration	The overall goal of an Environmental Product Declaration, EPD, is to provide relevant, verified and comparable information to meet various customer and market needs. The international EPD®system has the ambition to help and support organisations to communicate the environmental performance of their products (goods and services) in a credible and understandable way.

Regulation	A regulation is a legislative act of the European Union that becomes immediately enforceable as law in all member states simultaneously.
Value network	All actors that are involved in the creation and capture of value (Van Ostaeyen and Duflou, 2010)
Relationship management	The active and skilled pursuit of a long-term system of working together between actors (Specify the kind of connection between the stakeholders.)
Stakeholder property	Characteristics that need to be defined to create sustained value network for PSS.
Capability	Skills require to undertake set of activities.
Commitment	An act of engaging in the activities.
Culture	The behaviours and beliefs characteristic of a particular department, organization or group.
Delegate role and responsibilities	Ability to frame and assign the role and responsibilities among stakeholders
Integration	An act of blending teams, groups and organization.
Performance	The efficiency with which work is executed.
Recognition	An act of acknowledging achievement, merit, etc.
Relationship	Specify the kind of connection between the stakeholders.
Trust	Degree to which each stakeholders relies between each other.
Mindset	A habitual or characteristic mental attitude that determines how a person or an organisation will interpret and respond to situations.
Sacrifice	Tolerate the loss of something or surrender something for the sake of something more valuable.
Self-esteem	The degree to which one values oneself. www.winning-teams.com/definitions.html
Product-Service	Product service: a mix of tangible products and intangible service designed and combined so that they are jointly capable of satisfying final customer needs. Tukker, A. and Tischner, U. (2006) "New Business for Old Europe", Greenleaf Publishing (UK).
Product	Physical entity. Things that are manufactured or produced.
SAPPhIRE representation	The causal description language is acronym as the SAPPhIRE model, SAPPhIRE standing for State-Action-Part-Phenomenon-Input-oRgan-Effect. Using the constructs and relationships of this model, function, behaviour and structure of product could be linked to each other. (Chakrabarti et al., 2009)
Part	A set of physical components and interfaces constituting the system and its environment of interaction.
State	The attributes and values of attributes that define the properties of a given system at a given instant of time during its operation.
Organ	The structural context necessary for a physical effect to be activated.
Physical effect	The laws of nature governing change.
Input	The energy, information or material requirements for a physical effect to be activated; interpretation of energy/material parameters of a change of state in the context of an organ.
Physical phenomenon	A set of potential changes associated with a given physical effect for a given organ and inputs.
Action	An abstract description or high level interpretation of a change of state, a changed state, or creation of an input.
Product property	Characteristics that describe the product.
Functionally diverse	Measure of functionalities of the product with respect to customer needs.

Infomated	Infomated products as being those products which have diagnostics and prognostics technologies integrated within them. Neely, A. (2007), "The servitization of manufacturing: an analysis of global trends", Proceedings of the POMS College of Service Operations and EurOMA Conference, London.
Intelligent product	A product system which contains sensing, memory, data processing, reasoning and communication capabilities at four intelligence levels - Closed-loop PLM for intelligent products in the era of the internet of things, Dimitris Kiritsis, 2010
Infomated Product in Use Data	Infomated Product in Use Data is data collected from the monitoring sensors embedded within an asset.
Expert System	Expert System is a branch of artificial intelligence and it is a kind of intelligent computer program, using a knowledge base and inference engine to solve the problems solved only by experts. Wu Jinpei, Xiao Jianhua, "Intelligent Faults Diagnosis and Expert System." Science Technology Press. 1997
Longevity	Life span of the product.
Maintainable	Ease with which actions performed to keep some machine or system functioning.
Product flexibility	It refers to designs that can adapt when external changes occur. en.wikipedia.org/wiki/Flexibility_(engineering)
Reliability	The ability of a system or component to perform its required functions under stated conditions for a specified period of time. en.wikipedia.org/wiki/Reliability_(engineering)
Reparable	The ease by which a component can be repaired.
Robustness	The degree to which a system or component can function correctly in the presence of invalid inputs or stressful environmental conditions. www.ee.oulu.fi/research/ouspg/sage/glossary/
Visibility	A property defines understanding of the product by the customer.
Service	Services are entities that will ensure the smooth functioning of the whole system. Results generated, by activities at the interface between the supplier and the customer and by supplier internal activities, to meet customer needs (Service is intangible and as such cannot be stored) BS7000-3:1994.
Service type	Different types of services.
24/7 Service - Call centre	To provide required information to customers at all the time.
Complete product Health Monitoring	Service in which customers can be warned about potential product problems with respect to the usage time.
IVHM	IVHM includes vehicle-based and ground-based elements to manage health at the level of subsystems, vehicles, and fleets. On-board the vehicle IVHM includes Built-In-Test (BIT) and diagnostic and prognostic reasoning. Off-board IVHM includes historical data storage and analysis (mining), advanced reasoning, predictive and condition-based maintenance, and interfaces with vehicle users, planners and maintainers. K Keller, Health Management Engineering Environment and Open Integration Platform, IEEE Aerospace Conference, March 2007. An IVHM is a condition monitoring system that delivers value in supporting efficient fault detection and reaction planning. It offers a capability to make intelligent, informed, and appropriate decisions based on the assessment of present and future vehicle condition. The IVHM logic is premised on integrating vehicle components and subsystems to increase the level of health state determination and improve the ability to formulate responses. These systems tend to be customized as they focus on the functions that deliver the greatest value to their users and on the key components and subsystems that have the most relevant impact on vehicle performance. O Benedettini, T S Baines, H W Lightfoot, R M Greenough, 2009, "State-of-the-art in

