Healthcare product-service system characterisation - implications for design

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Abstract

The engineering design process transforms stakeholders' needs and desires into design specifications. In this process, manufacturers make decisions that impact how much value can be generated from a new product/service. Clear design specification can enhance the value of a product/service. This research study focuses on the engineering design process for systems of products and services - product-service systems (PSSs).

An unambiguous PSS classification could help manufacturers to produce clearer design specifications, however there is a lack of clear PSS classifications for engineering design. Existing classifications rely on an out-dated distinction between tangible objects as products, and everything else as a service, a division that inappropriately classifies digital products as services. To develop a coherent PSS classification, it is necessary to understand which characteristics of PSS can clarify its design specification.

This research addresses this problem by determining the PSS characteristics that are useful for clarifying the design specification. The research aims to develop a PSS characterisation scheme and explore how the scheme influences design specifications. To achieve these aims, case study and action research methods are employed.

This study has developed a PSS characterisation scheme that clarifies design specifications and a method to systematically apply this scheme, the PSS characterisation approach. This approach proves useful for practitioners to clarify design specifications, and has extended the application of the theory of technical systems to instruments supporting the engineering design process. The PSS characterisation scheme comprises four characteristics: customer perceived value level, 'connectivity number', type and degree of connectivity and configuration type. The scheme does not use the 'tangibility' distinction, but incorporates concepts of value creation and interdependencies within a PSS and between a PSS and its environment. This novel characterisation scheme contributes to the development of a PSS classification scheme for engineering design and also to the literature of PSS classifications.

Dedication

To my mother, who showed me the true meaning of perseverance.

To the memory of my father, who believed in me.

Acknowledgement

I remember the day when I became very enthusiastic about an idea that might be suitable to investigate as a PhD project. From that moment onwards I embarked on my PhD journey, during which I am extremely lucky to have had many people to guide and support me.

My husband, Marc Sanson, encouraged me to pursue my PhD and has supported me in every possible way. He often jokes about being a PhD widower, which is not too far from the truth. Marc, thank you for your understanding and for keeping our lives going.

I thank my parents for their love and teaching. They have always asked me to embrace difficulties in life, to be humble and sincere, and most importantly, to put my heart and soul in everything I do. These wise words have served me very well. Parkinson's disease took my Dad from us in 2014. His health deteriorated rapidly during the course of my PhD. Mum, being Dad's full-time carer, bore the full physical and emotional load of Dad's condition. The so-called hardship of doing a part-time PhD while having a full-time job is nothing compared to what my parents were going through. I owe my peace of mind to my elder sister Lilian, who spent as much time as she could with Mum and Dad while I was 6000 miles away.

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I also want to thank the following individuals who have introduced me to the various bodies of knowledge that have inspired me. For introducing me to service research: Andy Neely, Irene Ng, Ivanka Visnjic and Veronica Martinez, whom I have met through the Cambridge Service Alliance. For introducing me to service design and medical device design: Krista Keränen and Jon Johnson. For introducing me to actor-network theory: Alexander Orona. For broadening my knowledge of healthcare regulations: Alan Davies.

The thesis writing process went relatively smoothly for me, and that is down to the support of these individuals: Alex for sharing with me a best practice thesis writing approach; Dimitra K. for the spirited discussion; Moyra, Daniela and Judith for being my writing companions; my cat Tio for keeping me warm in the early morning hours before the central heating came on; my fellow commuters on the Abellio Greater Anglia Cambridge/London services and the Chiltern Railway Marylebone/Amersham services, who kept my mobile office a relatively quiet place for writing; and finally, I thank Moyra Lawrence and Mark Elmslie for their time and effort proof-reading my thesis.

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Preface

Except for commonly understood or accepted ideas, or where specific reference is made, the work reported in this thesis is my own and does not include the outcome of any work done in collaboration. No part of the dissertation has been previously submitted to any university for any degree, diploma or other qualification.

This dissertation complies with the Department of Engineering Degree Committee word limit requirement (64987 of a maximum of 65000 words) and the limit on the number of figures (90 figures and 32 tables of a maximum of 150 figures).

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Table of contents

List of figures

List of tables

1 Introduction

Most would agree that design requires creativity. However, to transform a new design into a useful or enjoyable experience takes much more than a "eureka moment". Further, design is context dependent. Design in an engineering context can be seen as a process that involves systematic thinking, understanding customers' needs, generating and evaluating concepts that intend to achieve these needs, while being subject to a set of constraints (Dym, Agogino, & Eris, 2005). In many cases, companies find it difficult to make sense of what customers want, but often they have to march on in their development process in order to beat competitors to introduce new products and services to market.

Image removed for copyright reasons

Figure 1-1 The difficulty of having a clear and complete design specification (adapted from S. Adams, 2009)

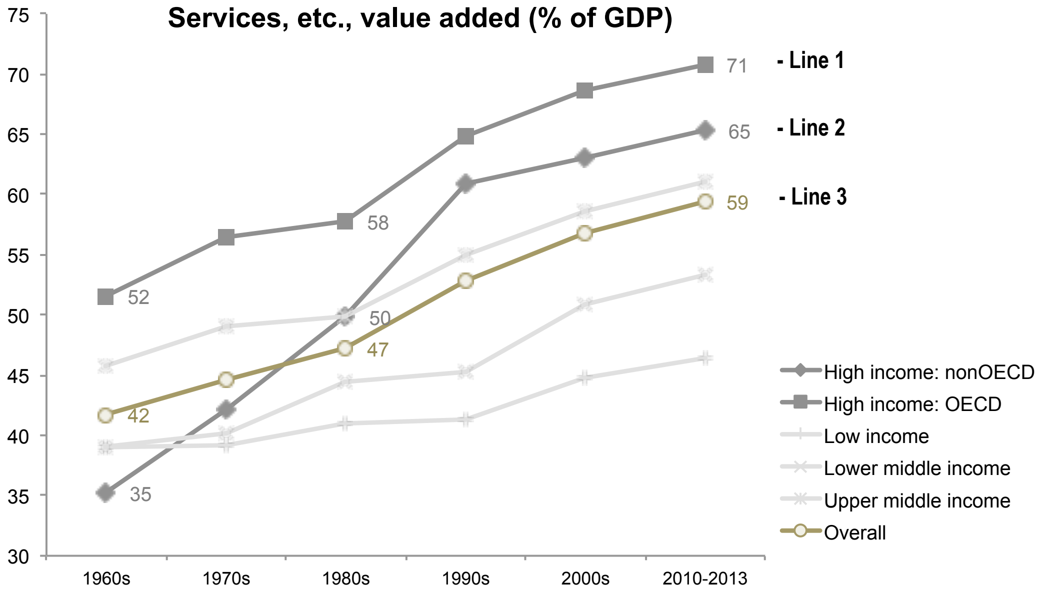
There are many phenomena worth investigation within the context of engineering design. Not unlike the process of evaluating a new development idea, selecting a phenomenon that is important, timely and relevant to society and appropriate to research within the time and resource constraints of a PhD, requires some preliminary assessment efforts. In the following sections, the relevance of service, engineering design process and healthcare to society is first explained. The focus of this research study is then introduced. The chapter concludes with the layout of this thesis.

1.1 Relevance of service, engineering design and healthcare to society

1.1.1 Service and product-service system

Product makers have long been providing services to society. For centuries, tailors have been taking measurements from customers and recommending suitable styles and fabric. Job-shop manufacturers have been providing different types of services to their customers, especially product-related services. However, it is observed that during the past 25 years, there has been a growing interest in the phenomenon of manufacturers providing services in addition to their product portfolio. This phenomenon has been labelled "servitisation", a term coined by Vandermerwe and Rada in 1988. Perhaps, there was a period that manufacturers have focused mostly on developing products that are packed with functionalities that could meet mass customer demand. Looking back in history, the advancement in technology brought about the industrial revolution in the 19th century, which has enabled manufacturers to mass-produce products, with the same design specification, and satisfy customers *en masse*. The manufacturers' mind-set at that time could be exemplified by the widely reported comment on Ford's Model T car: customers could have their cars painted in any colour as long as it's black. After all, who would have preferred the alternative: a horse-drawn carriage? Arguably, manufacturers' main contribution to society has been firmly established as the providers of new products since the early 20th century.

One century later, in the early 21st century, the importance of service to society has been advocated. Service's economic importance is generally supported by measurement such as percentage contribution to a nation's gross domestic product (GDP). For example, according to the World Bank Group's world development indicators, service is currently contributing over 70 percent of the gross domestic product (GDP) of the high-income Organisation for Economic Cooperation and Development (OECD) countries (Line 1 in Figure 1-2). Over the last 50 years, the service proportion in GDP has increased by 20 percentage-points, with the biggest increment being seen among high-income non-OECD countries (Line 2 in Figure 1-2). Overall, the importance of service as a contributor to a nation's GDP has increased faster between the 1980s and 2010s than between the 1960s and 1980s (Line 3 in Figure 1-2).



Extracted from "source note" of the data:
Services correspond to International Standard Industrial Classification (ISIC) divisions 50-99, include value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services.
Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources.

Figure 1-2 Service as a percentage of GDP (World Bank Group, 2014)

Although some may argue that the economic growth of service industries may be different under other methods for calculating manufacturing and service output, economic data such as the one shown in Figure 1-2 is an effective way to call for attention to investigate 'service'.

In academia, scholars in different disciplines, including, marketing, management, engineering design and service innovation (e.g., Browning, 2001; Grönroos, 2008; Spohrer & Maglio, 2008; e.g., Vargo & Lusch, 2004a), have recognised the growing economic importance of service to society. Service logic has been proposed in the early 2000s (Grönroos, 2008; Vargo & Lusch, 2004a) and has sparked debates on companies' value propositions and business models for companies to "co-create" values with their internal and external stakeholders. More recently, "service science" has been proposed as an emerging multidisciplinary field to provide a solid foundation for the understanding of complex service systems (Cambridge University IfM & IBM, 2008). New perspectives to study service, other than the traditional economists' classification of 'service' being anything non-manufacturing, have been promoted. Given that the trend of service importance is unlikely to be reversed, the study of service continues to be relevant and important.

In literature, 'service' has been recognised to be a **system** of products and services. **Service** is said to almost always imply the presence of products, as products are usually involved in aiding service preparation and delivery (Levitt, 1972; Wind & Mahajan, 1997). However, the term **product** is sometimes used as a generic term for both product and service. This can be seen from the usage of the term "service product" (Johne & Storey, 1998). **Product-service system** (PSS) has been proposed to represent a combination of products and services that jointly fulfil customers' needs (Goedkoop, van Halen, te Riele, & Rommens, 1999). This research has favoured the term PSS, because the main interest is the development of systems of products and services from the manufacturers' perspective. Extended from this definition, a PSS in this research can be comprised entirely of products, entirely of services or a mixture of both, and it includes the infrastructure that supports the operations of products and services.

1.1.2 Engineering design process

Research has shown a strong correlation between a company's profitability and its ability to introduce new products and services that customers value (Tidd, Bessant, & Pavitt, 2005). The new product development (NPD) or new service development (NSD) process is the process of transforming a company's business opportunities into products and services to be used by customers (Trott, 2005). Value is created when customers use the products or benefit from the services (Ballantyne & Varey, 2007). It means that the more capable a company is in this process of introducing new products and services that customers want to use, the more value will be created.

The NPD/NSD process generally starts with steps for idea generation and market and technical assessment, which are followed by concept and detail design, development and testing, and ends with market launch (R. Cooper, 1988). The activities before development can be called the engineering design process (Pahl, Beitz, Feldhusen, & Grote, 2007), which is the portion of the new development process that is examined in this research. The desirable output of the engineering design process is a clear design specification for development to proceed.

The engineering design process is interesting and important to investigate from both industry and academic perspectives. Resource commitment increases with time through the new development process (Tidd et al., 2005; Trott, 2005), and decisions made in this process have a significant impact on the quality and cost of the new offering (Handfield, Ragatz, Petersen, & Monczka, 1999). Design for manufacture and assembly (DFM and DFA) are techniques proposed and adopted by industry to minimise the need to redesign later when the design is evaluated to be ready for production, and also to lower manufacturing cost (Warwick Manufacturing Group, 2007). In academia, prior to Simon's proposal to view design as the process to transform natural resources into artefacts that can be products or services (Simon, 1969), design was mostly perceived as merely an analytical activity (Maier & Fadel, 2008). Since the 1990s, engineering design has been rigorously incorporated in the engineering curriculum, with real projects sponsored by industry (Dym et al., 2005).

However, there remains a gap between a recognition of the importance of service and the engineering design process, and the PSS engineering design process models adopted by "servitised" manufacturers. It has been reported that manufacturers usually rely on product-focused new development processes that do not meet the requirements for developing new PSSs (Kowalkowski & Kindström, 2009).

With the growing importance of service to a country's economy, and the significance of manufacturers' capability to introduce new PSSs in meeting customers' wants, studies of the engineering design process for PSS are much needed. In particular, studies that help manufacturers to transform ideas to clear design specifications effectively in the engineering design process.

1.1.3 Healthcare industry

A relatively complex industry is desirable for exploring the engineering design process for PSS. This is because a complex industry is more likely to provide a rich context for the main objective of this thesis: to identify the PSS characteristics that are useful for engineering design. Moreover, a complex industry is expected to enhance the robustness of the identified characterisation scheme, which may then have a higher potential to transfer to other equally or less complex industries.

One may argue that there are many other industries that are as complex as healthcare. However, there are good reasons for basing this research in the healthcare industry. First, the aging population is an unprecedented, enduring, and pervasive "global phenomenon", affecting economic, social, and political aspects of life (Population Division DESA United Nations, 2002). On the one hand, there is a growing demand for new medical technologies from healthcare service providers. On the other hand, governments are reducing their spending in health ("The outlook for medical devices in western Europe," 2012).

Second, healthcare is a fast-changing industry. There have been studies and debates about preventive care as a potential remedy for reduced spending in health, and how this can be implemented at a national level through policy and technology (e.g. Australian National Preventive Health Agency, 2013; Economist Intelligence Unit, 2012; Jochelson, 2007). A trend toward more personalised treatment and drug therapy in the healthcare service delivery process has also been observed in the industry (Miller, 2013; Mittermeyer, Njuguna, & Alcock, 2010); drawing the attention of both policy makers and pharmaceutical companies.

Third, there are multiple governing regulatory bodies, quality standards and guidance-providing organisations that impact the design and delivery of products and services in the healthcare industry. For example, in the United Kingdom (UK), the Medicines and Healthcare Products Regulatory Agency (MHRA) regulates a wide range of products, from pharmaceutical and biological medicines, to medical devices used in the prevention, diagnosis, treatment and monitoring of illness and disability (MHRA, 2008). All companies producing new products regulated by MHRA need to obtain a 'marketing authorisation' before releasing their products to market (MHRA, 2003). A Non Departmental Public Body, the National Institute for Health and Care Excellence (NICE), provides evidence-based guidance and advice for England, and issue quality standards and performance indicators (NICE, 2014a). For example, the Quality and Outcomes Framework (QOF) provides incentives for general practitioner (GP) practices in the UK to deliver better patient care (NICE, 2014b). There are also other incentive schemes for healthcare service quality improvement in the UK, such as the Commissioning for Quality and Innovation (CQUIN) schemes, regulated by the National Health Service (NHS) Institution for Innovation and Improvement (NHS Institute for Innovation and Improvement, 2013a). Quality and service improvement tools are also available online from the NHS Institute for Innovation and Improvement (NHS Institute for Innovation and Improvement, 2013b).

Fourth, at an individual level, everyone has experience as a user of healthcare products and services, and therefore is impacted physically, emotionally and financially by healthcare PSSs. There are also personal reasons why healthcare is chosen as the industry to investigate within. The researcher had been working in the service operations function of a healthcare manufacturer and service provider for five years before commencing her PhD research, and continued to work with this employer during her study. As a result, she has some insights into the current issues faced by servitised manufacturers in the healthcare industry. Her personal interests in preventative healthcare through general fitness maintenance, and access of elderly people to professional and auxiliary care are also reasons why healthcare is selected over other industries.

In conclusion, healthcare is a fast changing industry that has many stakeholders, especially government and standards bodies. Healthcare affects everyone in society directly in terms of accessibility to affordable health and care. The healthcare industry presents a rich and complex environment for the investigation of the PSS engineering design process; thus the results of this research may arguably be more transferrable to other industries.

1.2 Research objectives and layout of the thesis

The underlying process for investigation in this research is the engineering design process for healthcare PSS. A clear PSS design specification is difficult to achieve, but it is important for developing a new PSS that customers would use and which would create value for both customers and manufacturers. Identifying PSS characteristics that are useful, especially in clarifying PSS design specifications, is an essential step toward developing a PSS classification scheme for engineering design.

To pursue this aim of having a clearer PSS design specification, a research programme was designed, as shown in Figure 1-3. The details of the research design will be presented in chapter 3.

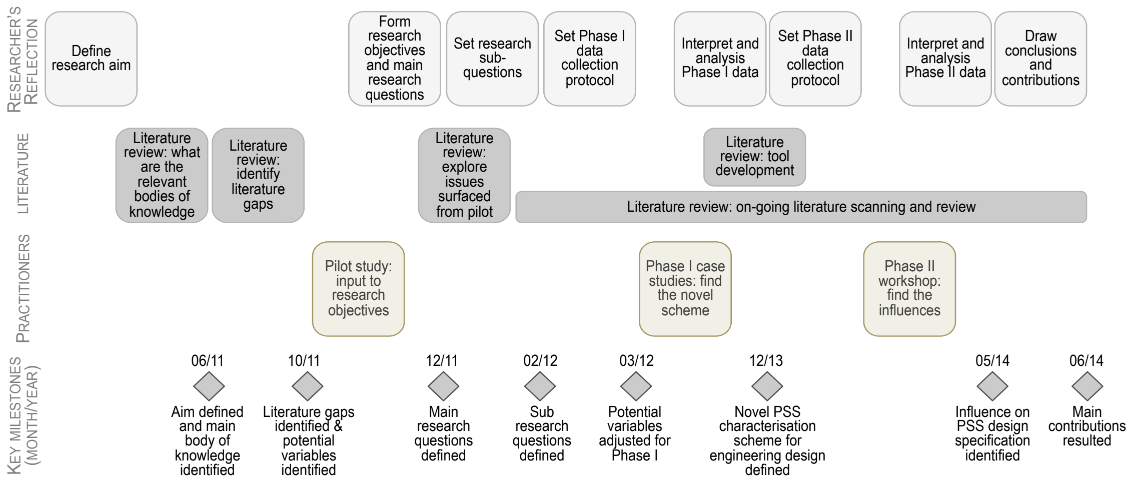


Figure 1-3 The research programme – activities and key milestones

The research activities in Figure 1-3 are arranged along three 'swim lanes' representing the main source of knowledge: researcher's reflection, literature or practitioners. The key milestones are provided in the bottom of the diagram.

The research objectives are to devise a novel method of PSS characterisation that is useful for manufacturers in their engineering design process, and to explore the influence of the scheme on PSS design specifications. To ensure a broad application context for this research, the following definitions are used for 'manufacturer' and 'healthcare' industry:

- 'Manufacturers' refers to both manufacturing companies and service providers.
- 'Healthcare' industry includes healthcare equipment, device, software, healthcare professional services, physical fitness services and mental fitness services.

As a clear design specification is crucial for manufacturers and customers to create value, this research adopts a broad scope for PSS design specification. A PSS design specification in this research includes consideration of:

- Product and service features
- Stakeholder involvement
- Conditions of the relevant environmental factors

Following the research programme depicted in Figure 1-3, this thesis is divided into seven chapters (see Figure 1-4). After a review of relevant literature, the research design will be presented. This is then followed by the findings from the pilot study. This research has two main phases, and therefore there are two chapters, 5 and 6, presenting the findings and discussions of each phase. The thesis concludes with an overall discussion, including research limitations and future directions.

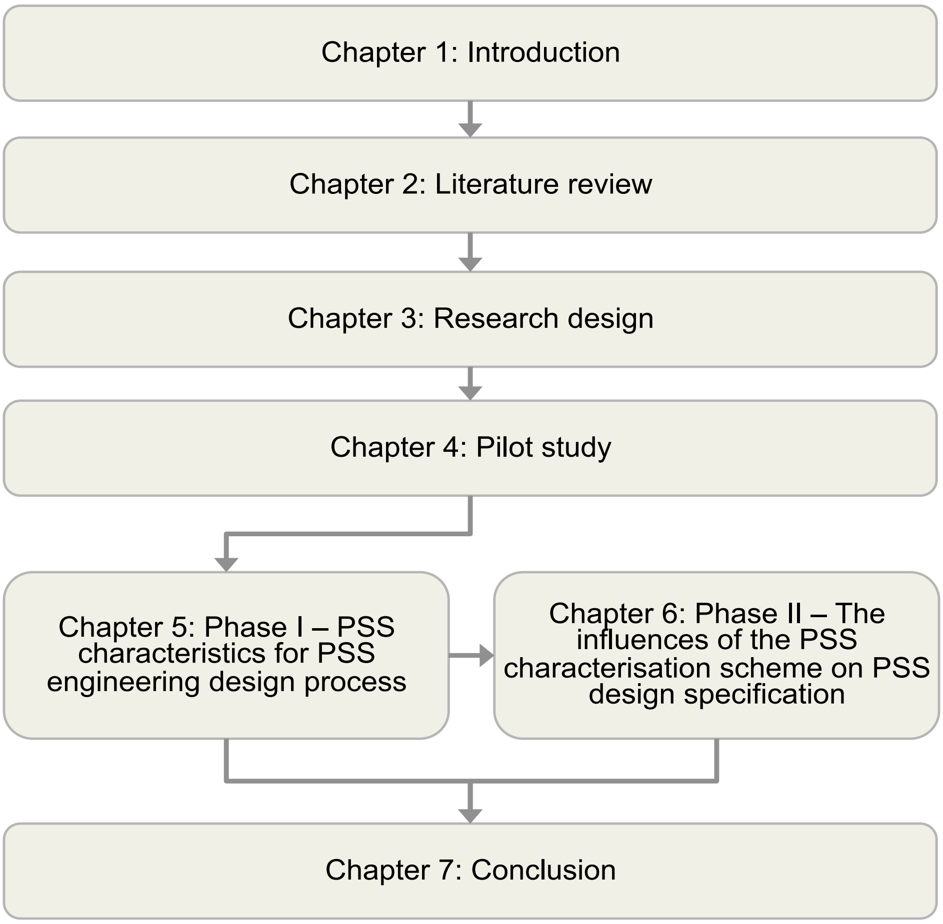


Figure 1-4 Thesis layout

2 Literature Review

2.1 Chapter introduction

The topic of interest in this research, the product-service system (PSS) engineering design process, touches multiple disciplines and many bodies of knowledge. The bodies of knowledge considered in this research are shown in Figure 2-1, with those that are most relevant to the research objectives depicted in the primary ring, and those that are less relevant but have informed the research in the secondary ring. The bodies of knowledge that have been considered but not pursued are in the tertiary ring.

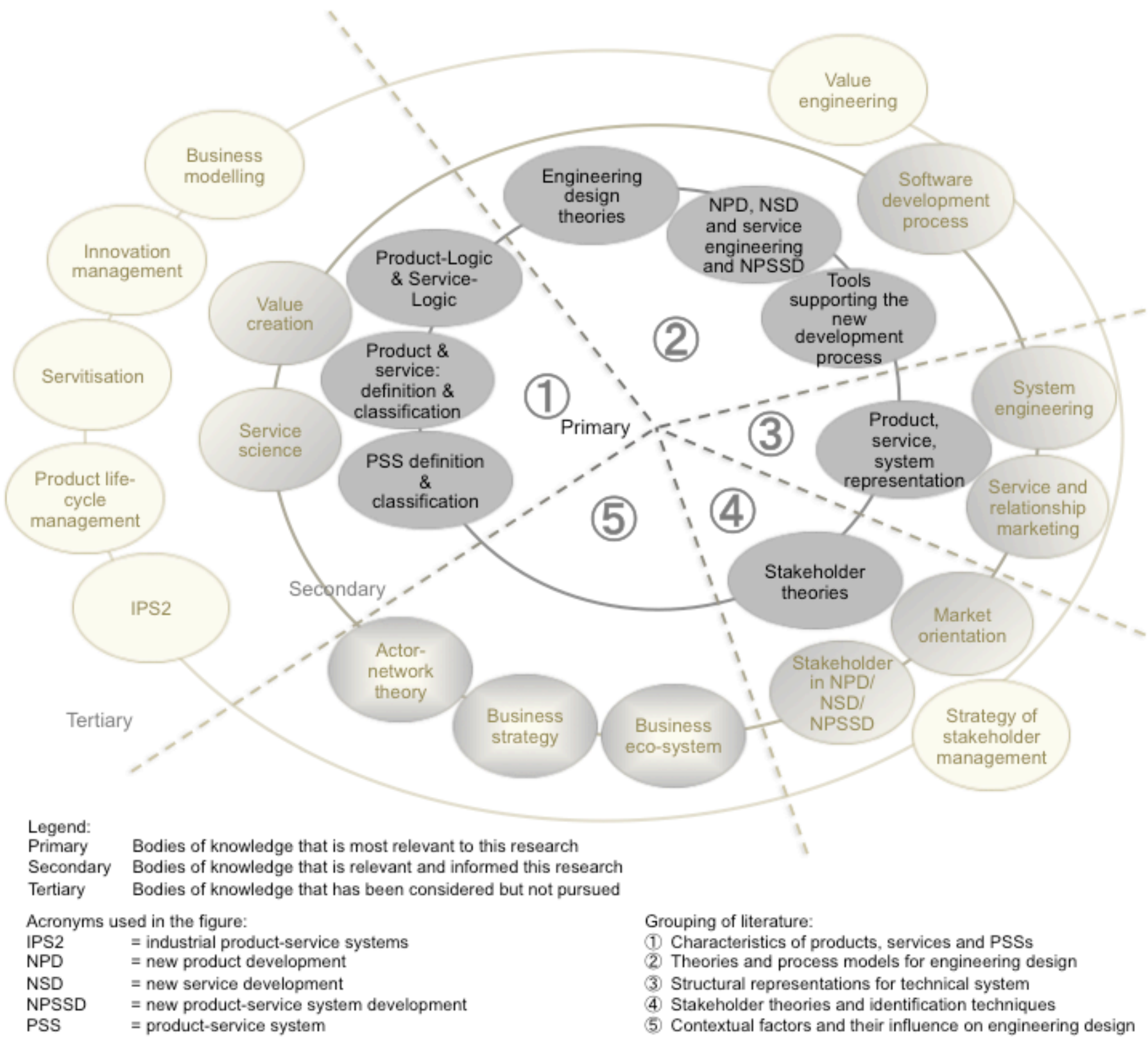


Figure 2-1 Bodies of knowledge relevant to this research

Another way to organise the relevant literature is to compartmentalise it into the disciplines of engineering, management and sociology. Within the discipline of engineering, the know-how of designing a new product, service or system is especially relevant. The process of engineering design involves coordinating individuals to work together, in order to create something new for use in society. Therefore, the management of the design process, including the understanding of the parties who are interested in or will be impacted by the new PSS, and the marketing concerns of the new PSS are the most relevant topics within the discipline of management for this research. The design, operations and use of any new PSSs are all happening within society. Human and non-human actors such as computer systems interact with each other during these processes. Environmental factors such as the infrastructure of a healthcare system where the PSS is being produced and utilised, interact with other environmental factors and the actors connected to the PSS. Therefore, within the discipline of sociology, the literature of particular interest for this research is sociotechnical studies, in particular the actor-network theory.

In this chapter, only the most relevant literature is reviewed, which is organised into five sections (see Figure 2-1): the characteristics of the product, service and PSS, the theories and process models for engineering design, the structural representations for technical systems, the stakeholder theories and identification techniques for engineering design, and the contextual factors and their influence on engineering design. The main theories, concepts and frameworks are first reviewed in each section. Their relevance to this research is then discussed, followed by a summary of the learning. This chapter will conclude with an overall summary of the relevant theories and concepts, the key learning achieved and the literature gaps identified.

2.2 Characteristics of products, services and product-service systems

In this thesis, the word ‘product’ is not used to represent both product and service; instead ‘product’ can be understood as a ‘good’ as normally used in marketing and economics literature. There have been several different perspectives taken since the

18th century when product and service were initially defined and classified. Summarised chronologically, these perspectives are: first, the traditional perspective of product logic or goods-dominant logic (GD-logic) (Vargo & Lusch, 2004a), that is the opposite of service logic as used by Grönroos (2008); second, the perspective of service logic (Grönroos, 2008) and service-dominant logic (SD-logic) (Vargo & Lusch, 2004a) that has emerged before 1990s, but has gained a lot of popularity in the 2000s; and third, the recently proposed perspective of service science (Cambridge University IfM & IBM, 2008). In this section, each perspective will first be presented. Under each perspective, the definition and the main classification schemes of product, service and PSS proposed will be reviewed. The theoretical perspectives and concepts that are relevant to this research are highlighted, and literature gaps are identified.

2.2.1 Product logic perspective

The traditional perspective of product logic or goods-dominant logic (Vargo & Lusch, 2004a) probably originated from Adam Smith's discussion of the exchange value of tangible goods. Anything that could not be classified as manufacturing was referred to as the "service sector" (Spohrer, Vargo, Caswell, & Maglio, 2008). In this perspective, a service is differentiated from goods by four characteristics; a service is: intangible, heterogeneous, inseparable and perishable, also shortened as IHIP (Gummesson, 2007; Vargo & Lusch, 2004b). According to some scholars, the reference to these characteristics of IHIP can be traced back to Adam Smith and Jean-Baptiste Say in the 18th century, Nassau Senior in the 19th century and Joan Robinson in the 20th century (Gummesson, 2007; P. Hill, 1999). However, using tangibility to differentiate between products and services has become problematic with the introduction of digital technology (P. Hill, 1999). There are some proposed product features that remain applicable to intangible products, and service features that do not apply for intangible products. These features are captured in the following definitions, which are adopted in this research: a product "exists independently of its owners and preserves its identity through time" (P. Hill, 1999, p. 437), and a service cannot be stocked and is constrained by the need to have both producer and consumer interacting at the same time (P. Hill, 1999).

Under the product logic, product classification proposals include: durable or nondurable; industrialised or customised; and differentiated or commoditised (Bell, 1986; Kotler, 1972). Service classification proposals appear to form three different groups. The first group relates to the relationship of a service to a product: rented goods services, owned goods services or non-goods services (Judd, 1964); and pure goods, goods with service support, services with goods support, or pure services (Rathmell, 1966). The second group relates to the impact created by a service: people-impacting or object-impacting (T. P. Hill, 1977; Lovelock, 1983); temporary impact or permanent impact (T. P. Hill, 1977); reversible impact or irreversible impact (T. P. Hill, 1977). The third group relates to the nature of the "service act": tangible or intangible actions (Lovelock, 1983).

2.2.2 Service logic perspective

The perspective of service logic views a service as a value-supporting process and a product as a value-supporting resource (Grönroos, 2008). Similar to SD-logic (Vargo & Lusch, 2004a), service logic also deals with the roles of customers in value creation (Grönroos, 2008). However, the two logics differ in how they view the role of the customer in the value creation process. This will be discussed later in this sub-section. Vargo and Lusch proposed eight foundational premises (FP1 to FP8) of SD-logic in 2004, which was subsequently increased to ten in 2008. The foundational premises (FP) of SD-logic have formed the basis of scholastic debate and investigation in the marketing, management and manufacturing communities (e.g., Kowalkowski, 2011; Payne, Storbacka, & Frow, 2007; Vargo, Maglio, & Akaka, 2008). Two of these FPs are particularly relevant to this research (Vargo & Lusch, 2008, p. 7, Table 1):

> *FP9: "All social and economic actors are resource integrators"*
>
> *FP10: "Value is always uniquely and phenomenologically determined by the beneficiary"*

FP9 deals with the role of individuals and organisations in value creation, and the context of value creation. Vargo and Lusch have defined "resource integrators" as those who integrate and transform competences into complex services (Vargo & Lusch, 2008), and explained that FP9 implies that value is always created in networks of networks. FP10 stresses that value is always determined by the one who is experiencing the service, and as a result, value is "idiosyncratic, experiential, contextual, and meaning laden" (Vargo & Lusch, 2008, p. 7, Table 1).

The review of service logic is not complete without discussing the topics of value-in-use, value creation, value co-creation and value co-production. These terms have become more and more popular. Value co-creation in particular can be seen in academic journals and is in day-to-day usage by industry practitioners. Value-in-use, may also be written as value in use, is not a new concept. Vargo, Maglio and Akaka (2008) cited Adam Smith's (1776) definition of value-in-use as "the utility of some particular object" (Vargo et al., 2008, p. 147). In Lancaster's new approach to consumer theory (Lancaster, 1966), it was proposed that consumers derive utility from the properties or characteristics of a product or a combination of products and services, rather than from the object itself, which had been the traditional approach. Levitt (1972) also proposed that customers buy products as a mean to achieve their intentions. In other words, consumers gain value by consuming or using products or combinations of products and services. In summary, the role of product in the perspective of service logic is a mechanism for customers to attain the value they want.

The term value co-creation appeared in the early 2000s to encourage companies to provide an environment suitable for customers to jointly define and construct the experience they want (Prahalad & Ramaswamy, 2004). Some scholars view the two terms of value co-creation and co-production as synonyms (Payne et al., 2007). However, some scholars define co-production as a non-mandatory component of value co-creation (Vargo & Lusch, 2008). Some also view co-creation as entirely different from co-production because co-creation requires "dialogical interaction" (Ballantyne & Varey, 2007, p. 12).

There are two main views of the role of companies and customers in the value-creation process. The FP6 and FP7 of SD-logic proposes that "the customer is always a co-creator of value" and "the enterprise cannot deliver value, but only offer value propositions" (Vargo & Lusch, 2008, p. 7, Table 1). This is essentially the same as the proposals by Prahalad and Ramaswamy, that companies are in the position to let customers co-create value by allowing customers to participate in the "value co-creation process" (Prahalad & Ramaswamy, 2004). Proposing an opposing view is Grönroos, whose proposition is that companies are merely value facilitators. Companies cannot offer customers to co-create value, but at best fabricate the opportunities to create (or co-create) value with their customers (Grönroos, 2008). Grönroos (2008) has also added a market-offering proposition along with this value-creation proposition. The market-offering proposition is that companies can make the strategic decision of what to offer by understanding whether customers are going to buy, or can be persuaded to buy products and services as value-creating processes, or whether customers only want to buy products and services as resources. A company can react to this information in one of the two ways: if customers are purchasing products and services as value-creating processes, the company should adopt a service logic. Otherwise, the company should adopt a product logic.

Grönroos' value-creation and market-offering propositions came during the time when the number of studies in servitisation was growing. Servitisation is a term coined in the 1980s to describe the phenomenon where manufacturers offer services on top of products (Vandermerwe & Rada, 1988). The types of studies in servitisation include the clarification of the concept of servitisation (e.g., Baines, Lightfoot, Benedettini, & Kay, 2009; Ren, 2009; Vandermerwe & Rada, 1988), the rationale for manufacturers to add services to their product portfolios (e.g., Chase & Garvin, 1989; Gebauer, Fleisch, & Friedli, 2005; Tukker & Tischner, 2006; Wise & Baumgartner, 1999), the transition strategies of servitisation (e.g., Fang, Palmatier, & Steenkamp, 2008; Kowalkowski, 2011; Oliva & Kallenberg, 2003) and the financial consequences of servitisation (Neely, 2009). Comparing Grönroos' value-creation and market-offering propositions and the servitisation literature, Grönroos' view is broader as it takes manufacturers adopting a non-servitised (product) logic as a rational alternative strategy to adopting a servitised (service) logic. Servitisation literature has assumed manufacturers have decided to adopt servitisation as a strategy.

The term product-service system (PSS), introduced in the late 1990s (Baines et al., 2007), is closely related to the concept of value co-creation. PSSs as a concept has often been investigated together with value co-creation and servitisation (e.g., Kowalkowski, 2011; Neely, 2009; Ng, Parry, Smith, & Maull, 2010; Ng, Parry, Smith, Maull, & Briscoe, 2012). A PSS was formally defined in 1999 as "a marketable set of products and services capable of jointly fulfilling a user's need" (Goedkoop et al., 1999, p. 111). However, the idea of customers buying bundles of products and services was proposed 30 years earlier by Levitt (Bell, 1986). The concept of a product-service continuum was also proposed in the 1960s-70s (Rathmell, 1966; Shostack, 1977). A PSS can range from having pure product content (e.g. salt) to pure service content (e.g. teaching). An example of a 50/50 product-service content is a fast-food outlet (Shostack, 1977). More recently, recognising that one of the main investigators of the PSS is the environmental sustainability community, PSSs are described as something which "offers the opportunity to decouple economic success from material consumption" (Baines et al., 2007, p. 1545).

The commonalities among these PSS definitions are that: (1) PSS is a set of products and services grouped together by companies as offerings; and (2) the set of products and services work together to generate values for the customers, the companies and other stakeholders in society. These definitions reflect the service logic perspective, and have implied the multiple roles products play within a PSS. As a constituent part of PSS, product can be an aid to service delivery or can be handed-over (and consumed) by the customers (e.g. Shostack, 1977). Product can also be the object for manufacturers to realise a business model that support sustainable consumption via PSS (Baines et al., 2007; Tukker & Tischner, 2006). These roles are to be revisited in the PSS classification discussion in Table 2-1.

Under the service logic, no new product classification proposals have been found. This could be because service logic literature concentrates on service. Instead of looking at the service's relationship with the product and the impacts that service brings, the classification of service focuses on three things: the process of service delivery, the role and status of people involved in the service delivery process, and the level of technology employed in delivering the service (C. H. Liu, Wang, & Lee, 2008). Service can be classified by the number of people processed per day, by whether it focuses on people or object (Silvestro, Fitzgerald, Johnston, & Voss, 1992); by the degree of interaction, customisation and labour intensity when producing the service (Schmenner, 1986; Wemmerlöv, 1990); and by the types of channel access available to the service (Tinnilä & Vepsäläinen, 1995).

Upon review of the classification schemes for PSS, it is found that 'tangibility' as a demarcation between products and services is still being used, even though the term PSS was defined in the age of digital (intangible) products. The three frequently-used PSS classifications, namely product-oriented, use-oriented and result-oriented, were first proposed by Hockerts and Weaver in 2002 (cited in Neely, 2009) and was extended to include integration-oriented and service-oriented PSSs (Neely, 2009).

Table 2-1 compares three existing classification schemes (Goedkoop et al., 1999; Mont, 2002; Neely, 2009) and explains the confusion between intangible products and services shown in these proposed schemes, which may invalidate these classification schemes. In addition, the reasons why these schemes are not useful for companies to support their PSS engineering design process are also discussed.

Table 2-1 Issues with existing PSS classifications (adapted from Yip, Phaal, & Probert, 2014a, 2014b)

Three existing PSS classification schemes reviewed:				Researcher's analysis of these schemes:	
Goedkoop et al. 1999	**Mont, 2002**	**Neely, 2009**	**Examples in literature**	**Example displays product or service characteristics according to Shostack, 1977 and P. Hill, 1999**	**Why the classification scheme is not useful for PSS engineering design (PSSED)**
Product-Service (Ps) – services are connected to products	Point of sales	Product-oriented – products plus product-related-services; tangible product ownership transferred	Personal assistance in shops	Service	If a manufacturer provides service for a product it does not sell, according to Neely (2009), it would be an integration-oriented PSS. This classification does not inform manufacturers about the service requirements.
	Maintenance		Installation service	Service	
	Revalorisation		Product recycling service	Service	
	No matching classification	Integration-oriented – products plus downstream services; tangible product ownership transferred	Asset utilisation advisory service Consulting service	Service	Not much different from product-oriented PSS. The need to integrate vertically impacts the business model, but not informs the manufacturer about the requirements for PSSED.
Service-product (Sp) – products given to customer	Result- oriented Substitutions of products by services	Result-oriented – replaces product with service	Credit card (replaces cash) Electronic money Voicemail	Credit card – product Lending & borrowing money – service, facilitated by credit card Voicemail and electronic money are intangible products - producer and consumer do not need to be present at the same time, identities preserved over time.	Not much different from user-oriented PSS, apart from the tangibility of the product concerned. Arguably, it is more of a concern for business modelling than for PSSED. It does not inform the manufacturer about the specifications of the new PSS.
Service-product (Sp) – product as a production aid	Use-oriented	Use-oriented – service delivers through a tangible product; often tangible product ownership retained	Automatic teller machine (ATM) Lease of equipment	ATM – product Cash withdrawal at ATM – service Lease of equipment - service	Product ownership is arguably more of a business modelling concern. At best, it reminds the manufacturer to consider the life-cycle cost of the product.
Product-Service (PS) – products and services fulfil needs jointly	Combinations of products and services	Service-oriented – product coupled with a value-add service; tangible product ownership transferred	Intelligent vehicle health management	Intelligent vehicle health management system is software (a product) that exists independently. The provider could offer proactive maintenance (a service) that needs producer and consumer to interact.	At best, this classification makes the manufacturer aware that it can choose to develop new services such as proactive maintenance. However, it does not inform what are the requirements for PSSED.
Change of system – substitutes by a new system	Result-oriented	Result-oriented	See examples for Sp – products given to customers	See above	Change of system (Goedkoop et al., 1999) appeared to display similar characteristics as Sp and Ps depending on its scale of impact. It is mapped to Result-oriented, use-oriented, integration-oriented PSS (Neely, 1999), which implies Change of system may not be needed.
	Use-oriented	Use-oriented	See examples for Sp – products as a production aid	See above	
	No matching classification	Integration-oriented	See examples for Ps	See above	

2.2.3 Service science perspective

The third and the last perspective to be reviewed is that of "service science". "Service science" is an interdisciplinary field of inquiry that creates new theories and practices to bridge and integrate disciplines concerning complex service systems. It aims at providing structure and rigour for on-going service innovation (Cambridge University IfM & IBM, 2008; Ostrom et al., 2010). Some of the many disciplines which are to be connected by "service science" are marketing, operations management, engineering, human resources and information and communications technology (ICT) (Cambridge University IfM & IBM, 2008).

From this perspective, the term service system is used instead of product and service. A service system is defined as a dynamic configuration of people, technology, organisations and information, in which the entities interact with one another and integrate with other resources to create and deliver value (Cambridge University IfM & IBM, 2008; Chase, 1978; Spohrer et al., 2008). "Service science" is relatively new. The lack of a shared language and taxonomy of service systems relevant to both companies and academia is a recognised research challenge (Cambridge University IfM & IBM, 2008). As a result, it is not surprising that contributions have been made to the concept development of service systems, such as the abstract representation of service system (Spohrer et al., 2008); however, little effort has been invested in the classification of service system.

2.2.4 Learning from literature on product, service and product-service system

Summarising the reviewed literature in this section, the idea of representing a PSS on a product-service continuum as proposed by Shostack (1977) is interesting, as it enhances the understanding of different PSSs from a product-service content perspective. The theoretical perspectives that are most relevant to this research are the value-creation proposition proposed by Grönroos (2008), and the FP9 and FP10 of the SD-logic proposed by Vargo and Lusch (2008). These are most relevant because Grönroos' proposal has clarified the role of companies and customers in the value-creation process, and Vargo and Lusch's proposal have provided theoretical references to the networks involved in value creation and how value is perceived. As for the definition of products and services, there are three relevant differentiating characteristics. These are: whether the matter concerned can be stocked, whether its identity is preserved over time, and whether producers and consumers need to interact at the same time (P. Hill, 1999).

In conclusion, the literature gaps identified in the characteristics of products, services and PSS are: (1) the general confusion of the definition of product and service as a result of using 'tangibility' as the main differentiating characteristic between product and service; (2) the fact that existing PSS classification schemes may not be valid as a result of the use of the 'tangibility' distinction, as concluded in the previous point; and (3) the fact that PSS classification schemes proposed are more relevant for supporting business modelling than for the engineering design process.

2.3 Theories and process models for engineering design

In this section, the definition and philosophical position of engineering design process adopted in this research are first presented. This is followed by a review of the proposed theories, process models and main stages of the engineering design process. A review of the process frameworks and supporting tools for new product, service or PSS development relevant to this research is then presented. The section is concluded with a summary of learning from the literature of PSS engineering design theories and process models.

2.3.1 Definition of the engineering design process

The activities and purposes of the engineering design process involve: (1) information processing and transformation; (2) humans and tools; (3) creativity; (4) specifications to support desirable behaviours and avoid undesirable ones (Finkelstein & Finkelstein, 1983; Hubka & Eder, 1987; Maier & Fadel, 2008). A definition which covers all four elements and is adopted in this research, is an application of the theory of technical systems to the engineering design of mechanical systems (Hubka & Eder, 1988):

> *"…a process performed by humans aided by technical means through which information in the form of requirements is converted into information in the form of descriptions of technical systems, such that this technical system meets the requirements of mankind." (Hubka & Eder, 1987, p. 124)*

The philosophical position adopted in this research for the engineering design process is one of a prescriptive nature, that is, it is assumed that a better PSS design specification would result if the design engineers follow a prescribed process for the clarification of task or the problem that the new PSS is to solve (shortened as "Clarification of design task" hereafter). Sub-section 2.3.2 provides more information on the prescriptive theories, and sub-section 2.3.3 on the engineering design process stages.

2.3.2 Engineering design theories

In the engineering design literature, it appears that the word 'theory' is sometimes used to describe the proposal of a prescriptive method. Hubka and Eder (1987) consider the structure of the technical system, systematics, designer, technical means, working conditions, design strategy, design tactics and evaluation as parts of design theories. Hatchuel, Weil and Le Masson (2013) consider the development of formal engineering design theories a journey to generality, abstraction and rigour. A number of reviews of engineering design theories have classified these theories as to whether they focus on the design process or artefact, and/or whether the theories are prescriptive or descriptive (e.g. Finger & Dixon, 1989a; Konda, Monarch, Sargent, & Subrahmanian, 1992).

The assumption behind prescriptive process theories is that the designer would arrive at a better design if he or she follows the process (Finger & Dixon, 1989a). In a prescriptive process, the design should move from abstract to concrete, and complex problems can be approached by dividing them into sub-problems for sub-solutions generation, which are then synthesised into an overall solution (Konda et al., 1992).