	integrated vehicle health management" Proc. IMechE Vol. 223 Part G: J. Aerospace Engineering
Maintenance	The work needed to maintain an asset in a condition that enables it to reach its service potential. www.qgcio.qld.gov.au/qgcio/resources/glossary/Pages/glossarym.aspx
Preventive Maintenance	Preventative maintenance is the sum of the tasks performed on equipment, based on the manufacturer's schedule, to prevent failure of an instrument. It is a proactive process designed to prevent testing errors from instrument failure; it is part of the quality assurance process. http://deliver.jsi.com/dhome/resources/glossary/labglossary
Reactive Maintenance	A form of maintenance in which equipment and facilities are repaired only in response to a breakdown or a fault. http://dictionary.bnet.com/definition/reactive+maintenance.html
Overhaul	A major repair, renovation, or revision. en.wiktionary.org/wiki/overhaul
Repair	To restore by replacing a part or putting together what is torn or broken. wordnetweb.princeton.edu/perl/webwn
Testing	An examination of the characteristics of system (how well the system works). wordnetweb.princeton.edu/perl/webwn
Training	Enables the transfer of product and operational knowledge to the customers.
Engineering service	Providing specialist technical advice and expertise to meet the challenging and varying demands of operational requirements.
Information management service	Managing the information in the process starting from specification, creation, storage, sharing and exploitation.
Inventory management	Forecasting and procuring parts based on usage and trends in consumption.
Service properties	Properties help to define the scope and nature of service. Service characteristics - features and attributes that make up the totality of the service BS7000-3:1994.
Agility	Perpetual state of innovation, moving quickly yet thoroughly through product and process development that creates competitive advantage and increases stakeholder value. www.mgrush.com/content/view/70/33/
Flexibility	The quality of being adaptable or variable. wordnetweb.princeton.edu/perl/webwn
Maturity	A property defines the level of detailed implementation of the process across the system.
Service location	Location where the service activities are carried out.
Turning time	Non-functional time of the product.
Responsiveness	The ability to meet changing requirements quickly.
Product-Service property	Specification that characterizes the combination of tangible products and intangible service.
Alteration	The degree in which product and service attributes could be changed.
Substituttion	The degree in which product and service attributes could be replaced between them.
Connectivity	The variables which represent the integration between the product and service.
Business model	A business model describes the rationale of how an organization creates, delivers, and captures value - economic, social, or other forms of value. (Business Model Generation, A. Osterwalder, Yves Pigneur, Alan Smith, and 470 practitioners from 45 countries, self published, 2010)
Product oriented	The business model is still dominantly geared towards sales of products, but some extra services are added. (New Business for Old Europe)
Component care	Stand alone package that offers service such as repair, replacement and maintenance of components.
Consultancy	As PSS evolves so does the level of consultancy rather than just service.
Fixed amount contract	Set of services is provided with fixed amount throughout the specified period.

Incentive to maintain	The more expensive the component, the more the impetus to maintain it (rather than replace it).
Reserves	Strategy in which the leasers will be paid for the additional products. The idea was that the reserve should cover product maintenance and at the end of the contract the leaser would pay the customer back (however, sometimes the bill was a lot larger than the reserve and the customer had to pay the difference).
Warranty claims	An act of providing assurance of product availability for a particular period of time.
Result oriented services	The client and provider in principle agree on a result, and there is not a pre-determined product involved. (New Business for Old Europe)
Power-by-the-hour	It is a trade mark by GE. However, it is often used to describe RR offerings. Power-by-the-hour is the old version of total care. Power-by-the-hour was based on providing spare parts and labour associated with overhauling and maintaining engines (GE approach).
Risks and reward contract	Responsibilities of risks are shared and rewarded mutually.
Total care	The concept of a managed risk transferred in long term service arrangement. It can vary for different customers. It is a service and a support package (a contract for about ten years including maintenance and overhaul). TC is easier to sell to customers who have limited knowledge of the asset. Total Care was developed as a reaction to increasing maintenance costs. Total Care does not normally cover until the end of life of the engine (at the end of 15-20 years, the engine is sold to the owner of the plane: the asset can then be sold on by the owner). Total Care is trademarked by RR. Explored when working on Boeing 747 to then deliver total asset management solutions i.e. availability of power to a customer - no upfront investment, they simply pay for usage of that asset. Total Care Aims: 1. Eliminate the variability of maintenance (which happened in 'power by the hour' type offerings) 2. Reduce the net cost of operation by having OEM manage it: a.OEM fused incredible intellectual property around the design of the engine: very difficult to replicate. b. Massive volume of data from engines in service to, reactively manage engine maintenance, proactively manage to avoid disruption, avoid additional costs. c. Attempts to eliminate unscheduled removals Covers all repairs, supply of materials, replacements, repair of accessories, spare engine support and logistics management. Power-by-the-hour - is a trade mark by GE however, it is often used to describe RR offerings. Power-by-the-hour is the old version of total care. Power-by-the-hour was based on providing spare parts and labour associated with overhauling and maintaining engines (GE approach).
Comprehensive Total Care	Comprehensive types of Total Care. Covers all repairs, supply of materials, replacements, repair of accessories, spare engine support and logistics management.
Stakeholders of Total Care	RR Product teams, sales, customer service, financial and commercial teams determine the structure and strategy of the offering. Externally, the market and competition is the main driver.
Total Care Business Case Construction	Decide on the service, label and commercial structure offered with the engine. Decide on a share of the market – could be 7% or more. Decide on the marketing and sales messages (min Service Level Agreement).
Use oriented services	The traditional product still plays a central role, but the business model is not anymore geared towards selling products. The product stays in ownership with the provider, and is made available in a different form, and sometimes shared by a number of users. (New Business for Old Europe)
Lease/Rent/Pool Business Model	Manufacturer owns the product and lease, rent, pool the product for the usage hours.
Revenue model	The revenue model: the description of the formal relations within the value network, defining how revenues and costs are divided between the different actors. (Van Ostaeyen and Duflou, 2010)

Business model property	Properties help to define the scope and nature of offerings.
Cost	An engineer whose judgment and experience are utilized in the application of scientific principles and techniques to problems of estimation; cost control; business planning and management science; profitability analysis; project management; and planning and scheduling (AACE International Cost Engineering, 2010).
Manufacturing cost	The total of variable and fixed or direct and indirect costs chargeable to the production of a given product, usually expressed in cents or dollars per unit of production, or dollars per year. Transportation and distribution costs, and research, development, selling and corporate administrative expenses are usually excluded (AACE International Cost Engineering, 2010).
Operating cost	The expenses incurred during the normal operation of a facility, or component, including labour, materials, utilities, and other related costs. Includes all fuel, lubricants, and normally scheduled part changes in order to keep a subsystem, system, particular item, or entire project functioning. Operating costs may also include general building maintenance, cleaning services, taxes, and similar items (AACE International Cost Engineering, 2010).
Start up costs	Initial costs incurred to initiate tasks. High start up costs can be a barrier for entry to PSS.
Cost dynamics	Trends over time change the balance between cost drivers http://www.brekiri.com/blog/290/competitive-advantage-by-michael-porter-part-3/
Total cost management	TCM- The effective application of professional and technical expertise to plan and control resources, costs, profitability and risks. Simply stated, it is a systematic approach to managing cost throughout the life cycle of any enterprise, program, facility, project, product, or service. This is accomplished through the application of cost engineering and cost management principles, proven methodologies and the latest technology in support of the management process. Can also be considered the sum of the practices and processes that an enterprise uses to manage the total life cycle cost investment in its portfolio of strategic assets (AACE International Cost Engineering, 2010).
Whole life cycle cost	Costs incurred to keep the system functional throughout its life time.
Ownership	The relation of an owner to the thing possessed; possession with the right to transfer possession to others (wordnetweb.princeton.edu/perl/webwn)
Customer Non-Ownership	Customer Non-Ownership Risk- The OEM retaining the asset can lead to and trading problems for the client (i.e. if the engine is owned by the OEM, then the aircraft that eventually gets traded is just a carcass)
Customer Risk Decreases	Main selling point for Total Care is the transference of risk and smaller payments (rather than one lump sum).
Customer Risk in Pooling	Customers may not wish to share an asset that is also being either used by an unknown party or being used by another customer that may misuse (and hence degrade) the asset.
Customer Risk Regarding Repair	Some customers prefer the part to be replaced as they believe this is the only way to ensure that the component is reliable.
Provider Product Ownership	"Time and materials" serviced engines would mean revenue the OEM when they had to be repaired. However when the OEM retains ownership, it means loss of revenue when such services have to take place. Therefore the incentive is to keep the asset intact.
Shared Risk across the Network	Important to be engaged with the network from the start rather than at the end and to get signed agreements on reliability and cost of overhaul up front as well as passing indemnity down the chain. This never used to happen before PSS.
Add-on	Represents the flexibility in offering to include or remove products and services.
Customization	Specify the adaptability of the offering to customer needs. Tailored to the customer's needs and the product's capability.
Market penetration	The percentage of the market owned by a company as represented by share of revenue. (www.csumb.edu/site/x7101.xml)

Marketable	Easiness through which offering is sold.
Penalties	Loss incurred due to the contracts requirements not being met.
Renewal contract characteristics	Should show lower cost, reliability, more responsiveness in order to secure further customer commitment.
Support	Delivering the contracted level of support and beyond as well as ensuring performance is critical as these will be scrutinized by the customer.
Incentivisation	Process of providing of an incentive.
Feasibility	Business model strategically and practically interesting for a company. Feasibility assessment requires a qualitative approach (Joris Van Ostaeyen, 2010). The 'fit' between the different business model design parameters (Bouwman, H. et al., 2008).
Profitability	Assessment of the profitability of a business model requires a quantitative approach. For an alternative business model, benefits vs. costs and risks need to be determined in order to calculate the expected profit potential. Financial implications of the business models (Joris Van Ostaeyen, 2010).
Business element	Parameters describing the business process, issues and solutions.
Business development	Initiating and planning for new products and services.
Business strategy	Current and future aim and objectives of the organization.
Joint Venture	Collaboration between the organizations to satisfy customers' needs.
Leverage	Strategic advantage; power to act effectively; (wordnetweb.princeton.edu/perl/webwn)
Customer influence	The ability of the customer facing business team to influence the OEM has increased.
Economies of data	OEM can deal with the data more effectively (as they have access to all the engines) than an airline with just 2-3. 70 data sets gives a clearer picture than just 2-3. OEM has intellectual capability to interpret the data. OEM can prioritise remedy expenditure and investment to pre-empt problems. Aggregation of the demand forecast with the demand signal – economies of scale also with reference to the supply chain.
Market challenge	Issues to be resolved to penetrate the market.
Market opportunity	Perceived potential area in business to explore.
Installed base	The sum of products that are being used in the field.
Performance indicator	A high level metric of effectiveness and/or efficiency used to guide and control progressive development. (thiyagarajan.wordpress.com/glossary/)
Shared Vision	Represents the commonality in aims between stakeholders.
Organizational transformation	Represents the transformation of the business aim and objectives. In an organizational context, a process of profound and radical change that orients an organization in a new direction and takes it to an entirely different level of effectiveness. Unlike 'turnaround' (which implies incremental progress on the same plane) transformation implies a basic change of character and little or no resemblance with the past configuration or structure. http://www.businessdictionary.com/definition/transformation.html Organisation Transformation (OT) can be defined as a holistic, ecological, humanistic approach to radical revolutionary change in the entire context of an organisation's system. Organisation Transformation involves transformative changes in the fundamental nature of the organisation in relation to its ecosystem and requires completely new ways of thinking, behaving, and perceiving by the members of the organisation. (Levy and Merry, 1986)
Staff Business Awareness	Awareness of employees about the current business models.
Enculturation	Staffs who are moved from one side of the business to another can become enculturated very quickly and lose their original perspective.

Globalization	The process of increasing the connectivity and interdependence of the world's markets and businesses. http://www.investorwords.com/2182/globalization.html
Volume of demands	The amount of products that consumers are willing to purchase.
PSS life cycle	An integration and connection of the life cycles of services and products to a common life cycle. The integrated PSS life cycle takes into account the service characteristics (according to the depicted life cycle for Service LCM), while the requirements for the life cycle of the product are considered as well. The life cycle can be applied regardless of how distinctive the service part or the product part is in the PSS. (C. Herrmann, K. Kuntzky, M. Mennenga, M. Royer-Torney, L. Bergmann (2010): Joint Framework for Product Service Systems and Life Cycle Management, in: Proceedings of the 2nd CIRP International Conference on Product-Service-Systems 2010, Linköping, Linköping University, 2010, pp 353-359)
Product life cycle	The stages that a product goes through during its life: introduction, growth, maturity, and decline. (www.glencoe.com/sec/busadmin/marketing/dp/ad_serv/gloss.shtml)
Concept	Produce a statement of the outputs that users require from the system, framed as a User Requirements Document (URD) http://www.aof.mod.uk/aofcontent/tactical/ppm/content/lifecycles/cadmid.htm
Assessment	Produce the System Requirements Document (SRD), defining what the system must do to meet user needs as stated in the URD. http://www.aof.mod.uk/aofcontent/tactical/ppm/content/lifecycles/cadmid.htm
Demonstration	Eliminate progressively the development risk and fix performance targets for manufacture, ensuring there is consistency between the final selected solution and the SRD and URD. http://www.aof.mod.uk/aofcontent/tactical/ppm/content/lifecycles/cadmid.htm
Manufacture	Deliver the solution to the requirement within the time and cost limits. http://www.aof.mod.uk/aofcontent/tactical/ppm/content/lifecycles/cadmid.htm
In-Service	Confirm the capability provided by the system is available for operational use. http://www.aof.mod.uk/aofcontent/tactical/ppm/content/lifecycles/cadmid.htm
Upgrade	Improving product performance and continuous capability enhancement to meet operational requirements.
Closed loop	Production system in which the waste or by-product of one process or product is used in making another product. http://www.businessdictionary.com/definition/closed-loop-recycling.html#ixzz18raoupKW
Reuse	To use a product more than once. This includes conventional reuse where the item is used again for the same function and new-life reuse where it is used for a new function.
Remanufacture	Remanufacturing is a process of bringing used products to a like-new functional state with warranty to match.
End-of-life	Refers to the time when a product's value to the user, generally the first user, has been expended and the product is available for reuse, recycling or disposal. www.girpm.com/articles/glossary.asp
Disassembly	dismantling: the act of taking something apart (as a piece of machinery); wordnetweb.princeton.edu/perl/webwn
Recycle	Discards are separated into materials that may be incorporated into new products.
Landfill	Disposal: Carry out plans for efficient, effective and safe disposal of the equipment. http://www.aof.mod.uk/aofcontent/tactical/ppm/content/lifecycles/cadmid.htm
Service life cycle	The stages that a service goes through during its life.
Demand identification	This task primarily involves situation analysis, market survey and specification of service targets (Aurich et al., 2006)
Feasibility analysis	This task primarily involves specification of target customers and assessment of costs and benefits (Aurich et al., 2006)
Concept development	This task primarily involves service solution findings. (Aurich et al., 2006)