Prescriptive artefact theories, on the other hand, are “based on the premise that design starts with a reasonably complete functional specification and that universal methods purportedly exist which can be used to produce artefact specifications” (Konda et al., 1992, p. 28).

Figure 2-2 shows a selection of engineering design theories and models, focusing on process theories. The theories and models are grouped according to their main purpose or characteristics. Figure 2-3 presents the theories and models chronologically. The time span of each group of theories and models depicted in Figure 2-3 shows approximately when the initial proposal of each of the theories or models in the group was made, but not the duration of its impact. For example, the first proposal from Pahl and Beiz in 1977 for systematic engineering design, grouped under systematic transformation in Figure 2-2 and Figure 2-3, has had newer editions, and has been translated into English and other languages (note: the 6th German edition was published in 2005 and the 3rd English edition was published in 2007) (Pahl et al., 2007). Prior to Simon's definition in 1969 that design is a process to transform information, engineering design was mostly perceived as an analytic activity (Maier & Fadel, 2008; Simon, 1969). As seen in Figure 2-3, since Simon’s publication, many more proposals in engineering design theories and models have been made.

All prescriptive process theories and models captured in Figure 2-2 and Figure 2-3 follow the rational problem-solving logic, with the exception of reflection in action (RIA) which views design as an art and social phenomenon (Spitas, 2011). The theories and models captured in these two figures are mostly based on previous reviews of engineering design theories (Finger & Dixon, 1989a, 1989b; Finkelstein & Finkelstein, 1983; Hatchuel, Weil, & Le Masson, 2013; Jänsch & Birkhofer, 2006; Konda et al., 1992; LaFleur, 1991; Le Masson, Dorst, & Subrahmanian, 2013; Maier & Fadel, 2008; Shishko & Aster, 1995; Spitas, 2011). The highlighted group, systematic transformation, includes the theory of technical systems that has provided the definition of engineering design process adopted in this research.

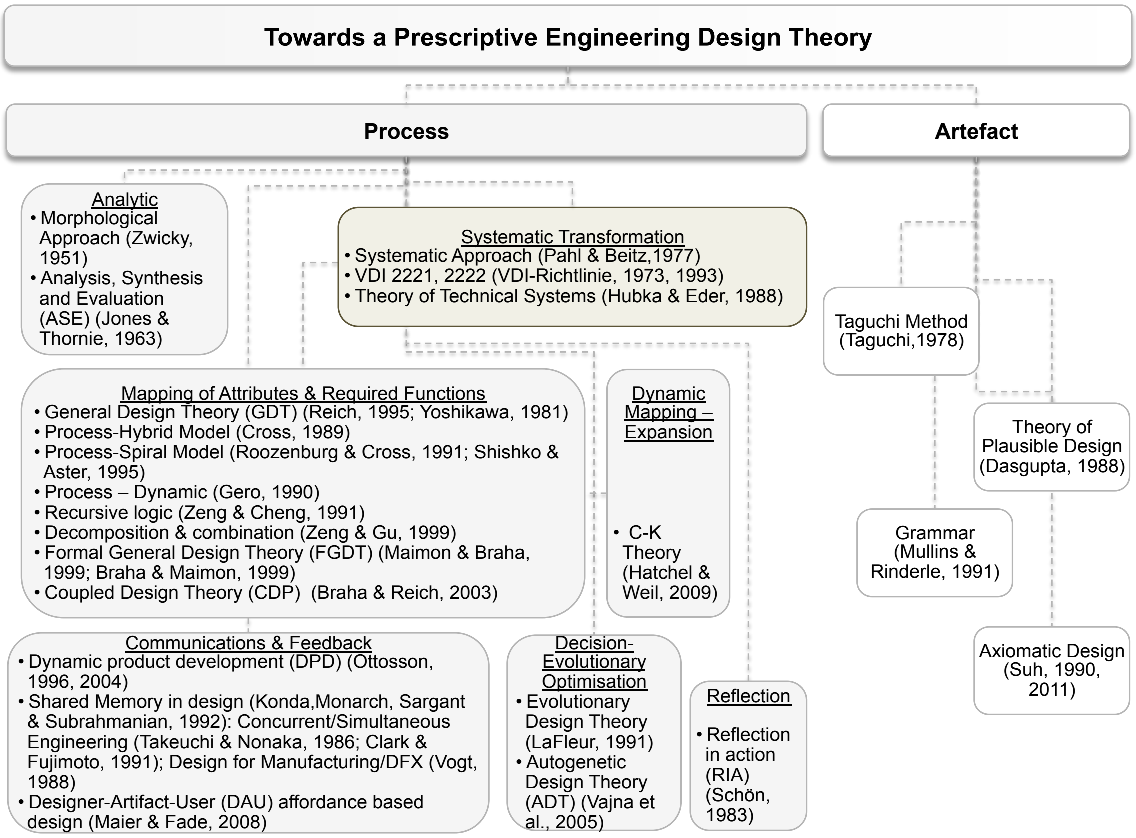


Figure 2-2 Prescriptive engineering design theories and models

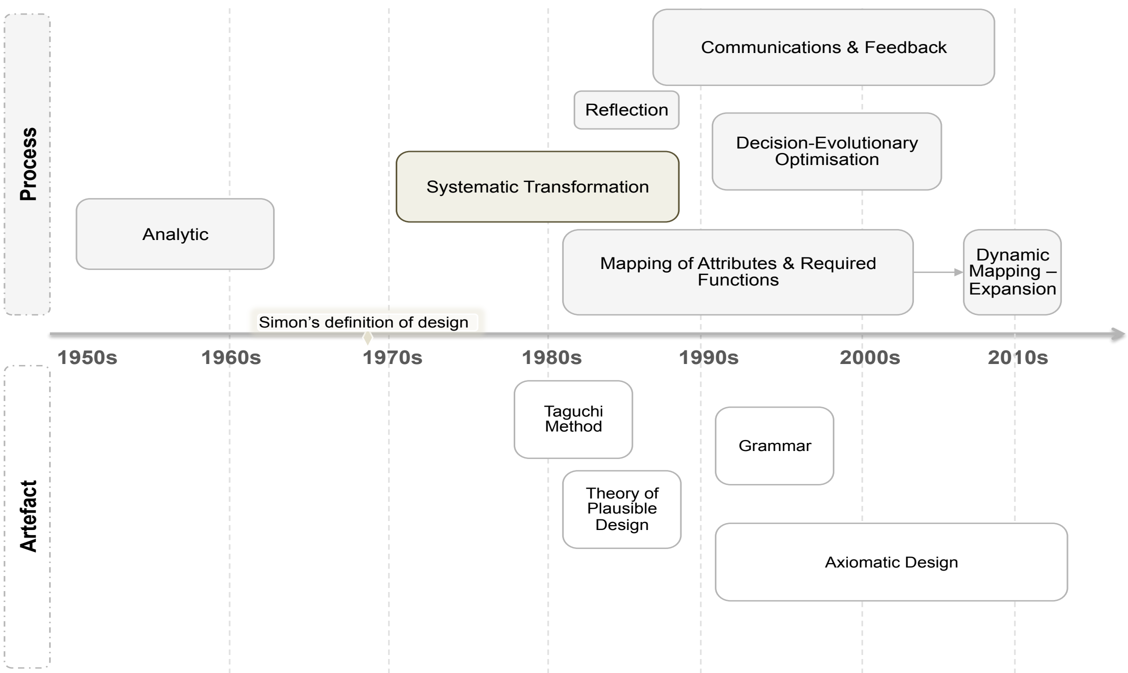


Figure 2-3 A chronological view of prescriptive engineering design theories and models

In the application of the theory of technical systems to engineering design, “technical systems” are things that aim at "exerting particular effects on the operands in the technical process” (Hubka & Eder, 1988, p. 91), where operands can be materials, people, energy and information, and the technical process refers to the process of engineering design (Hubka & Eder, 1988). This theory is valid for all technical systems (Hubka & Eder, 1988). It is therefore important to understand the properties of technical systems to see if the application of the theory can be extended to other things, such as instrument supporting the engineering design process. Proposition 7.5 of the theory of technical systems describe the properties of technical systems:

> *"Every function (or [behaviour]) is a system that contains as its elements a set of partial functions (or partial [behaviours]), and that is decomposable to elementary functions (or elementary [behaviours])… …we can work with various degrees of abstraction (ranging from an abstract function to the actual [behaviour] of a concrete technical system)…The particular functions "connecting" and "separating" are assumed to be elementary functions at a high level of abstraction. They combine a series of functions from various steps in the hierarchy of abstractions…"* (Hubka & Eder, 1988, p. 237)

2.3.3 Main phases of the engineering design process

Among the literature reviewed, the most commonly stated sequence of phases or activities in the engineering design process are: (1) classification of the task; (2) conceptual design; (3) embodiment design; and (4) detailed design (Finger & Dixon, 1989a; Finkelstein & Finkelstein, 1983; Horvath, 2004; Hubka, 1982; Konda et al., 1992; Pahl et al., 2007; Wallace & Burgess, 1995). Wallace and Burgess’s (1995) depiction of the engineering design process covers these four phases with the input and output of each phase clearly presented. Figure 2-4 is adapted from Wallace and Burgess’s (1995) proposal, synthesising the contributions from the reviewed literature. Iterations of evaluation and refinement activities are performed in each engineering design phase (Konda et al., 1992; Pahl et al., 2007), and are represented by curved feedback arrows between two adjacent phases in Figure 2-4.

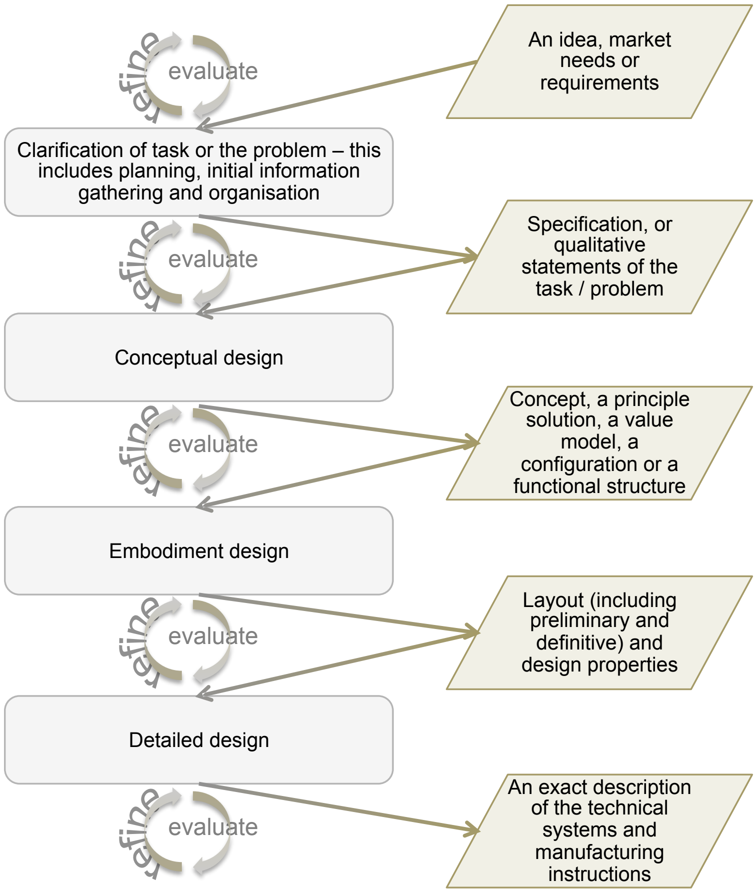


Figure 2-4 The main phases of the engineering design process - (adapted from Wallace & Burgess, 1995)

One could argue that the format of treating the engineering design process as a series of steps with inputs, outputs and refinement loops at each step can also be used to depict other business and operational processes. For example, a process flow format can be used to depict the process of strategy formation, sales and operations planning, or project management. Strategy formation starts with an organisation's mission, vision and values, which through iterations of evaluation and refinement, is transformed into long, middle and short-term objectives for each department (Kaplan & Norton, 2008). Sales and operations planning starts with the long-term forecasted demand and forecasted capacity, which are transformed into daily production output to which the sales and production plans are evaluated against, and capacity plan is adjusted accordingly (Olhager, Rudberg, & Wikner, 2001). Project management involves five main process steps: initiation, planning, executing, controlling and closing. The project output is checked against the project plan, and the plan is updated via iterations of the project management process (Lawson, 2009). Despite its generic format, depicting the engineering design process is a useful way to align understanding of this process.

In this research, the activities explored in the engineering design process belong to the first stage in Figure 2-4, that is the clarification of task or the problem that the new PSS is to solve ("Clarification of design task"). The main output of this phase is a PSS design specification.

2.3.4 Development process models and tools

The input of a typical NPD/NSD process is stakeholders' needs and desires, and the output is usually a market launch of the new product, service or PSS (R. Cooper, 2008; Kindström & Kowalkowski, 2009). For the purpose of this research, the engineering design process can be understood as the early stage of the new product development (NPD), new service development (NSD) or new PSS development (NPSSD) process. This is because, as explained in sub-section 2.3.1, the engineering design definition adopted in this research states that the output of this process is a description of the technical systems to be developed, which is the final output of the engineering design process depicted in Figure 2-4.

2.3.4.1 NPD and NSD process models

There have been lots of interests in investigating NPD and NSD since the 1950s. The findings that successful new product introductions were low and that most failures are preventable, drew the attention of business managers and researchers in the 1960s and 1970s (Booz, Allen, & Hamilton, 1982). Standardising the process was considered a remedy. Booz, Allen, and Hamilton proposed a NPD model in the 1960s – in its revised format, the 7-step model (Booz et al., 1982), is frequently referred to in later studies. The reviewed NPD models mostly consist of development activities and evaluation points where go/kill decisions are made between development stages (e.g. R. Cooper, 1994). Contrasting with the relatively linear stage-gate approach, and taking on a broader perspective of NPD, is the development process framework proposed for complex system. System can be understood as a set of interrelated components organised in a way to achieve a common purpose; and it exists within a broader super-system (Shishko & Aster, 1995). One example of a system design engineering process is NASA's spiral model that shows the pursuit of successive rounds of goal identifications, concept creations, design alternative studies and selections (Shishko & Aster, 1995, p. 7 Figure 3). Another example is the software and systems development process "V-Modell XT", which depicts four process modules of system development as the downward-stroke of an alphabet "V". The upward-stroke of the alphabet "V" consists of the four outputs of the development process. Each output is lined-up horizontally to its appropriate development module which it is verified and validated against (Meisinger & Kruger, 2007).

NSD and service engineering are two terms encountered in the literature for the design and development activities for new services. Before going into the review of the process models, the meaning of NSD and service engineering are first compared. Some scholars believed that service engineering and NSD were coined at the same time in the mid 1990s (Bullinger, Fähnrich, & Meiren, 2003); however, proposals of NSD process models have been published since the 1980s (Bushman & Cooper, 1980; Scheuing & Johnson, 1989).

Service engineering is a more technical and systematic approach than NSD and utilises existing engineering know-how in NPD for developing innovative services. On the other hand, NSD is viewed as more marketing-driven, or "strictly marketing-oriented" (Bullinger et al., 2003, p. 276). Service engineering is also compared to value engineering. The former is seen as a discipline or method to increase the value of services to the parties receiving the services (Sakao & Shimomura, 2007; Tomiyama, 2001); the latter can be understood as a synonym of value analysis. Value analysis is the evaluation of new design based on cost for the function that the new product is to reliably provide (Miles, 1962). In this research, the meaning of value is taken as customer-perceived value. The customer-perceived value in turn generates value for the company and other stakeholders.

Because of the service characteristics of intangible, heterogeneous, inseparable and perishable (IHIP) as presented in Section 2.2.1, NSD is often seen as more *ad hoc* than NPD (de Jong, Bruins, Dolfsma, & Meijaard, 2003; Rathmell, 1966). Not surprisingly, as IHIP are the result of a product logic perspective (see Section 2.2.1), among the reviewed NSD models, quite a number of them resemble Booz, Allen, and Hamilton's NPD model; some of them are industry specific while some are more generic.

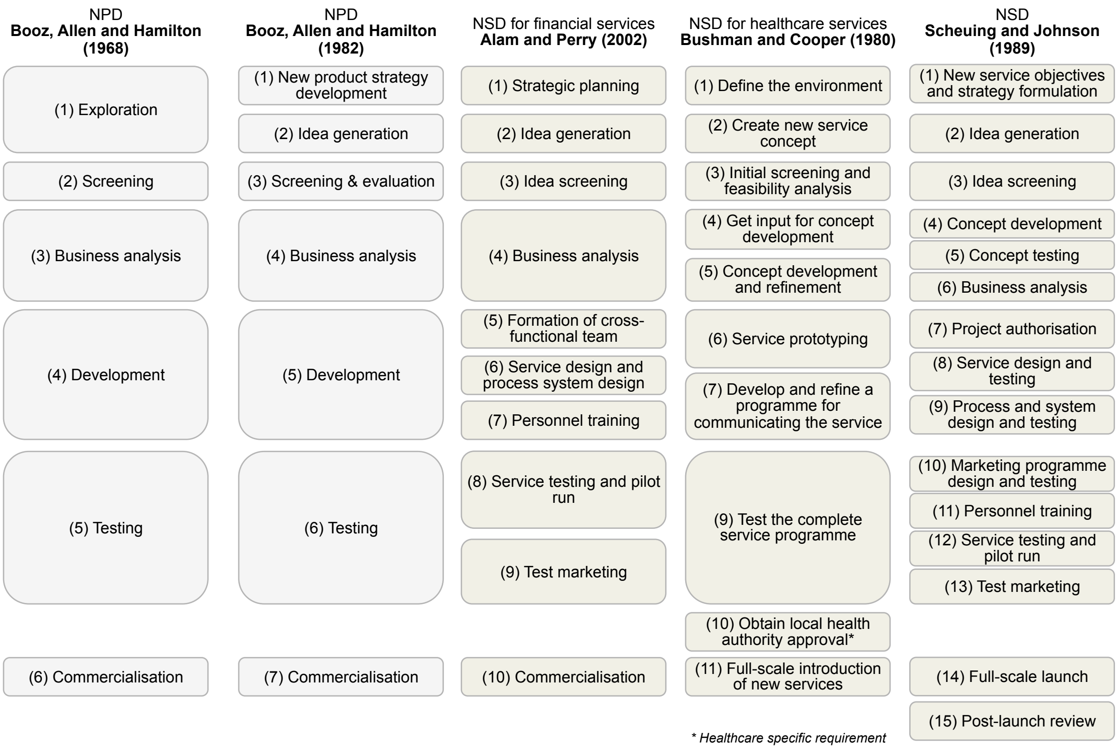


Figure 2-5 NPD and Booz, Allen, and Hamilton-like NSD models (adapted from Alam & Perry, 2002; Booz et al., 1982; Bushman & Cooper, 1980; Scheuing & Johnson, 1989)

Examples are a 10-step NSD model proposed for financial services (Alam & Perry, 2002), new healthcare services development process models (Bushman & Cooper, 1980; P. Cooper & Butterbaugh, 1993), information technology services design process model (Taylor, Lloyd, & Rudd, 2007), and a more generic 15-step NSD model (Scheuing & Johnson, 1989). Some of these models are compared side-by-side to the two generations of Booz, Allen, and Hamilton's NPD models in Figure 2-5.

However, some other NSD models consider the process of producing, delivering, and receiving services. These proposed models depict the preparation and the planned interactions between customers and service delivery employees. These models are designed with the perspective of service logic (see sub-section 2.2.2). The following paragraphs provide a summary of the review of some of these proposed models. The key concepts of these proposals are amalgamated into Figure 2-6, showing the complexity of service interaction. By putting the key concepts of these proposals side-by-side, one can see how one concept complements another. This figure uses a new running group offer developed by a running club is used as an example.

One frequently cited model is Shostack's service blueprint (Shostack, 1984) that contains four steps: (1) identify process; (2) isolate fail points; (3) establish standard time; and (4) analyse profitability. Unique to this model is the concept of the "line of visibility", which can be further examined using an on-stage/backstage theatrical metaphor (Polaine, Lovlie, & Reason, 2013). The "line of visibility" can be seen in the middle of Figure 2-6, separating the backstage and the on-stage. The building of a service blueprint helps the development team to capture the overall picture of what the service is about, the user journey and the interconnections among the actors, which can be both humans and non-humans, on either side of the metaphorical "stage" (Polaine et al., 2013). Shostack pointed out that the tangible service evidence is what customers see and how customers evaluate service effectiveness, and therefore needs to be considered in NSD.

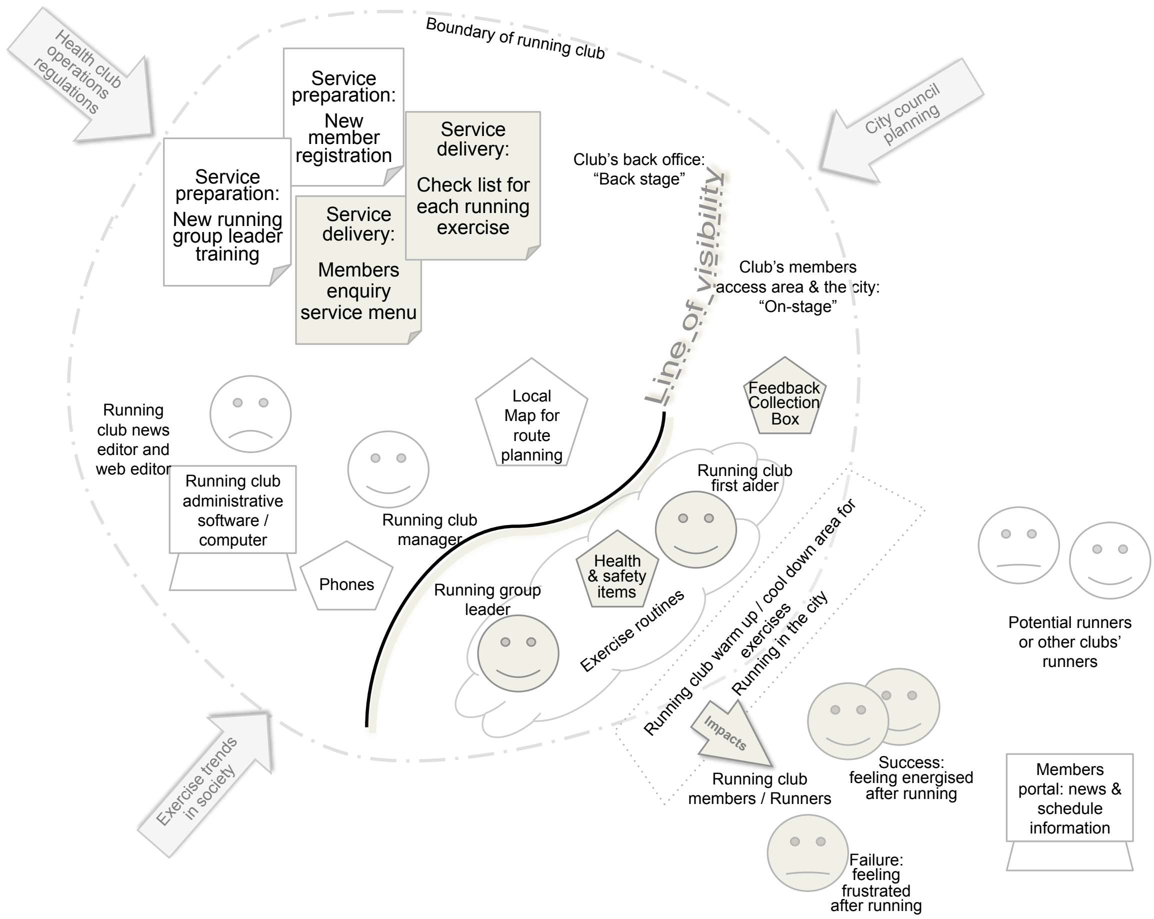


Figure 2-6 A generic view of the complexity of service interactions for NSD (adapted from Bullinger et al., 2003; Edvardsson & Olsson, 1996; Polaine et al., 2013; Shostack, 1984; Tomiyama, 2001)

Edvardsoon and Olsson have proposed a NSD model that consists of the development of service concepts, service systems and service processes (Edvardsson & Olsson, 1996). They propose that the main objective of a NSD process is to create the right service prerequisites for the right customer outcome. The service concepts, service systems and service processes are developed at the same time. The service preparation and delivery processes are depicted in the backstage of Figure 2-6, and the right customer outcomes around the customers receiving the service. The proposal by Bullinger et al. (2003) bears some similarities to Edvardsson and Olsson's (1996), but with additional considerations on how the new service may impact people and systems external to the company. Bullinger et al.'s (2003) proposal is that when a company develops a new service, three dimensions are to be considered: structure, process and outcome. Structure deals with the company's ability and willingness to deliver the new service. Process is about the interaction and integration of the company's actions on or with the external factors when producing the new service. The company's boundary and the external factors are depicted in Figure 2-6 as arrows going into the company. Outcome is the material and immaterial impacts of the new service on the customer and other objects external to the company (Bullinger et al., 2003, p. 277 Fig. 2), represented by an outward arrow going from the on-stage area to the customers just outside the boundary of the company in Figure 2-6.

Another interesting NSD model was proposed by Tomiyama and sees the change of state of the receiver of a service, which can include changes in the receiver's locations and emotions, as an outcome of a service delivery. The *service contents* are to be provided by a *service provider* to a *service receiver* via a *service channel* that could be enhanced by means of an artefact, resulting in a *change of state* of the receiver (emphasises in original text) (Tomiyama, 2001). The service contents are the exercise routines included inside the cloud shape, and the service channel is represented by a dotted-line trapezoid in Figure 2-6. Tomiyama proposed that service engineering, which includes service design, production and development, is a method used to intensify and improve the framework for generating and consuming the services. The value of service (V) is proposed to be defined as the product of its functionality (F) and quality (Q), that is $V = F * Q$ (Tomiyama, 2001, p. 616).

Figure 2-6 shows the interactions among the systems and people directly involved in the preparation, production and receipt of services. Within the company's boundary (Bullinger et al., 2003), some service preparation activities (Edvardsson & Olsson, 1996) that are performed by the company's employees happen "behind line of visibility" in the backstage and are not visible to the customers (Polaine et al., 2013; Shostack, 1984). Some other company's employees are on-stage (Polaine et al., 2013) and interact with the customers to deliver the services required. The customers receiving the services change state (Tomiyama, 2001), either the desirable state-change is achieved or an undesirable one. Potential customers, other systems and other external factors can impact the actions taken by the company in service production (Bullinger et al., 2003). In summary, if NSD is about the process of service production and delivery, many different factors need to be considered. Without clear guidelines for how to take account of these factors, NSD can appear chaotic.

2.3.4.2 NPSSD process models

Many new PSS development process models proposed in the 2000s are built upon earlier NPD and NSD models. As observed by Maussang, Zwolinski and Brissaud, many approaches have a product-focused or a service-focused (Maussang, Zwolinski, & Brissaud, 2009). There are also many NPSSD suggestions that are at a business strategy level and do not provide guidelines on how to put them into practice. Selected examples of these biased proposals are reviewed below, followed by two holistic NPSSD process models.

Examples of product-focused NPSSD models include an industrial PSS design and development model that consists of two processes, one for the development of the industrial product components and the other for the design of service components that create more value for customers during the lifecycle of the industrial product (Aurich, Schweitzer, & Mannweiler, 2008). Another example is an automobile after-sales service development process model, which develops products and services almost completely separately (Juehling, Torney, Herrmann, & Droeder, 2010). Both of these models treat service development as supplementary to product development.

An example of a service-focused NPSSD framework is Gummesson's service encounter model (Figure 2-7). The service encounter model brings to attention the different parties and service systems in the environment. The parties include not only service delivery personnel and other customers that are around during the service interaction, but also management and support staff in the provider's organisation, competitors to the service provider and society. Products are mentioned in the model as part of the servicescape. Servicescape is the built environment, that is the man-made, physical surroundings where the services are delivered (Bitner, 1992). The model focuses on service delivery and service consumption. Product requirements are not given an equal amount of attention. Moreover, this is a strategic business model, and does not provide enough details to indicate how the model can be used in daily design and development activities.

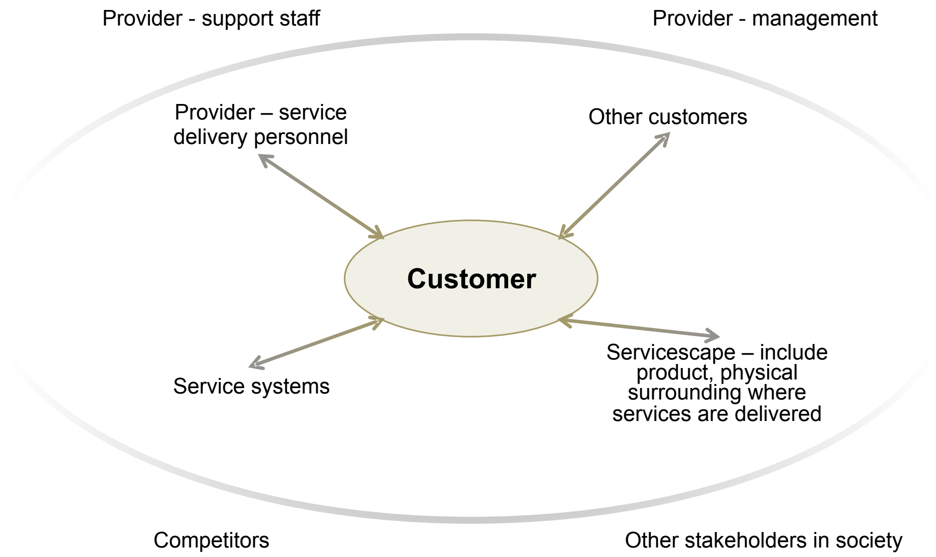


Figure 2-7 A service encounter model (adapted from Gummesson, 2007, p. 122 Figure 1)

Some NPSSD approaches proposed stay at a business level without providing any suggestions of how to operationalise them. One example is a model that shows how product and service development projects are to be coordinated with the business strategies of customers and partners (Tan, McAloone, & Matzen, 2009). Another example is a life cycle model adapted from e-commerce (Yang, Xing, & Lee, 2010), which does not provide any advices in terms of the timing of the execution of each suggested activity.

In the reviewed literature, there are two holistic models that are at an operational level for NPSSD. The functional development process (FDP) process model by Isaksson, Larsson and Öhrwall Ronnback (2009) has challenged the traditional NPD that it only emphasises on multi-disciplinary collaboration in the development process, but neglects the continuous involvement of customers. They have also criticised that the published service design proposals by suggesting they have overlooked the impact of artefact usage in service delivery. As seen in Figure 2-8, the FPD process model proposes a much better understanding of the customers' needs by involving customers more intensely. The model has recognised that a solution to the customers' needs could equally possible be a product, a service, or a combination of both. To operationalise this model, Isaksson et al. have further suggested modelling and simulating all aspects of PSS in early phases.

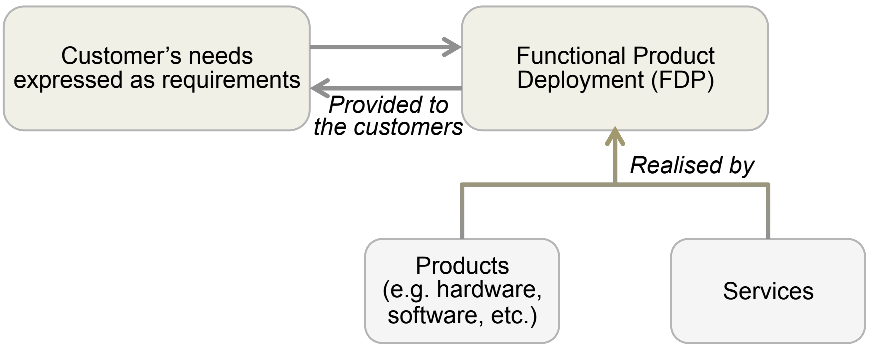


Figure 2-8 The functional development process (adapted from Isaksson, Larsson, & Öhrwall Ronnback, 2009, p. 338 Figure 5)

The other process model that tackles product and service design holistically and has taken care of the details required for its development within the NPSSD, is the model proposed by Maussang, Zwolinski and Brissaud (2009). The proposal consists of three steps:

- List the functions customers and other actors in the PSS would expect from the product during the PSS lifecycle, the impact of the PSS functions to the external elements and the response of the outer environment to these functions. The constraints on the design are detailed in a graphical format.

- Define the technical functions the PSS has to perform, propose solutions to these needs at the sub-function levels and specify the product and service elements required by each solution.
- Visualise the PSS architecture by using a "functional block diagram" to capture the product and service elements involved, as well as the contracts and functional flows among the elements. All the links and elements in the PSS architecture are detailed with operational information such as how many times per day each link is used and the people to be involved in each link. Each design choice for realising a function in a use-scenario is called a "design buckle".

Figure 2-9 is an example of a "functional block diagram" using a hypothetical example of a new running group offer developed by a running club. The "design buckle" in this example is a new running group.

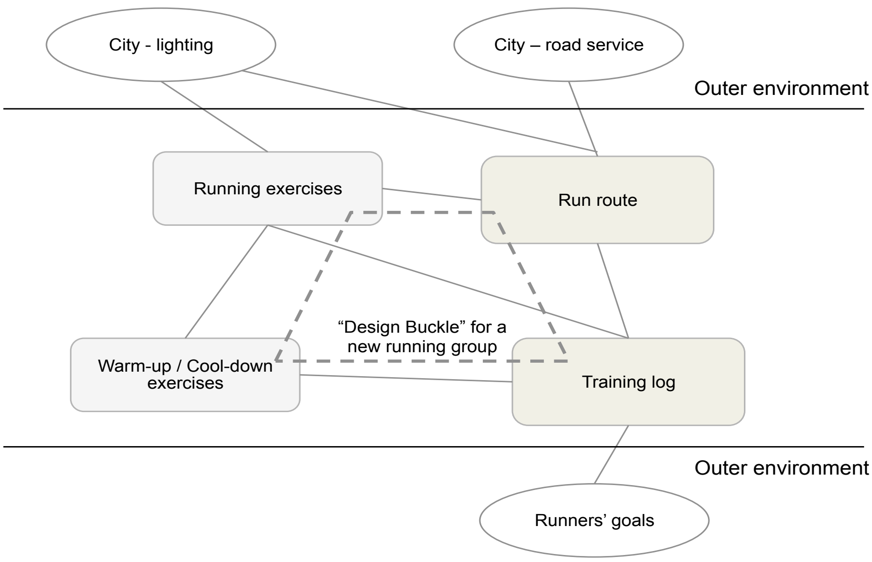


Figure 2-9 Visualising elements and their interactions in a new PSS (adapted from Maussang et al., 2009)

This model has proposed a formal representation and analysis of different use-scenarios. It has captured the product and service elements, the links between the different elements and the outer environment. At the same time, its technical functions can be defined at the required level for the purpose of product development.

2.3.4.3 Tools supporting the development process

Many tools have been proposed to support the new product/service/PSS development process. This sub-section does not intend to provide an overview of all the relevant tools, but only to provide a review of the tools that are most relevant to this research, that is those that aim at introducing customers' values into the design specification. Two groups of tools are evaluated. One group originally developed to support product design, and another group developed to support PSS design. The first group has had paramount impact on the field of engineering design since the 1970s. It consists of charts that support the translation of customer demands into quantitative quality characteristics (Akao, 1990). This group can be put under the umbrella of visual charts for quality function deployment (QFD). The second group focuses on eliciting the desires of users or customers and has a strong focus on the process of service production, delivery and consumption. It is called persona modelling.

QFD began in post-Second World War Japan when product development was shifting from imitation to original design. QFD is a design approach to build quality into a product, under the umbrella of total quality management (TQM) (Akao & Mazur, 2003; Akao, 1990). The term "quality function deployment" was first coined by Akao in 1972, and has been developed for and improved by practitioners in manufacturing. These include Mitsubishi Heavy Industry and Toyota Auto Body (Akao & Mazur, 2003). QFD in the form of a "house of quality", that is a quality chart with a triangular roof, was first developed by Toyota Auto Body (Akao & Mazur, 2003).

The concept and features of QFD were brought about by three drivers: (1) there was a general realisation of the importance of having quality designed into products before the start of production, but there was no published work that addressed this need; (2) manufacturing firms had been using quality charts from statistical quality control (SQC) and were searching for a way to show the relationship between the quality required by customers and the various functions within the company; (3) around the same time, value engineering had shown how to define functions of a product (Akao & Mazur, 2003). QFD aims at "satisfying the consumer and then translating the consumers' demands into design targets and major quality assurance points to be used throughout the production stage" (Akao, 1990, p. 3).

QFD usually consists of a series of quality charts of two-by-two matrices, which translate the demanded quality expressed in customers' verbatim to the targets and controls used during the mass production process. According to Akao (1990), the first quality chart translates the demanded quality to the quality characteristics that need to be deployed. The second quality chart translates the quality characteristics to be deployed into the means of achieving these characteristics. The third quality chart translates the means of deploying the required quality to the technical characteristics of elements or parts. The fourth quality chart specifies the methods and conditions for production. Figure 2-10 illustrates the translations that happen in QFD.

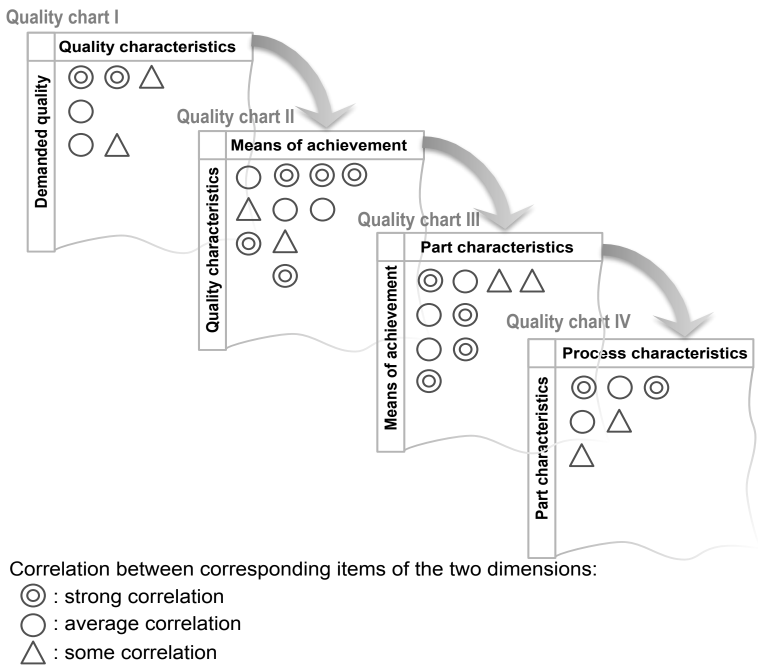


Figure 2-10 Depiction of the translation of customer demanded quality using quality charts (adapted from Akao, 1990, p. 98 Figure 4–3)

As seen in Figure 2-10, the strength of the relationships amongst the two dimensions of each matrix is captured in the body of the matrix as either having strong, average or some correlation. The elements in each dimension can also be prioritised and indicated in the chart accordingly. The relationships amongst the elements of the same dimension can also be captured in a triangular shape (a triangular roof) against the dimension concerned.

Although QFD is used extensively in manufacturing, it can also be used in service industry (Akao, 1990). Figure 2-11 is an example of how QFD can be used to for the design of a new running group offer developed by a running club.

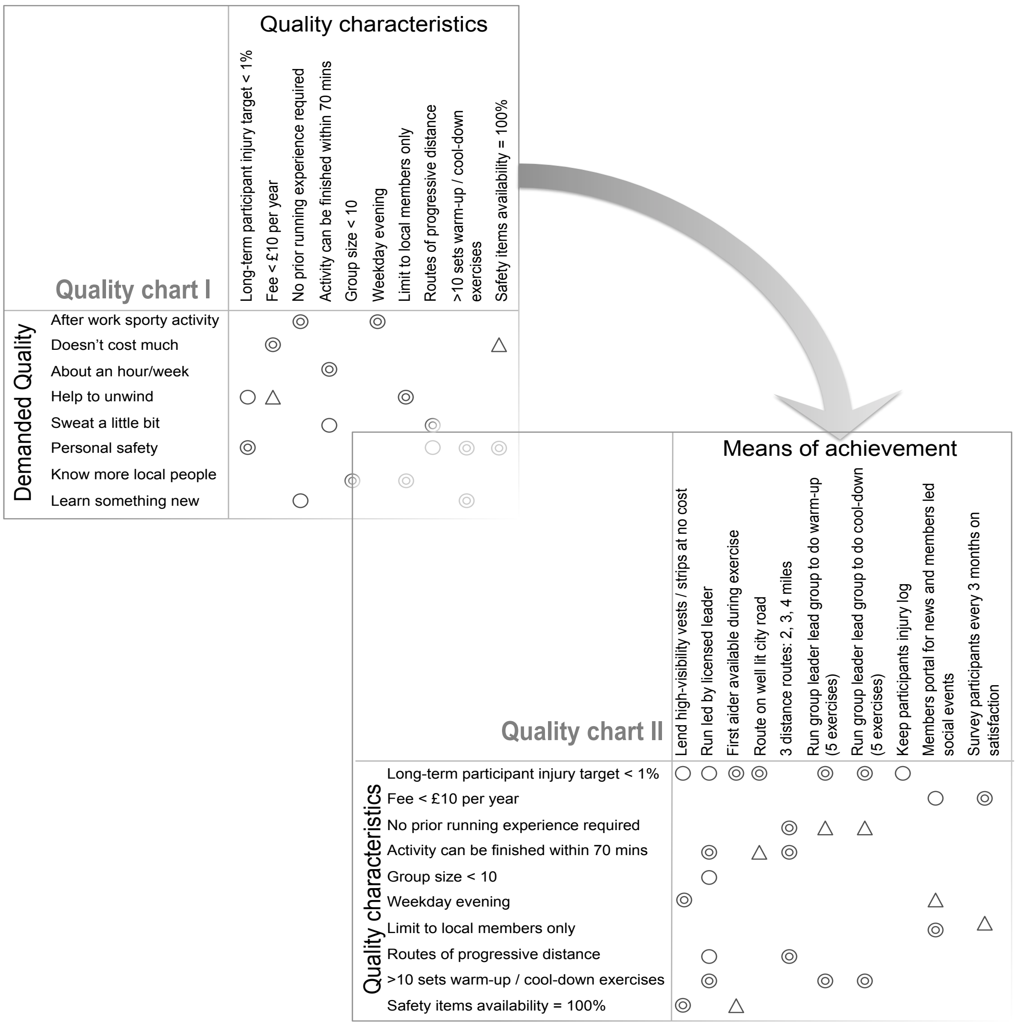


Figure 2-11 An example of the first two levels quality chart for service design

QFD-based tools for product and service development include integrated QFD for integrated product and service development (e.g. An, Lee, & Park, 2008), fuzzy QFD that applies fuzzy logic on QFD in order to overcome qualitative judgements (e.g. Bottani & Rizzi, 2006; H. T. Liu, 2011). Analytic network process (ANP) is also proposed to be applied on QFD for understanding the interrelationships between and within the components of QFD (e.g. Raharjo, Brombacher, & Xie, 2008), and to calculate the initial importance weights of the technical characteristics from customers (Geng, Chu, Xue, & Zhang, 2011).

QFD is important to this research as it shows how customers' desires can be systematically analysed and defined as quality characteristics of the products and services involved in the new development. The characteristics required for lower level product and service elements, such as parts, can be defined in measurable units. The production process for the products and services are also considered in QFD. The relationships between demanded quality and certain quality characteristics are represented with the quality charts. A quality plan for the design can be developed accordingly. Although QFD has been used in the service industry, and there are examples of applying it for PSS development, it mostly focuses on the backstage preparation for service prerequisites (see section 2.3.4.1), and less on the on-stage real-time interactions between the service delivery staff and the customers.

To design a PSS, it is recognised that designers have to address the part of the design that is not addressed in the design of the product, and both products and services are utilised in various design alternatives for attaining stakeholders' values (Sakao, 2011). There is a group of tools that helps designers to draw out latent user needs, or the attribute-based values desired by users, which then form part of the specification of the PSS. This includes giving users prototypes or artefacts that represent a non-existing invention, and asking these users to record their experience and any sudden realisation of the new invention or services related to it (Mukhtar, Ismail, & Yahya, 2012). Another tool that helps to gain insight from customers or users in terms of what they desire in a new PSS is the use of personas and avatars. Personas are created by the manufacturers to represent the voice of customers, while avatars are created by real users (Mukhtar et al., 2012).

There are also tools for modelling personas in terms of what these imaginary customers want from their service experience. For example, Service CAD, where CAD stands for computer-aided design, has been shown to support the systematic conceptual design and modelling of new PSSs (Komoto & Tomiyama, 2009). Service Explorer is a Service CAD tool that supports PSS concept generation and evaluation (Hara, Arai, & Shimomura, 2006), and is developed for the NSD model proposed by Tomiyama (2001) (see section 2.3.4.1) that depicts the required change of state of the receiver of a service by means of service contents flowing from a service provider to a service receiver via a service channel.

Service Explorer models different potential service scenarios by means of defining: (1) the personas for whom a set of satisfaction indicators called receiver state parameters (RSP) can be specified; (2) how the service flows from the manufacturer to the customers, or the receivers, in these scenarios; and (3) what functions and associated artefacts or service are required for the RSPs (Hara et al., 2006).

Persona definition includes the specification of the persona's demographic and psychological data, and basic values such as "sense of accomplishment", "being well-respected" and "self-fulfilment" (Sakao & Shimomura, 2007, p. 601). Service flow covers the path from the manufacturer or provider through intermediate agents to the customers, who are represented by the personas. The functions to be achieved can be associated with both products and services. The RSPs that must be achieved for a persona can be depicted in a "view model" (Hara et al., 2006). Figure 2-12 shows how a scenario of an offering of a new running group by a running club can be represented in a "view model".