Service modelling	This task primarily involves modelling of service system and specification of service product model. (Aurich et al., 2006)
Realization planning	This task primarily involves resource planning and development of deployment plans. (Aurich et al., 2006)
Service testing	This task primarily involves prototypical service testing and identification of improvement potentials (Aurich et al., 2006)
In-Service	The operational phase in which tested service units are implemented.
Total life cycle management	The TLCM is a systemic and life cycle oriented framework for a life cycle phase comprehending point of view on products and the corresponding processes (Herrmann, C., Bergmann, L., Thiede, S., Zein, A., 2007, Total Life Cycle Management – A Systems and Cybernetics Approach to Corporate Sustainability in Manufacturing, in: sustainable manufacturing V: Global Symposium on Sustainable Product Development and Life Cycle Engineering, Rochester.)
Process management	Holistic management approach that promotes business effectiveness and efficiency while striving for innovation, flexibility, and integration with technology. (vom Brocke, and Rosemann,.2010).
Planning	Exploring and sketching the initial ideas of design/development of PSS consisting both product and service.
Development	Integrated development of product parts and service parts.
Distribution	The PSS is marketed and the product, service as well as the physical portion of the available potential is prepared.
Implementation	Implementation of the PSS offering including not only product but also services
Use phase	The customer and the customer's processes need to be a part of the service provision and use. The phase in which customer is realising the benefits of the PSS offers.
Monitoring	Monitoring the outcomes of products and services in the PSS offering
Adaptation	Adaptation of products and services with respect to the customer's needs.
End-of-life	The time when a PSS's value to the user has been expended.
Knowledge and information management	Knowledge Management comprises a range of practices used by organisations to identify, create, represent, and distribute knowledge.
Environment management system	An Environmental Management System (EMS) is a structured framework for managing an organisation's significant environmental impacts. Refers to the management of an organisation's environmental programs in a comprehensive, systematic, planned and documented manner. It includes the organisational structure, planning and resources for developing, implementing and maintaining policy for environmental protection.
Customer's activity cycle	The pre-purchase, purchase and post-purchase sequences. If getting results over time is the competitive goal, then the means or mechanism is the design, delivery and support of solutions through the customer's activity cycle, or the pre-purchase, purchase and post-purchase sequence. Whosoever finds the opportunity for providing the value during this process holds the competitive advantage. Vandermerwe, 2002.
Pre-purchase	The stage in which needs are recognized and problem is defined.
Purchase	The stage in which purchasing framework is structured and purchase is made.
Post-purchase	The stage involves operation, production, sales and services.
PSS - Design	PSS-Design is a process to synthesise and create sustained functional behaviour through tangible products and intangible services. (PSS conceptual design team - Cranfield University, 2009)
Design strategy	Design strategy helps firms determine what to make and do, why do it and how to innovate contextually, both immediately and over the long term. http://en.wikipedia.org/wiki/Design_strategy
Co-design	Firms do not really provide value, but merely value propositions (Vargo and Lusch, 2004) and it is the customer that determines value and co-creates it with the firm.

Co-creation of value	Process through which desired outcomes are jointly created by the stakeholders.
Eco-design	Terms to denote the willingness to develop products complying with the principles of sustainable development.
Life cycle design	Design theory and methodology for developing product life cycle systems that reduce drastically environmental loads, resource consumption, and waste generation, as well as increase living standards and corporate profits. Integrated design of business strategy; including the post mass production paradigm and servicification, Life cycle strategy of circulation, such as reduce, reuse, and recycling, Product and life cycle processes and Life cycle management. (Umeda, 2010)
Domain specific	Specifying the domain in which business has to be focused. B2B, B2G, B2C.
Concurrent approach	Work methodology based on the parallelization of tasks (i.e. performing tasks concurrently). http://en.wikipedia.org/wiki/Concurrent_engineering
Design process	The sequence of activities to be carried out to develop a PSS.
System design	PSSs as systems made up of service units and physical objects. The physical objects are functional entities that carry out the elementary functions of the system, the service units are entities (mainly technical) that will ensure the smooth functioning of the whole system. These elements have relationships and interactions that lead to take into account the specificities of each ones during the design process. Nicolas Maussang, Peggy Zwolinski, Daniel Brissaud, “Product-service system design methodology: from the PSS architecture design to the products specifications.”, Journal of Engineering Design, Volume 20, Issue 4 Augus 2009 , pages 349 - 366
Object	PSSs are defined as systems composed of physical objects, service units and relations between each others that ensure to the customer a result, a function or a use.
Function	A function is interpreted as a specific process, action or task that a system is able to perform. en.wikipedia.org/wiki/Function_(engineering)
Scenario	Scenarios can detail the activities that are performed in the system.
PSS Architecture	Entity which describes the system level abstraction in PSS

Conceptual Stage	"The conceptual stage plays an important role in the entire PSS procedure. Implementation of PSS is complicated, because solutions have wider possibilities and services are dynamic and intangible. The conceptual design works as a compass in the implementation. It consists of customer values and features of the offering. Designers make decisions as to how to provide the features according to the conceptual design. Therefore, the conceptual stage defines almost all of the value provided to customers." Koji Kimita and Yoshiki Shimomura, Tamio Arai "Evaluation of customer satisfaction for PSS design", Journal of Manufacturing Technology Management Vol. 20 No. 5, 2009 pp. 654-673 ________________________ "During the preliminary design phase (conceptual design), designers should not focus at first on a solution based on a physical product or a service unit. Different alternatives should be considered and compared with each other. Then, the objective is to establish the global organisation of the system. Who does what? What is the relationship between the elements? How can engineering designers trade off against the solutions?" Nicolas Maussang, Peggy Zwolinski, Daniel Brissaud, "Product-service system design methodology: from the PSS architecture design to the products specifications.", Journal of Engineering Design, Volume 20, Issue 4 Augus 2009 , pages 349 - 366. The individual and organizational metric should be aligned according to PSS offering. Short time-to-market (from the concept to new PSS on the market) enabled by ICT applications, which will increasingly be relevant in manufacturing industries (Factory of the Future PPP Strategic Multiannual Roadmap, 2010, pag. 13)
Detail stage	The stage in which conceptual solutions are expanded which could be produced and implemented appropriately.
Product design	Product design can be defined as the idea generation, concept development, testing and manufacturing or implementation of a physical object or service. Product Designers conceptualize and evaluate ideas, making them tangible through products in a more systematic approach. ... en.wikipedia.org/wiki/Product_design
Service design	Steps illustrate to develop new services. Concept, Viability, Implementable, Costing and Infrastructure Requirement. Service design (noun) 1) Set of instructions (specifications, drawings and schedules, etc.) necessary to construct an artefact or service. 2) Artefact or service itself. Service design (verb) generation of information by which a required service or product can become a reality BS7000-3:1994.
Service delivery specification	Document that specifies those supplier activities and resources needed to supply the service. The service delivery specification forms part of the service specification. BS7000-3:1994.
Service design brief	Document that describes the primary purpose of a service and gives guidance. Guidance can relate to such matters as its style, grade, performance, appearance, conditions of use including health and safety considerations, characteristics, packaging, conformity, reliability, maintenance. BS7000-3:1994.
Service quality control specification	Document that specifies the requirements for effective control of the service to ensure that it consistently satisfies the service specification and the customer requirements BS7000-3:1994.
Service specification	Document that prescribes the requirements with which the service has to conform. A service specification should refer to or include drawings, patterns or other relevant documents and should also indicate the means and the criteria whereby conformity can be checked. BS7000-3:1994.

Evaluation	Stage where offerings are tested for the feasibility and intended function. Design evaluation - systematic examination of the result of an activity to establish the degree to which the original objectives have been fulfilled (BS7000-3:1994).
Evaluation method of business model	Evaluation of the feasibility of a business model (business model strategically and practically interesting for a company) and on the other hand the “profitability” (financial implications of the business models).
Evaluation method of environmental benefit	Evaluation methods related to the environmental benefits of a PSS.
Evaluation method of product-service	Evaluation methods to assess the benefits of product-service combination.
Documentation	Capturing process to store and share the required information and knowledge evolved PSS design process.
Process property	Distinguishing feature or quality of the processes.
Feedback	Sharing of information between different stages of the process.
Integration of process	Integration is the delivery of coherence across different processes.
Level of confidence	Percentage of belief that the process would satisfy the purpose.
Optimize	Degree to which the processes are effective to satisfy the purposes.
Representation	Richness through which process is displayed.
Transparency	Degree to which the process is visible to stakeholders.
Volatile	Defines the instability of the process.
Support system	Elements which are used to assist in delivering the PSS offerings.
Infrastructure	The basic physical systems of a business - http://dictionary.reference.com/browse/infrastructure
Hard infrastructure	Refers to the large physical networks necessary for the functioning of the system. http://www.opendb.net/element/19099.php
Asset	Anything tangible or intangible that is capable of being owned or controlled to produce value.
Informated product	Informated products have diagnostics and prognostics technologies integrated within them. Neely (2007)
Health monitoring device	A device which records and share the functional properties of the product.
Sensor	A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. http://en.wikipedia.org/wiki/Sensor
Communication support	A communication channel for various flows such as static data flow, dynamic data flow, service content flow, etc according to the agreed protocols. [Yang., X, Moore, P., Chong, S. K., “Intelligent products: From lifecycle data acquisition to enabling product-related services.”, Computers in Industry 60 (2009) 184–194]
Soft infrastructure	Refers to all the actors which are required to maintain the economic, health, cultural and social standards of the system. http://www.opendb.net/element/19099.php Sustainable manufacturing possible due to cultural change of individuals and corporations supported by the enforcement of rules and a proper regulatory framework co-designed between governments, industries and society (http://data.fir.de/projektseiten/ims2020/files/IMS2020_Action-Roadmap_Executive-Summary.pdf , pag.3)
IT Systems	Information Technology Systems in place.
Asset Management System	Data platform for managing the lifecycle data needs of the asset.

Legacy Systems	A legacy system is an old method, technology, computer system, or application program that continues to be used, typically because it still functions for the users' needs, even though newer technology or more efficient methods of performing a task are now available. A legacy system may include procedures or terminology which are no longer relevant in the current context, and may hinder or confuse understanding of the methods or technologies used.
Infomated Systems Architecture	PSS Infomated Systems Architecture is a proposed architecture which is based around an expert system. This will allow data collected from sensors to be computationally analysed, interpreted and then form the basis of a services. These services will inform the provider as to use patterns, performance and proffer design advice as well as giving feedback and advice to the customer. [Based on the proposed architecture of Yang., X, Moore, P., Chong, S. K., "Intelligent products: From lifecycle data acquisition to enabling product-related services.", Computers in Industry 60 (2009) 184–194]
Information requirement	The information needed to support a business or other activity. encyclopedia2.thefreedictionary.com/information+requirements
Standardised data architecture	Accomplished by looking long term and choosing a future point then determining the information that is required rather than trying to integrate existing data.
Privacy concern	Restriction on searching for or revealing facts that are unknown or unknowable to others http://www.businessdictionary.com/definition/privacy.html#ixzz18h7EevwV
Supply Network	Service delivery - supplier activities necessary to provide the service BS 5750-8. All interconnected companies that exist upstream to any one company in the value system. Service Network is mostly used where ever services are supported instead of supply network (Choi and Krause, 2005)
Design (Defining supply network)	Defining the related processes and practices of the supplier side.
Availability of supply	Percentage of times required parts are obtained immediately.
Demand signalling	Sending an ICT request for supplies (can be triggered by the provider or the customer)
Inventory Management	Inventory management, or inventory control, is an attempt to balance inventory needs and requirements with the need to minimize costs resulting from obtaining and holding inventory.
Logistics	The management of the flow of goods information and other resources including energy and people, between the point of origin and the point of consumption in order to meet the requirements of consumers.
Resources	Firm specific tangible or intangible assets those are difficult but not impossible to imitate (Teece, et al., 1997).
Supply Base	A portion of the supply network that is actively managed by the focal company through contracts and purchasing of parts, materials and services(Choi and Krause, 2005)
Supply chain management	supply chain management of servitised products is the management of information, processes, capacity (people, equipment and facilities), products, services and funds from the earliest supplier to the ultimate customer (Ellram et al., 2004).
Vendor management	Process through which suppliers are co-ordinated and structured.
Supply modelling approach	Different types of supply modelling techniques.
SCOR (Supply Chain Operation Reference Model)	SCOR is a management tool, spanning from the supplier's supplier to the customer's customer.
Plan, Source , Make, Delivery, Return	The five distinct management processes in the SCOR model.
CPFR (Collaboration, Planning, Forecasting and Re-plenishment)	CPFR is a business practice wherein trading partners use information technology (IT) and a standard set of business procedures to combine their intelligence in the planning and fulfilment of customer demand. (VICS CPFR Committee (2004). Nine-Step Process Model (http://www.vics.org/topics/cpfr/cpfr).)
Provider Supplier relationship	Specify the kind of connection between the OEM and supplier.