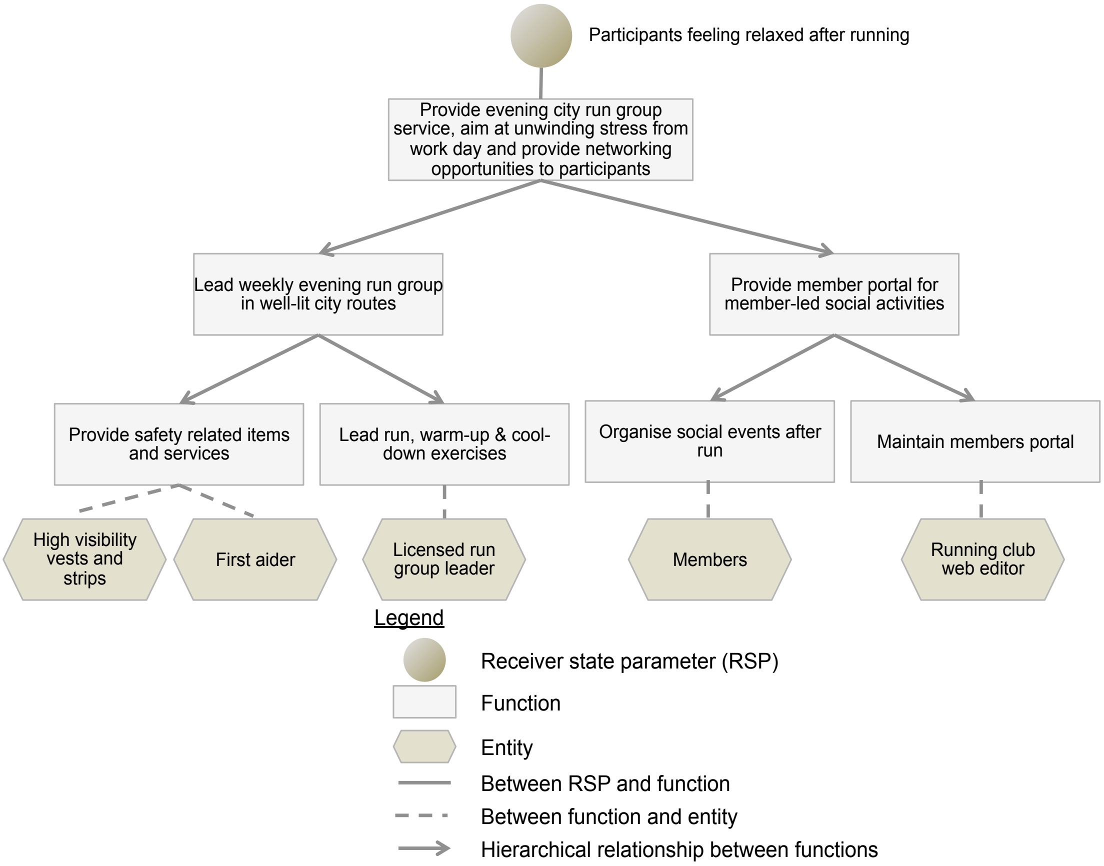


Figure 2-12 An illustration of scenario building using persona (adapted from Hara et al., 2006)

To holistically evaluate the PSS concepts generated, a tool called Integrated Service CAD and Life Cycle Simulator (ISCL), which is an integration of a service CAD tool and a life cycle simulator, has been proposed (Komoto & Tomiyama, 2009). The service CAD allows the designer to look for potential PSS solutions by combining different service contents, service channels and other related activities. The life cycle simulator (LCS) holistically evaluates the economic and environmental performance within a product life cycle. In ISCL, the LCS evaluates the different PSS options based on the changes in the potential PSS' service activities and channels' capacity (Komoto & Tomiyama, 2008).

The use of personas to generate attribute-based customer values has shown some success in the design and development of new PSS in some case studies (e.g. Hara et al., 2006; Sakao & Shimomura, 2007). The modelling of service flows in different scenarios represented by different personas appears to be an interesting way to generate required attributes for a new PSS. The contextual factors impacting the required attributes are represented in this model either directly as a RSP of an intermediate agent of the environment, or indirectly as a RSP of a customer (Sakao & Shimomura, 2007). This group of tools help to identify and generate customers' latent requirements, but it does not analyse which products or services associated with the required functions are more important in the PSS within a service scenario and among different service scenarios.

2.3.5 Learning from literature on engineering design theories and process frameworks

In this section, the existing engineering design theories are landscaped, and the engineering design definition from Hubka and Eder's (1987) application of the theory of technical systems (Hubka & Eder, 1988) to engineering design is adopted. However, the original application of the theory of technical systems to engineering design was for products, or more specifically, for mechanical systems. Nevertheless, the application of this theory may be extended to the engineering design of PSSs, and also to the instruments supporting the engineering design process. The theory of technical systems is one of the many prescriptive process theories proposed. In particular, it belongs to the group of theories that view engineering design as a systematic transformation. For this research, the study focuses on the activities in the first stage of engineering design, called the "Clarification of design task", which takes an idea as an input and gives a specification as an output.

Alongside the development of engineering design theories, active proposals of NPD, including new system development, and NSD process models were being suggested. More recently, NPSSD models have also been proposed, mostly based on existing NPD/NSDs. Service engineering is a discipline for new service development that takes a more customer-value-focused, more technical and methodical approach, in comparison to approaches called 'NSD'. For this research, service engineering is therefore defined as a technical and systematic process for NPSSD, with an emphasis on customer value.

Although most of the reviewed NPSSD models are either product or service-biased, or do not enable the generation of enough details for technical development, two exceptions have been identified: the FDP model by Isaksson et al. (2009) and the three-step approach by Maussang et al. (2009). Supporting tools such as QFD and Service CAD have been proposed to translate customer desires into the design of product, service and PSS.

To conclude, in terms of engineering design theory, there is potential to extend the application of the theory of technical systems (Hubka & Eder, 1988) from the engineering design of mechanical systems to PSS engineering design. In terms of engineering design process models, gaps have been identified in the literature that few approaches consider holistically the product and service elements within a PSS. There is a need for more un-biased approaches to help engineering designers to generate not only the big picture of the value creation process but also the technical details within a PSS. In terms of supporting tools, QFD is a useful example for the systematic translation of customer demands to required quality characteristics. Additionally, the use of personas to generate attribute-based customer values, and to understand the relationships between the stakeholders and the functions to be developed, is useful for NSD and NPSSD. However, the existing QFD does not explore how the real-time interaction aspect of a service can be represented, and the service modelling of personas does not analyse which products or services are more important within the PSS. Therefore, there is a need for supporting tools that systematically translate customer's desires to both product and service attributes, and at the same time examine the interdependencies among these attributes in delivering the required outcome.

2.4 Structural representations for technical systems

This section follows from the previous section about theories, process models and tools for engineering design. It focuses on the structural representations to depict the content of a product, service or PSS. At first glance, the proposed structural representations can be grouped into representations for product or service. However, the proposals reviewed are all robust enough to be used for representing a PSS, even if the proposal has been developed with a product in mind, for example, a mechanical system. Therefore, instead of using product and service perspectives to guide the literature review of structural representations, the selected models reviewed in this section are chosen for their diversity. The conclusions arising from studying these structural representations are given at the end of this section.

2.4.1 Product-based representation

NASA's engineering design problem is probably one of the more complex design tasks in current use. The NASA's system engineering handbook (Shishko & Aster, 1995) has provided a hierarchy of system terminology. This conveys the importance of using the same terminologies across a large team of system engineering designers. The concept of super-system is also introduced as a collection of related systems. The terms, in order of progressive degree of resolution, are: system, segment, element, subsystem, assembly, subassembly and part (Shishko & Aster, 1995, p. 3 Sidebar "A hierarchical system terminology"). How NASA represents the structure of their systems or subsystems for engineering design purposes is an example of structural representation for complex systems.

NASA utilises a product-based work breakdown structure (WBS) to plan and represent subsystems and the services required for their development. Necessary services include management, logistics and integration and verification. A WBS contains a product breakdown structure (PBS). A PBS starts with the system at the top, and is then broken down into different segments, elements, subsystems and so on, until the lowest level products are reached. An example of a lowest level product is a document, such as a user menu. Figure 2-13 shows an example of a product-based WBS, illustrating how a complex technical system can be systematically represented.

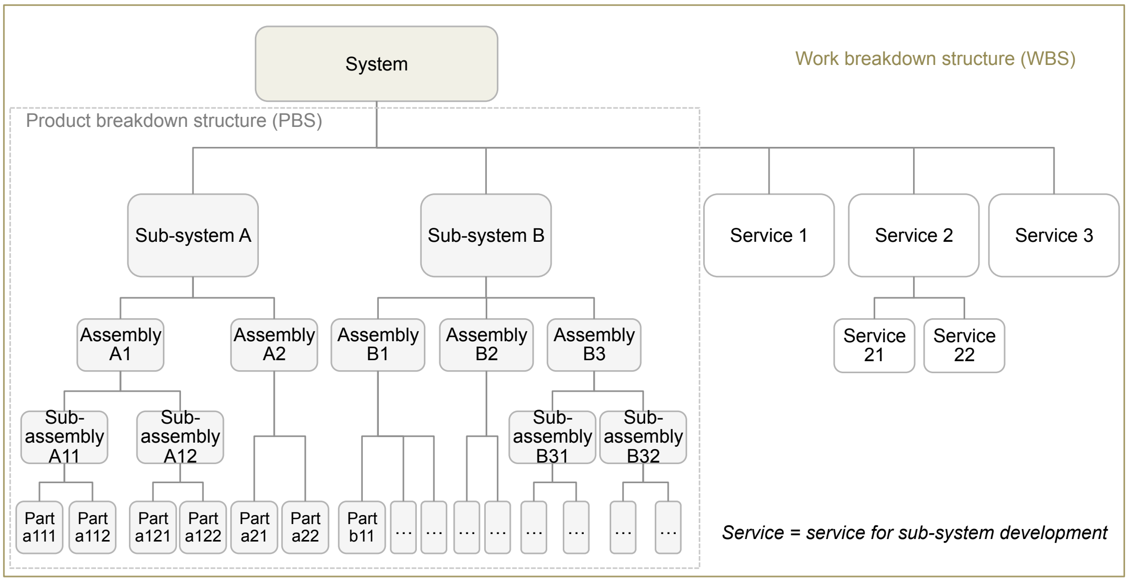


Figure 2-13 A work breakdown structure and its product breakdown structure (adapted from Shishko & Aster, 1995, p. 31 Figure 10)

It is important to note that the product-based WBS is entirely focusing on the products within the system. The services represented in the WBS are internal services to support sub-system development. An example of such service is management of the development. Any customer-facing services are not represented in this structure. This type of representation might only be useful for a PSS design that has no or minimal service elements.

2.4.2 Characteristics-based representation

The second structural representation reviewed is one that looks at innovation using different sets of PSS characteristics. This model, proposed by Gallouj and Weinstein in 1997, is based on Saviotti and Metcalfe's product representation proposal in the 1980s (Saviotti & Metcalfe, 1984), which was in turn founded on Lancaster's theory of consumer demand (Lancaster, 1966). Traditionally, goods are treated as the "direct objects of utility", but Lancaster's theory has proposed that it is the "properties or characteristics of the goods which utility is derived" from, and "consumption is an activity in which goods, singly or in combination, are inputs and in which the output is a collection of characteristics" (Lancaster, 1966, p. 133). In Saviotti and Metcalfe's (1984) proposal, a product is considered to be a combination of three sets of characteristics: technical (or internal), service (or use) and process (or production) characteristics. Each set of characteristics is represented as a vector. The process vector is mapped to the technical vector, which is then mapped to the service vector of the product.

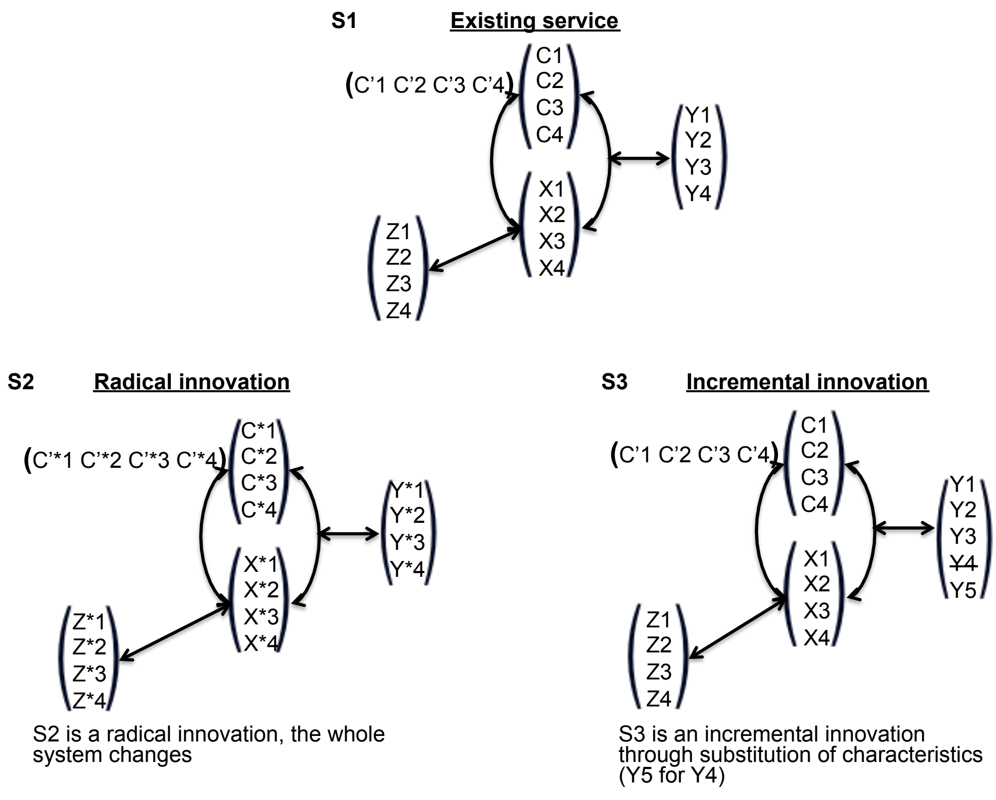


Figure 2-14 Vector representation for service innovation (adapted from Gallouj & Weinstein, 1997)

Gallouj and Weinstein proposed a service's use characteristics [Y] to be mapped to its internal characteristics [X]. The internal characteristics [X] incorporate its production characteristics [Z] as per Saviotti and Metcalfe's proposal. An additional set of characteristics, competencies that comprises both the competencies of the provider [C] and the customer [C'], is added to Saviotti and Metcalfe's proposal. Radical service innovation can be denoted by changing the entire system of {[C'], [C], [X], [Y]}, while incremental service innovation can be represented by substituting a characteristic in [Y], or by splitting or combining characteristics in [Y]. This proposal is seen as one of the first attempts to synthesise research on product and service innovations (Droege, Hildebrand, & Forcada, 2009). While the application of the vector representation to support the engineering design process is not illustrated in the reviewed literature, the proposal has provided a useful way to represent different degrees of service innovation.

The customer aspects [Y] and technological approaches [X] (that have also incorporated the production characteristics [Z]) of innovation are brought together in the vector representation. Depending on the level of details of each vector, and how the mapping among the vectors is done, one can see the flexibility of this model for representing the characteristics of a new PSS design. However, this representation does not help engineering designers to understand the interactions at the element level.

2.4.3 Biological representation

The third type of structural representation is an analogy to biological systems. In the 1980s, the 'molecular model' and the 'organ structure' were proposed. The 'molecular model' was developed to help marketing professionals to visualise and understand a commercial offering, as well as to show the structural relationships among the elements within an offering (Shostack, 1982). The organ structure was proposed to assist engineering designers to visualise the functional connections among the components of a technical system (Hubka & Eder, 1988; Hubka, 1982). Figure 2-15 and Figure 2-16 show these two models respectively, using the same hypothetical example of a new running group offer developed by a running club.

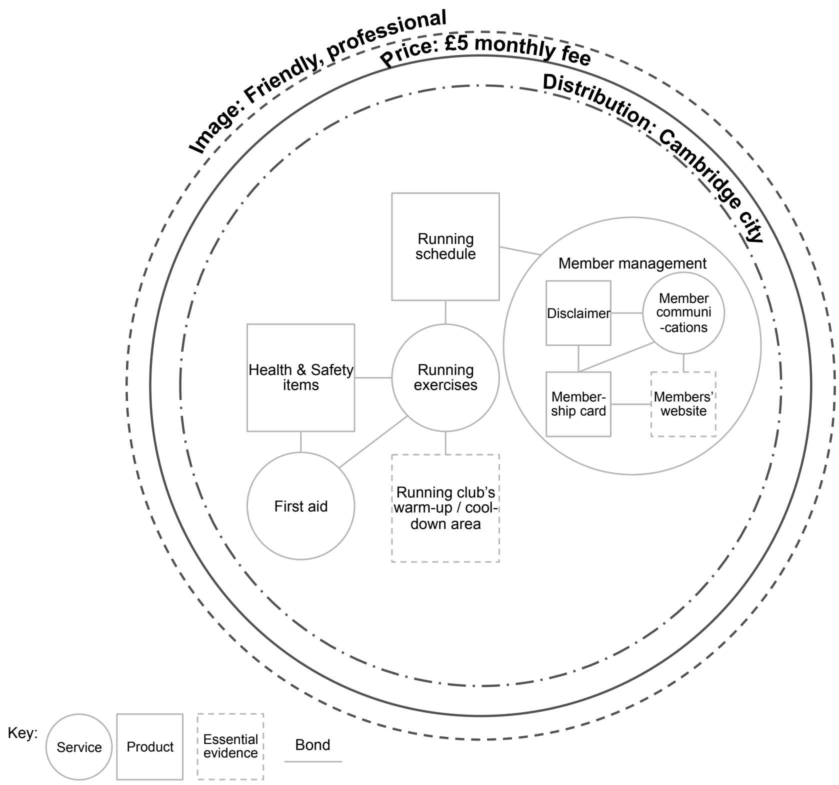


Figure 2-15 An example the 'molecular model' (adapted from Shostack, 1982)

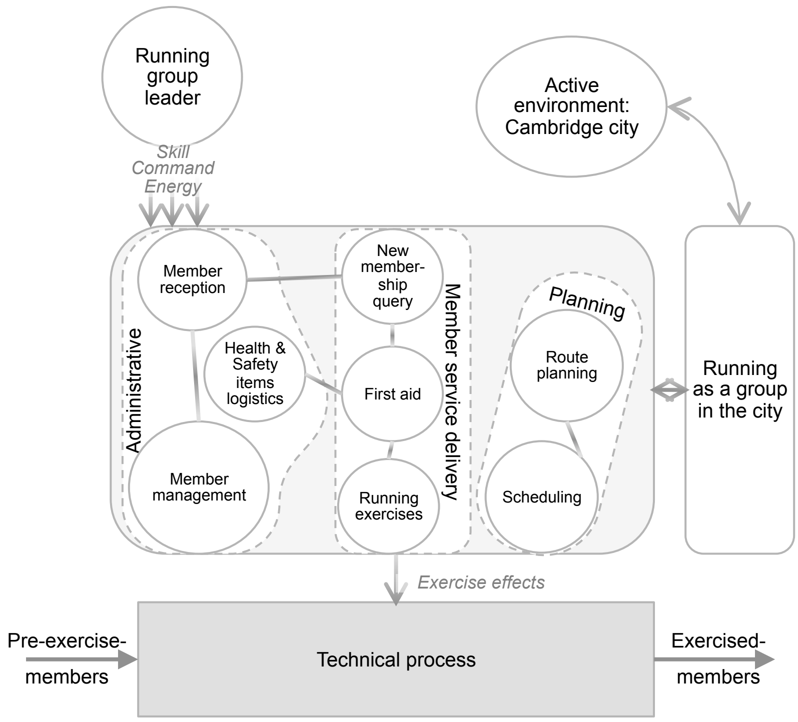


Figure 2-16 An example of the 'organ structure' (based on Hubka & Eder, 1988)

In Shostack's 'molecular model', the key product elements, service elements and essential evidence, are drawn inside rings representing the company's advertising (image), pricing and distribution strategies. Each key product and service element can have sub-product and sub-service elements. The key elements are the primary ones that customers would be buying or consuming, and the essential evidence comprises of products that are not to be given to the customers (Shostack, 1982). For example, a member-access only web portal is essential evidence to membership management services. An environment where a service is delivered, such as where the running group does the warm-up and cool-down exercises, can also be considered as essential evidence. The analogy of the product and service elements being atoms of a molecular structure helps marketing and management to consider the potential impact of rearranging or modifying one of the elements within the PSS offering. A company could also use the 'molecular model' to show the structure and relationships among elements within a potential PSS offering (Shostack, 1982).

The 'organ structure' is different from the 'molecular model'. It is designed for mechanical technical systems, and the product elements are not listed out individually. The proposal is based on an "anatomy structure" of hierarchical levels, described by different "degree[s] of complication" (Hubka, 1982, p. 18). For machine-based systems, the degrees of complication would be equipment, machine, assemblies and parts. Organs are defined as function-carriers, which can be grouped into different categories: "transformation organs" that cause the main transformation; "auxiliary organs" that produce supplementary effects needed for the main transformation; "energy organs" that deliver the energy needed for the transformation; "control organs" that process information; and "connection organs" that provide the interfaces with other organs or the fixed system (e.g. the ground) (Hubka, 1982). When organs are linked with a suitable "transformation organ," a "transformation organism" is formed (Hubka & Eder, 1988).

Within the process of engineering design, the 'organ structure' supports the process of defining the required functional structure of a new technical system (Hubka, 1982). 'Organ structure' is different from a 'function structure', which is a structure representing the general functions of a technical system. The 'organ structure' shows the functional connections between components (parts) by means of different organs. An organ can also perform multiple functions (Hubka & Eder, 1988). With an 'organ structure' defined, an engineering design team can work on defining a more detailed, or a less abstract, form of representation to shows all the component parts and their relationship. This representation is called a component structure.

Figure 2-17 shows the different level of abstraction in representing a technical system in one dimension, and the interested functions of the organisation in the other dimension. The 'organ structure' has an abstraction level between a 'function structure' and a 'component structure'.

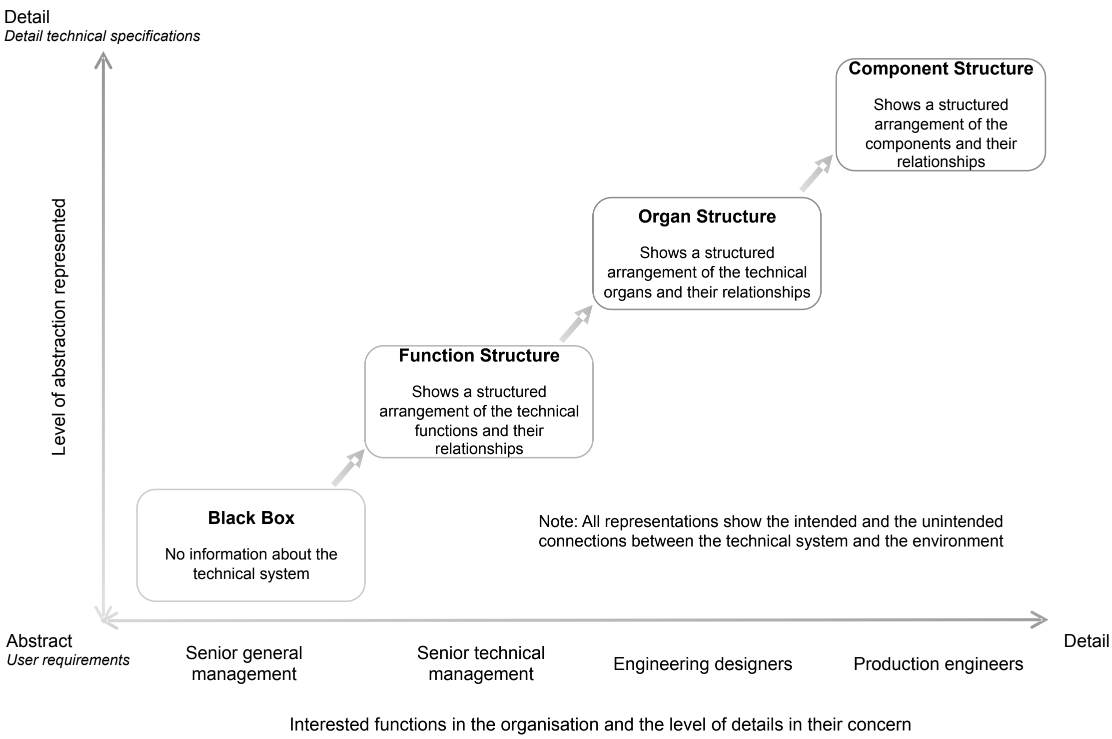


Figure 2-17 Different level of technical system representation (adapted from Hubka & Eder, 1988, p. 66)

2.4.4 Service system interaction representation

The last structural representation reviewed in this section is one that examines the interactions within a service episode. It is called the ISPAR model of service systems interaction episodes, which stands for "Interact-Serve-Propose-Agree-Realize" (Spohrer et al., 2008, p. 6). In order to appreciate the ISPAR model, the definitions that Spohrer et al. (2008) have used need to be first recapitulated. Service is defined as "the application of resources for the benefit of another" (Spohrer et al., 2008, p. 1). A service system is defined as "a dynamic value co-creation configuration of resources, including people, organizations, shared information (language, laws, measures, methods), and technology, all connected internally and externally to other service systems by value propositions" (Spohrer et al., 2008, p. 5).

According to Spohrer et al. (2008), only those system interactions that result in considerable 'value co-creation' are service interactions. The ISPAR model has generalised that every service interaction involves three main activities: (1) one service system making a proposal to another service system; (2) the latter service system agreeing to the proposal; and (3) the service systems realising the proposal. After the acceptance of a proposal, the proposed value might be evaluated as successfully realised or not by one or both parties. If the realisation is unsuccessful, the parties could find themselves in dispute with a satisfied or unsatisfied resolution.

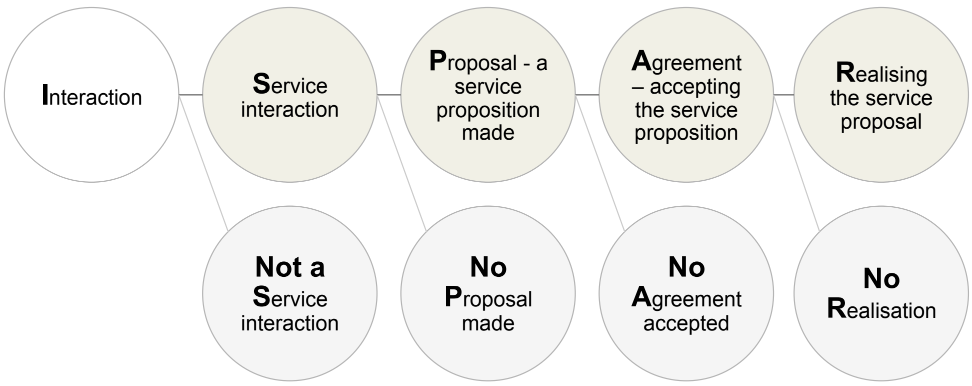


Figure 2-18 A simplified service system interaction model (adapted from Spohrer et al., 2008, p. 6 Figure 1)

As seen in Figure 2-18, the ISPAR model is a generic representation of service systems in the world, allowing analysis of potential service interaction episodes between pairs of interacting service systems. The historic occurrence of different outcomes during life cycle service interaction episodes can help companies to evaluate the value created in each service interaction episode, and to make improvements accordingly (Spohrer et al., 2008).

2.4.5 Learning from literature on structural representations

This section has provided a brief review of a variety of structural representations of a PSS. Despite the diversity of the origins of these models, which range from economics, marketing, service management, to technical system engineering and complex system engineering, these models show potential to be applied in PSS engineering design.

The product-based WBS model used in NASA and the two biological representations, the 'molecular model' and the 'organ structure', pay more attention to the internal elements and their dependencies. In particular, the 'organ structure' is capable of depicting the functional connections among components within a system. Although the WBS facilitates the handling of complex technical systems, it could potentially be less suitable for PSS with a lot of service content. On the other hand, the 'molecular model' is designed for handling PSS representations. Interestingly, despite being developed with a mechanical system in mind, the 'organ structure' is equally applicable to other PSSs, as shown in Figure 2-16. Both the WBS and the 'organ structure' show limited linkages to the environment. The WBS shows the services in the development environment upon which system development depends upon. The 'organ structure' shows the physical linkages between the PSS and its operating environment.

The vector representation and the ISPAR model pay more attention to the potential value created as a result of a service interaction. The vector representation maps the characteristics of internal, process, and company's and client's competencies to the use characteristics of a new service. The use characteristics of a product or service are where the utilities are derived, according to Lancaster's theory of consumer demand. This representation can be used to list in detail the characteristics of the constituent elements within a PSS and to identify characteristics which customers might value. The ISPAR model does not limit the study of service systems to a commercial PSS. For its application in PSS engineering design, the ISPAR model allows companies to systematically evaluate the outcomes of different service interaction episodes using historic scenarios and outcome data.

The reviewed structural representations show the considerations which companies may need when designing a new PSS: what the key product and service elements and their sub-elements are, their relationships, their functional connections, how the PSS is being produced and consumed, and when value is created for both the company and the customers. The 'organ structure' is the only representation depicting connections between the PSS and its operating environment, which is arguably a concern as the operating environment may put additional constraints on the PSS design specification. Depending on the complexity of the PSS, some structural representations may be more appropriate than others in supporting the engineering design process.

2.5 Stakeholder theories and identification techniques for engineering design

As seen in the section 2.3, an engineering design process involves human and non-human actors. Therefore, a review of stakeholder theories and stakeholder identification theories and techniques for the engineering design process is necessary for this research. In this section, the primary definitions and theories of stakeholder theories are first reviewed, followed by a review of relevant stakeholder identification techniques and studies on stakeholder involvement in NPD, NSD or NPSSD. Literature gaps are highlighted, and a short description of the work completed in this research to address the identified gaps is provided in the section conclusion.

2.5.1 Stakeholder definitions

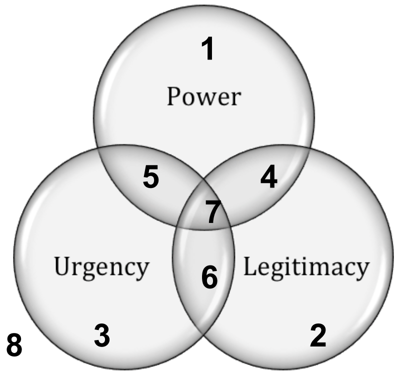
Many researchers have summarised discussions about stakeholder definition (e.g. Bryson, 2003). Some views limit stakeholders to those who have legitimate claims on the company (Donaldson & Preston, 1995). Building upon Thompson's (1967) claim that stakeholders are "those groups which make a difference" (cited in Freeman, 1984, pp. 42, 45), Freeman (1984) proposed a broader stakeholder definition. He defined a stakeholder as:

> *"... any group or individual who can affect or is affected by the achievement of the firm's objectives."* (Freeman, 1984, p. 25)

This wider definition of a stakeholder is more appropriate when investigating stakeholder involvement in the engineering design process, because multiple internal and external stakeholder groups, not just those who might become claimants of the companies, may be impacted by the new PSS. Therefore, modified from Freeman's definition, a stakeholder is defined in this research as **any group or individual who can affect or is affected by the new PSS**.

2.5.2 Stakeholder theories

In this sub-section, stakeholder theories for management strategies and theories of stakeholder influence in NPD/NSD are reviewed. For management strategy, one of the more frequently cited theories of stakeholder identification is the proposal by Mitchell, Agle and Wood (1997). Mitchell et al. suggested eight stakeholder typologies that are based on three stakeholder attributes: power, legitimacy and urgency (see Figure 2-19) (Mitchell, Agle, & Wood, 1997). These typologies have been adopted by other researchers (Bryson, 2003; Smirnova, Podmetina, Väätänen, & Kouchtch, 2009; Susnienė & Vanagas, 2007a). A stakeholder with only one attribute is a "latent stakeholder", with two is an "expectant stakeholder" and with all three is a "definitive stakeholder". This proposal also argued that the stakeholder attributes are variable, and depend on subjective perceptions of parties in the relationship. The stakeholder may not be aware of possessing the attribute or may choose not to impose it.



Stakeholder who possesses:
One attribute: Latent stakeholder
Two attributes: Expectant stakeholder
Three attributes: Definitive stakeholder

Typology:
1=Dormant 5=Dangerous
2=Discretionary 6=Dependent
3=Demanding 7=Definitive
4=Dominant 8=Non stakeholder

Brief explanation of the attributes:
One has power if one party can impose on the other what it desires through coercive means
One's actions are legitimate if they are generally seen as appropriate within the social norms
One's claim is urgent if it is time-sensitive and critical, such as requiring immediate managerial attention

Figure 2-19 Stakeholder Typology (adapted from Mitchell et al., 1997, p. 874 Figure 2)

Mitchell et al. (1997) have further proposed a theory of stakeholder salience, which is a dynamic model that allows managers to evaluate and predict how stakeholder could change from one class to another. For example, an "expectant stakeholder" (having only two attributes) could be expected to attempt to acquire the remaining attribute in order to become a "definitive stakeholder".

A brief description of other stakeholder theories for management strategy is summarised in Table 2-2.

Table 2-2 Proposal of selected stakeholder theories for management strategy

	Brief description of contribution
Proposed a stakeholder theory	Extended agency theory to explain the relationships among firm's stakeholders and managers' behaviours (Hills & Jones, 1992; Quinn & Jones, 1995)
	Trustworthy and cooperative firms tend to have competitive advantage (Jones, 1995)
	Predicts a firm's reactions to stakeholders' demand using social network analysis (Rowley, 1997)
Proposed an approach to stakeholder theories	Existing stakeholder theories can be classified as: descriptive, instrumental and normative; all share a common normative core (Donaldson & Preston, 1995)

The management strategy literature does not offer further insight into how stakeholders affect the NPD/NSD process. However, market-orientation literature has provided theories about the processing of market information for NPD (Driessen & Hillebrand, 2013). One proposal viewed market-orientation as three processes: intelligence generation, intelligence dissemination and responsiveness (Kohli & Jaworski, 1990). This organisational learning perspective has been adopted by other scholars (M. Adams, Day, & Dougherty, 1998; Moorman, 1995). The three market-orientation processes are subsequently adapted as: market information acquisition, market information dissemination and responsiveness to the market information (Driessen & Hillebrand, 2013).

Another proposal views market-orientation as a business culture with three behavioural components: customer-orientation, competitor-orientation and inter-functional coordination (Narver & Slater, 1990). This perspective is resulted from an empirical study on the impact of market orientation and interdepartmental integration on new development performance (Kahn, 2001). Interestingly, Kahn's study has shown that none of the market-orientation components proposed by Narver and Slater are relevant to the managers in the research and development department in terms of achieving new development success.

From the stakeholder theories from management strategy and market-orientation, a definition of stakeholder involvement in the engineering design process for this research is resulted. In this research, stakeholder involvement in the engineering design process is: the process of acquiring the perceived-value of each stakeholder for the dissemination to and responses by the engineering design team. Figure 2-20 depicts this potential process for stakeholder identification and engagement in PSS engineering design.

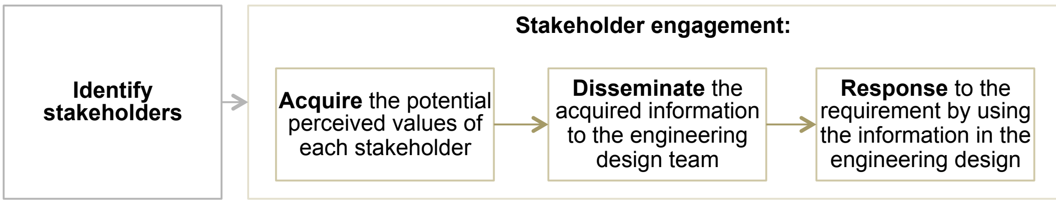


Figure 2-20 A potential stakeholder identification and engagement process for PSS engineering design (adapted from M. Adams et al., 1998; Freeman, 1984)

2.5.3 Stakeholder identification and analysis techniques

Stakeholder analysis aims to integrate stakeholder interests into the company's strategy and operations plan (Freeman, 1984; Susnienė & Vanagas, 2007b). In general, an analysis involves: the identification and prioritisation of stakeholders, an understanding of the values hold by the stakeholders and by the company, an understanding of the impact of environmental factors on stakeholders' values, and an evaluation of how to incorporate stakeholders' values into company's strategy (Bryson, 2003; Freeman, 1984; Susnienė & Vanagas, 2007a).

Most of the proposed stakeholder analysis tools are in the format of a two dimensional grid, with one dimension being "power" (e.g. Bryson, 2003; Freeman, 1984; Kipley & Lewis, 2008; Williams & Lewis, 2008). "Interest", "influence", "threat" or "resistance" to a company's decision are candidates for the other dimension of the two dimensional grid. Appendix 01 provides a summary of the tools for stakeholder analysis, which are grouped into three categories according to purpose: to identify and categorise stakeholders; to identify stakeholder and analyse sources of influence; and identify stakeholders and guide stakeholder management strategies formation.

2.5.4 Stakeholder involvement in the engineering design process

Many published studies of stakeholder involvement in NPD and NSD have focused relatively narrowly on the interactions between companies and their customers or lead users. These studies have shown mixed results. The findings include:

- Positive impact: Lead users' involvement is important to NPD in high-tech industry (scientific instrument) (Von Hippel, 1976), low-tech industry (Herstatt & Von Hippel, 1992), and commercial banking industry (Oliveira & von Hippel, 2011).
- No impact: No impact results from involving customers in NPD in a case study in Russia (Smirnova et al., 2009).
- Negative impact: Customer involvement in NSD does not improve market measurements of competitiveness and sales, but improves internal operational metrics of innovation speed and technical quality (Carbonell, Rodiguez-Escudero, & Pujari, 2009). This implies a company cannot improves its market performance by involving customer in is NSD process.

In the last 10 years, some stakeholder involvement investigations have extended to suppliers and other stakeholders such as outside research organisations. For example, it has been reported that it is important to have suppliers' involvement, but how to involve them to achieve better results is yet to be identified (O'Sullivan, 2006). It has also been reported that there is a positive impact resulting from involving external research organisations in the new development process (Smirnova et al., 2009).

A wider, multiple stakeholder view, or the criticism of the lack of such a view (Wind & Mahajan, 1987), has also been the topic of investigation in some studies of marketing and NPD activities. For example, the empirical study mentioned in sub-section 2.5.2 by Khan has looked at internal stakeholder groups including the managers of marketing, manufacturing, and research and development departments. A wider range of stakeholder groups has also been involved in a study on new product launch tactics (Talke & Hultink, 2010). This study has included customers, suppliers, dealers, legal and political institutions, internal frontline employees and competitors.

2.5.5 Learning from literature on stakeholder identification and involvement

Stakeholder concepts, theories from management strategy literature and market-orientation literature, and stakeholder analysis tools and techniques have been reviewed in this section. The studies of stakeholder involvement in NPD/NSD have historically been focusing mainly on lead users or customers and have not had any conclusive results. There is an increasing interest in recent years in studying the involvement of other stakeholder groups. However, many of these studies are case specific and do not have an interest in the engineering design process, which is the focus of this research.

As a result, in the Phase I of this research (to be presented in chapter 5), an investigation of the stakeholder groups which are relevant to the engineering design process in healthcare PSSs was carried out. This has resulted in a preliminary proposal of the stakeholder identification framework, which has been developed using 11 cases. This stakeholder identification framework has four levels and consists of 32 stakeholder groups (see Appendix 02). This framework was then used in all workshops involved in the Phase II of this research, to support the exploration of the influences of applying the proposed PSS characterisation scheme (the main finding of Phase I) on PSS design specification. Two examples of the application of this framework in new PSS development, one in the healthcare informatics sector (Yip et al., 2014b) and the other in the financial service industry (Yip & Juhola, 2014), have been published in the Engineering Management Journal and the conference proceedings of Portland International Center for Management of Engineering and Technology (PICMET) respectively.

2.6 Contextual factors and their influence on engineering design

As reviewed in the previous section, the environment where a service is being prepared and delivered is complex (see Figure 2-6). The value-creation process centred on the usage of the new PSS is context-dependent. In this section, the concept of contextual factors in the environment is reviewed from the perspectives of technical systems, business strategy, and sociotechnical studies. The different disciplines involved are engineering, business strategy and sociology. The relevant concepts from these disciplines are first reviewed, followed by a presentation of the inspirations obtained for this research.

2.6.1 The perspective of technical systems

The concepts of the environment and the "active environment" can be seen in the theory of technical systems, which aims to promote the understanding of technical systems (Hubka & Eder, 1988). In this sub-section, the transformation system is reviewed as a whole, in order to provide the context for the understanding of "environment" from the perspective of technical systems.

The theory of technical systems was built upon a broad view of sociotechnical transformation systems. As a result, the statements and propositions proposed under this theory are robust when used to describe any processes where inputs are transformed to outputs to fulfil human needs, by means of the systematic effort of a combination of human and technical operators in society (Hubka & Eder, 1988). The applications of the theory of technical systems to the engineering design process and to a newly designed PSS are explored in the following paragraph.

When the theory of technical systems is applied to the engineering design process, design activities can be viewed as technical processes that transform information from a list of customer requirements to a specification of a product, service or PSS (Hubka, 1982, 1983). The environment where the designers work impacts this information transformation process. When the theory is applied to a newly designed PSS, the transformation is about the change of state of an operand in the operating environment where the preparation, production and consumption of the products and services are located (Hubka & Eder, 1988). As recognised by Pahl et al. (2007), "systems connected to the environment by means of inputs and outputs" (Pahl et al., 2007, p. 27).

Figure 2-21 illustrates the two transformation systems of design and service delivery. The operand being transformed in the diagram on the top portion of Figure 2-21 is information. The operands being transformed in the diagram on the bottom portion of Figure 2-21 are people (T. P. Hill, 1977), for example, exercisers going through a running routine and have their heart and metabolic rate, mood and perception about their health status changed. The transformations of the operands are achieved by the application of purposeful effects of materials, energy and information (Hubka & Eder, 1988; Pahl et al., 2007).

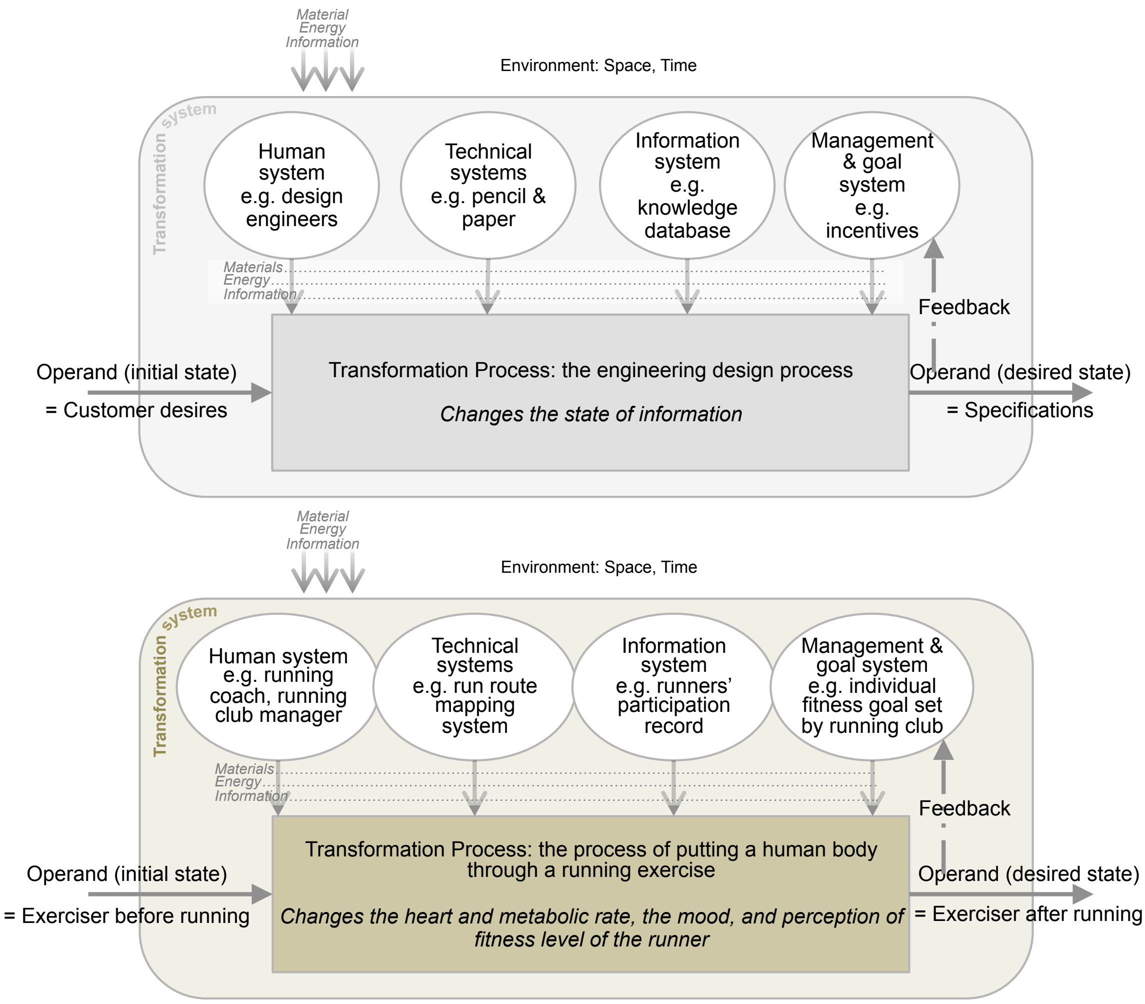


Figure 2-21 Transformation system (adapted from Hubka & Eder, 1988, p. 24 Fig. 3.2; Hubka, 1983, p. 188 Figure 1)

As seen in Figure 2-21, the transformation system is situated within an environment. According to Hubka and Eder (1988), a transformation can be influenced by many factors including: human operators; technical systems or artefacts that are involved in transforming the operands; management and goals which guide or direct the transformation; and information required for the transformation. The portions of the human, technical, management, information and management systems that are actively involved in the transformation process are considered to be part of the "active environment". The time and space where the transformation takes place also constitutes the "active environment".

Hubka and Eder (1988) further explained the concepts of system environment and "active environment". As seen from the quotes below, while the components of a system environment are drawn from a broad view of sociotechnical systems, the definition of "active environment" of a system is more restrictive.

> *"Every system environment contains the following constituents: geosphere, atmosphere, biosphere (including humans), technosphere and astrosphere" (Hubka & Eder, 1988, p. 246).*
>
> *"The active environment of a system S is the environment that contains the systems that ... must have at least one element that receives as its input an output from an element of the system S" (Hubka & Eder, 1988, p. 246).*

"Geosphere" in the above statement refers to the land and water. "Biosphere" refers to the living world that encompasses all living organisms and the locations where they live. "Astrosphere" can be taken as climate and atmosphere in most cases. According to Hubka and Eder (1988), the "geosphere", "biosphere" and "atmosphere" combined to form various ecosystems. Among the "geosphere", "biosphere" and "atmosphere", relationships exist that enable the processes of transformation, and their balance must be respected when developing a new transformation system. There are also relationships between the ecosystem and the "technosphere". The term "technosphere" is used to refer to “all technical systems that have been or will be produced by humans within the space and time under consideration” (Hubka & Eder, 1988, p. 32).

The concept of environment from the perspective of technical system essentially follows the theory of technical systems. The theory of technical systems has provided an input/output view of a systematic transformation of operands’ states in an “active environment” by means of the intentional effects of material, energy and information. The “active environment” is presented as the subset of system environment which is involved in the transformation process. The system environment is part of the broader ecosystem of “geosphere”, “biosphere” and “atmosphere”. In this perspective, for the engineering design of a new PSS to fulfil a specific human need, the considerations to be taken by the engineering designers include: what and how the PSS is intended to transform, under what “active” environmental conditions is the transformation going to take place, and how the PSS could impact the contextual factors within the “active environment”.

2.6.2 The perspective of business strategy

External environment is an important aspect in the design of new offering, as it influences both the design and the customer experience (Cook, Bhamra, & Lemon, 2006; Gummesson, 2007; Maussang et al., 2009). Literature about business ecosystem and strategy provides frameworks to describe and identify contextual factors that influence engineering design.

In the literature about business ecosystem, there is much debate as to whether an analogy should be drawn between biological and business ecosystems (e.g. “Business as a living system: the value of industrial ecology (a roundtable discussion),” 2001) and how the two differ (e.g. Peltoniemi, 2006). These debates are omitted in the review below, as they have little relevance to this research. Table 2-3 summarises the key concepts that are shared among the reviewed business ecosystem literature.

Table 2-3 Business ecosystem key concepts

Key concepts	California Management Review (2001)	Iansiti and Levien (2004)	Moore (1993, 1996, 2006)	Peltoniemi (2006)	Peltoniemi and Vuori (2004)	Wenzek (2004)
Businesses co-evolve			x	x	x	
Compete and cooperate/collaborate at the same time	x	x	x	x	x	x
Ecosystem sets constraints for businesses	x	x	x		x	
Difficult to draw the precise boundary, it spans across industries	x	x	x		x	
Modular/Platform approach in product design		x	x			x
Different roles in the business ecosystem		x	x		x	x

(Reference: "Business as a living system: the value of industrial ecology (a roundtable discussion)," 2001; Iansiti & Levien, 2004; Moore, 1993, 1996, 2006; Peltoniemi & Vuori, 2004; Peltoniemi, 2006; Wenzek, 2004)

The concept of the business ecosystem boundary is the most applicable to this research as it relates to where a company can identify its stakeholders. Figure 2-22 provides insights into who may impact a company, if the company can look beyond the extended enterprise boundary to include government, regulatory bodies and other stakeholders.

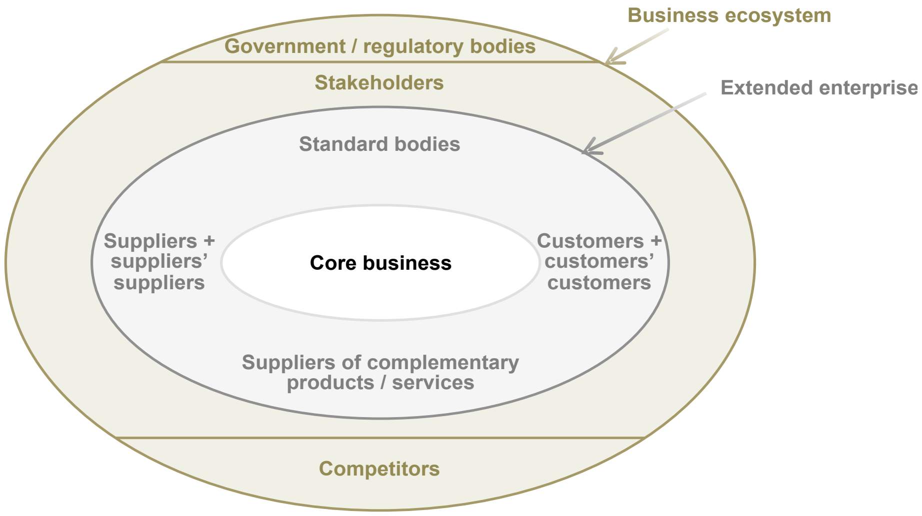


Figure 2-22 The scotch egg model of sources of stakeholders (adapted from Moore, 1996, p. 27 Fig. 2.1)

Another category of frameworks for exploring environmental factors from a business strategy perspective is strategy frameworks. Two business strategy frameworks by Porter are reviewed as they help structuring the contextual factors that influence a company's new product or service strategy. The 'diamond framework' (Porter, 1990a) captures the four determinants of the competitive advantage of a nation. This framework was used to understand the external factors that could impact a company's competitiveness in a study of corporate philanthropy (Porter & Kramer, 2002). The 'value chain framework' (Porter, 1985) depicts a firm's activities without the constraints imposed by traditional departmental boundaries. This framework could help companies to identify how stakeholders may be impacted by a new PSS, similar to the illustration by Porter and Kramer's corporate social responsibility study (Porter & Kramer, 2006). Examples of using these two frameworks to identify contextual factors that may influence a new healthcare PSS are provided in Appendix 03.

The literature of business ecosystems and strategy provide frameworks for depicting the interactions across different industries, among different firms and within a firm. The models reviewed in this sub-section discuss the contextual factors of a new PSS.

2.6.3 The perspective of sociotechnical studies

According to actor-network theory (ANT), a theory derived from Science and Technology Studies (STS), the work of engineering is not fundamentally different from other social activities (A-Ritzer-Encyclopedia.qxd, 2004). ANT is a theory of agency that encourages researchers to explore social effects when examining how things are structured and organised (Law, 1992). ANT is different from the Edinburgh's school of sociology of scientific knowledge (SSK). SSK studies the preconditions in society that influence the creation of scientific knowledge, that is the study of 'society in science'; ANT studies the role of science in society, that is the study of 'science in society' (Seguin, 2000).

ANT proposes that actors related to an area of interest include both humans and non-humans, and that all actors connect to each other continuously, forming an extended network. Within the network, one can follow a sequence of impact without 'jumping' from a 'local site' to a 'larger framework'. By 'jumping', it means things within a room are studied differently than things within a global framework. The connections among actors can be examined as part of a "flattened topography". This forces all actors to be placed side-by-side regardless of their level of categorisation (Latour, 2005).

According to Law (1992), using the actor-network theory, an organisation is an achievement, a process, a consequence and a precarious effect. Applying this rationale to the study of PSS engineering design, a new PSS can be viewed as a precarious effect of human and non-human actors (Latour, 2005) that belong to different levels within the environment. More specifically, using the previous example of a new running group offer developed by a running club (see sub-section 2.4.3), the application of the ANT approach is illustrated in Figure 2-23.

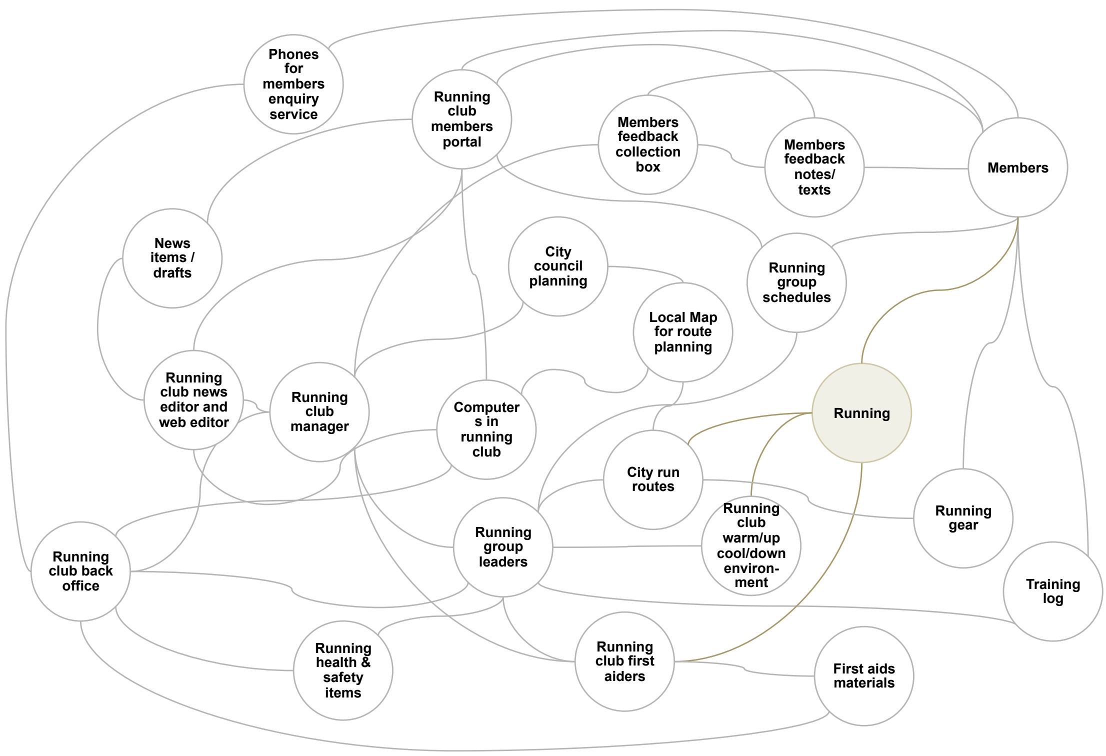


Figure 2-23 Applying ANT approach to a hypothetical example of a new running group offer development

ANT is a useful approach to explore how contextual factors, comprising human and non-human actors, connect with a new PSS. In particular, how the actors link to one another, from the 'local site' of the engineering designers' office to the 'larger framework' where a PSS is purchased, used, consumed and recycled is evident in this approach.

2.6.4 Learning from literature on contextual factors

In this section the concept of contextual factors in the environment is reviewed from the perspectives of technical systems, business strategy, and sociotechnical studies. From the theory of technical systems (Hubka & Eder, 1988), the concept of the "active environment" is presented as a subset of system environment. This subset is involved in the transformation process. The system environment is in turn part of the broader ecosystem of "geosphere", "biosphere" and "atmosphere".

From the perspective of business strategy, business ecosystem and two business strategy frameworks are reviewed. The concept of the business ecosystem extends the boundary of companies beyond enterprise, across firms and industries. The 'diamond framework' and 'value chain framework' proposed by Porter are found to be useful tools for identifying relevant contextual factors for new PSS development. Compared to the concept of "active environment" from the technical systems perspective, the view of relevant environmental factors from the business strategy perspective appears to be broader and less restrictive.

From the perspective of sociotechnical systems, actor-network theory (ANT) can be used as an approach to study the contextual factors influencing PSS engineering design, where humans and non-human actors connect to one another, forming an extended network. These connections, when drawn by forcing the actors to be put next to one another, without prejudicing the positions of the actors, can help the company to understand the environment for the design, development, production, consumption and recycling of a new PSS.

In this research, contextual factors are understood as the factors in an "active environment" where the new PSS is to be operated and used. Tools supporting the engineering design process are also technical systems that transform PSS ideas into PSS design specification. The "active environment" for these tools consists of the materials, energy and information used in the engineering design process, and the space and location where the engineering design process takes place.

2.7 Summary of literature review

In this chapter, the five areas of literature which are most relevant to this research are reviewed: the definitions and classifications of product, service and PSS, the theories and process models for engineering design, the structural representations, the stakeholder theories and identification techniques, and the exploration of contextual factors for the engineering design process. This work is summarised in Figure 2-24.

As presented in Chapter 1, the definition of PSS design specification in this research includes: (1) the product and service features; (2) the stakeholder involvement needs; and (3) the contingent environmental factors. The four gaps identified directly relate to the three aspects of PSS design specification:

- Lack of a valid and useful PSS classification scheme that does not rely on 'tangibility' to separate products and services. This impacts the clarity of product and service requirements.
- Lack of an holistic prescriptive method that helps engineering designers to generate both the overall value creation process and provides the PSS technical details. This impacts the effectiveness of identifying all three aspects of a PSS design specification.

- Lack of structural representation that depicts the connections between a PSS and its operating environment. This impacts the clarity of both product and service features and the contingent environmental factors.
- Lack of studies of multiple stakeholder involvement in the engineering design process. This impacts the clarity of stakeholder involvement needs.

A clear design specification is crucial for manufacturers to develop a new PSS that customers desire and one that they can create value with customers when the new PSS is in use. Therefore, it is important to address the identified gaps.

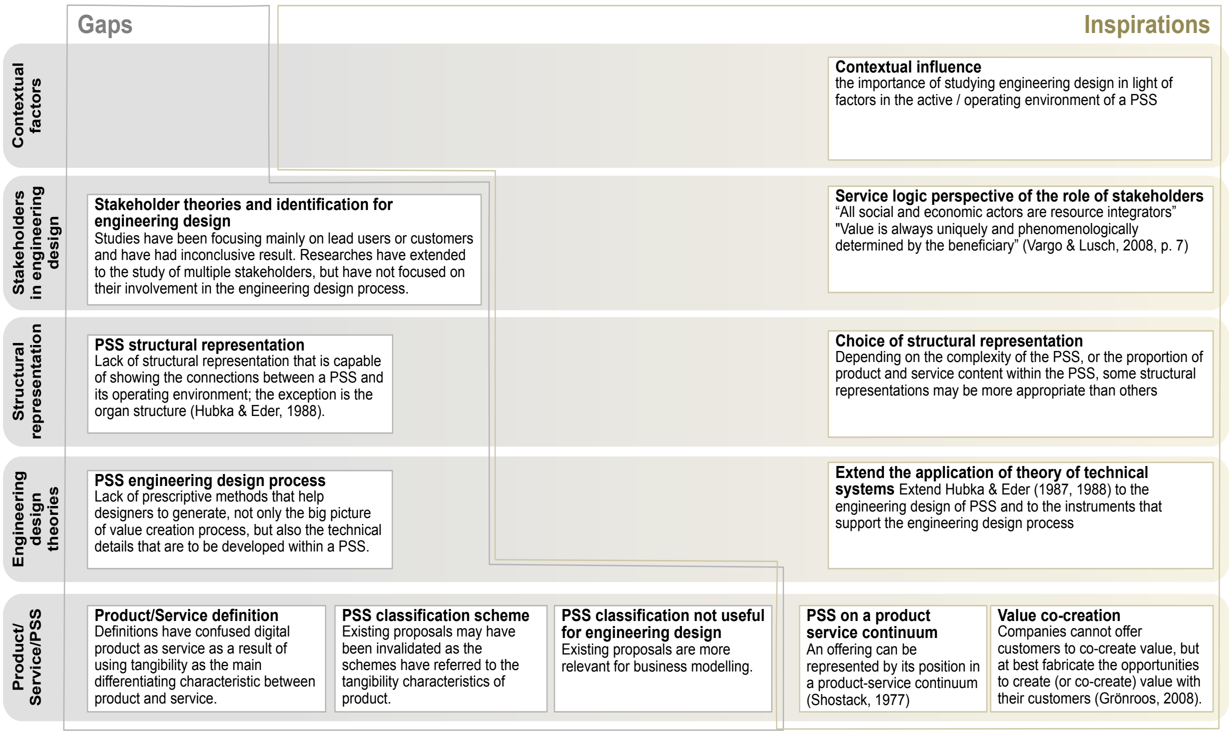


Figure 2-24 Literature: gaps and inspirations

Inspired by the theory of technical systems proposed by Hubka and Eder (1988) and the main phases of an engineering design process proposed by Wallace and Burgess (1995), the philosophical position assumed for the engineering design process in this research is summarised in Figure 2-25. It has also been concluded in section 2.3 that the application of the theory of technical systems can be extended to PSS engineering design and instruments supporting the engineering design process.

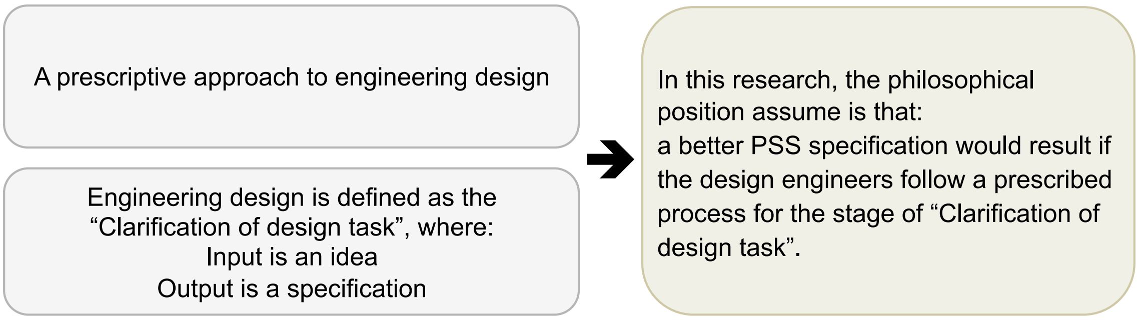


Figure 2-25 The philosophical position for engineering design of product-service system

Stimulated by the literature, in particular, the product-service continuum (Shostack, 1977), the 'molecular model' (Shostack, 1982), the 'organ model' (Hubka & Eder, 1988), the representation of the "active environment" in a technical system structure diagram (Hubka & Eder, 1988), and the idea of a business/industry environment in the ecosystem (Moore, 1996), the following PSS representation schema for different product-service content is generated (see Figure 2-26). This schema is tested in the pilot study that is to be presented in chapter 4.

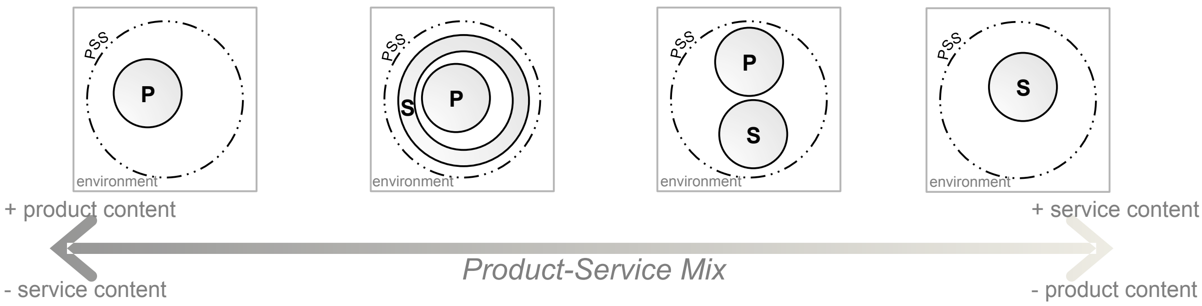


Figure 2-26 PSS representations to be tested in pilot study

Throughout this chapter, definitions of terms adopted are provided. For easy reference, Figure 2-27 presents a summary.

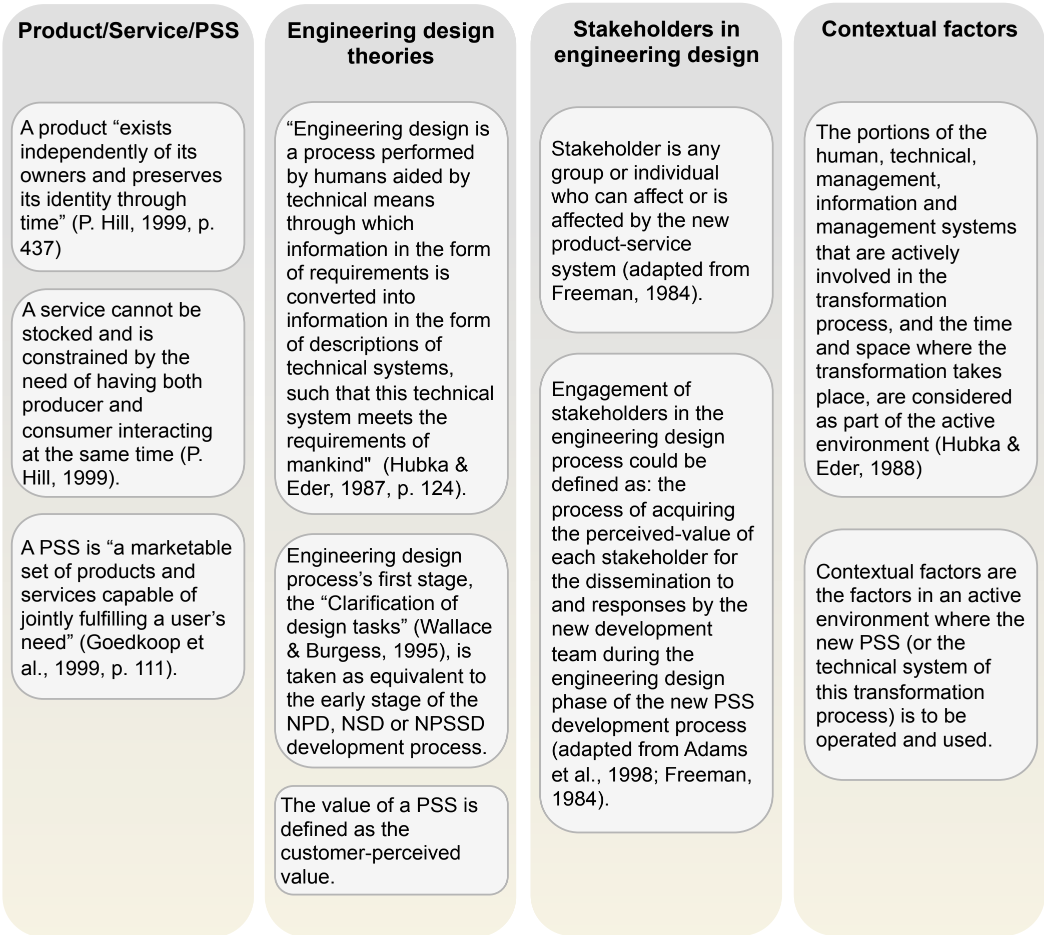


Figure 2-27 Definitions adopted in this research

As seen in this chapter, the topic of interest, the PSS engineering design process, touches multiple disciplines. The review of literature has mostly either followed a product or service perspective, or a technical, business, or sociotechnical perspective, depending on the evolution of the relevant literature in the areas of interest. The rich body of work from these disciplines has informed the background of this research. Building upon the existing work, this research addresses the literature gaps identified by determining the PSS characteristics that are useful for clarifying its design specification, which includes product and service features, stakeholder involvement needs and contingent environmental factors. It contributes to the literature of PSS classification literature and engineering design. The next chapter presents the design of this research and the reason for the appropriateness of the method selected.

3 Research Design

This chapter first presents the research objectives and research questions, followed by the philosophical position. The research methodologies chosen are then presented and explained.

3.1 Chapter introduction

As described in the previous chapters, even though the importance of service to society has been recognised, and many studies have been undertaken to make sense of and to define the concepts of servitisation and value co-creation, previous studies of service innovation appears to be fragmented; at best, they have provided some reasons for why service innovation is an important topic of investigation. Existing theories from engineering, management and sociology have provided good bases for understanding the different perspectives of the PSS engineering design process, but fail to address this cross-disciplinary topic as a whole.

It has also been established that clear PSS design specification is critical for manufacturers and customers to create value through the development and usage of new PSSs. However, existing work may not have addressed this need. The rich body of knowledge in terms of the know-how of new product and new service development (NPD and NSD) has also provided insights into how new product-service system development (NPSSD) can be carried out. However, as discussed in chapter 2, there is a lack of holistic prescriptive engineering design process for PSS. Many approaches either treat services as products, or have focused too much on services and therefore do not provide the technical details required. The literature review has also revealed issues with the commonly used product and service definitions in previous studies, and the general confusion between services and intangible products.

A PSS classification scheme that is useful for engineering design may help manufacturers to generate clear PSS design specifications. One would argue that having unambiguous product and service definitions and knowing which PSS characteristics can clarify design specifications are fundamental to the identification of such a PSS classification scheme.

Therefore, there is an urgent need to research the 'how' of PSS engineering design, for the purpose of arriving at clearer PSS design specification for the development team. This includes how to characterise PSSs for an holistic engineering design process, how to consider both the view of customer-perceived value and environmental influence when characterising PSSs and how a PSS characterisation scheme impacts PSS design specifications.

The following sections first present the research objectives, main research questions and the sub-questions. The philosophical position assumed for this research is then presented. As a result of the objectives defined for the research and the philosophical position adopted, the choice of research methodology is explained and presented.

3.2 Research objectives and questions

This research has two main objectives. The first objective is to define a PSS characterisation scheme that is useful for the purpose of PSS engineering design. Following from the first objective, the second objective is to examine how this PSS characterisation scheme influences PSS design specification. The industry focus for investigation is chosen to be the healthcare industry, for its relevance to society and also because of its complexity, as explained in chapter 1.

To achieve these two objectives, the main research question is: "How may a healthcare product-service system (PSS) be usefully characterised in the PSS engineering design process, and how might this characterisation scheme influence PSS design specification?" This two-part research question can be divided into two phases, with the aim of realising the first research objective in Phase I and the second objective in Phase II. For Phase I, three sub-questions are formulated:

- Sub-question 1: How useful are the existing product, service and PSS classification schemes for the PSS engineering design process?
- Sub-question 2: How to represent the structure of product, service and PSS for the PSS engineering design process?
- Sub-question 3: How to consider the impact of contextual factors in a PSS engineering design?

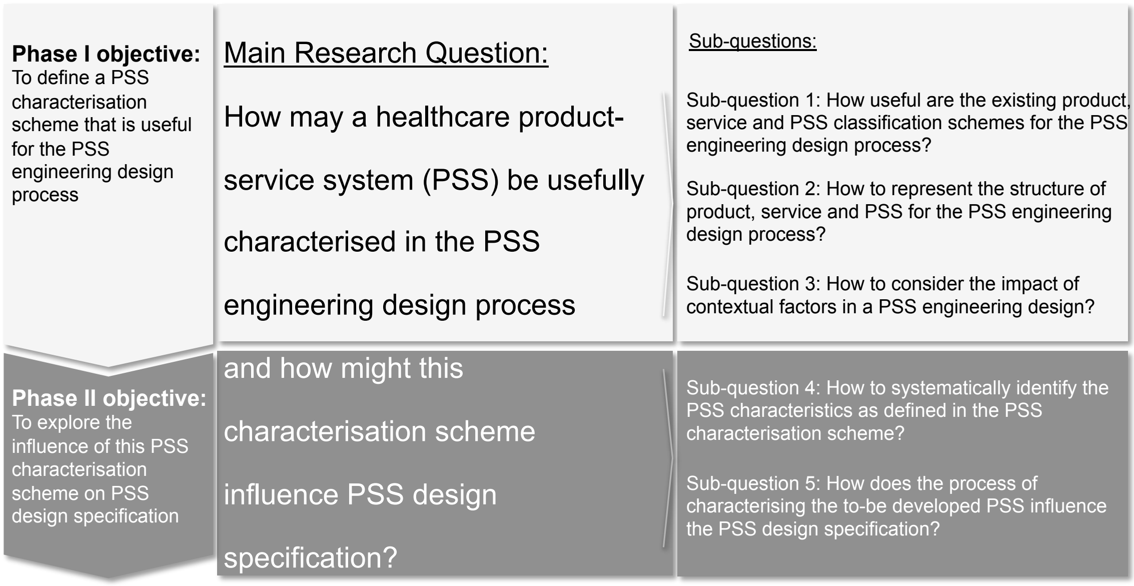


Figure 3-1 Research objectives, main question and sub-questions

These sub-questions intend to explore the potential variables defined during the literature review and in discussions with practitioners in the pilot study (to be presented in chapter 4).

In Phase II, two sub-questions are to be addressed:

- Sub-question 4: How to systematically identify the PSS characteristics as defined in the PSS characterisation scheme?

- Sub-question 5: How does the process of characterising the to-be developed PSS influence the PSS design specification?

These two sub-questions intend to generate knowledge about the impact of the new PSS characterisation scheme on PSS design specification. Figure 3-1 summarises the research objectives, the main research question and the sub-questions.

3.3 Research philosophical position

The philosophical position of this research is internal realism, also known as intersubjectivism. This means that the facts and values are seen as separable, and that 'reality' is believed to be fabricated through the interaction of individuals' consciousness (Runde, 2010). A pragmatic approach is a research method of connecting theory and data through abduction, that is moving back and forth from data to theory via induction and assessing the inferences through action (Morgan, 2007). As the ontological position taken is internal realism, creating knowledge through a practical approach is appropriate (Morgan, 2007).

3.4 Research methodology

Some research strategies are more appropriate than others, depending on whether the nature of the research is exploratory, explanatory or descriptive (Yin, 1994). This research is exploratory in nature. As the research objectives are to propose a PSS characterisation scheme useful for engineering design and to explore the influence of this proposed scheme on PSS design specification, this study could be considered as the initial stage of proposing a direction for new theory building about PSS classification and engineering design. Therefore, this belongs to a theory-building type of research. Given the philosophical position assumed, an appropriate methodology is chosen for each phase of the research for fulfilling the two research objectives.

3.4.1 Phase I research methodology

The research objective of Phase I is to define a PSS characterisation scheme that is useful for the PSS engineering design process, with the intention of identifying variables useful to theory building. The sub-questions that contribute to the identification of variables are exploratory in nature. Because smaller companies do not necessarily have a standard NPD/NSD process, and there is a concern that what is being done may not have followed the documented standard procedure, this research is designed to focus mostly on on-going new development projects. Therefore, the researcher is to work within the constraint of having minimal control over the behavioural development of these contemporary events.

As a result of the nature and intention of the research, and the concerns explained above, the use of case study is an appropriate research strategy (Yin, 1994). Case study is a methodology that allows rich knowledge to be obtained when the boundary between the phenomenon of interest and its context is unclear (Yin, 1994). As described in the literature review, the relationship among the engineering design process, the stakeholders, and the contextual factors is complex and unclear. Furthermore, building theory from cases has a higher probability of generating a novel theory that is more likely to be testable and empirically valid (Eisenhardt, 1989). Therefore, case study is selected as the research methodology for Phase I.

The case study is designed to have a single unit of analysis over multiple cases (Yin, 1994). The unit of analysis is defined as an on-going or recently completed new product, service or PSS development projects, conducted by manufacturers in the healthcare industry (see section 1.2 for the definitions of manufacturers and healthcare) industry). Multiple cases are chosen instead of a single case, because this enables comparisons among cases and allows the investigation of whether an emergent finding can be seen across several cases (Eisenhardt, 1989).

The research design does not start with a definite theoretical proposition, but only some potentially important variables from extant literature. This is because the aim of the research is to contribute theoretical perspectives, and theory-building research is "begun as close as possible to the ideal of no theory under consideration and no hypotheses to test" (Eisenhardt, 1989, p. 536). The potentially important variables for this research are first identified from literature and then discussed with practitioners of multiple stakeholder groups in a pilot study.

The research is also designed with the quality of the findings in mind. For exploratory studies, the key aspects of research quality are construct validity, reliability and external validity (Yin, 1994). To have construct validity, multiple data sources are used during the data collection process (Yin, 1994). The primary data source is through interviews with employees of the manufacturers who have participated in the product, service or PSS development projects concerned. The secondary data source is the documentation produced by the case companies relating to the development projects selected. These documents may include standard development process flows, drawings and other representations of the new development.

To ensure the reliability of this research, a case study protocol is developed to guide the documentation of the research procedures and findings (Yin, 1994). For research findings to have external validity, the replication of findings is required. Multiple-case research design is the tactic used to achieve replication. The case selection strategy follows the logic of theoretical sampling, where cases are targeted to replicate emergent findings and also to extend the relationships among variables (Eisenhardt & Graebner, 2007; Yin, 1994).

Data collection and data analysis are designed to overlap in order to allow adjustments to be made on the data collection instruments or sources, if and when initial reflections indicate such needs (Eisenhardt, 1989). Constant reflection on whether the case selection strategy is appropriate occurs during the overlapped phases of data collection and analysis, in order to confirm the emergent variables. The number of cases required is not pre-determined in the research design, as the objective is to get as close as possible, where time and other resources permit, to the point that no new learning about the phenomenon of interest is gained by adding more cases (Eisenhardt, 1989). Figure 3-2 shows how the case selection strategy has changed as a result of the initial data analysis conducted on earlier cases.

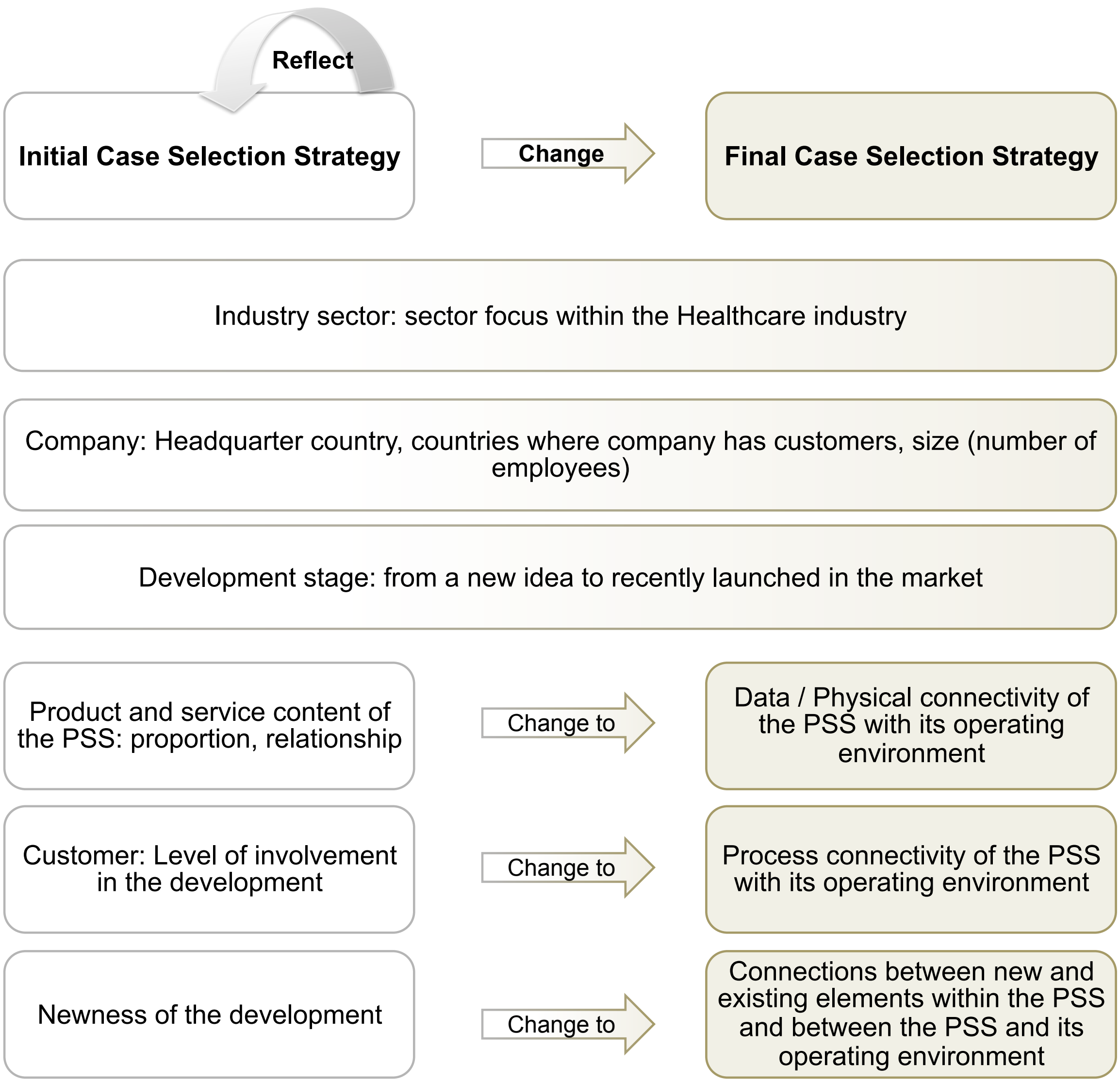


Figure 3-2 The case selection strategy for Phase I

3.4.2 Phase II research methodology

The Phase II research objective is to explore the influence of the PSS characterisation scheme (proposed in Phase I) on PSS design specification. In this research, PSS design specification includes technical, procedural and stakeholder requirements defined as an output of the PSS engineering design process. As described previously, the PSS engineering design process is a complex transformation, involving multiple stakeholders and often has many connections with its "active environment". To make sense of how the proposed PSS characterisation scheme may influence PSS design specification, the knowledge and experience of the people who are involved in the new PSS development are invaluable for the interpretations of the results, as these individuals are best positioned to understand the process of applying the PSS characterisation scheme and the actions that may result (Brydon-Miller, Greenwood, & Maguire, 2003). As a result, action research is an appropriate method for Phase II of this research.

In order to effectively facilitate the application of the PSS characterisation scheme to a developing product, service or PSS idea, a systematic approach is required as a research instrument. In the beginning of Phase II, a prototype of the research instrument used in this phase is to be first developed. This research instrument is called the PSS characterisation approach. Action research is also an appropriate method to build, test and refine the PSS characterisation approach as a research instrument (Maslen & Lewis, 1994; Platts, 1993).

Similar to Phase I, the unit of analysis is a new product, service or PSS idea that is under development. In each workshop, the participating company can choose to analyse one or multiple new PSS ideas that are intended to fulfil a specific customer need. There is no pre-determined number of workshops planned, as the objective of Phase II is to allow constructs to emerge and be validated through subsequent workshops. Figure 3-3 shows the distribution of the companies participated in Phase II. A by-product of Phase II is a stabilised research instrument, with its development tracked through the decreasing number of primary, secondary and territory changes recommended by workshop participants. The method to develop this research instrument is captured in Appendix 04. Figure 3-3 also shows the selected workshops against the four stages of the development of this research instrument. Note that Workshop P is a hypothetical case conducted with graduate students for the initial build of the research instrument. Workshop O is a test workshop using a PSS that was commercially launched two years prior to the workshop. Workshop O was conducted to ensure the PSS characterisation approach can be applied in industry settings without negatively influencing a new PSS in development.

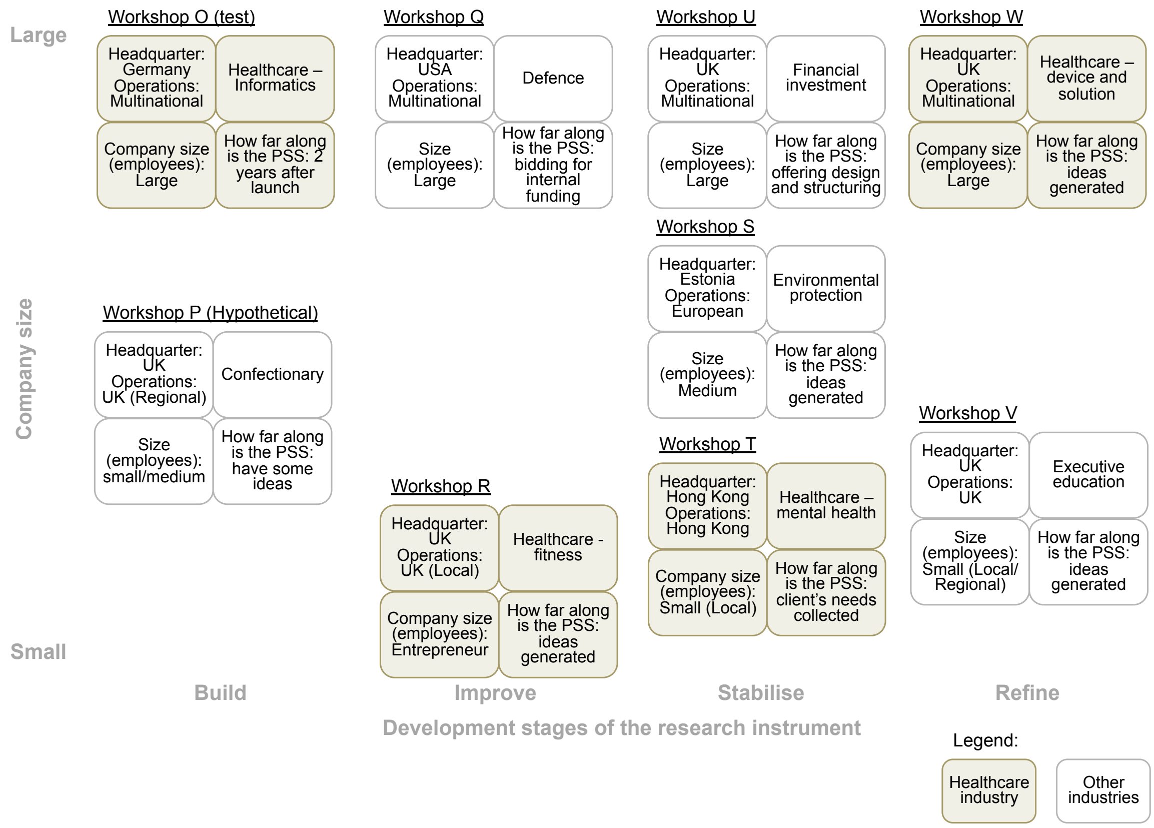


Figure 3-3 Profile of companies participated in Phase II

Each workshop is designed to be facilitated by the same researcher, and the participants are required to be individuals who have direct involvement in the development of the new PSS. Both healthcare and non-healthcare new PSS developments that are still within the engineering design process, from companies of different sizes and countries, are targeted to investigate how the PSS characterisation scheme works in different contexts. However, there is a pre-requisite for the participating companies: the companies must have a clear new product and/or service strategy.

The primary data source is the recorded discussions between the researcher acting as the facilitator and the participants during the workshops. The observations made by the researcher during the workshops, output in the forms of drawings and structures built using the research instrument, and comments made by the participants and independent observers where available, are the secondary data sources.

3.4.3 Summary of the selected research methodologies

Figure 3-4 summarises the methodologies selected for the Phase I and Phase II of the research. The methodologies chosen match the objectives of the research and the philosophical position assumed for the study.

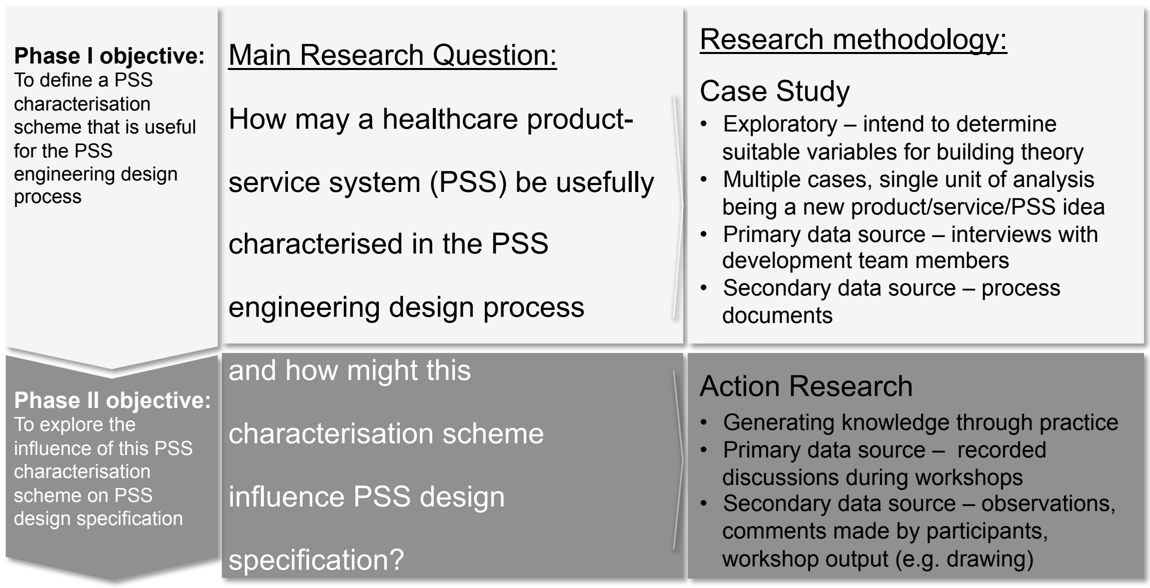


Figure 3-4 The research methodology selected for each phase of the research

As summarised in section 3.1, there is no existing theory that can offer an answer to the research objectives; therefore, it justifies the need to build theoretical perspectives from cases (Eisenhardt & Graebner, 2007). Because of the complexity of the engineering design process, the expertise of the individuals who are directly involved in the engineering design process is important in order to generate new knowledge about the influence of the new PSS characterisation scheme on PSS design specification. Therefore, case study and action research are selected methodologies for the two phases of this research.

3.5 Summary of research design

To summarise, the main research question addressed in this research is "How may a healthcare product-service system (PSS) be usefully characterised in the PSS engineering design process, and how might this characterisation scheme influence PSS design specification?" This question addresses two research objectives and is divided into five sub-questions. The first three sub-questions explore the potential variables for characterising PSS, which is the objective of Phase I. The fourth sub-question prepares the Phase II study by constructing a method to systematically apply the new PSS characterisation scheme. The last sub-question aims directly at the Phase II objective, which is to explore the influence of the PSS characterisation scheme and PSS design specification. Case study methodology is chosen for Phase I of the study and action research is selected for Phase II. These methodologies are chosen for their suitability to the nature of the research, the sub-questions asked and how data is interpreted.