Cultural change	The swift in the behaviours and beliefs characteristic of a supplier.
Holistic mindset	The degree to which the behaviours and beliefs characteristic of a supplier is fixed.
Hard metric	Evaluation criteria to judge supplier's capability.
Initial cost for supplier	Cost incurs to supplier before initiating the business.
Strategic alignment	Swift in supplier's objectives to match with OEM's needs.
Supplier performance measurement	Process through which suppliers are evaluated.
Transparency of organizations	Degree to which the supplier's process is visible to OEM.
Types of supply chain	Different types of supply chain i.e. Production or after sales.
Aftermarket supply chain	Representing linkages between OEM and Suppliers after sales.
Production supply chain	Representing linkages between OEM and Suppliers during manufacturing.
Open network	Rapid formation of open networks in both traditional and emerging sectors will bring significant increases in capability, profitability and productivity for all European businesses. The establishment of environmentally benign product-based service companies will create a net increase in employment (ManuFuture ETP Strategic Research Agenda, 2006, pag.16)
Internal pre-delivery operation	The operations needed for the delivery of products/services internally in an organisation
Supply Network property	Properties of the particular or general network
Capability of supply network	The strength or proficiency of a bundle of interrelated routines for performing specific tasks. (D.X. Peng et al. / Journal of Operations Management 26 (2008) 730–748)
Capability of an individual supplier	Required skills of a supplier to undertake a set of tasks or activities.
Competence	Competences are special (valuable) capabilities which enables the firm to deliver a fundamental customer benefit (Hafeez et al., 2002).
Complex Adaptive Systems	No single firm can purposefully design the supply network from end to end. Part of it is controllable and can be designed and managed, and part of it is out of each individual firm's direct control. It is the joint agency of the firms populating the network that shape its structure over time, the latter bearing CAS properties such as emergence, adaptability and self-organization. Very rarely a 'grand designer' exists, and this can only happen in very specific contexts (Choi and Hong, 2002).
Long-term relationship orientation	Closer relationships form a mutually beneficial environment where buyer and supplier share risks and rewards over the long term (Xu and Beamon, 2006).
Supply chain cohesion	Impetus is to involve the supply chain more in the PSS and make sure the same metrics flow through the whole process. For PSS closer liaison and deeper relationships between suppliers and with the OEM are required (possibly at the expense of other clients suppliers may have)
Trust and Confidence	Building Trust and Confidence between OEM and Supplier is needed to act towards the shared vision.
Financial	Economics concerned with resource allocation as well as resource management, acquisition and investment. http://www.investorwords.com/1940/finance.html
Human resources	Describe the individuals who comprise the workforce of an organization. http://en.wikipedia.org/wiki/Human_resources
Quality	A characteristic property that defines the individualistic nature of suppliers.
Technical	Having special skill or practical knowledge in particular domain area.
Information security	Security of information exchange.
Threat	Threats such as patent rights and confidentiality.
Vulnerability	Vulnerability occurring due to shared confidential information.

Protection method / technique	Various methods for information security.
PSS outcome	Results and expectations of products and services which have been created in a multi-dimensional perspective.
Economic	Economic benefits of PSS e.g. Revenue.
Tangible	Tangible outcomes of PSS
Increased revenue	Increased revenue generated by PSS
Availability	The degree to which a system is functioning. http://en.wikipedia.org/wiki/Availability.
Profit	Total income or cash flow minus expenditures en.wiktionary.org/wiki/profit
Service result	Measure of the achievement of service delivery BS7000-3:1994.
Customer satisfaction	A receiver is satisfied when his/ her state changes to a new, desired state. (Arai, T., Shimomura, Y., 2004 Proposal of Service CAD System—A Tool for Service Engineering, Annals of the CIRP, 53/1: 397–400.) Process which evaluates customer satisfaction through the proposed offering.
PSS Quality	A characteristic property that defines the individualistic nature of offerings. Improved performance.
Reduce cost	Reduction in cost compared to previous solutions
Service quality	A measure of agility, responsiveness of all the customers problems processed.
Disruption index	The critical events that occur to products during customer's use, e.g. Faults.
Bankrupt - loss	The losses and risk of bankruptcy due to changes to the new business model
Intangible	Intangible outcomes of PSS that generally leads to long term benefits.
Improving decision making	Improving the decision making process by involving multiple stakeholders.
Improving customer satisfaction and loyalty	Improving the perceived customer satisfaction and loyalty
Improving the quality of product and service	Improving the perceived quality of product and service
Inventiveness	skill of inventing or creating
Shared responsibility	Shared responsibility between different stakeholders e.g. Alliances, joint ventures, suppliers.
Holistic perspective	To look at sustainability from a more holistic perspective by including multiple issues related to sustainability, but including the more specific project-related business decision-making aspects that employees from the factory floor to top management will need to address in daily work. Metrics and tools to measure sustainable impact (NACFAM, 2010)

Value	"Value for customers means that after they have been assisted by a self-service process (cooking a meal or withdrawing cash from an ATM) or a full-service process (eating out at a restaurant or withdrawing cash over the counter in a bank) they are or feel better off than before." Gronroos, C., "Service logic revisited: who creates value? And who co-creates?", European Business Review , Vol. 20 No. 4, 2008 pp. 298-314 ___________________________ "Sometimes the value that has been created can be measured in financial terms, for example through effects on revenues or wealth gained or through cost saving, but value always has an attitudinal component, such as trust, affection, comfort and easiness of use." Gronroos, C., "Service logic revisited: who creates value? And who co-creates?", European Business Review , Vol. 20 No. 4, 2008 pp. 298-314 -- The market increasingly demands products that are customised, yet available with short delivery times. Consequently, the business focus must shift from designing and selling physical products, to supplying a system of products and services ('product/services' or 'extended products') that are jointly capable of fulfilling users' demands, while also reducing total life-cycle costs and environmental impacts (ManuFuture ETP Strategic Research Agenda, 2006, pag.9)
Value co-production	"A PSS is a social construction, based on ''attraction forces'' (such as goals, expected results and problem-solving criteria) which catalyse the participation of several partners. A PSS is the result of a value co-production process within such a partnership. Its effectiveness is based on a shared vision of possible and desirable scenarios." Morelli, N. (2006), "Developing new product service systems (PSS): methodologies and operational tools", Journal of Cleaner Production, Vol. 14 No. 17, pp. 1495-501.
Value-in-use	"However, the value for the supplier of the customer's value foundation is dependent on the value the resources have for customers (value-in-use). As Alderson (1957) already noted 50 years ago, the value created when products are used is more important both for the customer and for the firm than the value that is exchanged between them. Applying the terms value-in-use and value-in-exchange, the former is more important than the latter. If customers cannot make use of a good, Service logic revisited value-in-exchange is nil for them. Since they have paid good money for nothing, it is actually negative. Only during consumption, realised value in the form of value-in-use is created." Gronroos, C., "Service logic revisited: who creates value? And who co-creates?", European Business Review , Vol. 20 No. 4, 2008 pp. 298-314 ____ "…a customer's outcome(objective) that is served directly through the product/service consumption." Vargo, Stephen L. and Robert F. Lusch (2004), "Evolving to a new dominant logic for marketing." Journal of Marketing, 68 (January),1-17.
Value proposition	The benefits delivered through products and/or services by the vendor to the customer in return for the customer's associated payment. (Van Ostaeyen and Duflou, 2010)