The next chapter describes the pilot study performed before entering Phase I of the study. The purpose of the pilot study is to identify potential variables which inform the interview protocols for Phase I. Chapter 5 presents Phase I of the study and chapter 6 Phase II of the study.

4 Pilot study

In this chapter, the purpose of the pilot study which was conducted before Phase I is presented, followed by its design, findings and conclusions.

4.1 Chapter introduction

There are two main purposes for conducting a pilot study. One purpose is to identify potential variables for the data collection in the Phase I case study. Some potentially important variables are identified from literature for discussion with practitioners to see how important these variables are from the industry's point of view. This is because, to generate theoretical perspectives from case study, it is best to begin "as close as possible to the ideal of no theory under consideration" (Eisenhardt, 1989). The other purpose is to examine whether the phenomenon of interest, that is the PSS engineering design process, is a current and relevant problem to industry.

In the following sections, the design of the pilot study is first presented, followed by the data collection strategy and the distribution of the interviewees. The findings and learning from the pilot study is then presented. This chapter is concluded with the potential variables to be used in Phase I.

4.2 Design of pilot study

The pilot study is designed to learn from practitioners, facilitated by a draft research conceptual framework which is informed by literature (see Figure 4-1). Through the interviews with individuals representing different stakeholder groups of a new product, service or PSS development, the pilot study's results help to focus research on the problem which is most relevant to practitioners.

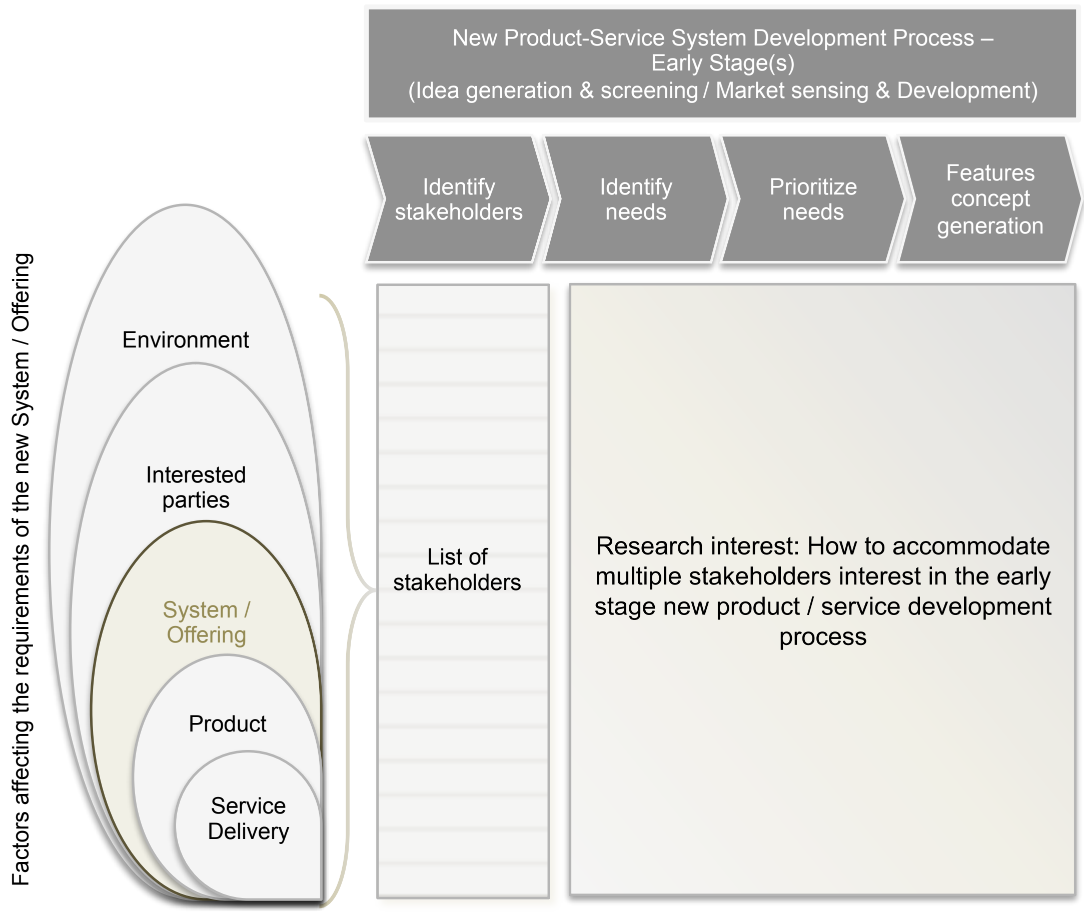


Figure 4-1 The initial conceptual framework for the research interest (adapted from Alam & Perry, 2002; Kindström & Kowalkowski, 2009; Moore, 1996; Webster & Wind, 1972)

The draft interview questions and the interviewee selection are underpinned by the conceptual framework depicted in Figure 4-1. There are two different types of interviewees: stakeholders who have been involved in a particular new product, service or PSS development project, referred to as project-specific interviewees hereafter; and stakeholders that are not involved in any particular development projects, referred to as non-project-specific interviewees hereafter.

The key purpose of the pilot study is to gain diverse perspectives from stakeholders of new product, service or PSS in the healthcare industry. Therefore, after every project-specific interview, the interviewee(s) was/were asked to suggest other interview candidates from the same project. For non-project-specific interviews, the interviewee(s) was/were asked to suggest candidates in stakeholder groups which had not been interviewed.

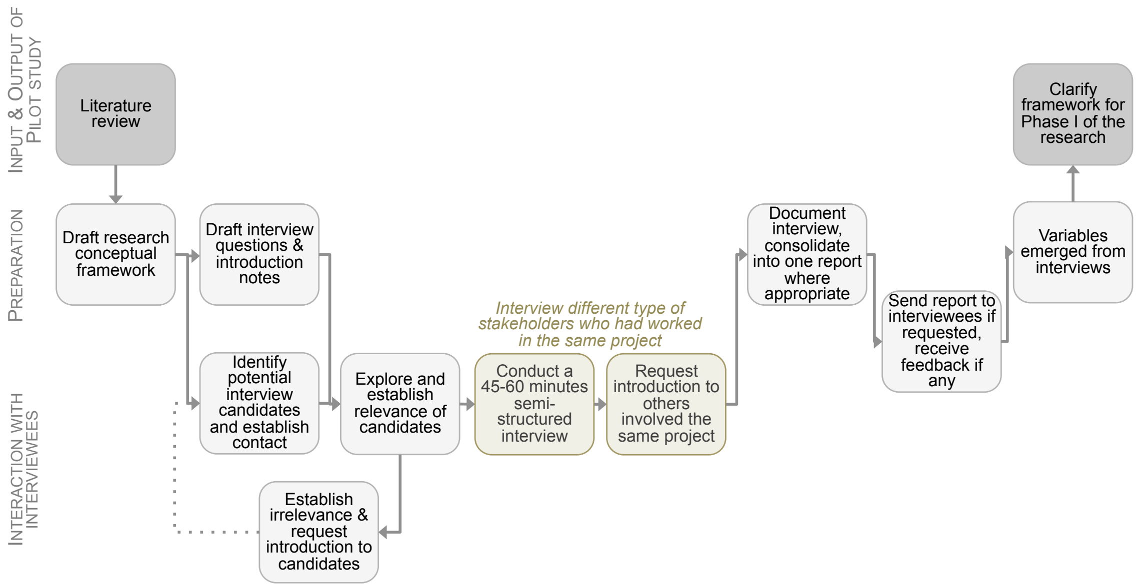


Figure 4-2 Pilot study approach

Figure 4-2 summarises the pilot study approach. The lowest part of Figure 4-2 shows the interactions with interviewees. These include the telephone conversations, e-mails and the actual interviews which were conducted face-to-face or over the phone / internet-phone. The middle portion of the diagram shows the preparation and documentation activities performed by the researcher. Pre-interview activities include writing telephone introduction scripts for cold-calling, writing interview invitation scripts and preparing interview note-taking and report templates. Post-interview activities include updating the interview record table, writing interview reports and consolidated reports for project-specific-interviews. The top part of the diagram shows that the pilot study is informed by the literature review and intended to provide information for clarifying the research conceptual framework to be used in the Phase I study.

4.3 Data collection

In this section, the data collection strategy is first presented, followed by a presentation of the data collected in the pilot study.

4.3.1 Data collection strategy

The strategy used to select interviewees in the pilot study is to first select a product, service or PSS designed and developed by a manufacturer in the healthcare industry, followed by thinking through the stakeholder groups related to the selected product, service or PSS. A suitable new product, service or PSS development project is either an on-going or recently completed project (within approximately five years of the interview date). This is then followed by interviews with other stakeholder groups that are not covered by the project-specific interviews. The left-hand side of Figure 4-1, that is the part that resembles a vertically sliced onion, is used to guide the stakeholder group identification. The root of the 'onion slice' contains the stakeholder groups that are closest to the beneficiaries of the service. The other stakeholder levels, represented by the 'onion rings', are progressively further away from the beneficiaries of the service.

The objective of the pilot study is to have at least one stakeholder group per stakeholder level interviewed. For each targeted development project, at least two different stakeholder groups are to be interviewed; and at least two people from each non-project-specific stakeholder group are to be interviewed. A protocol consisting of four groups of open-ended questions is designed to guide the semi-structured interviews (see Appendix 05 for the protocol used). As shown in Figure 4-3, the questions are designed to explore four different aspects of the conceptual framework: the PSS developed, the engineering design process steps used, the stakeholders involved or should have been involved, and at what points in the process they were involved.

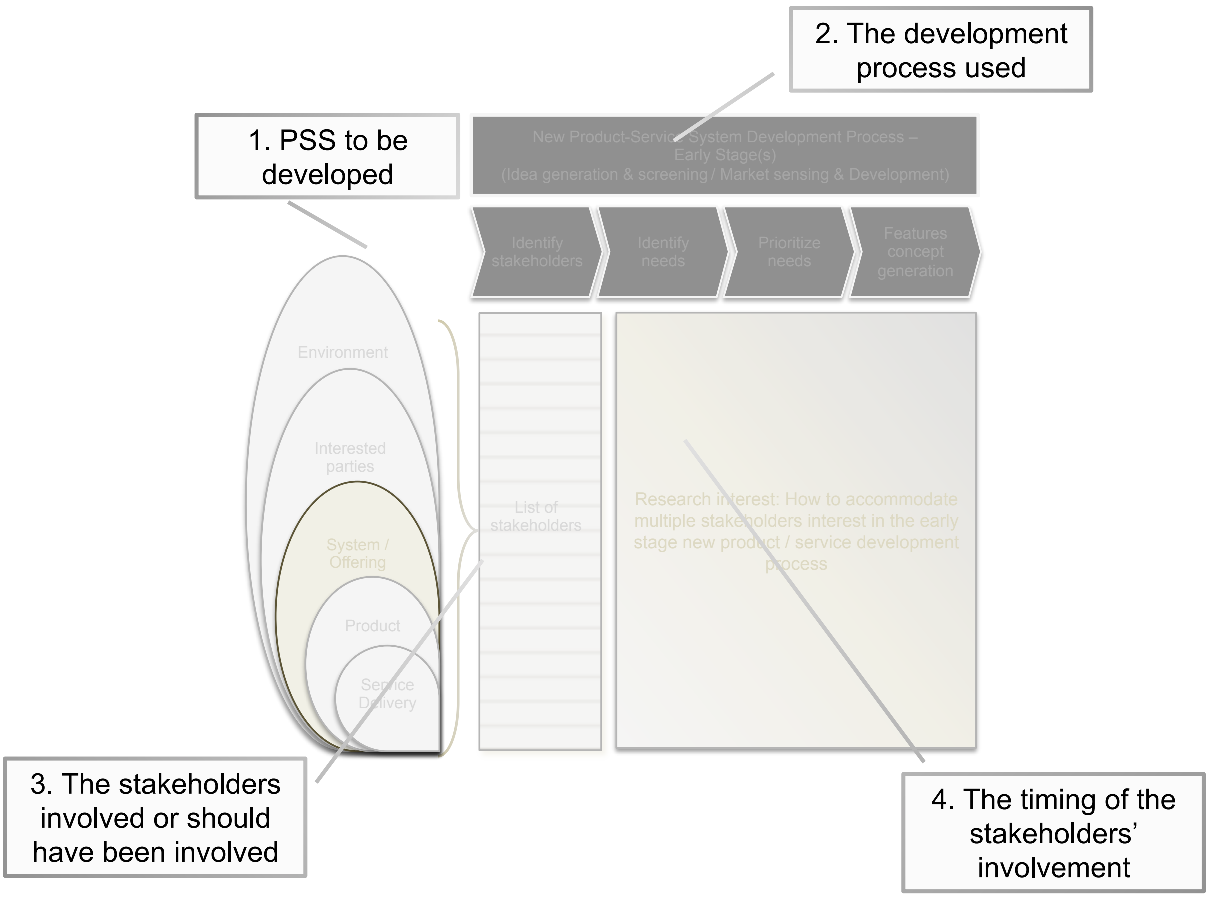


Figure 4-3 The four groups of pilot study interview questions

The four groups of questions are detailed below:

1. Characteristics of the PSS developed – description of the PSS and what problem it is intended to solve.
2. Descriptions of the NPD/NSD process – the development steps used and whether the process is typical in the organisation.
3. Categories of influence – role of the interviewee in the development project and whether he/she represented other parties' interests.
4. Interaction between roles and process steps – examples of when and how the interviewee was involved and whether he/she thought the involvement could/should have been different; who else was involved and whether other stakeholders' involvement could/should have been different.

4.3.2 Data collected

The pilot study was held between August and December 2011. Twenty-five people were interviewed, representing fourteen stakeholder groups. Ten were project-specific interviewees from four projects and fifteen were non-project-specific interviewees. The stakeholder groups interviewed are shown in Figure 4-4. The profile of the four projects is captured in Table 4-1. All project-specific interviewees, the "customer service delivery" and the "quality & regulatory" interviewees work in the same manufacturer. However, they work in different business segments (see Table 4-1).

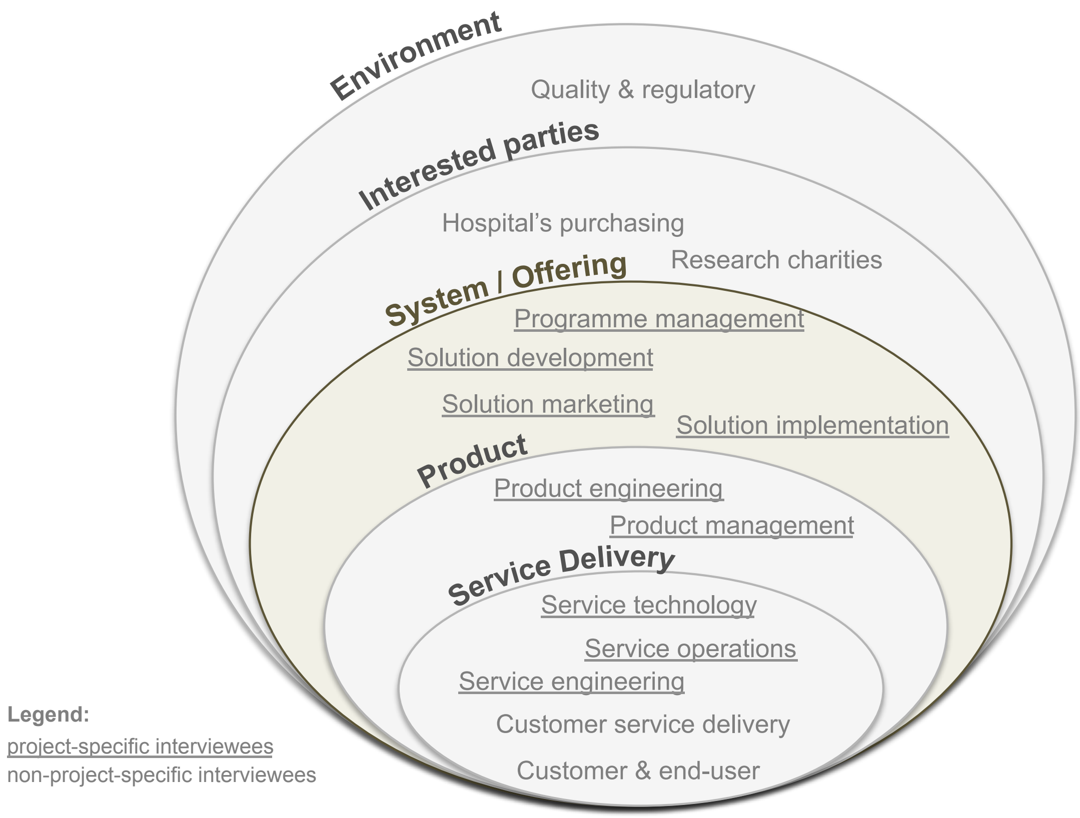


Figure 4-4 The onion diagram of stakeholder groups interviewed

Table 4-1 Pilot study – project background

Project name and business segment	Type of development	Stakeholder groups interviewed	Location of interviewees	Number of people interviewed
Project A in medical device	NSD	Product Engineering, Service Engineering, Service Technology, Service Operations	North America	4
Project B in health informatics	NPD	Product Engineering, Product Management	North America	2
Project C in hospital turnkey solutions	NPSSD	Solution Marketing, Solution Development	Europe	2
Project D in healthcare delivery advisory	NPSSD	Programme Management, Solution Development, Solution Implementation	North America	2

4.4 Pilot study findings

In this section, a summary of the findings are first provided, followed by a discussion of the findings. As an example, the consolidated interview report for Project A is provided in Appendix 06.

4.4.1 Project-specific interview findings

As seen in Table 4-1 in the previous section, the four projects used for data collection in the pilot study have covered NPD, NSD and NPSSD. The product and service content and their relationships with each other are shown in Figure 4-5, following the schematic introduced in chapter 2. All selected projects were completed within two years of the date of the interviews.

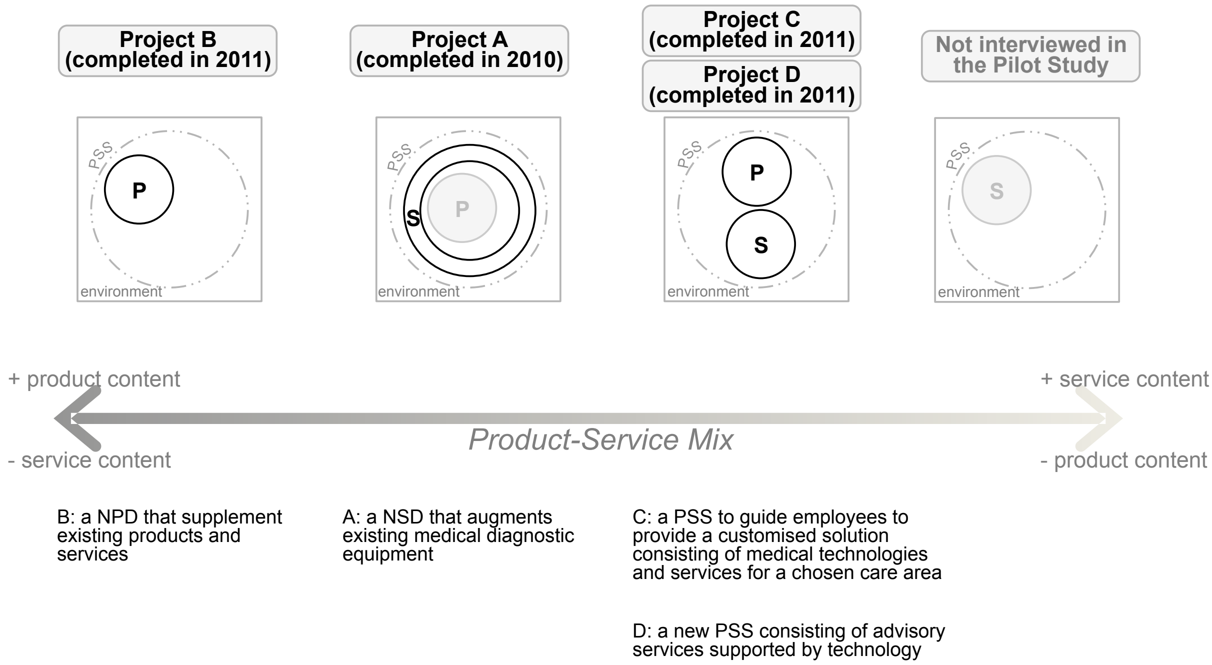


Figure 4-5 An abstract representation of the PSS configuration in the pilot study

As shown in Figure 4-4, the project-specific interviewees represented nine stakeholder groups. However, the interviewees mentioned nineteen more stakeholder groups that were either involved in the engineering design process, or should have been involved (see Appendix 07). Project A's interviewees mentioned that there was a lack of product engineering engagement in the NSD project. Project B's interviewees mentioned that only the timing of customers involvement was specified in the development process, but not that of other stakeholder groups. Project D's interviewees said that stakeholder involvement required close administration by the company's management.

The activities involved in the engineering design process, as viewed by the interviewees, were explored in the pilot study. The process steps are captured in Figure 4-6. In most cases, the interviewees of a project have only slight differences in their views of what activities are within the engineering design process boundary. However, Project D's interviewees have completely different opinions: one considered "Pilot solution / simulate model" as within the boundary, whereas the other did not see this activity as part of the process. One interesting observation is that Project C's interviewees described a process that showed the PSS was a combination of products and services from the company and other third parties. Interviewees of other projects did not consider third parties' offerings. As seen in Figure 4-6, comparing to the engineering design process in literature, the processes described by the interviewees shown a similar sequence of activities.

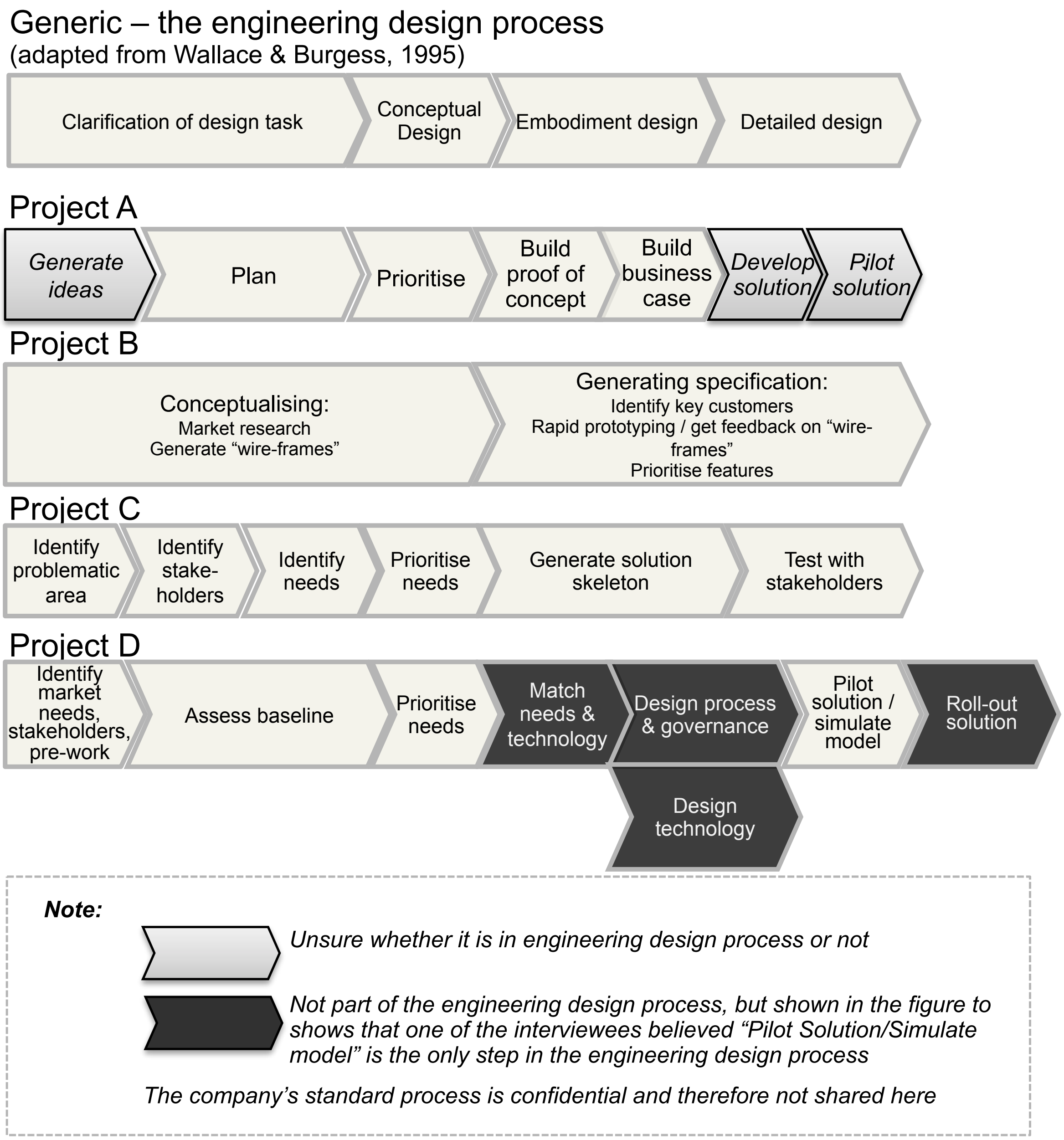


Figure 4-6 Process steps perceived to be within the engineering design process

4.4.2 Non-project-specific interview findings

Fifteen non-project-specific individuals representing five stakeholder groups were interviewed (see Figure 4-4). Their views of their involvement in the engineering design process are captured in Table 4-2.

Table 4-2 Stakeholder groups' involvement according to non-project-specific interviewees

Stakeholder groups	Number of interviewees	Opinions of how to be involved in the engineering design process
Customer and end user	6	No consensus, but a slightly stronger preference toward limited participation: invited by manufacturers in selected activities such as concept generation.
Customer service delivery	2	Have experience using manufacturers' standard feedback process to request new features on existing products.
Hospital's purchasing	2	Believed that the technical requirements are captured in the tender document. Users and experts in the medical technology field concerned are usually involved in specifying technical requirements.
Research charities	2	Have experience in idea generation session hosted by manufacturers. Also have experience in the later stage of the development process: provide feedback on prototypes, supported testing.
Quality and regulatory	3	Employees of manufacturer representing the interests of quality and regulatory have been involved. Believed that the company's quality management system needs to be updated to reflect the higher service content of new offerings.

4.4.3 Discussions of pilot study findings

From the interviews with the stakeholders of these four projects, it appears that there is a need to define the meaning of a 'service'. For example, the interviewees of Project A referred to the offering, which is a service by this research's definition, as a service, software, an algorithm and a new product feature. The development in Project B is a product by this research's definition and was referred to as a product by one interviewee, and as a service by the other. This created inconsistency, if not confusion, when describing the development projects.

The four projects belong to different business segments of the same company, and the processes are governed under the same quality management system as informed by the quality and regulatory stakeholders interviewed. The processes described are different from one another (see Figure 4-6) and are different from the company standard process. However, interviewees in Project A, B and C either believed the process used was typical in the company or that the process would be used again for similar developments in the future. Some interviewees have also suggested that improvements in the standard process are required to guide new developments with high service content, as it was developed for new product development.

Many interviewees struggled to name the process steps that belong to the engineering design process. In general, activities in the engineering design process are described as identifying the customers' problems which need to be solved, understanding the customers' requirements and conceptualising potential solutions. However, some interviewees include activities such as generating ideas, developing a prototype and piloting a solution as part of the engineering design process. A definite boundary for the engineering design process is clearly lacking.

In terms of how different stakeholder groups are involved or preferred to be involved in the engineering design process, it appears that there is a lack of consensus for how to involve stakeholders who do not work for the manufacturers (external stakeholders). Projects B, C and D incorporate explicit steps to involve customers and Project C and D mentioned the involvement of other external stakeholders. Moreover, all projects have identified some stakeholders they wished to have engaged with differently. This implies a need to have a systematic approach to identify stakeholders for the engineering design process.

In conclusion, the pilot study explored the conceptual framework that intersects stakeholder identification with the PSS engineering design process (see Figure 4-1). From the interviews with 25 people representing 14 stakeholder groups, it appears that the followings need to be prioritised for further investigation:

- Confusion concerning the definition of a service, as shown by interviewees using different terms to refer to the new service development and the same development being referred to as a product by one interviewee and as a service by another.
- Inadequate adaptation of the standard NPD process for NPSSD. Some interviewees felt that the standard NPD process needs to be improved in order to address the high service content of the new development.
- Lack of clarity on the boundary of the engineering design process, as shown by interviewees' different opinions of what activities it entails.
- Lack of guidance to systematically identify stakeholders for engineering design. Some interviewees identified stakeholders that should have been involved, and some interviewees believed that some stakeholders should have been involved differently.

4.5 Summary of pilot study

The pilot study was conducted for two main purposes: to identify potential variables for the interview protocol to be used in Phase I of the research; and to examine if the phenomenon of interest, that is the PSS engineering design process, is relevant to the current needs of the healthcare industry. The pilot study followed a strategy which target stakeholders who had been directly involved in a development project which was completed within five years of the interview date. For stakeholder groups that were not accessible via the selected projects, non-project-specific interviewees were selected.

The pilot study explored the opinions of 14 stakeholder groups on the development process used, the stakeholder groups involved and the timing of their involvement in the engineering design process. The results have suggested the research to focus on four areas: (1) a clear definition for 'service'; (2) a development process that caters for offerings with high service content; (3) a definite boundary for the engineering design process; and (4) a guidance to systematically identify stakeholders.

Of the four areas identified, a clear definition for 'service' is fundamental. As observed in the interviews, the confusion around 'service' obscured communication about the development projects. This implies that there is a need to clarify what a PSS is for the purpose of engineering design. The varied perceptions of the boundary of the engineering design process can be addressed by applying the established definitions from the engineering design literature (Figure 2-4 in chapter 2). As a result of the pilot study, some variables explored in the pilot study are to be kept or modified, and additional potential variables are to be explored in Phase I (see Figure 4-7).

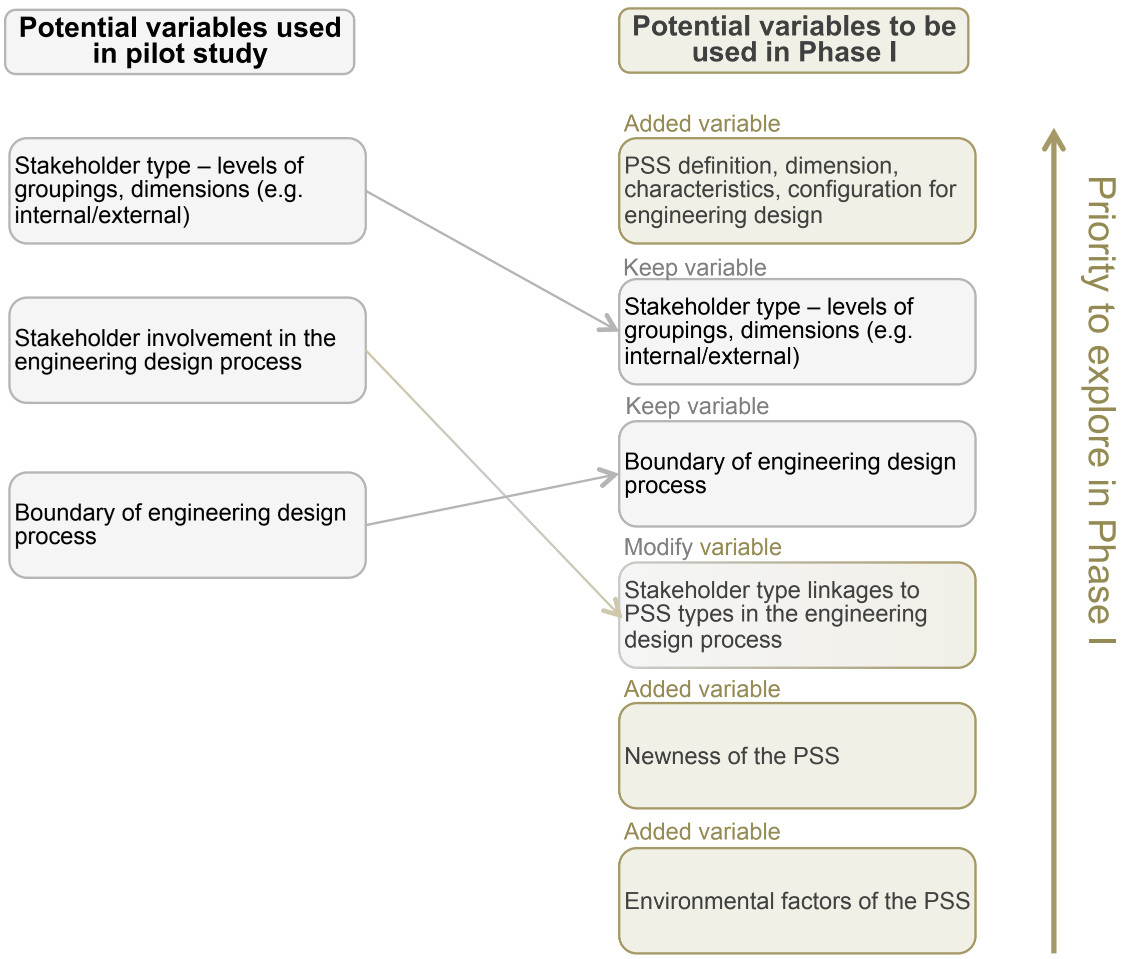


Figure 4-7 The potential variables to use in Phase I study

5 Phase I – PSS characteristics for the PSS engineering design process

Following the pilot study presented in the previous chapter, this chapter presents the journey of discovering a novel way to characterise PSSs for the PSS engineering design process, which has emerged from the three iterations of case studies. Eleven cases from nine companies in the healthcare industry, where each case is a new PSS development project, were conducted during Phase I.

5.1 Phase I introduction

The objective of Phase I is to define a PSS characterisation scheme which is useful for the PSS engineering design process. As explained in chapter 3, case study methodology is an appropriate approach for Phase I. Using the output of the pilot study as the starting point, six groups of potential variables (see Figure 4-7) are explored in Phase I case studies. Adjustments to the case selection strategy and variables for examination are introduced when deemed necessary.

This research methodology involves iterations of case selection, data collection and analysis, making the presentation of the findings difficult to read if they were presented in the order of the occurrence. Therefore, to bring clarity to this chapter, the relevant parameters which emerged are presented logically rather than temporally.

In the following sections, the overall process of the Phase I case study is first presented, along with a summary of the cases completed. The data analysis procedure used is then presented. This is followed by a presentation of the findings and a discussion. This chapter is concluded with the theoretical contributions of Phase I, the limitations and next steps.

5.2 Phase I data collection - case studies summary

This section first presents the case study process and the case selection strategy. A summary of the cases completed and interviewees involved is then presented.

5.2.1 The process of case study

For Phase I of this research, each case study corresponds to a new development project that consists of at least one on-going or recently completed development of a new product, service or PSS by manufacturers in the healthcare industry (see section 1.2 for the definitions used in this research for manufacturers and the healthcare industry). As explained in chapter 3, following the logic of theoretical sampling, the case selection strategy was adjusted to achieve the replication of emerging findings and to extend the relationships among the variables (Eisenhardt & Graebner, 2007; Yin, 1994). The data collection instruments were also adjusted when found necessary upon reflection (Eisenhardt, 1989). Therefore, the number of cases per iteration and the number of iterations were not pre-defined, but rather a result of the initial data analysis. Figure 5-1 illustrates the process of Phase I case studies.

There were three iterations during Phase I of this research. The emerging variables from cross-case analysis informed the case selection strategy. The loops of these different types of modification are represented in Figure 5-1 by the grey dotted-line arrows. The different versions of interview protocols can be found in Appendix 08.

The primary data collected in Phase I is from the interviews and most of them were recorded if the interviewees gave their consent. This primary data is supplemented by relevant documents that were made available to the researcher, such as the development conceptual diagram and media news items. Apart from documenting the interviewees' opinions directly in the interview protocols (see Appendix 08), a template was used to support the data collection process (see Appendix 09). This template was found to be useful for getting instant feedback from the interviewees. It has enhanced communications and therefore the quality of the data collected.

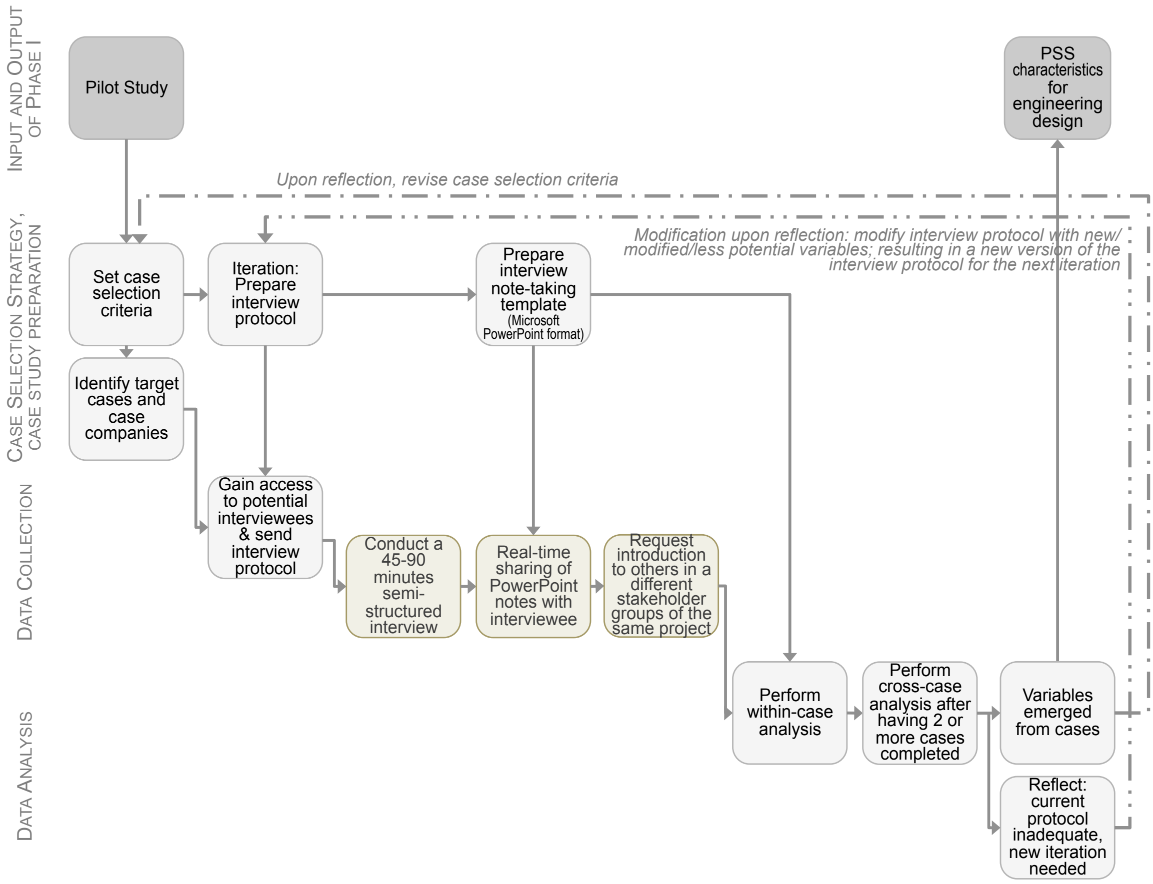


Figure 5-1 Phase I – the case study process

5.2.2 The case selection strategy

As the case selection strategy follows the logic of theoretical sampling, cases that are different in both organisational and offering dimensions are targeted. In the organisational dimension, companies in different industry sectors, locations and sizes in terms of number of employees are targeted. On the offering level, PSSs of different types and degrees of connectivity are targeted. The type and degree of connectivity describe the interactions both within a PSS and with its operating environment. This will be explained in section 5.4.1.

The context of the targeted cases is diverse for the purpose of replication and extension of the relationships among the variables. Table 5-1 shows the variety of the cases selected for Phase I at the organisational level. Figure 5-2 shows the distribution of the cases against the two types of PSS connectivity: physical/data connectivity and process connectivity.

Table 5-1 Diversity of Phase I cases at the organisational level

Iteration number and name of the case / offering reference number (O = offering)	Industry sector	Company: size, location, target market[1]
(1) Digital / O1, O2	Healthcare informatics	Small, Australia, UK
(1) Signal / O3, O4, O5	Healthcare informatics	*Same as Case Digital*
(1) FastReport / O6, O7, O8	Healthcare informatics	Medium, Sweden, UK and Australia
(1) BedManagement / O9, O10, O11	Hospital advisory	Large, USA, USA
(1) ProactSvr / O12	Medical device	Large, USA, USA
(2) PredictSvr / O13, O14	Medical device	Large, France, Europe
(2) eLearnHospital / O15, O16	Training for healthcare professionals	Small, Finland, Finland
(2) eLearnCharity / O17	Training for patient-facing workers	*Same as eLearnHospital*
(2) Stent / O18	Medical implant	Small, UK, UK
(2) GroupTraining / O19, O20, O21, O22	Fitness	Large, USA, International
(3) Biomechanics / O23, O24, O25	Fitness	Small, UK, UK

Note[1]: Company size is based on the number of employees; company location is where the development team members are mainly located; target market is the target market for the PSS being discussed.

UK = United Kingdom; USA = United States of America

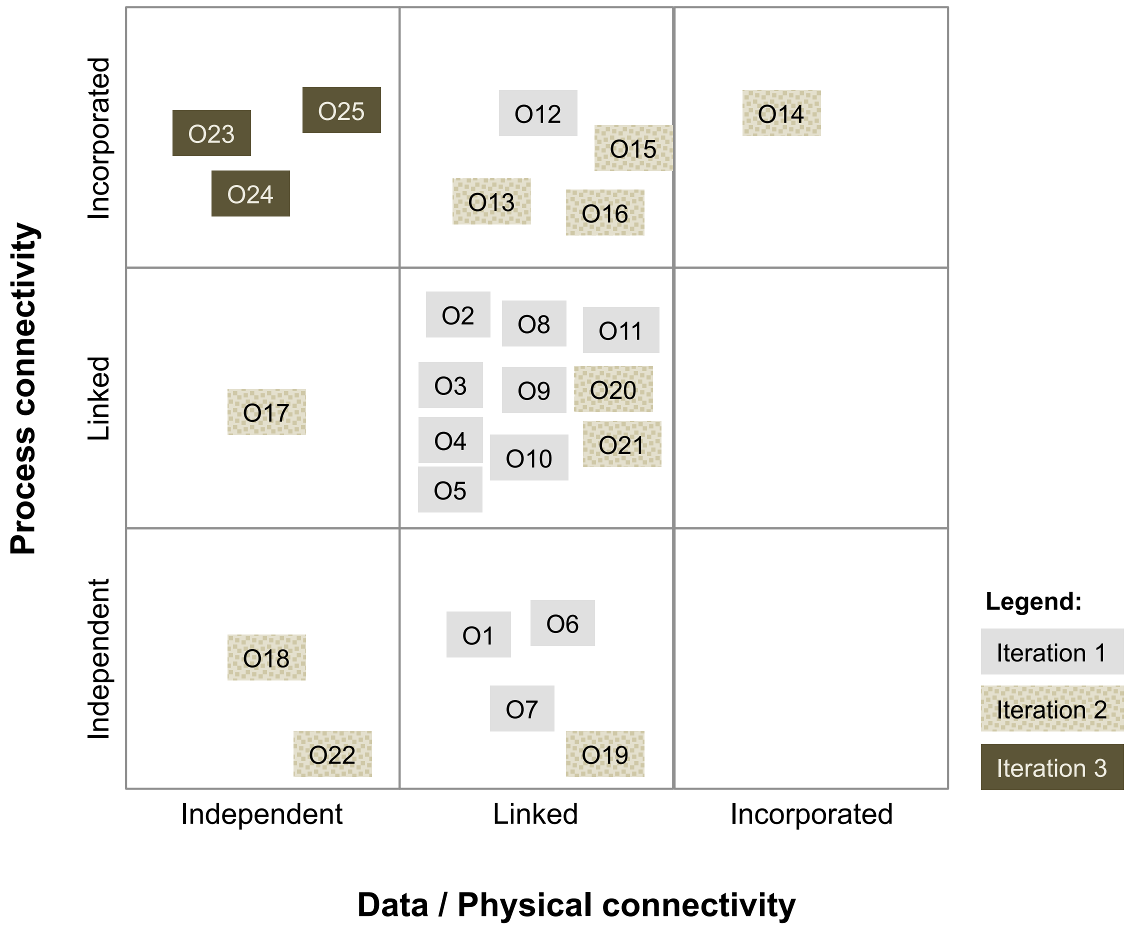


Figure 5-2 Distribution of Phase I case studies against the two types of PSS connectivity

5.2.3 A description of the cases and interviewees involved in Phase I

In each case, at least one development team member was interviewed. Due to the location of the interviewees, the interviews were mostly carried out using an Internet phone application (Skype), with some interviews being held face-to-face or over the phone. Some interviewees could not attend a live interview, but responded directly to the interview protocol and clarified their responses using e-mails. Table 5-2 summarises the interviews conducted.

Table 5-2 Summary of interviews in Phase I

Iteration number and name of the case	Interviewees per case	Role(s) represented[1]	Country interviewee is based[2]	Mode of interview	Interview protocol version[3]	Interview duration
(1) Digital	2*(one interviewee was also interviewed in Case Signal)*	Technical, management, service delivery	Australia	Skype (shared screen)	1.1	56 minutes
			UK	Face-to-face	1.1	60 minutes
(1) Signal	2	Technical, management, commercial	Australia	Skype (shared screen)	1.1	34 minutes
			UK	Phone	1.1	85 minutes
(1) FastReport	3	Technical, management, commercial, service delivery	Sweden	Skype (shared screen)	1.1	77 minutes
			UK	Phone	1.1	76 minutes
			Sweden	Skype	1.1	83 minutes
(1) BedManagement	2	Technical, service delivery	USA	Phone (3 sessions)	1.2	113 minutes
			USA	Skype	1.2	75 minutes
(1) ProactSvr	2	Technical, management, commercial	USA	Phone + shared screen (3 sessions)	1.2	129 minutes
			USA	Skype	1.2	72 minutes
(2) PredictSvr	3	Sales, marketing, technical	France	Skype	2.0	97 minutes
			France	Phone	2.1	91 minutes
			France	Phone + shared screen	2.1	92 minutes
(2) eLearnHospital	1	Management, commercial	Australia / Finland	Skype	2.1	130 minutes
(2) eLearnCharity	1 *(same interviewee as the one interviewed in Case eLearnHospital)*	Management, commercial	Australia / Finland			
(2) Stent	1	Management	UK	Face-to-face	2.1	75 minutes
(2) GroupTraining	2	Marketing, sales	USA	E-mail response	2.1	-
			UK	Phone	2.1	46 minutes
(3) Biomechanics	1	Management, technical, service delivery	UK	E-mail response	3.0	-
(3) Digital (follow-up)	2 *(both were interviewed in the first iteration)*	Technical, management, service delivery	UK	Face-to-face	3.1b	24 minutes
			Australia	Skype (shared screen)	3.1b	24 minutes
(3) Signal (follow-up)	2 *(one was interviewed in the first iteration)*	Technical, management, service delivery	Australia	Skype (shared screen)	3.1b	Same interview as (3) Digital (follow-up)
			UK	Skype	3.1b	28 minutes
(3) FastReport (follow-up)	1 *(interviewed in the first iteration)*	Technical, service delivery	Sweden	Skype	3.1b	32 minutes
(3) BedManagement (follow-up)	1 *(interviewed in the first iteration)*	Technical, service delivery	USA	E-mail response	3.1b	-
(3) ProactSvr (follow-up)	1 *(interviewed in the first iteration)*	Technical, management	USA	Phone	3.1b	35 minutes

Note[1]: Some interviewees have multiple roles in the development project; “Technical” here stands for both technical development and engineering for the product, service or PSS discussed
Note[2]: UK = United Kingdom; USA = United States of America
Notes[3]: Version 3.1b contains only the questions pertaining to the modified and added potential variables that were not explored in protocol Version 1

This section has presented the data collection process, the case selection strategy, the distribution of cases and the interviews conducted. The next section presents the data analysis process.

5.3 Phase I data analysis

In this section, the data analysis process is presented in Figure 5-3. The procedure of within-case and cross-case analyses is then presented, highlighting how the procedure allows relevant variables to emerge.

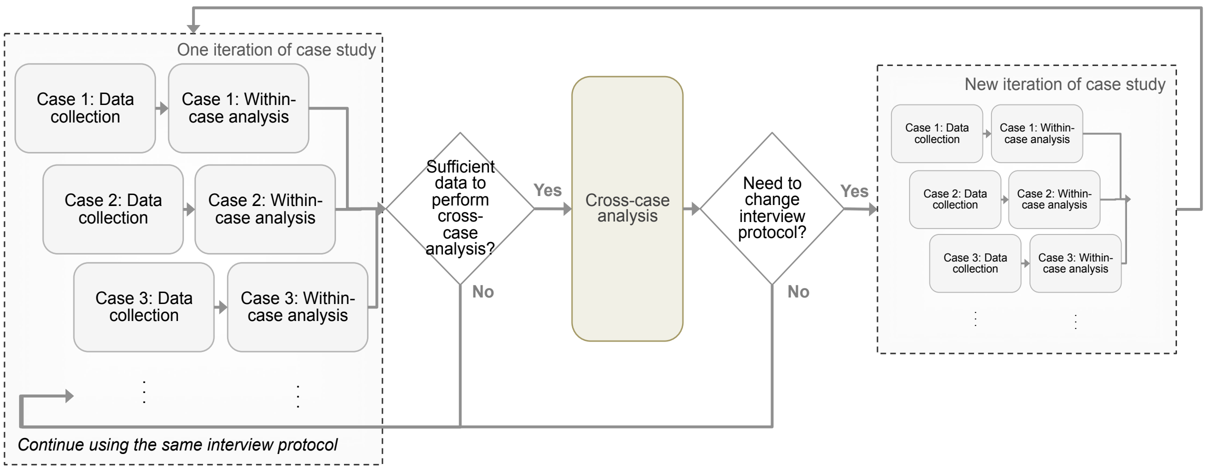


Figure 5-3 The analytic process of within-case and cross-case analyses

Within-case analysis is carried out for each case study as soon as all candidates from the case have been interviewed. This was done via a framework prepared in Microsoft Excel, containing the factors explored in the interviews (see Appendix 10 Figure A 12). Although cross-case analysis could be carried out after the completion of as few as two cases studies, in this research, cross-case analysis was performed only when common themes began to emerge from the within-case analyses and once sufficient data had been collected.

As seen in Figure 5-3, the case studies completed before a cross-case analysis were grouped together as one case study iteration. A change in the interview protocol led to a new iteration of case study, including data collection and within-case analyses. When changes in priority of the potential variables were deemed necessary, the within-case analyses were subsequently redone. When new variables were added to the revised interview protocol, new data were collected. The number of potential variables explored during Phase I is shown in Figure 5-4. Many new potential variables were introduced during the first iteration and were eliminated afterwards. More details about the potential variables explored during Phase I can be found in Appendix 11.

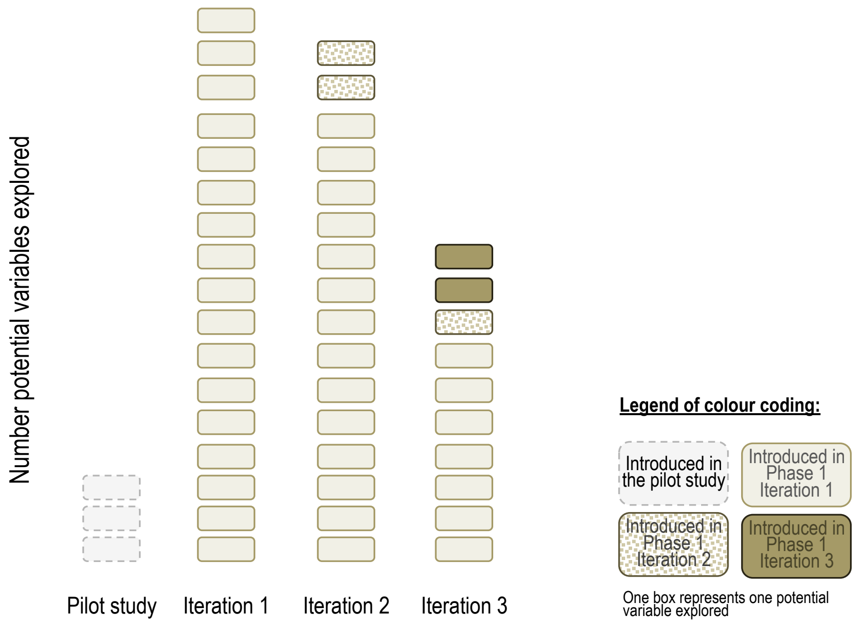


Figure 5-4 The exploration of variables in Phase I

The cross-case analysis consisted of two steps. First, the information collected for each potential variable from the completed cases was compared. Second, the data was grouped to examine any emerging patterns. Different ways of data grouping were tried. These included grouping cases that display the same results for one potential variable, a combination of potential variables, or a combination of other factors that were not considered as potential variables. An example of the framework used for cross-case analysis for one potential variable can be found in Appendix 10.

5.4 Phase I findings

The findings of Phase I, that is the relevant variables resulted from the last iteration of the case studies, are shown in Figure 5-5. In this section the primary findings concerning PSS characteristics are first presented. This is followed by a presentation of the secondary findings pertaining to the engineering design process: stakeholder types, stakeholder involvement, the influences of the environmental factors, the relationship between a PSS's "newness" and its stakeholder involvement in engineering design.

5.4.1 Primary findings - PSS characteristics for engineering design

Variables were explored in search of those which could be useful in describing a PSS for the purpose of engineering design. The most relevant variables are called **PSS characteristics** in this research. Appendix 11 gives more details on which variables led to the emergence of the PSS characteristics for the engineering design process. The top box in the first right-hand column of Figure 5-5 shows the four characteristics of PSS which emerged from the analysis:

1. The level of customer perceived value
2. The number of relationships between new and existing elements, expressed as a 'connectivity number'
3. The type and degree of connectivity
4. The type of configuration

These four characteristics are collectively called the "PSS characterisation scheme" in this research and are explained below. The values for the four characteristics of the PSSs involved in the Phase I case studies can be found in Appendix 12.

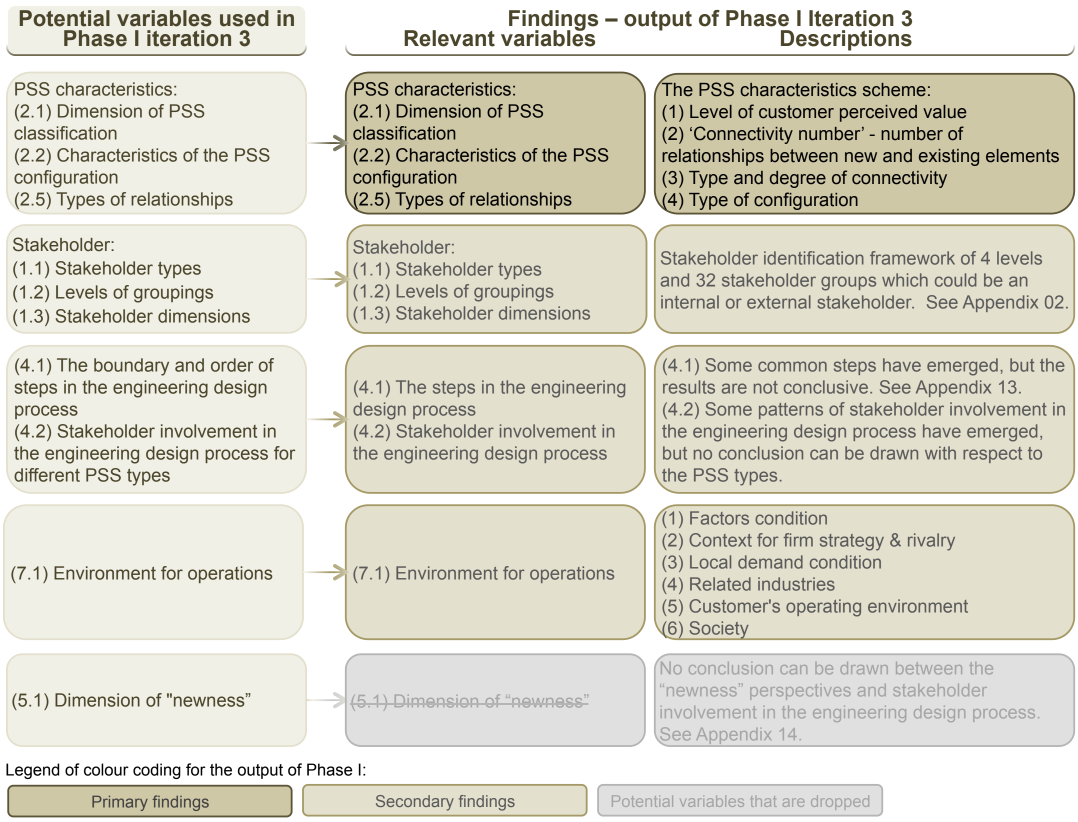


Figure 5-5 Findings of Phase I

5.4.1.1 First characteristic - level of customer perceived value

This characteristic is about how target customers of a new PSS perceive the value they can generate from the PSS when using it. A higher perceived value means that the target customers find the PSS more desirable. This further indicates the higher return the companies can obtain from offering the new PSS.

5.4.1.2 Second characteristic – 'connectivity number'

The 'connectivity number' deals with the relationships among elements within a PSS, and between the PSS and the infrastructure on which its operations depend. Three types of relationship have emerged from the case studies: "needs", "impacts" or "impacted by". If element A needs element B, it means A cannot exist without B. If element A impacts element B, it means A affects the functioning of B. If element A is impacted by element B, it means that the functioning of A is affected by that of B, which can also be expressed as element B impacts element A. The number of relationships can be added-up to arrive at the total number of relationships within a PSS.

However, one could argue that not all relationships are of the same importance to engineering design. Extra care is likely to be required for the development of a new element that may affect a functioning element in the PSS or the infrastructure on which the PSS relies. If a new element is dependent on the proper functioning of an existing element, the development team needs to understand the existing element well in order to design the new element. Relationships between two new elements are probably more of a routine design task to ensure two pieces of a new system work together. Relationships between two existing elements are basic knowledge required in the design context. Therefore, to capture the internal interactions of a new PSS, each relationship can be further analysed in terms of whether the relationships are between new and existing elements, among new elements or among existing elements. If the number of relationships is to represent the degree of care or effort to have during the development of a new PSS, a heavier weight needs to be applied on the relationship of 'new impacting existing' than that of 'new impacted by existing' (also referred to as 'existing impacting new'), and a discount is also applied on the nominal/routine effort required for elements having a 'new impacting new' or an 'existing impacting existing' relationship.

To take these factors into account, for Phase I, the number of 'new impacting existing' relationships is multiplied by two. A factor of zero is applied to the number of 'new impacting new' and 'existing impacting existing' relationships, that is they are not taken into account when considering the additional development effort required. A 'connectivity number' can then be calculated from the number of 'new impacting existing' relationships and 'existing impacting new' relationships for the PSS under development. This number represents the complexity both in terms of interconnectivity within a PSS and with its intended operating environment. This number also reflects the effort required by the development team for the PSS engineering design.

5.4.1.3 Third characteristic - type and degree of connectivity

This characteristic further elaborates the previous characteristic. It is about the type of connectivity among the elements of the PSS under development and other systems in its intended operating environment. The connectivity types which emerged are: physical/data connectivity and process connectivity. Physical/data connectivity describes the relationships that impact on the product elements within the PSS or on its intended operating environment, as it is either about the connections between two physical products or connections at the data level for intangible products. Process connectivity describes the relationships which impact service elements within the PSS or its intended operating environment. It is called 'process' connectivity because a service is an action which happens at the required time. The connections between service elements are activities which extend, add to or modify existing procedures or activities.

Each type of connectivity can further be described by its degree of connectivity. There are three degrees of connectivity: 'independent' when there is no connectivity; 'linked' when there is an interface, alignment or joining between the new and existing elements; and 'incorporated' when the new elements are embedded within the existing elements.

5.4.1.4 Fourth characteristic - type of configuration

This characteristic contains a set of ten PSS configurations which describe the internal structure of a PSS at an abstract level. It depicts how the configuration of the product and service portions of the PSS that interact with one another. Seven out of the ten configuration types are represented in the case studies, only with A1, B1 and C1 being absent. The configuration types involved in the Phase I study can be found in Appendix 12 Figure A 8. The key features of each PSS configuration type are described in Table 5-3, and explained using hypothetical examples relating to running.

Table 5-3 The PSS configuration types emerged from the Phase I (adapted from Yip et al., 2014a)

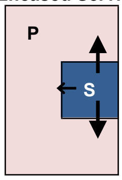
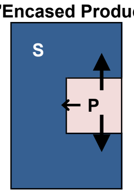
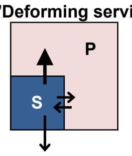
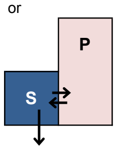
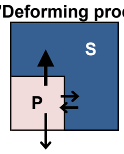
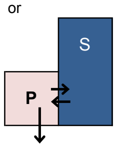
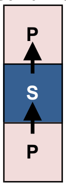
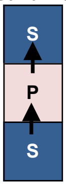
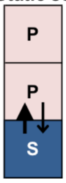
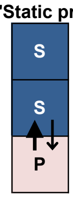
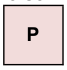
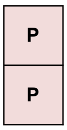
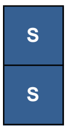
PSS configuration types emerged from the case studies	The element that is at a higher value-level	Key features	Hypothetical examples
A1 - 'Encased Service' 	Product	The service is most likely a basic operation The service impacts products above and below The service may impact product of the same level	A famous running coach who is offering a tailored package (higher level product) of running technique leaflets previously published (lower level products) by analysing the questions (service) runners have asked her in her coaching career and developing a map of runners' challenges to running techniques (mid-level product). The running technique leaflets (lower level products) are revised according to the insights gain from the analysis (service).
A2 - 'Encased Product' 	Service	The product most likely provides a basic function The product impacts services above and below The product may impact service of the same level	A running coach has a chat with a group of beginner runners in the running club (lower level service) and has found out that they do not understand some dynamic warm-up exercises. She then gives the runners some instruction sheets (products) and asks the runners to follow the sheets with her supervising (mid-level service) on the side, and continues to address other confusions that the runners have. This helps the coach to improve her runners' overall running experience (higher level service).
B1 - 'Deforming service'  or 	Product	The service causes the "bolt-on" configuration The service is a standalone service or an external operation The service impacts on the product above or interacts with the product at the same level	A running shoes retailer that provides gait analysis as a standalone service (service) and also sells specialised insoles (higher level product) for running shoes (lower level product).
B2 - 'Deforming product'  or 	Service	The product causes the "bolt-on" configuration The product is a standalone product or an external product The product impacts on the service above or interacts with the service at the same level	A running coach who uses gait analysis software (product) to help her to provide a more in-depth analysis on her client's running technique (service at the same level). She then designs new exercises that aim at improving her client's running technique (higher level service).

Table 5-3 ***(continued)***

C1 - 'Sandwiched service' 	Product	The product at the top level is an additional offering The product at the top level does not impact service in the middle The product at the lower level is fundamental to the service	A running technique improvement video (product) that is produced by filming a running coach correcting the techniques of different runners (service) in agility improvement exercises involving running around sports marker cones (lower level product).
C2 - 'Sandwiched product' 	Service	The service at the top level is a customer facing service The product in the middle is a production aid to the service on top The service at the lower level is fundamental to the product	A running coach who provides running technique improvement advice (service) uses some specialised video recording devices (product) to record how her clients run. These devices are rented (lower level service) from a photography equipment company.
D1 - 'Static service' 	Product	The product elements are using the service mostly as a static input to the product	A forum for amateur marathon runners to exchange tips and tactics on improving running abilities (lower level service), gives certificates of different levels of expertise (higher level product) based on users' level of contribution.
D2 - 'Static product' 	Service	The service elements need customer involvement in the production The service elements are using the product mostly as a static input to produce the service	A workshop for amateur marathon runners preparing for London Marathon 2015 (higher level service) has its content (lower level product) tailored based on the questions asked by the participants who have registered to attend the workshop.
E1 - 'No service'  or 	Product	The product element(s) are standalone product(s)	A recording of the 4x100m relay race in 2012 London Olympics.
E2 - 'No product'  or 	Service	The service element(s) are standalone service(s)	Watching a 4x100m relay race at the event venue.

Legend:

P Product element **S** Service element ➔ … have an impact on ⟶ … may have an impact on

The four characteristics of each PSS involved in the case studies in Phase I, which can be found in Appendix 12, were obtained using the PSS characterisation approach to be presented in chapter 6.

5.4.2 Secondary findings

The potential variables explored are referred to in the following sub-sections by their reference number. The reference key can be found in Appendix 11 Figure A 14.

5.4.2.1 Stakeholder types for the purpose of engineering design

Three potential variables (1.1, 1.2, 1.3) explored the stakeholder types and groupings for the purpose of engineering design. Four levels of stakeholder, environment, system/offering, product and service delivery have emerged in the Phase I study. This makes up 32 stakeholder types that either are employees of the manufacturer (internal) or are not employees (external). These groups are shown in Figure 5-6. The stakeholder identification framework that is used in Phase II (see Appendix 02) has been developed from this finding.

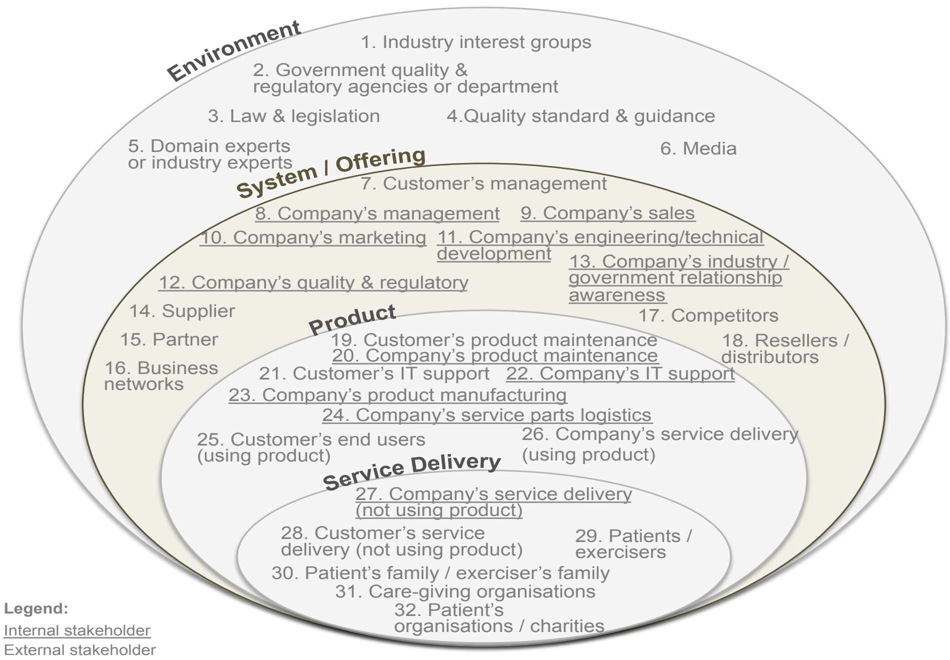


Figure 5-6 The updated onion diagram of stakeholder levels and groups

5.4.2.2 The engineering design process steps and stakeholder involvement

The potential variable "the ranges of engineering design process boundaries" (4.1) was explored for the boundary of the PSS engineering design process. Across the cases, the majority of the interviewees mentioned all or most of the seven steps of the engineering design process as shown in Figure 5-7. These steps can be grouped into the 'beginning phase', 'middle phase' and 'end phase' of engineering design.

The common steps and sequence of the engineering design process which emerged are similar to the generic engineering design process illustrated in the literature reviewed in chapter 2. A comparison can be found in Appendix 13.

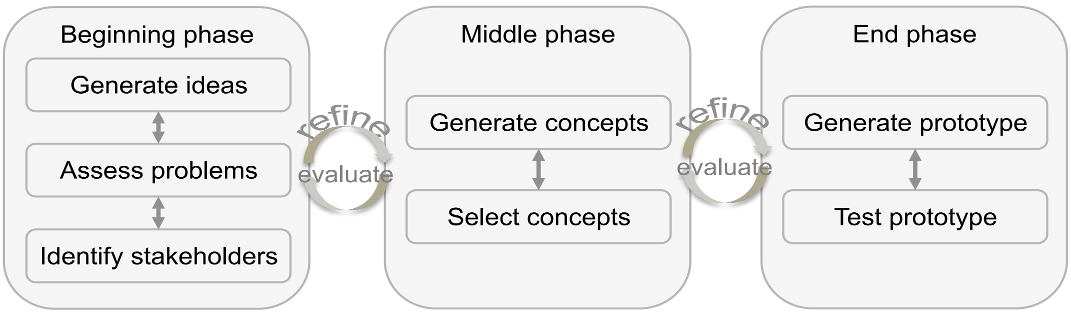


Figure 5-7 The boundary and steps of the PSS engineering design process

Three potential variables about stakeholder types, levels and dimensions (1.1, 1.2, 1.3), one about PSS configuration (2.2) and another one about ranges of PSS engineering design process boundaries (4.1), contributed to the exploration of how stakeholders are linked to different PSS characteristics (4.2). Although some stakeholders seem to be more associated with certain steps than others, no conclusion can yet be drawn on how PSS characteristics may lead to differences in the timing of stakeholder involvement. The limited findings are shown in Table 5-4.

Table 5-4 Limited findings of timing of stakeholder involvement for different types of development

Stakeholder level	Beginning phase[1]	Middle phase[1]	End phase[1]
Environment	2, 5 are important for all medical devices and services developments.	2, 5 are involved. 5 is required if the company lacks the required expertise.	2 is important for medical services involving hospital care delivery staff. 5 is involved if the company lacks the required expertise.
System/Offering	7 is important for all cases, except when the product is developed for mass market. 9, 10, 11 are important especially for developments with relatively high 'connectivity number'. 8 is only involved for service developments.	10 is important for all cases where service elements are dependent on product elements. 9 is important for service that uses a product-aid. 7 is important for all medical PSS where services are involved. 8 is involved in service development or PSS with relatively high 'connectivity number'.	7 is important and 8, 9 are involved for all cases except for product with relatively low 'connectivity number'. 10 is important for medical PSS and 11 is important for medical PSS with relatively high 'connectivity number'.
Product	25 is involved in all developments, but is important for service developments. 19, 20, 21 are important for all developments that rely on another product element.	19, 20 are important for PSS with relatively high 'connectivity number', where the new elements are dependent on existing product elements.	19, 20 are involved and important for PSS with relatively high 'connectivity number'. 21, 22 are involved where IT connectivity to the operating environment is important. 25 is important for all cases except for product with relatively low 'connectivity number'.
Service delivery	27 is involved for new service developments.	27 is involved for new service developments.	27 is involved for new service developments.

Note 1: Refer to Figure 5.6 for stakeholder reference numbers used in this table

5.4.2.3 Environmental factors that influence the engineering design

The potential variable "environment of operations" (7.1) explored the various perspectives of how the environment in which the new PSS is to operate could affect the engineering design. Six perspectives, adapted from literature of Gummesson (2007) and Porter (1990) were found to be useful in helping the development team think through what are the relevant contextual factors from the intended operating environment. They are the factor conditions[1], context for firm strategy and rivalry, local demand conditions, related industry, customer's operating environment and society (see Table 5-5). However, no specific impact on the stakeholder involvement requirements for new PSS development was found (7.3).

Table 5-5 Relevant contextual factors to consider during the engineering design process

Contextual factors	Sub-factors
Factor conditions	Industry/technology standard Skills availability in industry
Context for firm strategy and rivalry	Government law, regulation, incentive Competitor market positioning Company strategy
Local demand conditions	Market awareness, local or specific demand
Related industries	Industries of suppliers
Customer's operating environment	Actions and behaviours of those who provide end users support Expectation, perception and behaviours of users Expectation and experience of end customers
Society	Other interested parties in society

5.4.2.4 "Newness" of a PSS and its influence on stakeholder involvement in the engineering design process

The potential variables on "newness", (5.1, 5.2, 5.3), were introduced in the first iteration of the case study, and gradually dropped from the study. A framework adapted from literature was introduced in the second iteration (see Figure 5-8) to guide data collection.

[1] Factor conditions here refer to the conditions of the factors of production. Factors of production include human resources, knowledge, capital, physical resources and infrastructure.

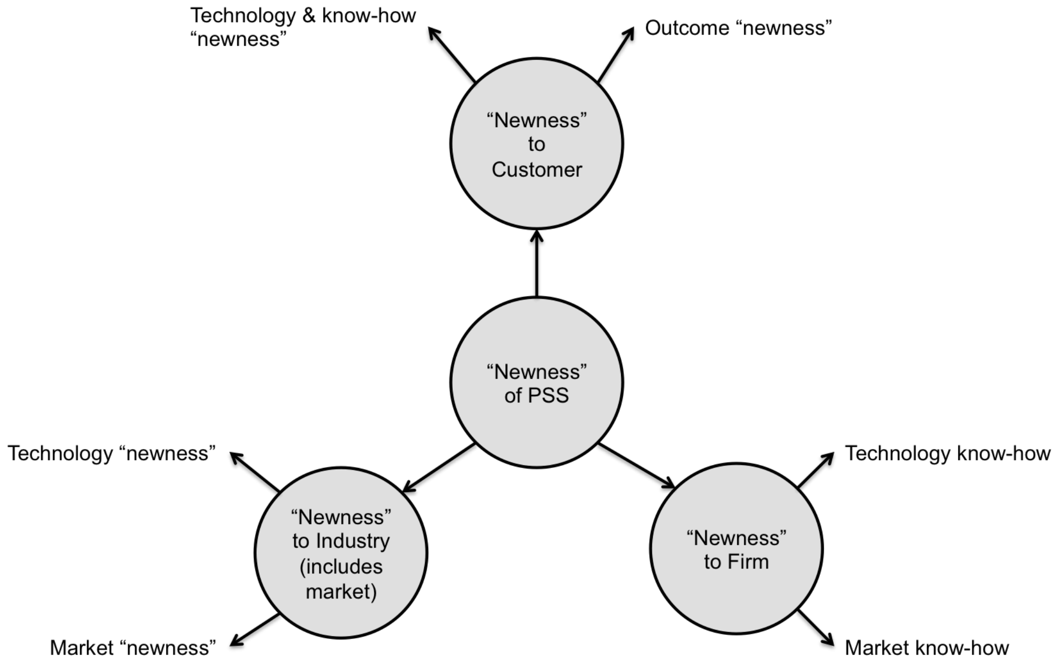


Figure 5-8 Types of "newness" (adapted from Garcia & Calantone, 2002)

The requirement for stakeholder involvement in the engineering design process is often thought to be affected by the "newness" of a PSS, and is therefore used in the data analysis. In this research, an analysis was completed on the impact of the "newness" of a PSS on the PSS engineering process (see Appendix 14). However, it is concluded that the "newness" of a PSS is not useful for PSS characterisation for engineering design.

5.4.3 Findings summary

In summary, Phase I identified four PSS characteristics which are useful for engineering design, and together they form the PSS characterisation scheme described in this thesis. Apart from this primary finding, this section presents four secondary findings on: stakeholder types for the purpose of engineering design; the engineering design process steps and timing of stakeholder involvement, the relevant contextual factors for engineering design; and that the "newness" of a PSS does not help to characterise PSSs for engineering design.

5.5 Phase I discussions

The previous sections presented the data collection and analysis process for Phase I and its findings. In this section, the impact of the potential variables explored on the research objective is first analysed. Then, a discussion of how the proposed PSS characterisation scheme addresses the three sub-questions in Phase I is then presented.

5.5.1 The research objective and the explored potential variables

Figure 5-9 shows a mapping of the research sub-questions with variables which survived three iterations of case studies. The variables are referred to in this sub-section using their reference number shown in this figure, such as (2.1) for "dimension of PSS classification".

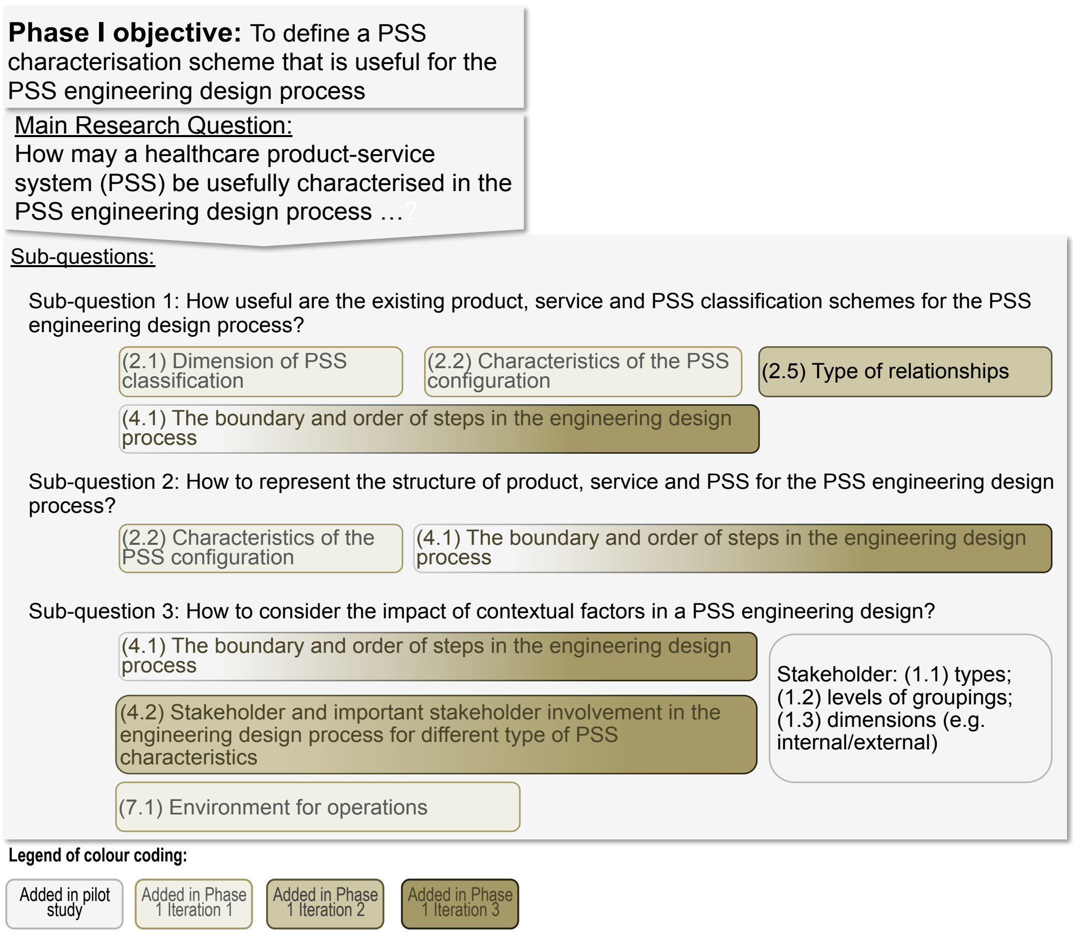


Figure 5-9 Mapping of variables from Phase I study to the research sub-questions

The common factor between the three sub-questions is the PSS engineering design process, which has been explored via (4.1). As presented in the previous section and Appendix 13, although some common steps of the engineering design process have been mentioned during the case interviews, the generic process from literature provides a more complete view of the engineering design process.

(2.1), (2.2) and (2.5) have enabled a better understanding of PSS characteristics which are useful for the engineering design process. Learning from the literature (chapter 2), contextual factors of the “active environment” where the new PSS is to operate in include both human and non-human factors. Stakeholders and their involvement in the engineering design process were examined through (1.1), (1.2) and (1.3); and societal and industry level factors that are mostly non-human factors were explored via (7.1).

How the proposed PSS characterisation scheme addresses the research sub-questions in Phase I is discussed in the following sub-section.

5.5.2 The PSS characterisation scheme and the research sub-questions

Through the completed case studies, a new way characterising PSSs for engineering design has emerged. The literature review in chapter 2 has established that there is a lack of a PSS classification scheme that is useful for the engineering design process. It has also revealed that the existing PSS classification schemes have mostly relied on ‘tangibility’ as the feature to separate services from products. The understanding of what PSS characteristics are useful for engineering design is a step toward developing a new PSS classification scheme for engineering design.

This proposed PSS characterisation scheme, as presented in the previous section, contains the four characteristics: (1) the customer perceived value level, (2) the ‘connectivity number’, (3) the type and degree of connectivity and (4) the type of configuration. This scheme does not refer to whether something is tangible or not; instead it is based on a PSS’s potential value to customers, its internal structural configuration and connections among its constituent parts and its operating environment.

This novel characterisation scheme addresses both sub-questions 1 and 2 (see Figure 5-9). Even though the environmental factors were explored separately in sub-question 3, factors which are most relevant to the engineering design process were incorporated into the characterisation scheme. The incorporation of the relevant human and non-human contextual factors is discussed below.

5.5.2.1 Human contextual factors

The literature discusses the customers' role in value creation and a company's options in participating in the value co-creation process. These discussions have provided insights in using potential customer value to describe a PSS, as seen in Figure 2-24.
From the case studies, the customer's perceived value level has appeared to be useful for the engineering design process. The emphasis of this characteristic is that whether customers use a PSS or not depends on how they perceive the potential value of the PSS. Customers here include stakeholders who are ultimately benefiting from the service generated by the PSS and those who purchase and/or use the PSS. Their expectations, perception and behaviour, as well as the preferences of other stakeholders of the PSS, impact how they view the value of the PSS. There are also other contextual factors that influence customers' perception. This includes government's regulations and incentives, and the general demand condition in the market. During the engineering design process, the development team not only needs to consider stakeholders who purchase and use the PSS, but also the interests and impact from stakeholders at the environment level.

5.5.2.2 Non-human contextual factors

'Connectivity number' has been proposed to represent the number of relationships between the new and existing product and service elements within a PSS and with the infrastructural elements (its operating environment). This ‘connectivity number’ has weighted the ‘new impacting existing’ relationships more than the ‘existing impacting new’ relationships. This is because, introducing a new element that impacts an existing system or its operating environment could hamper the functioning of an existing system, and the development team needs to pay more attention to this type of new element. It also does not include the ‘new impacting new’ and ‘existing impacting existing’ relationships. This is because the ‘connectivity number’ measures the extra effort required, in addition to the routine development effort. It can be viewed as a proxy to the complexity of a PSS development in terms of development effort. The equation for calculating the ‘connectivity number’ is:

‘Connectivity number’ = 2 × (number of ‘new impacting existing’ relationships) + (number of ‘existing impacting new’ relationships)

The type and degree of connectivity proposed further describe the connections within a PSS and with its operating environment in terms of whether the connections are relating to product or service elements. Connectivity relating to products is called physical/data connectivity, and connectivity between services is called process connectivity. A PSS’s degree of connectivity remains the same, regardless of whether the company or customer is to own the PSS, whether the PSS is tangible or not, or whether a manufacturer is changing its business model toward service provision (see Table 2-1 for the discussion of the issues of existing PSS schemes).

Contextual factors which have been incorporated into ‘connectivity number’ and the type and degree of connectivity include the locations of other physical products or data structures within the operating environment, the operating procedures used by the stakeholders of the new PSS, and the infrastructure of the operating environment itself.

Various structural representations have been evaluated in the literature review, giving some ideas of how the constituents of a PSS can be represented. Through the Phase I case studies, some PSS configuration types have become apparent, which are further developed into the ten proposed PSS configuration types. The configuration type shows the interdependencies between the product and service portions of the PSS. Contextual factors incorporated into the PSS configuration type include the company's strategy, its awareness of competitors' market positioning, and the stability of the supplying industry.

Figure 5-10 summarises the contextual factors from the case studies (7.1), and indicates which factors are incorporated in the proposed PSS characteristics.

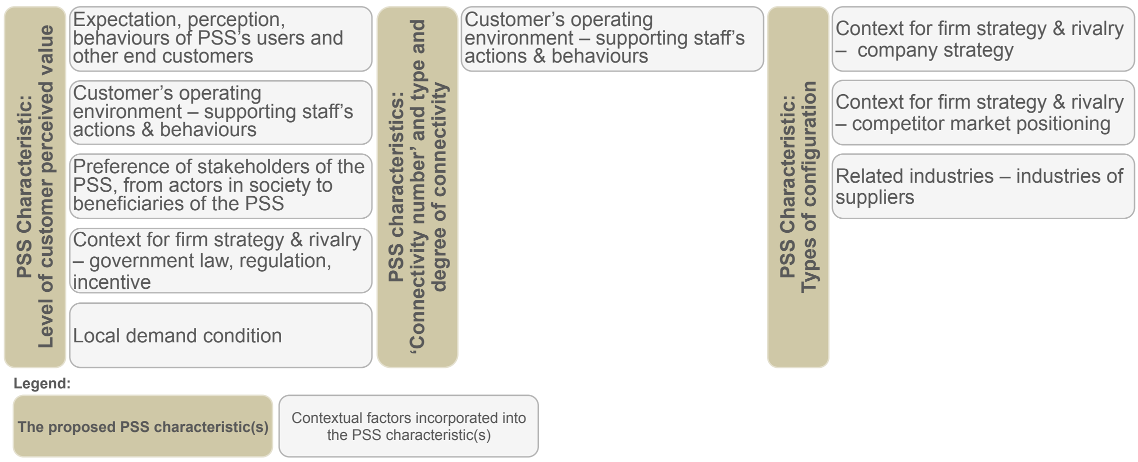


Figure 5-10 The PSS characterisation scheme and its incorporation of relevant contextual factors

This section discusses how the Phase I findings have addressed the first research objective. The following section concludes this chapter with the theoretical contributions and limitations of the Phase I study.

5.6 Phase I theoretical contributions and limitations

The main theoretical contribution of Phase I is the novel PSS characterisation scheme for the engineering design process. A secondary contribution is a stakeholder identification framework that was developed in the course of identifying this PSS characterisation scheme. To illustrate how the literature has inspired the interpretation of the Phase I case studies, and how the contributions of Phase I have addressed the identified literature gaps, Figure 5-11 is created, which is built on Figure 2-24 that was previously presented as a conclusion to the literature review. Figure 5-11 presents the literature gaps on the left, how the findings from Phase I have addressed these gaps, and in turn, how the literature has inspired these findings.

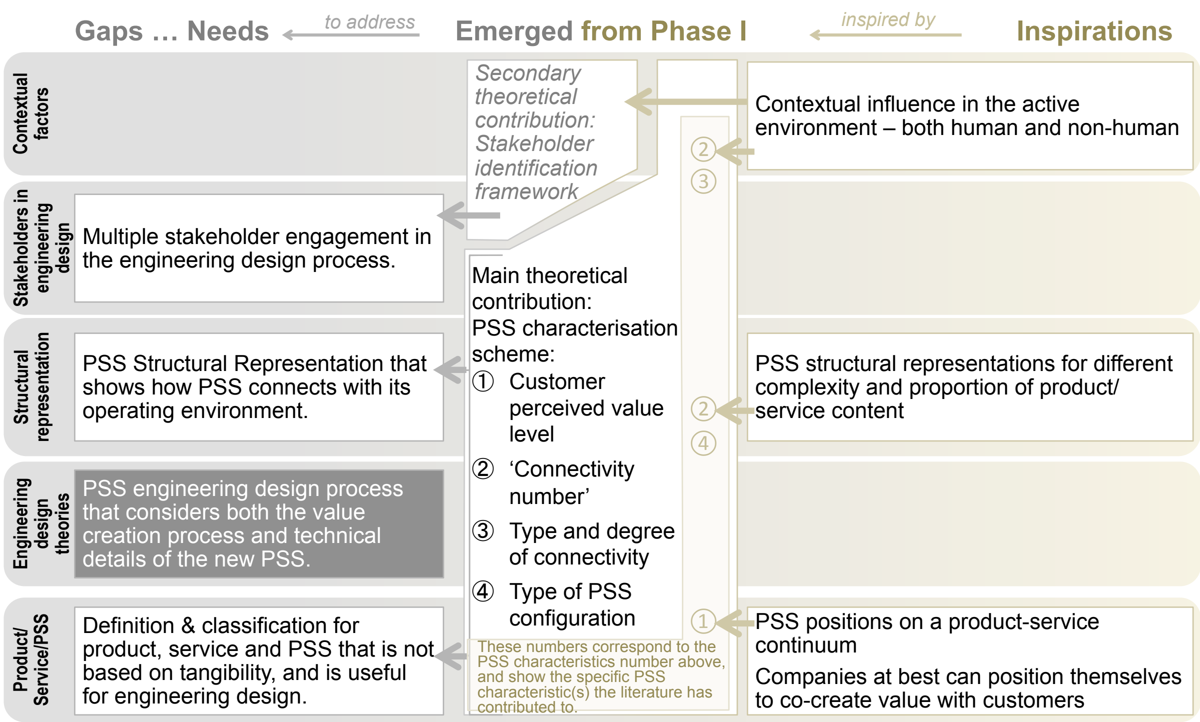


Figure 5-11 Inspirations from literature and literature gaps addressed in Phase I

5.6.1 Theoretical contributions from Phase I

Inspired by the literature, and emerging from the case studies, is a PSS characterisation scheme comprising four characteristics relevant for the PSS discussed in the cases. These four characteristics together form a novel way of describing PSS. The following aspects of the PSS, shown in the main portion of the middle column of Figure 5-11, are teased out by this characterisation scheme:

1. The potential value of the new PSS as perceived by the target customers.

2. The ‘connectivity number’, which represents the interactions between the to-be-developed elements of a PSS and the existing elements of a PSS and its intended operating environment.
3. The degree of connectivity, described as ‘independent’, ‘linked’ or ‘incorporated’, for the two types of connectivity: data/physical and process connectivity.
4. The PSS configuration type that best represents the structure of a PSS. The PSS configuration type consists of five mirroring pairs of abstract structural representation of how the product and service portions interact with one another within a PSS.

This PSS characterisation scheme is not based on the traditional reference of products as tangible objects and services as intangible, which is identified as a literature gap, as seen in the left-hand side of Figure 5-11. As seen in the right-hand side of Figure 5-11, the scheme draws on both human and non-human contextual factors of the intended operating environment of the PSS, and examines the potential complexity of the PSS development based on its relationships and connectivity within the PSS and with its “active environment”. The scheme has also drawn from the PSS structural representations in literature for its proposed PSS configurations schematic diagrams (the PSS configuration types).

Overall, the PSS characterisation scheme contributes to the literature of PSS classifications. Understanding which PSS characteristics are useful for engineering design is a step toward developing a PSS classification scheme for engineering design. Clear definitions for products and services are also adopted from literature for this characterisation scheme. Instead of using the ‘tangibility’ distinction, the proposed characteristics describe PSS by its value, configuration and internal and external connections.

The stakeholder identification framework developed is shown in the top middle portion of Figure 5-11. This four-level framework draws inspiration from the contextual influence to a PSS, with the highest stakeholder level being environment and lowest level being service delivery. This framework's application in Phase II study has further developed and stabilised it as a tool for development teams to identify stakeholders for new PSSs. The final version of this framework can be found in Appendix 02.

5.6.2 The limitations of Phase I findings

The case studies in Phase I all come from the healthcare industry. Therefore, the proposed PSS characteristics may be limited to healthcare PSS only. Moreover, the four characteristics are based on the interpretation of opinions of the interviewees. Although multiple development team members representing different stakeholder groups were targeted, not all cases have interviewees from different stakeholder groups. This may have biased the data collected. Furthermore, only participants from successful new development accepted the invitation to be interviewed. Those who have the experience of failed projects declined to participate in the case studies. The fact that only successful projects have been studied has limited the findings of Phase I.