Durable value	Re-orient the current production and consumption mechanism into a more sustainable direction across the sustainability dimensions: economic benefit, environmental impact and social welfare. NIST Workshop, 2009 Rapid and adaptive user-centred manufacturing which leads to customized and “eternal” life cycle solutions (http://data.fir.de/projektseiten/ims2020/files/IMS2020_Action-Roadmap_Executive-Summary.pdf , pag.3)
Risk Reduction	The reduction of risk concerns the reduction of the deviation of one or more results of one or more future events from their expected value. http://en.wikipedia.org/wiki/Risk
Environment	The effects of PSS on environment.
Environmental impact	Any change or disturbance to the environment.
Material	The amount of raw material consumed and waste created at the end of life of physical objects give an idea about the impact on the (tangible) resources
Energy	Different kinds of energy can be identified, for example electricity, water, fossil fuel, solar and wind.
Emission	Outputs towards air, water or soil.
Impact location	Geographical situation of the impact.
Recycling / recovery rates	Rates of recycling and energy recovery that can be expected at the end-of-life of a product or service.
Sustainability	Environmental sustainability e.g. Less use of materials and energy
Recycled material	Use of recycled materials
Social	Social outcomes of PSS
Hot spot	Social hotspots are unit processes located in a region where a situation occurs that may be considered a problem, a risk or an opportunity, in relation to a social theme of interest. The social theme of interest represents issues that are considered to be threatening social well-being or that may contribute to its further development. Guidelines for Social Life Cycle Assessment of Products - UNEP/SETAC Life Cycle Initiative
Social impact	Social themes of interest include but are not restricted to: human rights, work conditions, cultural heritage, poverty, disease, political conflict, indigenous rights, etc. Guidelines for Social Life Cycle Assessment of Products - UNEP/SETAC Life Cycle Initiative

Appendix – III

Text based Relationship Statements

Relationship statements are identified from experts' interviews discussing about current practices and challenges in PSS. Following relationship statements are converted based on the PSS Ontology concepts.

- 'Shared business vision' between 'customer', 'provider' and 'supplier' is crucial in PSS.
- 'Provider' has to differentiate between various 'business models' based on 'requirements' and 'outcomes'.
- 'Provider' needs new 'infrastructure' to 'support' emerging 'business models'.
- PSS 'business models' differ based on type of 'product' and 'volume of demand'.
- All 'components' in the 'product' are not 'serviceable'.
- PSS 'business models' could be different if 'products' don't have crossover ('flexibility').
- 'Market opportunity' and performance issues ('performance indicator') drive changes required for 'PSS business models'.
- Integrated 'services' require adequate 'support' and managed 'business strategy'.
- PSS 'Cost' has been majorly driven by 'availability' of 'product'.
- Designing 'business model' such as 'pooling' depends on matching 'customer expectation'.
- The team consists of 'product design', 'sales', 'service' and 'financial and commercial' drives the design of PSS 'business models'.
- 'Requirements' for 'products' due to 'PSS' seem to be similar but in the different context.
- Target 'requirements' have been set to reduce unit 'cost' of PSS 'business model'.
- 'Total care' of 'business models' should consider 'total life cycle' of 'product'.
- To secure 'renewal contracts', the 'receiver' wants at lower 'cost', higher 'reliability' of 'product' and more 'service' 'responsiveness'.
- Design of 'products' and 'services' should start very early ('conceptual') in 'design' with the 'business model'.

- ‘Provider’ tries to consolidate various skills to define the ‘capabilities’ which help to find commonalities and common elements between various teams (‘employee’) required for PSS.
- The variation in the ‘capabilities’ could be due to ‘product’, ‘location’, ‘customer’ etc.
- ‘Service life cycle’ includes ‘demand identification’, ‘feasibility analysis’, ‘concept development’ etc.
- ‘Provider’ lacks sufficient ‘infrastructure’ to deliver required ‘services’.
- In many cases, ‘repair’ service seems to ‘cost’ more compared to replacement of ‘component’.
- Much commonality exists between various ‘service types’ within ‘provider’ to deliver ‘services’.
- ‘Risk’ involved in the ‘business model’ hinder ‘outcomes’ of ‘PSS’.
- Currently ‘services’ are add-on to the ‘product’.
- ‘Provider’ working with ‘receiver’ gives more ‘visibility’ to their ‘products’.
- ‘Business elements’ varies for different ‘provider’ involved in the PSS.
- ‘PSS business models’ started by ‘joint venture’ between ‘provider’ and ‘receiver’.
- ‘Services’ primarily provided to build ‘trust’ and ‘relationship’ rather than to generate ‘profit’. But they aid to increase ‘volume of demand’ and bring additional ‘services’ to deliver.
- ‘Receiver’ should be locked in for long life ‘relationship’ to achieve intended ‘outcomes’.
- ‘Provider’s agility’ plays vital role to survive in these ‘business models’.
- ‘Business models’ are not driven from the ‘capabilities’ of ‘provider’.
- The ‘cost’ of ‘business models’ is fixed based upon volume of spends rather than to the ‘profits’.
- ‘Receiver’ could provide additional ‘services’ to ‘provider’ based on ‘profit’.
- Currently ‘provider’ is mixing regular business with PSS ‘business model’ to get ‘profits’ till it gets mature.
- ‘Incentive’ for ‘improved performance’ is currently missing.
- It is important for ‘provider’ to get engaged contractually with the ‘supply network’ from the start on certain level of ‘reliability’ and ‘cost’ of ‘services’.