5.6.3 The logical next steps

For reliability purposes, it is important to have a systematic process to identify the four PSS characteristics of any PSS, before investigating how this new characterisation scheme may impact on a PSS design specification. This is addressed by the development of the "PSS characterisation approach", which has become a research instrument for this study. The development process of this research instrument is captured in Appendix 04. The PSS characterisation approach has the potential to fulfil a need that has not been addressed by the Phase I findings - PSS engineering design process that considers both the value creation process and technical details of the PSS (see Figure 5-11). It will also be a useful theoretical and practical contribution to extend this PSS characterisation scheme to other industries. This objective is reflected in the case selection strategy of Phase II.

6 Phase II - the influence of the PSS characterisation scheme on the PSS design specification

Following the presentation of the findings of the Phase I study, this chapter presents the influence of the PSS characterisation scheme on PSS design specification. The researcher has facilitated nine workshops in which the participating development team members applied the PSS characterisation scheme to PSSs of interest. The results from the nine workshops are included in this chapter.

6.1 Phase II introduction

A novel PSS characterisation scheme is proposed in Phase I of this research. Phase II is designed to understand the influence of this PSS characterisation scheme on PSS design specifications. PSS design specification is the output of the "Clarification of the design task" step of the engineering design process discussed in section 2.3.3.

In the following sections, the overall process of the Phase II study is first presented, along with a summary of the workshops completed. The data analysis procedure used is then presented. This is then followed by a presentation of the findings and a discussion. The chapter is concluded with the theoretical and practical contributions of Phase II, the limitations and the next steps.

6.2 Phase II data collection – workshops summary

This section presents the Phase II research process and the control measures taken in the data collection process. A summary of the distribution of workshops is also presented.

6.2.1 The Phase II research process

Action research is selected as the appropriate research methodology for Phase II, because the PSS engineering design process is complex and the knowledge and experience of individuals in a new PSS development project is critical to the interpretations of the data collected. Similar to Phase I, the number of workshops conducted in Phase II was not planned in advance, as the objective is to allow the emergence of constructs and their validation via subsequent workshops. The workshop process steps are shown in Figure 6-1. As a result of the methodology used, the learning from the workshop participants feeds back to the data collection process. Upon reflection on the learning from the previous workshops, the criteria for subsequent workshop selection are adjusted. The data collection instrument, that is the PSS characterisation approach, is also modified based on the learning. These feedback loops are shown by dotted line arrows in Figure 6-1.

The development process for the PSS characterisation approach is also shown in Figure 6-1, toward the lower right of the flow chart, below the "collect data via workshops" step. It shows the primary, secondary and tertiary changes which arise from the observations and comments obtained during the workshops. The process develops the PSS characterisation approach as a stable research instrument and can be found in Appendix 04.

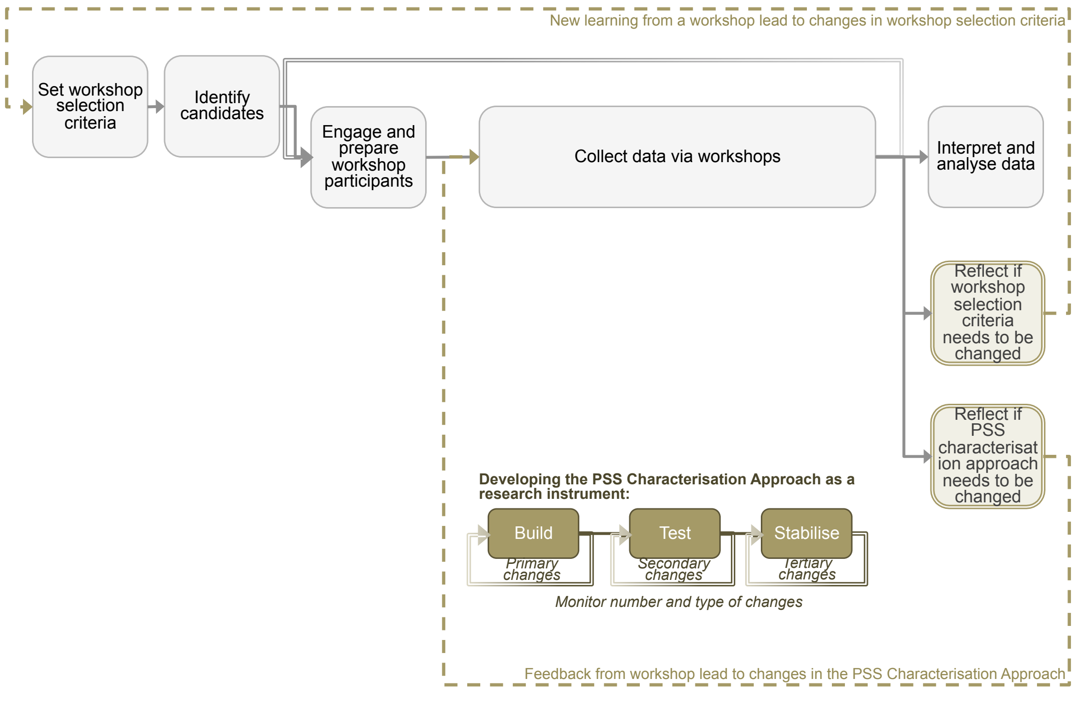


Figure 6-1 The Phase II workshop process

The main data collected in Phase II are workshop observations, audio-recordings and the researcher's reflections. A data documentation template is developed as part of the control measures taken in the data collection process, and will be explained in the next sub-section.

6.2.2 Control measures of the data collection process

Control measures are implemented in the workshop process in order to improve the reliability of the data collected. The control points are:

- When qualifying projects to participate in the workshop
- When preparing the workshop participants and the facilitator for the workshop
- When facilitating the workshops, in particular the facilitation style and data collection techniques

6.2.2.1 Qualification

To be qualified to participate in the workshop, the companies, including the self-selected ones that had responded to the researcher's advertisement and the targeted companies identified by the researcher, had to first confirm that the company had a clear new product and service development strategy, and that the workshop would be able to achieve both the company's and the researcher's objectives. Initial phone conversations were held with representatives from the candidate development project teams. The development teams that did not know, or would not be able to establish a new product and service strategy, did not qualify for the workshop. Likewise, if companies' needs were unlikely to be met by the workshop, the development teams were not selected for Phase II study. These controls aim to minimise the wasting of research time on other topics, such as setting a vision for a company or division, or establishing new product and service strategies.

6.2.2.2 Preparation

Once a company confirmed that a clear new product and service development strategy existed, a pre-workshop assignment was given to the participants. The participants were asked to read about what to expect in the workshop. They were asked to think about who the stakeholders would be for the PSS to be analysed, and what problems the new PSS intended to solve. Most importantly, the participants were asked to agree on the desirable outcomes of the workshop. This information was then passed on to the workshop facilitator. In order to gain more understanding about the participating company, the facilitator read about the company from public sources, such as the company's website. The facilitator also organised the workshop venue and adjusted the tools to support the workshop execution if needed. On the day of the workshop, the facilitator arrived early to set-up the workshop room. Guidance notes were printed out for the participants to refer to during the workshop. Photos of the set-up of some of the workshops are captured in Appendix 15 Figure A 16.

6.2.2.3 Workshop facilitation

The researcher facilitated all workshops. Extra caution was taken to maintain a consistent facilitation style in every workshop. This minimised variables such as the following: how the facilitator was to interrupt or intervene in a disagreement among the participants, how much assistance the facilitator was to give to the participants when they appeared to have difficulty following the workshop guidance notes, and how tightly the workshop agenda was controlled. Thus, the influence of workshop facilitation style on the data collected was minimised. The researcher has over 12 years of professional facilitation experience in industry, which enabled consistency in the facilitation style across the various workshops.

Audio recordings and photos of the drawings and diagrams were also made during the workshop. Where an independent observer was used, a conversation with the observer was held after the workshop and the observer's notes were collated. As the facilitation and observation happened at the same time, the facilitator recorded her learning from the workshop immediately after its completion in order to maximise the amount of data captured. A template used to capture data is shown in Appendix 15 Figure A 17.

6.2.3 The Phase II workshops

As discussed in chapter 5, one limitation of the PSS characterisation scheme is that the emerged PSS characteristics might only be applicable to healthcare PSSs. As a result, the Phase II workshop selection strategy targeted companies from different industries. This phase is summarised in Table 6-1. An explanation of the instrument development phases can be found in Appendix 04.

Table 6-1 Number of workshops per development phase in Phase II

Phase of developing the "PSS Characterisation Approach" as a research instrument	Healthcare workshop reference[1]	Non-healthcare workshop reference[1] (industry)	Comments
Build	O	P (Confectionary)	1 hypothetical PSS, 1 commercialised PSS
Improve	R	Q (Defence)	PSSs are within the engineering design process
Stabilise	T	S (Environmental protection) U (Financial investment)	PSSs are within the engineering design process
Refine	W	V (Executive education)	PSSs are within the engineering design process

Note 1: See Figure 3.3 for workshop details

6.3 The PSS characterisation approach

The PSS characterisation approach first emerged to systematically analyse the case studies in Phase I, and was the research instrument chosen for data collection in the Phase II workshops. This section presents the tested and stabilised approach using a hypothetical example. A prerequisite of the PSS characterisation approach is the existence of a company's new product and service strategy. The overall approach is shown in Figure 6-2. Step 0: Stakeholder identification is an optional step, which is used when the company has not yet identified the stakeholders before coming into the workshop. The four PSS characteristics of the proposed PSS characterisation scheme presented in chapter 5 are the outputs of Step 4 and 5 of this approach, as shown in the grey box in Figure 6-2.

This section presents the PSS characterisation approach in details with the help of an example. Two earlier versions of this approach were published in the conference proceedings of The XXIV International Society for Professional Innovation Management (ISPIM) Conference and the Portland International Center for Management of Engineering and Technology (PICMET) respectively (Yip, Phaal, & Probert, 2013; Yip et al., 2014a). The approach presented here is the final stabilised version. Feedback was collected at each workshop and changes to the approach were implemented before the following workshop.

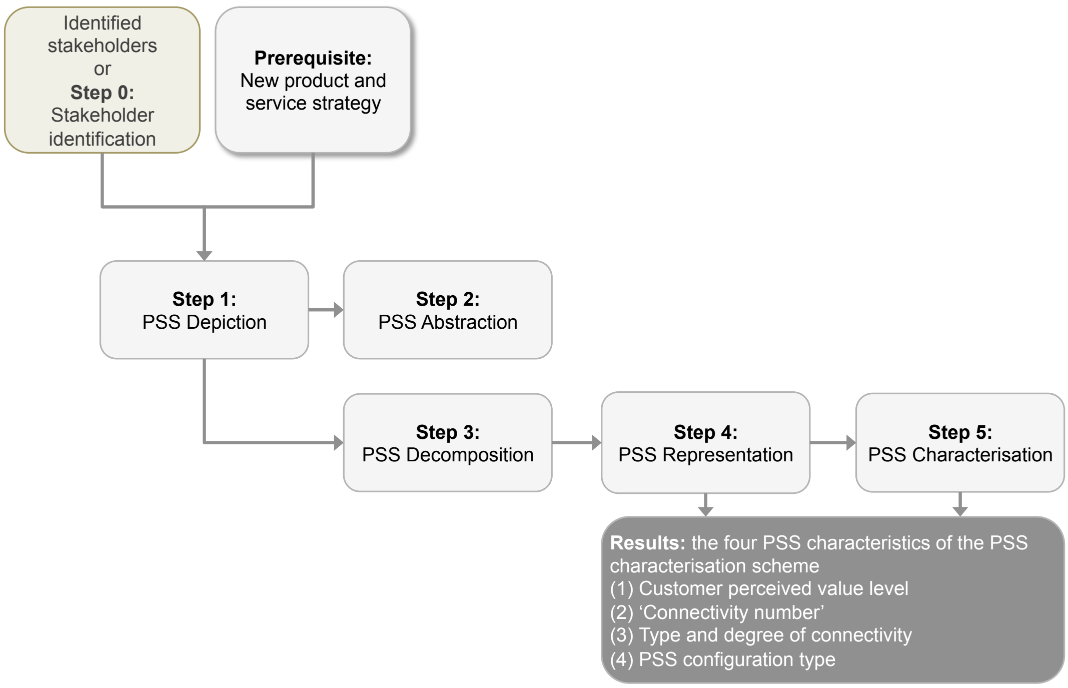


Figure 6-2 The PSS characterisation approach

The example used to illustrate the PSS characterisation approach to identify the four PSS characteristics is the development of a new running group by a local running club in Cambridge for its new and existing members. The new running group intends to promote health awareness and sense of belonging in the local community, by providing safe group running on weekday evenings for runners of all abilities. In this example, the club manager, one of the running group leaders, and the running club staff responsible for marketing, are the workshop participants.

Assuming that the workshop participants have not yet identified the stakeholders of the new offering, they opt to start with using the stakeholder identification framework (Table 6-2). This is Step 0 of the PSS characterisation approach.

Table 6-2 Step 0 – Stakeholder identification

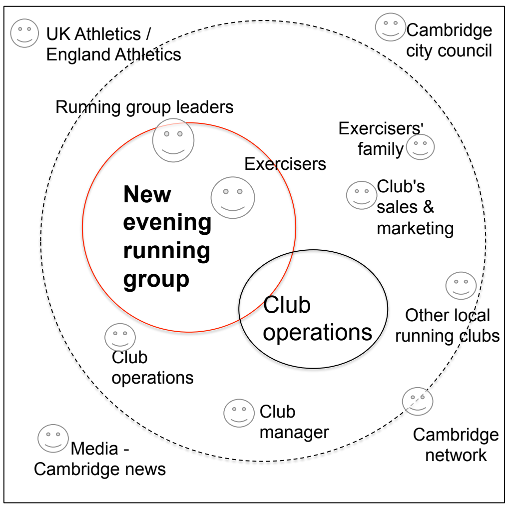
Stakeholder level	Stakeholder group – relevant to the new offering	Company's perspective
Environment	UK Athletics / England Athletics - group leading & coaching license	External
	Government Department - Cambridge city council	External
	Media - Cambridge news	External
System/Offering	Company's management - club manager	Internal
	Company's sales - club's sales & marketing	Internal
	Company's marketing – club manager	Internal
	Company's engineering/technical development - run route development by the running group leaders	Internal
	Company's quality & regulatory – club operations	Internal
	Company's industry/government relationship awareness - club manager & news editor	Internal
	Business networks - Cambridge network	External
	Competitors - other local running clubs	External
Product	Company's IT support	Internal
	Company's service delivery (using product) - running group leaders leading running exercises that involve health & safety materials	Internal
Service delivery	Company's service delivery (not using product) - running group leaders leading the warm-up & cool-down exercises	Internal
	Exercisers	External
	Exerciser's family (exercisers are spending time with other runners instead of with family)	External

6.3.1 Step 1: PSS Depiction

PSS depiction is a diagram showing the products, services, and key stakeholders within the intended operating environment of the new PSS. The diagram does not need to be precise, but it has to have enough detail to enable a meaningful discussion about potential commercial offerings. The depiction urges the development team to consider how key stakeholders and other existing product and service elements will interact with the new development. Information flow arrows can be added where the development team finds them useful.

Basic shapes used in PSS depictions include:

- Rectangle to represent the operating environment
- Dotted line circle/oval to represent the PSS
- Red (or grey if printed in black and white) circles/ovals to represent new functions or new products and services
- Black circles/ovals to represent existing functions, products and services
- Emoticons ('smiley faces') to represent key stakeholders of the PSS



New Functions	Elements for delivering the functions	New (N) or Existing (X)	Product (P) or Service (S)
New evening running group	Evening running group	N	S
	City run routes	N	P
	Warm-up/Cool-down exercises	X	S
	Suitable running gear	X	P

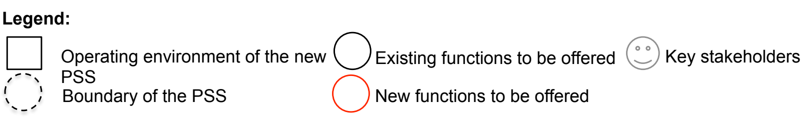


Figure 6-3 Step 1 - PSS depiction and elements identification table

After the PSS depiction diagram is drawn, a table that lists the new and existing functions and their constituent product and service elements is to be prepared. This table is an input to Step 3 – PSS Decomposition. Figure 6-3 shows the new running group's PSS depiction and its elements identification table.

6.3.2 Step 2: PSS Abstraction

PSS abstraction aims to produce an abstract diagram that represents the focus of the new development(s). It fosters discussion within the development team on a number of topics: the main PSS development as opposed to supplementary developments; why certain parts are more important than others; and where to focus development resources. The abstract diagram can be used as a communication tool to brief other company's employees on the new development project. The development team is encouraged to debate and come to an agreement on the meaning of the following in the abstract diagram:

- Size of the shapes representing product and service
- Position of the shapes representing product and service

The meaning of the sizes and positions of the product and service shapes may be used to represent their relative value to customers, the physical interactions and dependency between product and service, or the relative development cost and effort.

Basic shapes which are used in the PSS abstract diagram are (see Figure 6-4):

- Rectangle to represent the operating environment
- Dotted line circle to represent the PSS
- One pink and one blue (light and dark grey if printed in black and white) circles/rings to represent product and service elements respectively

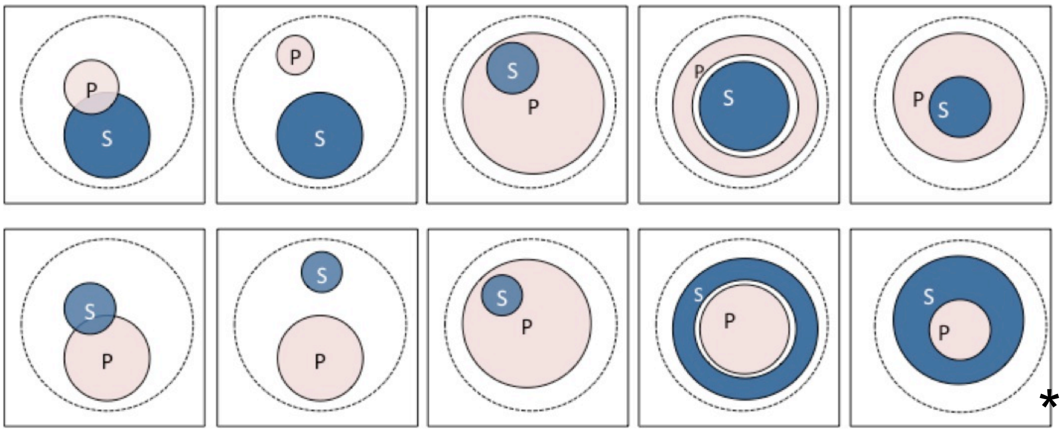


Figure 6-4 Step 2- PSS abstraction - potential diagrams

The running group example's PSS abstraction diagram is marked with an asterisk (*) in Figure 6-4. The product circle is completely inside the service circle. This is to show that the product elements are used in the delivery of the services in this PSS, for example the suitable running gear, are to be worn during the running exercise.

6.3.3 Step 3: PSS Decomposition

PSS decomposition involves progressively building a series of grids during the analysis of the constituent parts of the PSS. The interdependencies among the elements within a PSS are examined. In a waterfall-manner, this step decomposes the element that potentially provides the highest customer value, through its constituent elements, to infrastructural elements in the environment which the PSS operates in. The decomposition diagram requires the relationships among the elements to be identified and exhibited. The element which may provide the ultimate customer value may be part of the new PSS, or be an existing commercial offering from the company. In this example, the PSS is provided by the company (the running club). The concept and design of PSS decomposition is inspired by QFD, which has been reviewed in chapter 2.

The product and service elements identified in the elements identification table in Step 1 are captured on sticky notes. Each product element is captured on a pink note (light grey in Figure 6-5 and Figure 6-6 if printed in black and white). Each service element is captured on a blue sticky note (dark grey in Figure 6-5 and Figure 6-6 if printed in black and white). A red dot (grey dot if printed in black and white) is put on each sticky note describing a new element to be developed.

As illustrated in Figure 6-5, the 'Top grid' contains the elements that intend to provide the highest customer value in the top/horizontal row (labelled 'Top level'). In this example, the 'Top level' only contains the new service of "S1 - Evening running group". "S1 - Evening running group" interacts directly with some other elements, which are listed vertically ('Top-1 level'), forming the right-hand side of the 'Top grid'. In this example, "S1 - Evening running group" is interacting directly with: the "P1 - Evening city run routes", "P2 - Suitable running gear" and "S2 – Warm-up/Cool-down exercises".

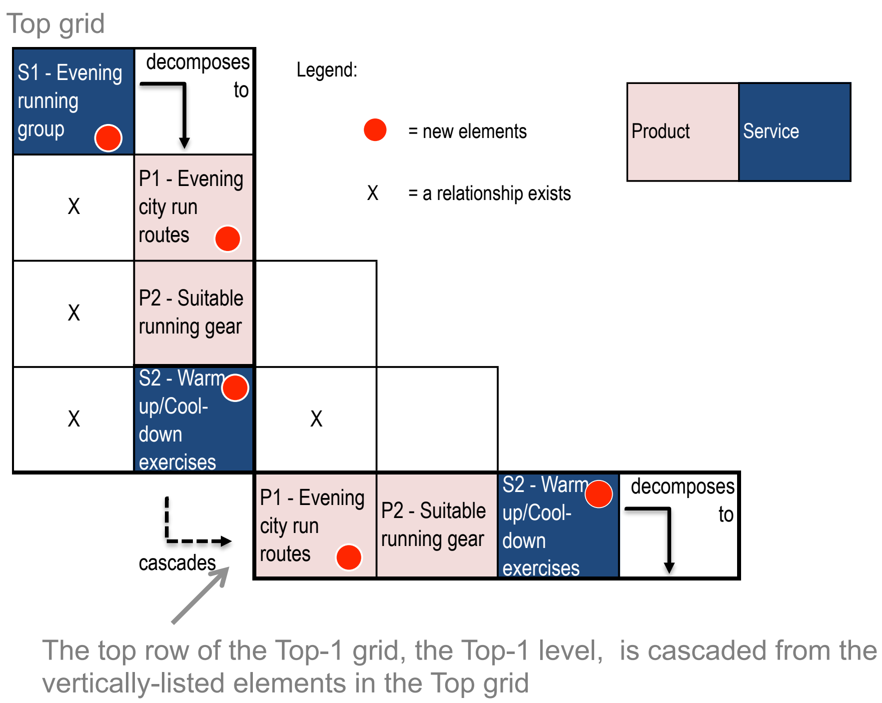


Figure 6-5 Step 3 - PSS decomposition – from 'Top grid' to 'Top-1 grid'

Whether an element is owned by the customers or by the company is not differentiated in the diagram, nor is it in the PSS characterisation approach, as ownership of a product or service is not of importance in the proposed PSS characterisation scheme. In this example, "P2 – Suitable running gear" belongs to the customers (exercisers).

The 'Top-1 level' elements then cascade down to form the top row of the 'Top-1 grid'. The elements that these 'Top-1 level' elements directly interact with, are listed vertically to form the right-hand side of the 'Top-1 grid', and these elements cascade down to form the top row of 'Top-2 grid'. In this manner, a series of grids are built until the infrastructural elements of the PSS operating environment are listed horizontally in a row (the 'Last grid').

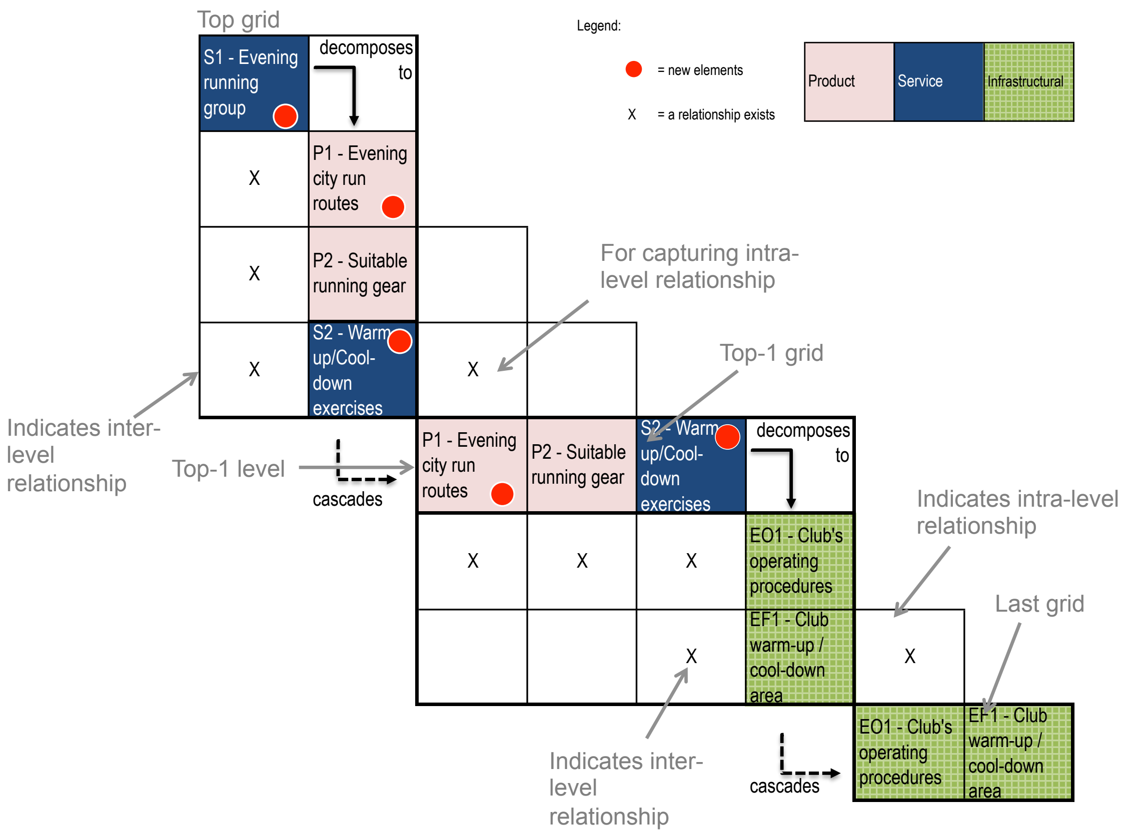


Figure 6-6 Step 3 - PSS decomposition – from 'Top grid' to 'Last grid'

Infrastructural elements are facilities and operations for which the company can assume existence. Here, they are "EO1 - Club's operating procedures" and "EF1 - Club's warm-up/cool-down area". Green sticky notes are used for capturing infrastructural elements (checks on light grey if printed in black and white). In this example, the 'Top-1 level' elements directly interact with the infrastructural elements (see Figure 6-6).

After forming the series of grids, the relationships among the elements within the grids are to be identified. As shown in Figure 6-6, the 'squares' inside each grid are used to denote the relationships between the elements in adjacent levels (inter-level relationships). Elements from the same level when interact with each other and create intra-level relationships. These are captured in the external 'squares' between two adjacent grids, as indicated in Figure 6-6. A relationship is represented by an 'X', and this means that one element impacts or is dependent on another element.

After all the relationships have been identified, the direction of impact for each relationship is determined. If element A impacts on the functionality of element B, then an arrow is placed pointing toward element B. Where element A and B impact each other, then two arrows are placed between them in opposite directions. Figure 6-7 illustrates the concept.

After the direction(s) of impact is/are identified for each relationship, the relationships between existing and new elements are further highlighted. As shown in Figure 6-7, if a new element (an element with a red dot or grey dot in black and white) impacts an existing element, the relationship arrow in between them is coloured black, for example a black arrow is used for the relationship of "P1 impacts P2". If a new element is impacted by an existing element, that is an existing element impacts a new element, the relationship arrow is striped, for example the relationship of "P2 impacts S1". The arrows for relationships between two new elements (e.g. P1 and S1), or two existing elements are left white. The complete PSS decomposition for this example can be found in Appendix 16.

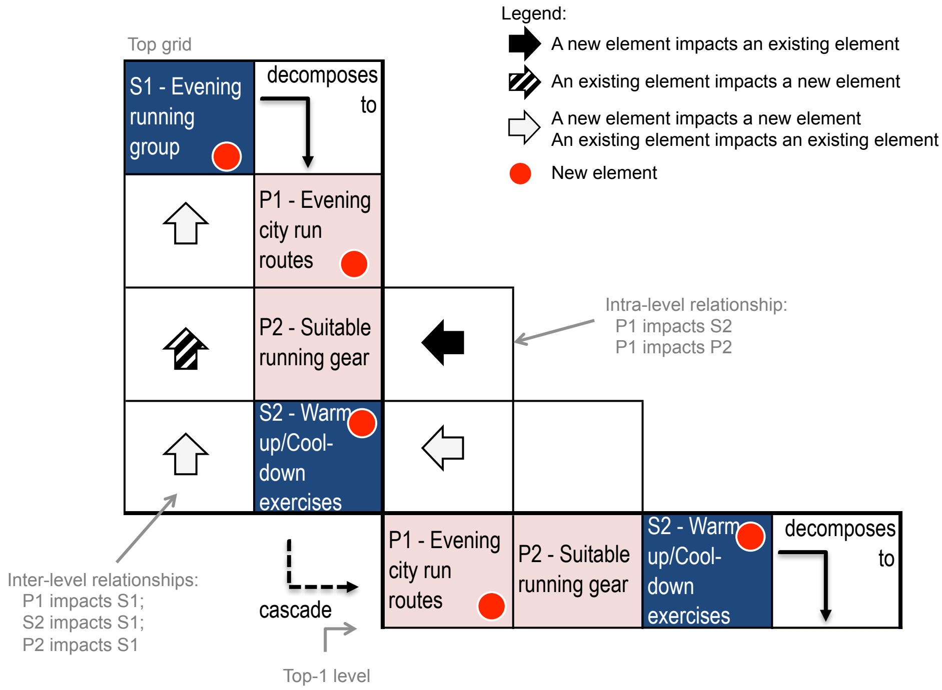


Figure 6-7 Step 3 - PSS decomposition – impact directions

6.3.4 Step 4: PSS Representation

PSS representation involves developing a structured-diagram (see Figure 6-8) representing the elements and the relationships identified during the PSS decomposition. The idea is to 'pack' the identified product, service, and infrastructure elements according to the 'levels' they belong to, and have all the inter-level and intra-level relationships within the PSS clearly marked. The height of the diagram is determined by the number of times the highest value-proposition element(s) is/are decomposed before reaching the infrastructural elements. The width of the diagram is impacted by how many elements have multiple relationships with other elements within the same level and with the adjacent levels. The width of each element is determined by the number of relationships it has with other elements at its adjacent levels.

The rules for building a PSS representation diagram are: (1) to minimise the width of each element, that is to only extend the width of each element by a unit if it is required by an additional inter-level relationship; and (2) to arrange the elements so that they are as tightly packed as possible. As shown in Figure 6-8, which is the PSS representation diagram for the running group example, the outer rim of the PSS representation (shaded area) represents the intended operating environment of the PSS and the dotted line represents the boundary of the PSS. The infrastructural elements are the base of the diagram and the coloured areas within the dotted line are the product and service elements in the PSS. The contours of the product and service elements give an impression of how these elements relate to each other.

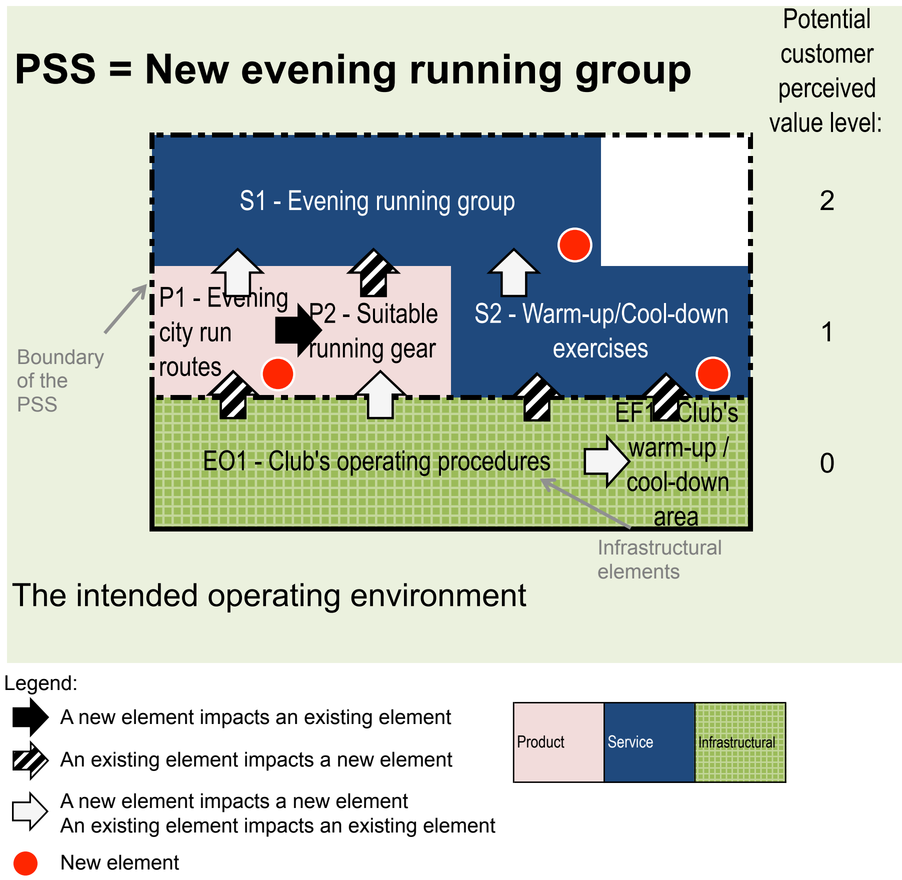


Figure 6-8 Step 4 – PSS representation

6.3.5 Step 5: PSS Characterisation

The PSS characterisation step quantifies/assesses the four PSS characteristics which emerged in Phase I: (1) the potential customer perceived value level, (2) the 'connectivity number' of the PSS, (3) the type and degree of connectivity and (4) the

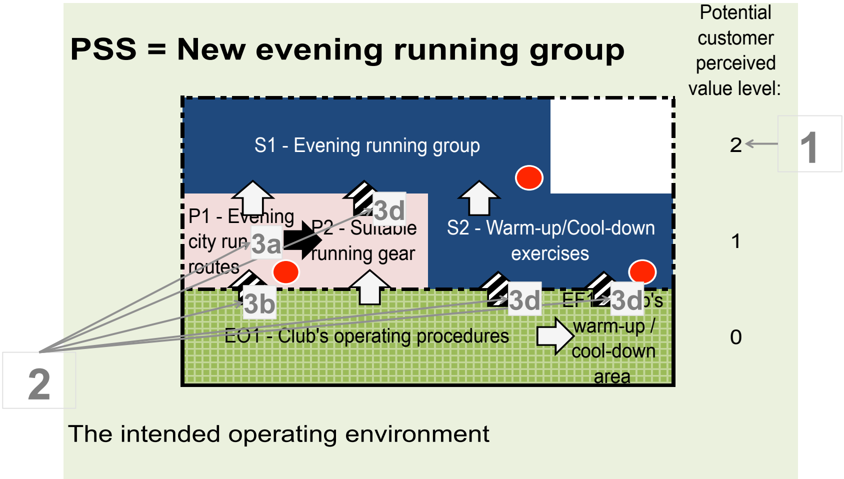
PSS configuration type. The explanation of these four characteristics has been given in chapter 5. To standardise how the degree of connectivity can be determined, the quantities of black and/or striped arrows are examined, as shown in Table 6-3. The quantification and assessment of the four characteristics in the new evening running group example is shown in Figure 6-9.

Table 6-3 Determining the degree of connectivity

Type of connectivity	Represented by which type of shape	Degree of connectivity
Physical/data connectivity:		
New product/service elements impacting existing **product** elements New **product** elements impacted by existing product/service elements	Black Striped	If the number of: Black>0 & Striped≥ 0: 'Incorporated' Black=0 & Striped>0: 'Linked' Black=0 & Striped=0: 'Independent'
Process connectivity:		
New product/service elements impacting existing **service** elements New **service** elements impacted by existing product/service elements	Black Striped	If the number of: Black>0 & Striped≥ 0: 'Incorporated' Black=0 & Striped>0: 'Linked' Black=0 & Striped=0: 'Independent'

While the first three characteristics, the potential customer perceived value level, the 'connectivity number' and the degree of connectivity for each type of connectivity, can be counted and calculated, the fourth characteristic of PSS configuration type is more subjective and is the result of discussions among the development team members. In this example, the workshop participants for the new evening run group offering have agreed that B2 "Deforming product" is the PSS configuration type that best represents their new offering. The reason is that, as shown in Figure 6-9, the "P1 - Evening city run routes" and "P2 - Suitable running gear" can be seen as the "deforming products". If runners were required to wear a uniform and there was only one route, then P1 and P2 would have become part of "EO1 - Club's operating procedures". The PSS configuration would become E2 "no product", as seen in Figure 6-10.

The PSS representation diagram from step 4



Step 5 PSS Characterisation - determining the four PSS characteristics

(1) Customer perceived value level

This is the height, or the number of layers, of the PSS representation diagram, counting upward the layer above the infrastructural level (labelled "1" in the PSS representation diagram)

In this example:

Customer perceived value level = 2

(2) "Connectivity number"

"Connectivity number" = 2 x number of "new impacting existing" relationships + number of "existing impacting new" relationships

In the PSS representation diagram, the "new impacting existing" relationship is represented by black arrow, and "existing impacting new" by striped arrow.

Therefore, "connectivity number" = 2 x number of black arrow + number of striped arrow (labelled "2" in the PSS representation diagram)

In this example:

Number of black arrow = 1; Number of striped arrow = 4; therefore "Connectivity number" = 1x2 + 4 = 6

(3) Type and degree of connectivity

There are two types of connectivity: data/physical and process.

To determine the degree of connectivity in each type, the connectivity concerning product and service elements are evaluated separately.

For data/physical connectivity, the followings need to be counted:

New product/service impacting **existing product** (labelled "3-a"), represented by black arrow pointing to pink* square

Existing product/service impacting **new product** (labelled "3-b"**)**, represented by striped arrow pointing to pink* square with red dot

If "3-a" > 0; then data/physical connectivity is "incorporated"

If "3-a" = 0 and "3-b" > 0; then data/physical connectivity is "linked"

If "3-a" = "3-b"=0; then data/physical connectivity is "independent"

For process connectivity, the followings need to be counted:

New product/service impacting **existing service** (labelled "3-c"), represented by black arrow pointing to blue* square

Existing product/service impacting **new service** (labelled "3-d"), represented by striped arrow pointing to blue* square with red dot

If "3-c" > 0; then process connectivity is "incorporated"

If "3-c" = 0 and "3-d" > 0; then process connectivity is "linked"

If "3-c" = "3-d" =0; then process connectivity is "independent"

In this example:

For data/physical connectivity: "3-a" = 1; "3-b" = 1; therefore degree of data/physical connectivity is "incorporated"

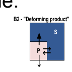
For process connectivity: "3-c" = 0; "3-d" = 3; therefore degree of process connectivity is "linked"

(4) PSS configuration type

This is to compare the shapes of the product (pink*) and service (blue*) portions of the PSS representation diagram with the ten PSS configurations types (see Table 5-3), and see which PSS configuration type it most resemble.

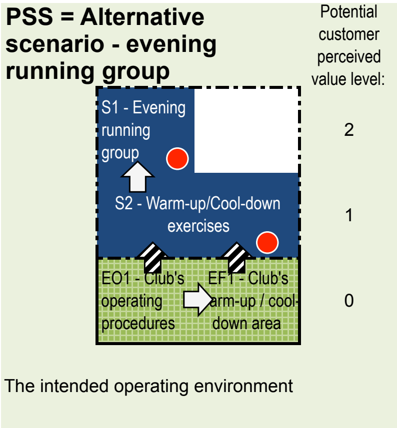
In this example, the PSS configuration type resembles B2 "Deforming product" the most.

The "P1-Evening city run route" and "P2-Suitable running gear" are the deforming product in this structure.



* Note that pink is light-grey and blue is dark grey when printed in black and white

Figure 6-9 Step 5 – PSS characterisation



(1) Customer perceived value level
This is the height, or the number of layers, of the PSS representation diagram, counting upward the layer above the infrastructural level.
Customer perceived value level = 2

(2) "Connectivity number"
"Connectivity number" = 2 x number of black arrow + number of striped arrow
"Connectivity number" = 0 x 2 + 2 = 2

(3) Type and degree of connectivity
For data/physical connectivity:
New product/service impacting **existing product** (3-a), that is black arrow pointing to pink* square
Existing product/service impacting **new product** (3-b), that is striped arrow pointing to pink* square with red dot
For process connectivity:
New product/service impacting **existing service** (3-c), that is black arrow pointing to blue* square
Existing product/service impacting **new service** (3-d), that is striped arrow pointing to blue* square with red dot
For data/physical connectivity: "3-a" = 0; "3-b" = 0; therefore degree of data/physical connectivity is "independent"
For process connectivity: "3-c" = 0; "3-d" = 2; therefore degree of process connectivity is "linked"

(4) PSS configuration type
Compare PSS representation diagram with the ten PSS configurations types (see Table 5-3), and see which PSS configuration type it most resemble.
The PSS configuration type resembles E2 "No product" the most.

Figure 6-10 PSS characterisation for an alternative scenario of the running group example

In the alternative scenario shown in Figure 6-10, the degree of connectivity for data/physical would be changed from incorporated to independent, and the connectivity number would be reduced from 6 to 2; however, the potential customer perceived value level would remain the same at 2. This could be an indicator that this alternative scenario is a less complex offering to develop and may provide as much value creation opportunity as the original scenario shown in Figure 6-9.

6.4 Phase II data analysis

The previous section presented the data collection instrument used and refined in Phase II, the PSS characterisation approach. This section presents the data analysis process used in Phase II. Similar to Phase I, the data analysis process used in Phase II was iterative. From the data collected from each workshop, observations and feedback relating to influences on the PSS design specifications and other aspects of the PSS engineering design process were highlighted. Influence groups were then made.

This process of data collection and reflection was repeated until common themes emerged (represented by the double-lined arrow in Figure 6-11); at which point, the influence groups were adjusted and data was re-analysed according to the revised groupings. Reflections were made again after several workshops, to allow further necessary to be made to the influence groups. At the end of the Phase II data analysis, the influences of the PSS characterisation approach on PSS design specification and other aspects were summarised.

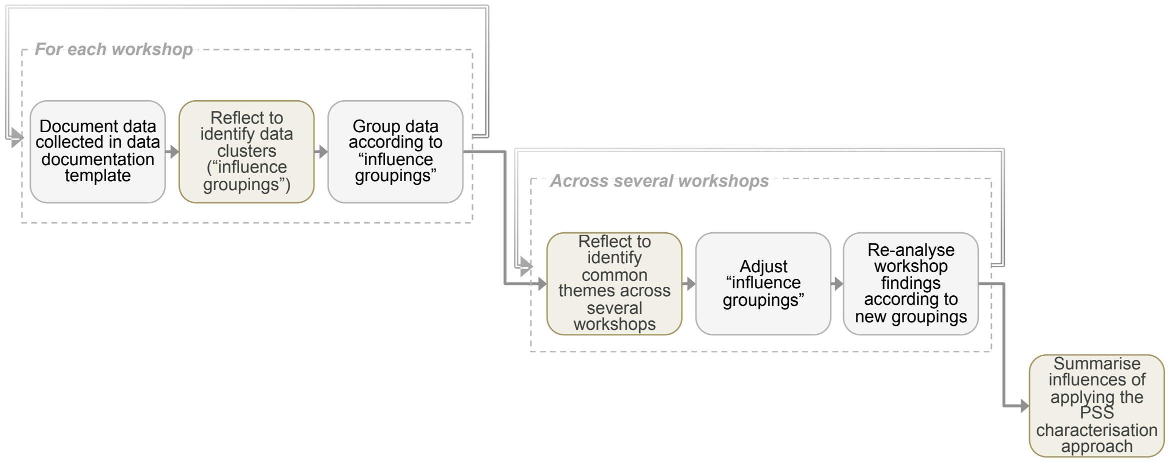


Figure 6-11 The Phase II data analysis process

As noted earlier, a by-product of Phase II is the PSS characterisation approach as a stabilised research instrument. Three aspects were used to guide the development of the instrument: feasibility, usability and utility of the instrument. Feasibility concerns the degree to which the process laid out for the workshop participants can be followed. Usability relates to the ease of following the approach. Utility focuses on whether the approach achieved its intended benefits for the participants, that is to clarify PSS design specifications. Observations and feedback from the workshop participants were collected, and changes to the PSS characterisation approach were classified according to their magnitude (see Table 6-4). The number of changes to the instrument was tracked and additional workshops were organised for the purpose of refining the research instrument until the number of changes resulted from the observations and feedback has tapered off. Changes to the instrument can be found in Appendix 04.

Table 6-4 The definition of magnitude of changes to the research instrument

Magnitude of change	Descriptions	Examples
Primary change	Change of the core content of a step. Add or remove main steps or sub-steps. Change the order of main steps. Reduce the number of symbols used in the instrument. Change the shape of symbols used in the instrument.	Adding a sub-step to identify the functions to be fulfilled before identifying the product and service elements needed in Step 1: PSS Depiction.
Secondary change	Change the order of the sub-steps. Add instructions into a sub-step.	The sub-step of colouring the arrows (solid black / striped) is to follow the identification of the directions of the arrows in Step 3: PSS Decomposition.
Tertiary change	Clarify the wordings in an instruction. Clarify the key to the symbols used in the instrument.	Clarify the wordings of "customer facing elements" to "what the customers potentially value the most" from Step 1 to Step 4.

6.5 Phase II findings

This section presents the influences of the application of the PSS characterisation scheme on PSSs in the engineering design stage of their development. The PSS characterisation approach was the data collection instrument used in Phase II for healthcare and four other industries (see Table 6-1). This instrument supported the transformation of information from new PSS ideas to PSS design specification. As described earlier in this chapter, the choice of using action research methodology in Phase II enabled the generation of knowledge with individuals who directly participate in new PSS development projects. From the discussions with the workshop participants, influence groups emerged. The report of the Phase II findings in this section excluded the results from the two workshops in the "build" phase of the data collection instrument development, workshop O and P. There are two main reasons for this. First, the purpose of these two workshops was to develop the data collection instrument and not to investigate the influences of the PSS characterisation scheme on design specifications. Second, workshop P was a hypothetical example and workshop O was for a PSS that was commercialised two years prior to the workshop date. Therefore, the results from these two workshops in terms of the influences of the PSS characterisation scheme on PSS design specifications would be purely theoretical, and unsuitable for combining with the results of other workshops.