- ‘Receiver’ expects ‘provider’ to help run their ‘products’ for best ‘efficiency’. This will increase levels of ‘reliability’ and refine ‘business models’.
- Smaller ‘receiver’ may be more amenable to ‘pooling’ of ‘products’ because of reduced ‘costs’.
- ‘Total Care’ (fixed ‘cost’ and high ‘availability’) trying to achieve: reduce total ‘cost’ and improve ‘performance’ to ‘receiver’.
- ‘Total Care’ is paid for ‘reserves’ also – all the ‘risk’ is taken by ‘provider’.
- ‘Provider’ hard on to decrease ‘supply costs’ and refusing ‘price’ increases to ‘supplier’.
- ‘Health monitoring’ and ‘maintenance’ schedule appear not to be a competitive advantage as competitors also do this.
- Decisions between teams (‘employee’) should be made clear to support PSS ‘business models’.
- Main strategy in ‘service’ seems to do ‘maintenance’ in the same ‘location’ of ‘product’ usage rather than moving it.
- The place to do ‘services’ is commonly ‘located’ near to the ‘receiver’ base.
- Currently failed ‘products’ are moved to ‘supplier’s’ ‘location’ to carry out ‘services’ incurring huge ‘loss’ in ‘logistics’.
- ‘Provider’ has clearly articulated defined ‘service’ delivery ‘locations’.
- ‘Provider’ and ‘supplier’ to work closely together to improve ‘service’ and it drive ‘costs’ out.
- There is an issue of ‘leadership’ in shared ‘relationships’.
- Multiple ‘suppliers’ providing different data systems (‘IT systems’) for different facets and management of a ‘product’ through its ‘lifecycle’.
- ‘Provider’ is not aggregating demand correctly, not sending a ‘demand signal’ to the ‘supply network’ correctly. This is often because the configuration of ’requirement’ of the product is changed all of the time by ‘provider’.
- There is some ‘Infomated Product in Use Data’ feedback used to help with indicating ‘maintenance’ costs, ‘component’ ‘redesign’ and ‘cost reduction’
- Difficult to ‘redesign’ ‘components’ as the ‘provider‘ does not capture ‘performance’ history.
- ‘Provider’ has intellectual ‘capability’ to interpret the ‘infomated product in use data’.

- ‘Cost’ data for ‘Total Care’ ‘business model’ could become increasingly ‘transparent’.
- ‘Provider’ and ‘customer’ could increasingly do ‘cost management’ modelling together.
- To ‘standardise the data architecture’ is difficult because at the moment every individual (‘employee’) will come out with a different view and they can’t be reconciled.
- New ‘support system’ is required which should integrate ‘IVHM’ and knowledge about ‘product’.
- ‘IVHM’ could help predict when ‘product’ needs ‘maintenance’.
- Could use ‘Infomated Product in Use Data’ to predict how long (‘longevity’) a ‘product’ could be in ‘service’ for.
- ‘Total Care’ is easier to sell to ‘receiver’ who has limited knowledge of the ‘product’.
- Data received through ‘Infomated Product in Use Data’ are used to calculate the ‘cost’ the ‘receiver’ will pay for ‘maintenance’.
- Extension of ‘service’ portfolio by ‘provider’ is a primary offering in PSS.
- ‘Total Care’ does not normally cover until the ‘end of life’ of the ‘product’.
- ‘Component Care’ can be offered with ‘Total Care’ or as a standalone package.
- ‘Receiver’ wants ‘customised’ ‘service’ packages.
- ‘Receiver’ expects a better level of ‘service’ with ‘PSS’ type ‘business model’.
- In ‘PSS’, overall ‘value’ delivered is more important compared to ‘cost’ per ‘component’.
- ‘Receiver’ prefers a new ‘component’ rather than ‘overhauled’ – see it as possibly having more ‘reliability’.
- The ‘provider’ is trying to develop predictive models to assess ‘customer’s expectations’.
- Because of ‘Total Care’, design of ‘product’ now endeavours to make them more ‘maintainable’.
- The ‘transparency’ between the ‘stakeholders’ is emerging in PSS.
- Due to ‘PSS’, ‘relationships’ have changed considerably internally and externally of the ‘suppliers’.
- ‘PSS’ leads to healthily ‘relationships’ between ‘supply network’ and ‘provider’.

- 'Employees' developing 'relationships' with the 'supply network' and 'receiver' are more vital to 'PSS' than 'technological systems'.
- Because of 'PSS', 'business models' and 'incentives' are more aligned across the 'stakeholders'.
- The 'revenue' generated due to 'PSS' is huge.
- 'Revenue' generation, 'profits' and increase in sale of 'products' forces organization towards 'PSS'.
- 'Receiver' is seeing better 'services' through 'PSS'.
- 'IVHM' has improved relationships with between 'receiver' and 'provider'.
- The 'provider' has a more 'visible' statement of intent towards 'services' due to 'PSS'.
- The 'provider' has more 'responsive' 'agile' 'service' centred behaviour due to 'PSS'.
- 'Trust' and 'confidence' in 'supply network' results in great 'inventory' and 'cost reduction' on the 'provider' side.
- A 'holistic' approach is needed from 'provider' and its entire 'suppliers' for the provision and support of 'PSS'.
- Challenges to initiate 'PSS' between 'provider' and 'suppliers' are to align the 'business models' and drive the right 'behaviours'.
- It is believed that there are different 'types of supply chain' for 'production' and 'aftermarket'.
- 'Supply network' should also transform itself to PSS 'mindset' avoiding the traditional 'business model' mindset.
- 'Strategic alignment' with 'suppliers' is crucial in 'PSS' offering for satisfying 'Requirements'.
- 'Agility' is an important characteristic of 'supply network'.
- 'PSS' could 'cost' higher initially to 'supplier'.
- 'Redesign' causes massive issues in terms of 'supply chain' and 'demand signalling'.
- 'Servicing' of 'product' can be hindered by the 'supply network'.
- 'Suppliers' finding difficult to lead 'PSS' with their 'suppliers' due to their small sized organizations and high 'risks' involved.

- Joined initiatives to share ‘resources’ between ‘suppliers’ and ‘provider’ to support services is required.
- ‘Inventory’ seems to be a ‘critical’ issue in ‘supply network’.
- ‘Risk’ sharing for ‘cost’ is a major driver for ‘provider’ towards ‘PSS’
- ‘PSS’ ‘business model’ would lead to added ‘value’ and increased control over raw ‘material’ and ‘energy’.
- ‘Maintenance’ for PSS should be designed at the ‘conceptual’ stage.
- Not only ‘manufacturing cost’ but also ‘whole life cycle cost’ should be calculated for ‘PSS business model’
- ‘PSS’ processes impose major change on ‘designers’ ‘behaviour’.
- There is a ‘trust’ issue between ‘provider’ and ‘supplier’ that makes ‘relationship’ very poor.
- More ‘resources’ for ‘PSS’ could be justified if ‘stakeholders’ understand its ‘outcomes’.
- ‘Quality’, ‘agility’ and ‘responsiveness’ are the major factors viewed as important from ‘receiver’ perspective.
- The ‘outcomes’ of ‘PSS’ should be ‘aligned’ throughout the ‘provider’ and its ‘supply chain’ according to ‘business model’.
- ‘Provider’ must consider the whole ‘lifecycle’ for ‘PSS design’.
- ‘Cultural change’ is the major challenge in the ‘PSS’.