Table 6-5 summarises the influence groups, their descriptions, which workshop(s) each influence group has come from, and whether the workshop was about healthcare or non-healthcare PSSs. The workshop reference can be found in Figure 3-3.

Table 6-5 The influence groups of the PSS characterisation approach

Influence groups	Descriptions	Workshops that mentioned this (workshop ref.)
Relate to the PSS engineering design process – focus on the PSS itself		
Bring out the intra-PSS relationships	Make the participants realise something more about the relationships among the product and service elements within the PSS	Healthcare: R, T, W Others: Q, S, U, V
Bring out the impact of the "active environment"	Make the participants realise the impact of the operating environment on the new development. Encourage discussions of who in the company is responsible for understanding this impact.	Healthcare: R, W Others: Q, S, U, V
Relate to the PSS engineering design process – focus on the priority of new developments		
Gain more clarity about the new PSS	Align development team's understanding of the new PSS to be developed. Enable participants to realise which part of the PSS is more important. This realisation further influences the development priority of the various parts within the PSS. Surface company's needs for new competencies.	Healthcare: R, T, W Others: Q, S, U, V
Indicate the relative complexity of different new PSS ideas	The 'connectivity number' and PSS Configuration type serve as potential indications of the level of complexity of the new PSS development.	Healthcare: R, W Others: Q, S, V
Relates to the PSS engineering design process – focus on the process of development		
Support an holistic approach to new PSS development	Allows discussions of technical feasibility and customer value at the same time.	Healthcare: W Others: S, V
Related to business model building and internal communications on business strategy		
Feedback to business strategy	Inform, clarify and build business strategy, business model and also the new product & service strategy.	Healthcare: R, W Others: Q, S, V
Facilitate strategy communications within the company	Support the communications of the business strategy and new product & service strategy, Enforce building commitments to the business strategy and new product & service strategy.	Others: S

As seen in Table 6-5, five influence groups were mentioned by the majority of the seven workshops:

- "Gain more clarity about the new PSS" and "bring out the intra-PSS relationships" (all workshops).
- "Bring out the impact of the active environment" (six workshops).
- "Indicate the relative complexity of different new PSS ideas" and "feedback to business strategy" (five workshops).

The following section discusses these aspects in more detail.

6.6 Phase II discussions

As seen in Table 6-5, some of the influence groups relate to the PSS engineering design process; but some relate to business model or strategy communications within a company. In this section, the influences on PSS design specification are first presented. The influences on aspects not relating to the PSS engineering design process are then briefly discussed. As discussed in chapter 3, PSS design specification includes the technical, procedural and stakeholder requirements defined as an output of the PSS engineering design process.

6.6.1 Influences on the PSS design specification

First of all, it appears that the PSS characterisation approach clarifies the development team's understanding of the new development. The participants learn more about the purpose of PSS that is to be developed and who is to be impacted by the new PSS. Through the workshop approach, the participating development team members have their understanding of the new PSS development aligned.

Second, the PSS characterisation approach surfaces individual team members' assumptions about the new PSS. These assumptions include where the new PSS is to be used, who is going to use the PSS, how it is to be used and how the company is to deliver the service. This is especially true for new PSS developments that are in the 'beginning phase' of the engineering design process of idea generation, problem assessment and stakeholder identification (see Appendix 13 for the different phases within the engineering design process). However, for PSS developments which are in a later phase of the engineering design process, the workshop participants also find out more about other development team members' assumptions on how the PSSs were to be used or which function in the company was to deliver the service.

Third, the PSS characterisation approach allows the interactions among the new elements introduced by the new PSS, the existing systems, and the infrastructure that the new PSS is to operate on, to be visualised and shared among the development team members. As presented in sub-section 6.3, four of the five steps of the PSS characterisation approach involve drawing or constructing a diagram: PSS depiction diagram, abstraction diagram, decomposition diagram and representation diagram. In particular, the PSS decomposition and representation diagrams have allowed the workshop participants to indicate, using standard symbols, the interactions between the existing and new elements within the PSS, and between the PSS and the infrastructure in its operating environment. Being able to visualise these interactions on the same diagram has enabled the development team to discuss the relative importance of the elements within the PSS. The workshop participants have also asked critical questions related to the PSS structure during these discussions, such as whether some of the interactions or interdependencies are necessary, and whether the new PSS has too many elements which rely on only one critical element and hence expose the company to more risk.

Fourth, the PSS characterisation approach has also led to discussion of whether the company is ready for the new PSS, what could be changed in the PSS to make it more likely for development resources to be approved by senior management, and how well the current PSS idea is aligned with the company's new product and service strategy.

Lastly, the PSS characterisation approach is also able to trigger discussions on whether the company is ready to deliver the new PSS and whether customers are ready for the new PSS. The discussions centre on the skills the company must possess or build in order to provide the new services or to support the usage of the new products. The concern of customer's readiness for the new PSS is about whether the targeted customers would be able to understand the potential value that they could generate from the new PSS, and what they need to do in order to benefit from the new PSS.

Table 6-6 provides a summary of the influences of the PSS characterisation scheme on PSS design specification.

Table 6-6 Influences of the PSS characterisation scheme on the PSS design specification

Influences of the PSS characterisation scheme on the PSS design specification	Elaborations
(1) Clarified the purpose of the PSS	
The offering as a whole and what problems it intends to solve	What the new PSS is about Why is it being developed now
Stakeholders and value creation	Who are the stakeholders and how are they involved in the value creation process as intended by the new PSS
(2) Made the assumptions of the PSS development explicit	
The operating environment	What are the assumptions on the intended operating environment of the new PSS
The stakeholders	What are the assumptions on how the stakeholders are to deliver, operate and benefit from this new PSS
(3) Visualised the interactions of the new PSS with existing systems and environment	
Dependencies among elements	What are the impacts and dependencies between the new and existing elements within the PSS and with its "active environment" Which element of the PSS is relatively more important and needs to be developed first within the PSS
Dependencies on the infrastructure	What are the infrastructural elements that the new PSS need for its proper functioning
(4) Understood company's readiness to develop the new PSS	
Competencies and culture for the new development	How ready is the company in terms of introducing the new PSS, for example, any missing competencies and senior management's mind-set
Strategy alignment	How aligned is the new PSS with the company's new product and service strategy
(5) Understood the readiness of the company and the customers for the new PSS	
Company's readiness to deliver the new PSS,	What skills and knowledge, system and processes are required by the company's staff to deliver the new service Are the targeted customers aware of the potential value that they can create with new PSS
Targeted customer's readiness to benefit from the new PSS	What skills and knowledge are required by the targeted customers in order to benefit from the new PSS

6.6.2 Influences on other aspects

Apart from influencing on the PSS design specification, the PSS characterisation approach is also beneficial in helping the participants to reflect on their company's business model and company's value proposition. The PSS abstraction diagram in the PSS characterisation approach is also a useful internal communications tool for conveying the new product and service strategy.

6.7 Phase II contributions and limitations

The PSS characterisation approach was a research instrument for data collection in Phase II. It was used to apply the PSS characterisation scheme emerged in Phase I on PSSs from different industries in order to explore the influences of this novel PSS characterisation scheme on PSS design specification. Of particular interest is whether the PSS characterisation scheme can clarify PSS design specification. This is because understanding which PSS characteristics contribute to clarifying its design specification is a step toward developing a PSS classification scheme for engineering design. In this section, to conclude this chapter on Phase II study, the theoretical and practical contributions of Phase II findings are presented, followed by the limitations and next steps of this research.

6.7.1 Theoretical contributions

6.7.1.1 Theory extension

As discussed in the literature reviewed in chapter 2, Hubka and Eder's theory of technical systems can possibly be extended to other applications in addition to that of mechanical systems design (Hubka & Eder, 1987, 1988). In Phase II, the PSS characterisation approach has been developed as a data collection instrument. The PSS characterisation approach has supported the transformation of information from new PSS ideas to clearer design specifications. This act of information transformation is similar to Hubka and Eder's application of their theory of technical systems to the design activities of mechanical systems (Hubka & Eder, 1987). In Hubka and Eder's

(1987) application of the theory of technical systems to mechanical systems, the design activity is viewed as a technical system. This technical system, that is the design activity, changes the state of information based on a method. In the Phase II workshops, the PSS engineering design process changes the state of information by means of a supporting method called the PSS characterisation approach. Figure 6-12 illustrates the concept of extending the theory of technical systems to the PSS engineering design process.

Figure 6-12 The PSS engineering design process as a technical system

Interestingly, the PSS characterisation approach itself also demonstrates the properties of a technical system. In particular, Hubka and Eder's proposition 7.5 deals with the properties of technical systems, are also displayed by the PSS characterisation approach:

> *"Every function (or [behaviour]) is a system that contains as its elements a set of partial functions (or partial [behaviours]), and that is decomposable to elementary functions (or elementary [behaviours])… …we can work with various degrees of abstraction (ranging from an abstract function to the actual [behaviour] of a concrete technical system)." (Hubka & Eder, 1988, p. 237)*

The PSS characterisation approach has a clear objective and transforms information from new PSS ideas to clarified design specifications. Therefore, the PSS characterisation approach could be considered as a technical system. Figure 6-13 illustrates the concept of viewing the PSS characterisation approach as a technical system that transforms information.

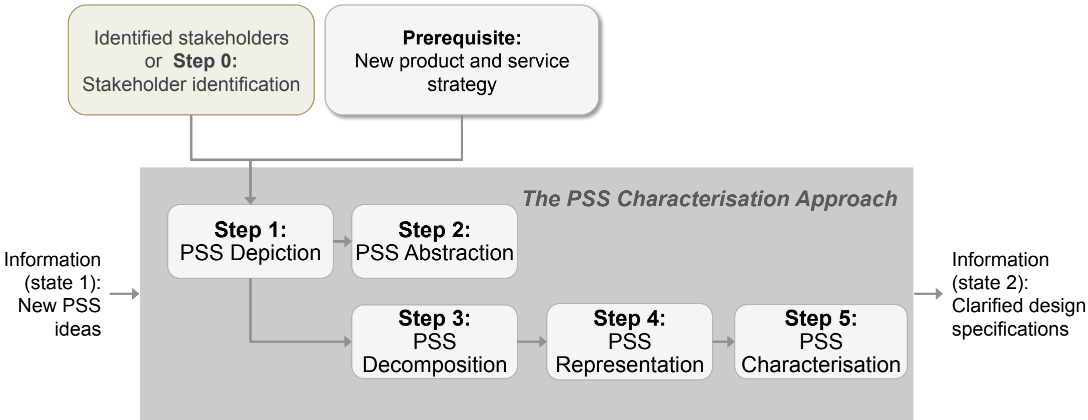


Figure 6-13 The PSS Characterisation Approach as a technical system

Figure 6-14 elaborates the application of the theory of technical systems to the PSS characterisation approach.

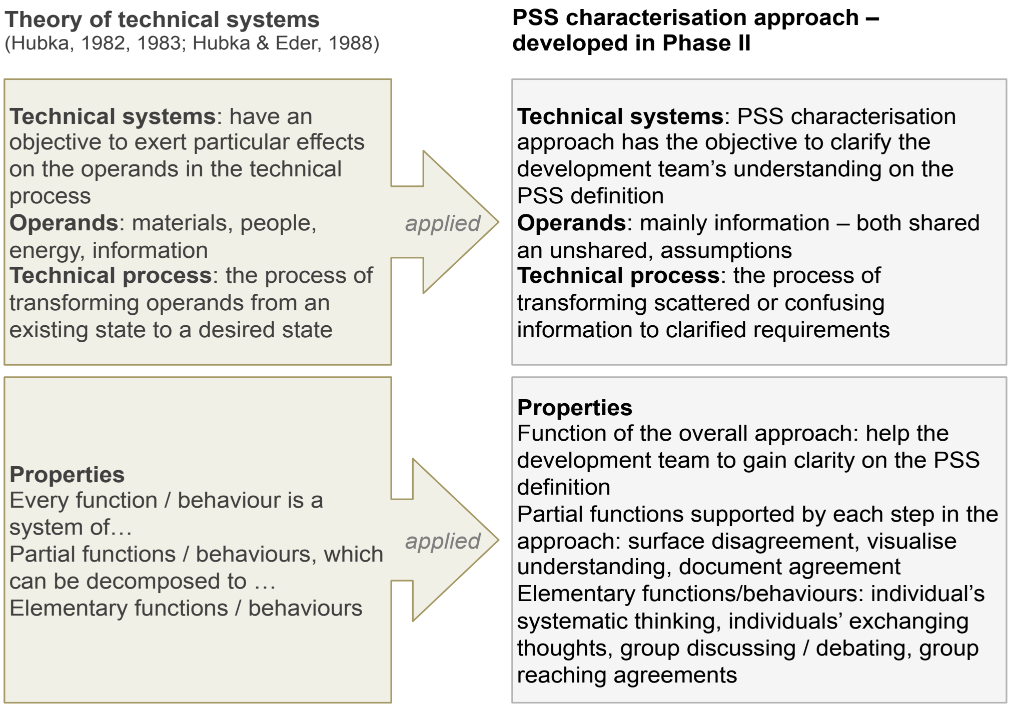


Figure 6-14 PSS characterisation approach as a technical system

In summary, the application of the theory of technical systems could be extended to the PSS engineering design process, as well as to instrument supporting the engineering design process.

6.7.1.2 Contribution to literature

In addition to theory extension, the findings from Phase II also contribute to the literature discussing the management of engineering design or new PSS development. The PSS characterisation scheme, when applied to PSSs under development, positively influenced the design specifications. The findings from Phase II concluded that participating development team members had gained more clarity on the new PSS development, and more understanding of the assumptions of other team members regarding the new PSS under development. The application of the PSS characterisation scheme increases team members' understanding about:

- the purpose of the PSS
- the requirements of and for the intended operating environment
- the requirements for the stakeholders
- the interactions between the new PSS and existing systems
- the interactions between the new PSS and the infrastructure of its intended operating environment
- the readiness of company and customers to develop, deliver and use the new PSS

Therefore, two conclusions are drawn here, which contribute to the literature of engineering design and new PSS development management.

The PSS characterisation scheme comprises the four characteristics: (1) customer perceived value level; (2) 'connectivity number'; (3) type and degree of connectivity; (4) type of configuration. When applied to new PSSs through facilitated workshop that utilises a systematic approach, this is useful for two aspects of the PSS engineering process.

> *Conclusion 1: It is useful to clarify the PSS design specification for the new PSS development team.*

> *Conclusion 2: It helps the new PSS development team to have a better understanding of the readiness of the company to develop and deliver the PSS, and the readiness of the targeted customers to benefit from the new PSS.*

Although the PSS characterisation approach has originated from case studies in the healthcare industry, its application in four other industries in Phase II has shown the potential generalisability of the above conclusions.

6.7.2 Practical contributions

Learning from the workshops conducted in Phase II, it appears that the PSS characterisation approach described here is a practical method which can trigger conversations among the participants from different functions, encourage the team members to share their thoughts, revealed disagreement among the team members, visualise the points discussed during the workshop and document the agreed points. The average time required for one workshop was 4.5 hours, with less complex PSSs completed within 3 hours. The workshop materials used were easily available stationery items: colour crayons, colour square sticky-notes, brown wrapping paper or flip chart paper, red-dot stickers, and adhesive arrows. Some participants mentioned after the workshop that they would like to apply the approach to other new PSS ideas in the future. After participating in one workshop, some participants said they would be confident enough to facilitate a similar workshop on their own if the instructions were made available for their use. In the workshop where an independent observer was engaged (Workshop V), the independent observer, who was an experienced facilitator in strategy workshops, also commented that the PSS characterisation approach could be repeated by trained facilitators.

As a result of the workshops, it can be concluded that the overall PSS characterisation approach with its five mandatory steps and one optional step, when applied in a workshop environment led by a trained facilitator, is feasible, usable and useful to practitioners of the engineering design process. The summary of the observations and feedback pertaining to the approach's feasibility, usability and utility can be found in Appendix 17.

6.7.3 The limitations of Phase II findings

As action research is used as the methodology for Phase II, the feasibility of the approach is influenced by the facilitation skills of the researcher who performed the facilitation. The interpretation of the workshop findings, especially the observations made by the researcher, is biased by the researcher's culture, background and knowledge of the PSS under discussion. The participants' state of mind on the day of the workshop, such as work-related pressure as expressed by some participants in Workshop Q and W, family commitments on the workshop day for one participant in Workshop W, and other urgent office matters that disturbed and disrupted the participants' contributions to the workshops held at the company's location (Workshop R, S, V, W), have certainly affected the contribution and quality of feedback provided by some participants.

Although PSSs from different industries were targeted in this Phase, only five industries were covered: healthcare, defence, financial investment, environmental protection and executive education. The findings in Phase II may have shown potential to be generalised across different industries, but since only five industries have been involved, more work is needed to confirm. The influences of the PSS characterisation scheme on the PSS design specification may also vary with the size of the company and in which country the company is based. These factors could not be analysed in Phase II due to the limited number of workshops conducted.

6.7.4 The logical next steps

To further explore the influence of the PSS characterisation scheme on PSS design specifications, workshops need to be conducted for new PSS ideas in different industries, preferably facilitated by different trained facilitators with the help of independent observers. More workshop data can also be used to further develop the sub-step necessary to assess the fourth PSS characteristic, the PSS configuration type. Currently, the PSS configuration type is a result of discussions among the participating development team members and there can be disagreement on this subject. While the discussion among the workshop participants may help to clarify PSS design specifications, the step to identify the PSS configuration type can also be improved in order to be more objective.

However, before conducting more workshops, time and funding is required to standardise the workshop materials and guidelines which are to be given to facilitators, participants and observers. Facilitator recruitment and training is needed if facilitator bias is to be minimised.

With more workshop data, the PSS characterisation approach can be further developed and its influences on design specification can be further understood. The identification of PSS characteristics that clarify design specification contributes to the development of a PSS classification scheme for engineering design. In the future, hypotheses relating to the application of such PSS classification scheme that is based on this characterisation scheme, on new PSSs in the engineering design process and other interesting NPSSD aspects could potentially be proposed. NPSSD aspects could include new PSS success, PSS development cost and stakeholder involvement requirements.

7 Conclusion

The motivation behind this research is the pursuit of a suitable way to characterise product-service systems (PSS) for the engineering design process in the healthcare industry. Being able to characterise PSS is a step toward developing a PSS classification scheme that helps manufacturers to clarify design specifications. A clear PSS design specification is the basis for manufacturers to develop, produce and deliver new PSSs that customers would use and generate value. However, there is currently no established PSS classification scheme for engineering design.

This research has provided new understanding of what PSSs are. A characterisation scheme consisting of four PSS characteristics is proposed as a useful way to clarify PSS design specifications. The PSS characterisation approach has been developed as a systematic approach to analyse PSSs for their four characteristics within the proposed characterisation scheme.

In this concluding chapter, the background of the research is briefly summarised. This is followed by a summary of the findings from literature, case studies and workshops, which have led to the theoretical and practical contributions of this research. The chapter concludes with a summary of the limitations of the research and future research directions.

7.1 Summary of the background of the research

The three background areas for this research are product-service systems, engineering design and the healthcare industry. PSS is a timely topic to investigate, because despite much research into the phenomenon of servitisation, existing studies seem to have focused mainly on a business strategy level and not an operational level. The engineering design process is important, because decisions made during this process have a significant impact on the quality and cost of the new PSS. The healthcare industry is chosen as the industry to investigate because it is a complex industry from both social and technical perspectives, and faces continuous changes and much scrutiny.

7.2 Summary of findings from literature

The literature reviewed crosses the disciplines of engineering, management and sociology, and can be grouped into five areas with key findings in Table 7-1 and elaborated in the following sub-sections.

Table 7-1 Summary of findings from literature

Literature reviewed	Key findings and influences on this research
Definitions and classifications of product, service and PSS	• The concept that products are tangible and all intangible offerings are services has been invalidated by the digital age.
Theories and process models for engineering design	• The theory of technical systems proposed by Hubka and Eder (1988) has inspired the PSS characterisation approach. • The lack of an holistic prescriptive method that helps the generation of the overall value creation process and provides enough technical details for the PSS development has motivated this research.
Structural representations for technical systems	• The 'organ structure' proposed by Hubka and Eder (1988) and the 'molecular model' proposed by Shostack (1982) have inspired the Phase I analysis of this research, and have inspired the PSS abstraction, decomposition and representation steps of the PSS characterisation approach.
Stakeholder theories and identification for engineering design	• The lack of studies of the involvement of multiple stakeholders in the engineering design process has motivated the development of the stakeholder identification framework.
Exploration of contextual factors for the engineering design process	• Latour's (2005) actor-network theory, in particular his "flattened topography", has inspired the PSS depiction step of the PSS characterisation approach.

7.2.1 The definitions and classifications of product, service and PSS

In chapter 2, different views on the potential value that customers create from a PSS have been discussed. One major limitation of the reviewed PSS classification schemes is that they have relied on a concept that is no longer valid: products are tangible objects and all intangible offerings are services. The digital age has made this reference out-dated, because products can be intangible, such as an electronic book downloaded from a server.

7.2.2 The engineering design theories and process models

Chapter 2 has provided a review of the existing theories of engineering design, among which, there is a group called the systematic transformation theories. A well-formed systematic transformation theory proposed by Hubka and Eder (1988), the theory of technical systems, views the engineering design process as a process to transform information from requirements to the specifications of technical systems. This theory has provided many properties of technical systems. One property in particular has inspired this PSS characterisation approach: the fact that system level functions and/or behaviours can be decomposed into lower-level functions/behaviours, and further into elementary functions/behaviours. This property emphasises the connections between the functions within a PSS, the interdependencies of system behaviours and human behaviours, and describes different levels of abstraction of complex systems. It provides insights for new ways of analysing PSSs.

With regards to new development process models, although there are a number of NPSSD process proposals, many have either a bias toward product or service. The product-focused models appear to consider service development as supplementary to product development, while the service-focused models do not give enough attention to the technical details required for product development. Prescriptive methods are needed to help engineering designers generate both the overall value creation process and provide the technical details required for the new PSS development. This need has motivated this research.

7.2.3 The structural representation of technical systems

The reviewed literature contains diagrams to represent the internal structure of a system and its linkages with the environment. Hubka and Eder (1988) proposed an 'organ structure' that shows both the structured arrangement of the technical organs and their relationships between each another and with their environment. This model may be most appropriate for engineering designers. Shostack's (1982) 'molecular model' helps marketing professionals to visualise an offering and to show the structural relationships among the products, services and service evidences within an offering. These proposals have inspired the analysis of the PSSs involved in the Phase I case studies, and the PSS abstraction, decomposition and representation steps of the PSS characterisation approach.

7.2.4 Stakeholder theories and identification for engineering design

Chapter 2 reviewed stakeholder theories, identification techniques and outcomes of involving stakeholders in the engineering design process. It revealed that previous stakeholder engagement studies have mainly focused on customers' and lead users' involvement, and have reported mixed results. There is a lack of field studies to generalise the impact of multiple-stakeholder involvement in engineering design. However, theoretical perspectives about the general roles of stakeholders were proposed by Vargo and Lusch (2008) for a service logic. They proposed that "value is always uniquely and phenomenologically determined by the beneficiary" (Vargo & Lusch, 2008, p. 7), and that all social and economic actors have a role to play in the process of value creation.

The lack of multiple-stakeholder views has motivated the development of a stakeholder identification framework (see Appendix 02) for supporting the engineering design process.

7.2.5 Contextual factors for the engineering design process

Chapter 2 showed that the scope of contextual factors for the engineering design process differs among the disciplines of engineering, management and sociology. The theory of technical systems in engineering literature considers only the "active environment", that is the environmental factors that are directly involved in the transformation process. Compared to the viewpoint of "active environment", the management perspective has a broader and less restrictive view of what can be considered as environmental factors. From the perspective of sociotechnical systems, Latour's (2005) actor-network theory has provided support to examine the connections among stakeholders, product and service elements in a "flattened topography". Latour's view has inspired the PSS depiction step of the PSS characterisation approach. Figure 7-1 shows the PSS depiction diagram, which is the output of this step.

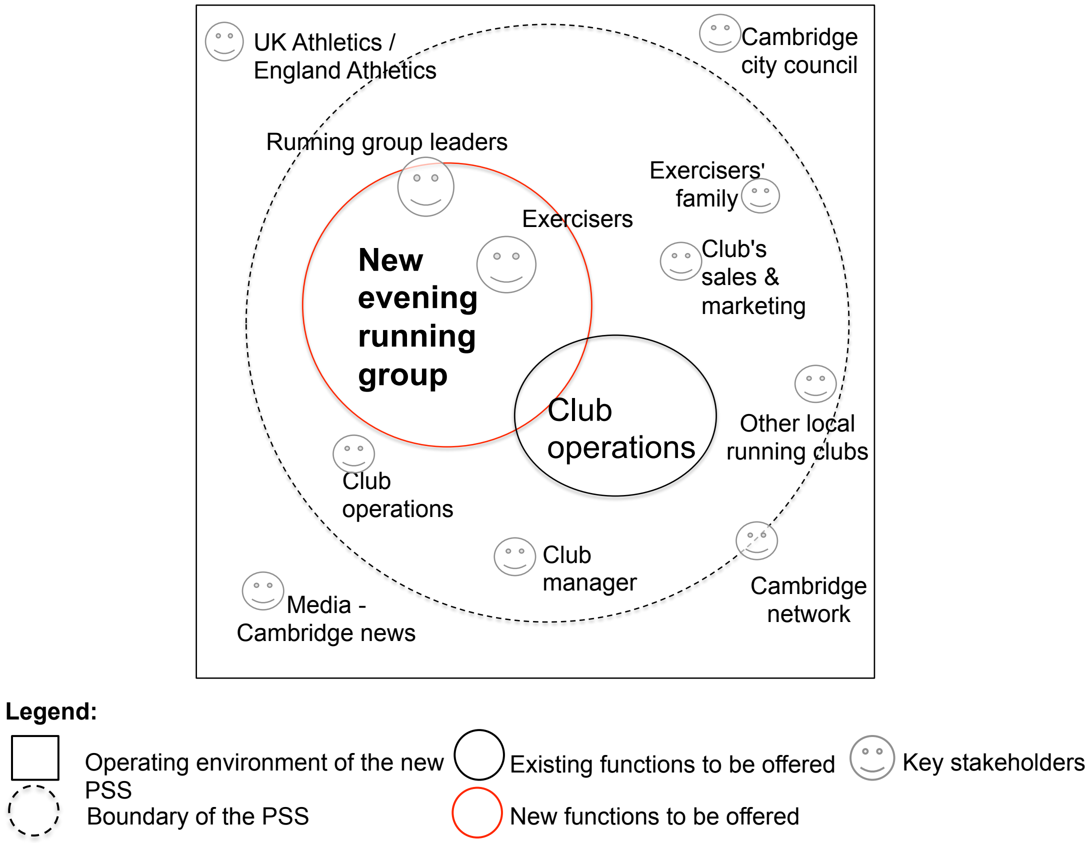


Figure 7-1 The PSS depiction diagram of the running group example seen in Chapter 6

7.3 Summary of findings from this research study

In this section, the findings from the Phase I case studies that have led to the proposal of the PSS characterisation scheme are first summarised. This is then followed by a recap of the PSS characterisation approach that was developed by the Phase II workshops. This section concludes with a summary of the influences of the proposed PSS characterisation scheme on design specifications.

7.3.1 The PSS characterisation scheme

Through case studies, variables pertaining to different aspects of PSS engineering design have been explored. Four key characteristics have emerged during Phase I which are found to be useful in analysing PSSs for engineering design. The four characteristics that form the resulting PSS characterisation scheme are summarised in Table 7-2 and elaborated in the following sub-sections.

Table 7-2 The four characteristics in the proposed PSS characterisation scheme

The four PSS characteristics	Description
Customer perceived value level	The value that the target customers perceive they can potentially generate from the new PSS.
'Connectivity number'	The number of interactions between the new, to-be-developed, elements of a PSS and the existing elements of a PSS or its intended operating environment. The higher the 'connectivity number', the more complex the PSS development potentially is.
Type and degree of connectivity	Related to the 'connectivity number', the type and degree of connectivity provides more information about the nature of the relationships among the new and existing elements of a PSS. Connectivity concerning product elements is described as data/physical connectivity. Connectivity concerning service elements is described as process connectivity. For each type, there can be three degrees of connectivity: • 'Independent' when there is no relationship between the new and existing elements. • 'Linked' when one or more new elements depend(s) on the existing element(s). • 'Incorporated' when one or more new elements impact(s) the existing element(s).
PSS configuration type	The PSS configuration type represents the structure of a PSS. There are ten representations, which are five-mirroring pairs of abstract structural representations of how the product and service portions interact with one another within a PSS.

7.3.1.1 <u>Customer perceived value level</u>

The first characteristic to emerge from the cases deals with the value of a new PSS to its target customers. The formulation of this characteristic is heavily influenced by the service logic perspective of value creation, that companies cannot offer customers to co-create value, but at best facilitate the process of value co-creation (Grönroos, 2008). To recap here, according to Grönroos (2008), companies can opt to participate in the value generation process by offering goods and services that require interactions with customers. Companies can also choose to participate indirectly by offering goods and services that customers buy as an input resource to their value generation process.

This first PSS characteristic, the customer perceived value level, represents how much value target customers perceive that they can create from the new PSS. For manufacturers, in the process of identifying the value levels of new PSSs, development teams can obtain a better understanding of who the target customers are and what or who in the operating environment can impact the target customers' perception. Manufacturers can also gain more insight into the value generation process, in which the target customers obtain what they desire from the new offerings. Development teams are more informed in their decisions on target customer groups and which locations or offices are best positioned or equipped to provide the new offerings.

This characteristic also allows manufacturers to compare different new PSS ideas in terms of their potential value for intended customers. Manufacturers may want to prioritise the development of PSSs with higher customer perceived value levels, as the higher the value level, the more value the customers perceive they can potentially generate from the PSSs.

7.3.1.2 'Connectivity number'

The second PSS characteristic provides a measure of the complexity of a PSS development. From the PSSs involved in the case studies in this research, the linkages among different elements within a PSS and with its operating environment are determined. The PSS decomposition step of the PSS characterisation approach is the step when relationships among elements within a PSS are identified. The identification of the impact direction of each relationship is visualised in this step by different coloured/patterned-arrows. The connections between new and existing elements are considered as having a higher impact on the PSS development than the connections between new elements or between existing elements. This is because introducing a new element that will impact an existing element that has been functioning well may warrant special attention of the development team. The development team also needs to take care of how existing elements may impact the desired functions of the new to-be-developed elements.

As discussed in chapter 5, in this research, to calculate the 'connectivity number' of a PSS, the 'new impacting existing' relationship is weighted twice as important as the 'existing impacting new' relationship. The 'new impacting new' and 'existing impacting existing' relationships are discounted to zero, because the 'connectivity number' represents additional development effort required.

> *'Connectivity number' = 2 × (number of 'new impacting existing' relationships) + (number of 'existing impacting new' relationships)*

The higher the number of interdependencies among the new and existing elements, the higher the 'connectivity number' is.

During the Phase II study, it was found that the PSS decomposition and PSS representation steps, which contribute to the determination of the 'connectivity number', enabled development teams to tease out some unshared assumptions about the PSSs. One assumption was about stakeholders' roles and processes to follow in delivering, operating and benefiting from the new PSSs. Another assumption was about the intended operating environment for the new PSSs. By decomposing a PSS idea into its lower level product and service elements and structuring them to form the PSS representation diagram, participating development teams were able to see which new element was the key building block of the new PSS design.

Together with the first characteristic of the potential customer perceived value level, manufacturers may compare new PSS ideas that are competing for development resources, to see if one idea is less complex than another, while providing the same value creation potential for target customers.

7.3.1.3 Type and degree of connectivity

The third characteristic to emerge from the case studies is the type and degree of connectivity. In addition to counting the number of new and existing interdependencies, the connectivity of a PSS can be further understood by differentiating whether a new element impacts an existing product or service, and whether an existing element impacts a new product or service. The connectivity concerning the product elements within the PSS is called physical/data connectivity, because these elements connect either physically or at a data exchange level. The connectivity concerning the service elements within the PSS is called process connectivity. This is because services are actions, and the connections among services mean that series of actions or processes are being connected.

For each type of connectivity, the degree of connectivity can be 'independent', 'linked' or 'incorporated'. If there is no interdependency between the new and existing elements, the degree of connectivity is the lowest and it is named 'independent'. If the new elements are to be based on the functioning of some existing elements, the degree of connectivity is deemed 'linked'. If the new elements are designed to impact some existing elements, the degree of connectivity is described as 'incorporated', which is the highest degree of connectivity. The type and degree of connectivity of a PSS provide more information about how the different technical and process elements interact with one another.

This research has demonstrated that the participating development teams gained additional perspectives about their PSS development by knowing about these interdependencies. In particular, the visualisation of the interactions among the elements in the PSS representation diagram led to useful discussions among the development team members about the relative importance of the elements to be developed and which element needs to be first developed within the PSS. In addition to adding more clarity to PSS design specification, this characteristic also gives manufacturers new common terminologies to describe new PSSs.

7.3.1.4 PSS configuration type

The fourth characteristic is the PSS configuration type. Observed from the case studies, a PSS can be represented by a block diagram that shows how the product and service portions of each PSS fit with each other. These observations are extrapolated into five pairs of PSS configuration type, depending on the relative positions of the product and service portions of the PSS, and the impact directions between them. They are summarised in Figure 7-2. Examples of each PSS configuration type can be found in Table 5-3.

PSS configuration types A to D are differentiated by the main role of the product and service elements in the PSS. For example, D2 'static product' indicates that the product element is most likely a static input to the production of the service that is of a higher potential value to the customers. These proposed PSS configuration types provide manufacturers with new configuration typologies to describe their new PSSs, and enables them to understand which stakeholders they may need to engage with in the engineering design process. For example, a new development team may be assigned to develop the higher-level service of a C2 'sandwiched product'. As shown in Figure 7-4, a 'sandwiched product' is configured with product elements between lower-level service elements and higher-level service elements. This higher-level service development team may need to consider the physical/data interfaces and process involved with the product development with another team, as well as the outbound processes from the lower-level services of the PSS.

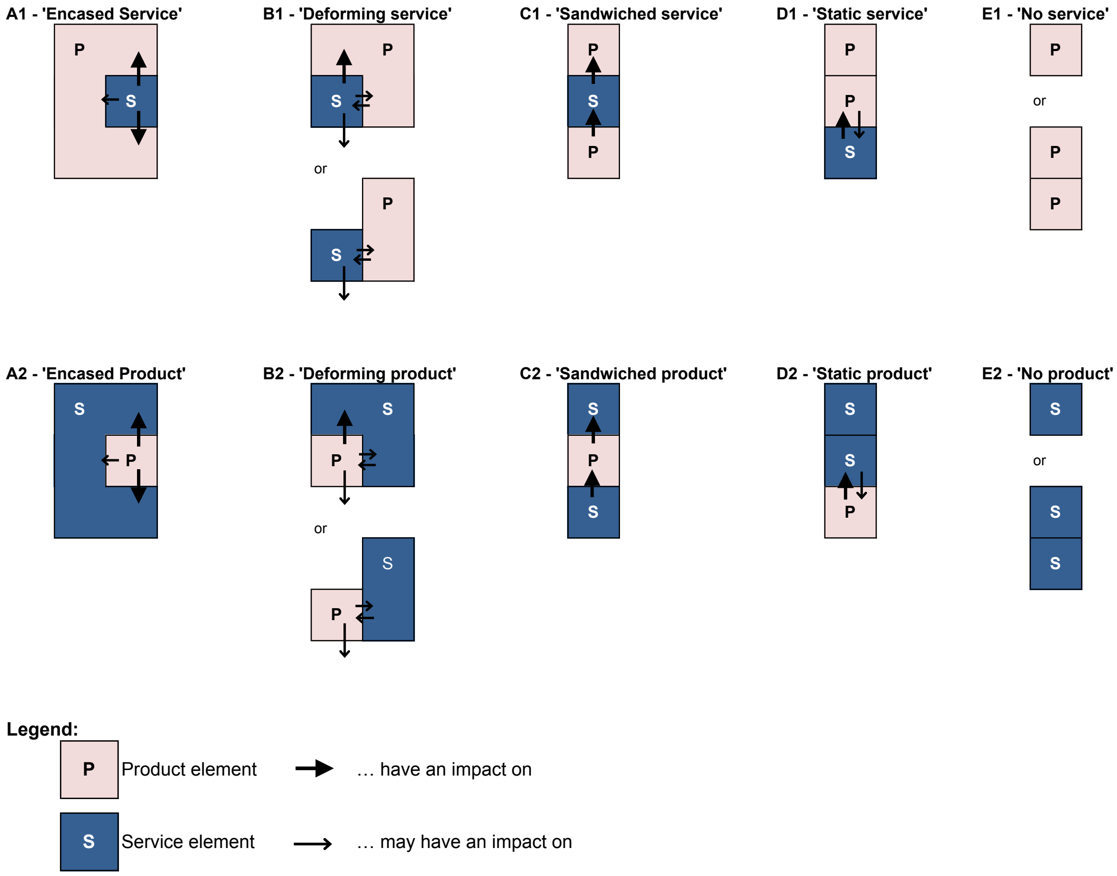


Figure 7-2 The five mirroring-pairs of PSS configuration type proposed

7.3.1.5 Significance of the proposed PSS characterisation scheme

The PSS characterisation scheme proposed here is a novel way to characterise PSSs for engineering design. It is inspired by relevant concepts from literature from engineering, management and sociology, such as Hubka and Eder (1988), Shostack (1982), Grönroos (2008) and Latour (2005). It addresses the key literature gaps identified: (1) this characterisation method does not rely on 'tangibility' to differentiate between products and services; and (2) the structural representation shows a PSS's internal configuration and its linkages to the operating environment. The characteristics were grounded in the Phase I case studies and were found in Phase II to be useful for development teams in clarifying PSS design specifications.

7.3.2 The PSS characterisation approach

The PSS characterisation approach which has been developed in this research is a systematic way to identify the four PSS characteristics summarised in the previous sub-section. Through its application to the workshops in Phase II of this study, the PSS characterisation approach has been improved and refined as a research instrument.

The main steps and sequence of this approach are: PSS depiction, abstraction, decomposition, representation and characterisation. There is an optional step, stakeholder identification, which a development team can consider adding before PSS depiction. This step is only needed if the development team has yet to identify who the stakeholders are for the new PSS. The PSS characterisation approach requires a clear new product and service strategy as an input, and produces the values of the four PSS characteristics in the proposed PSS characterisation scheme (see Figure 7-3).

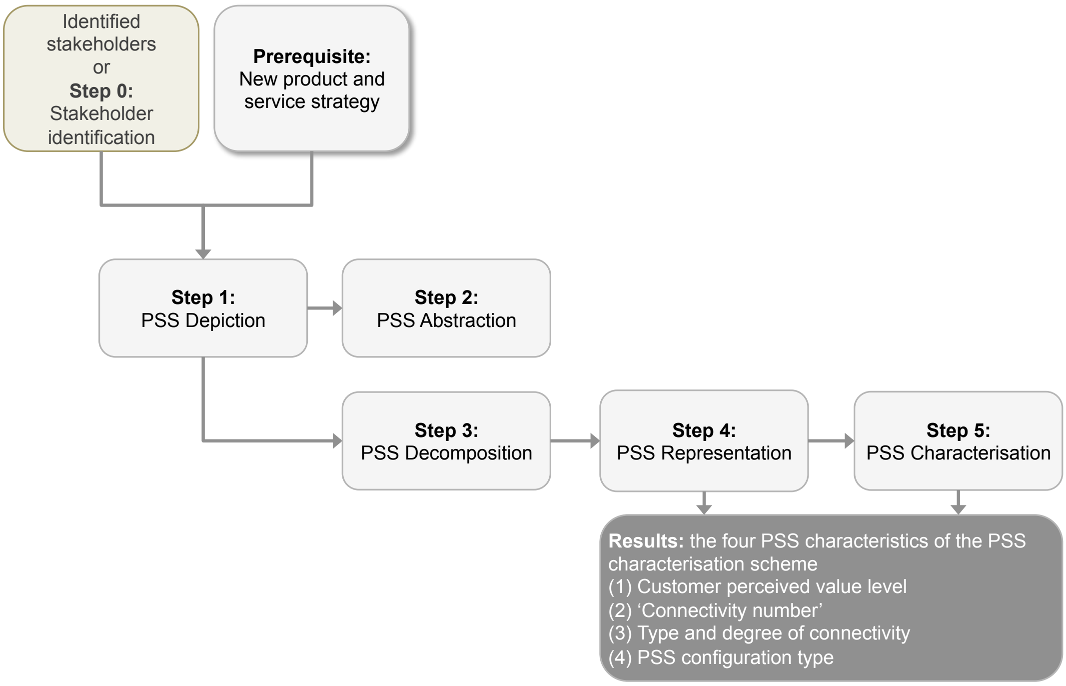


Figure 7-3 The PSS characterisation approach (repeated from Figure 6-2)

From this research, it is found that a PSS characterisation workshop takes about four to six hours on average, and can be broken into sub-workshops if required. The approach is shown to be repeatable by the researcher. The opinion is that a trained facilitator is needed to help the participating development teams to analyse their PSSs.

7.3.3 The influences of the PSS characterisation scheme on design specification

The PSS characterisation scheme, when applied to PSSs through the systematic method of the PSS characterisation approach, clarifies the development team's understanding of the purpose of the PSS under development, as concluded from the Phase II study. This approach makes explicit many assumptions about the new PSS, such as the environment that the new PSS will be used in, how it will be used and who will deliver the service. From the workshops, it was observed that the diagrams made by the participants, as per the PSS characterisation approach, were effective visual aids that added to the discussions (see Figure 7-4).

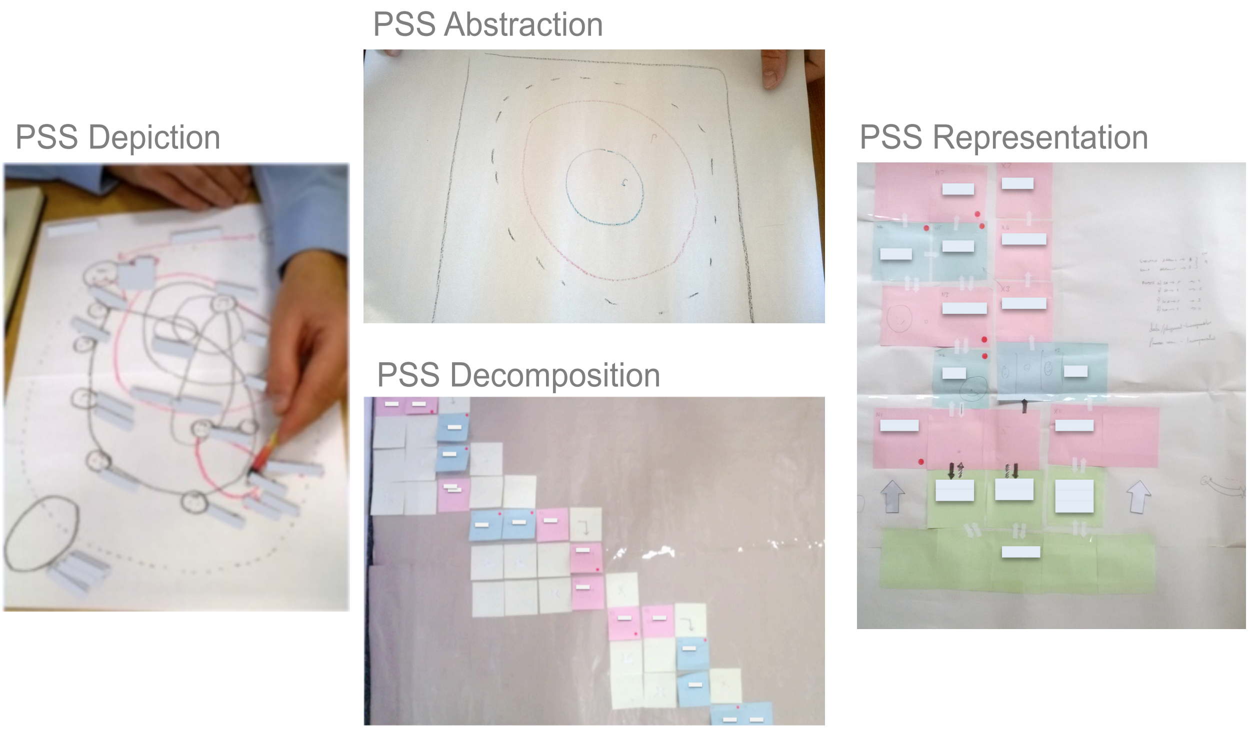


Figure 7-4 Diagrams from the PSS characterisation approach

The participants found the discussions most useful in clarifying the PSS design specifications. The PSS characteristics were represented in visual diagrams that participants could point to and debate. Initial alternative ideas for the PSSs in development were also explored on paper immediately by moving the sticky-notes on the diagrams in the PSS characterisation approach, allowing participants to see the impacts of structural alternations on the four characteristics detailed in the proposed PSS characterisation scheme.

7.4 Theoretical contributions

There are two main theoretical contributions of this research:

- The PSS characterisation scheme is a novel way to characterise PSSs that is useful for engineering design. It contributes to the development of a PSS classification scheme for engineering design and contributes to the literature of PSS classifications.
- The PSS characterisation approach has extended the theory of technical systems proposed by Hubka and Eder (1988).

The PSS characterisation scheme is generated from healthcare cases, but it has been applied via the PSS characterisation approach proposed to PSS ideas in healthcare and four other industries. This indicates the potential generalisability of this research's theoretical contributions.

7.4.1 Contribution to the PSS classification literature

As discussed previously, existing PSS classification schemes have built upon the out-dated concept that products are tangible and all intangible offerings are services. Moreover, existing schemes are more relevant for supporting business modelling than for engineering design. The proposed PSS characterisation scheme is different. It has emerged from interviews about new PSS development projects, and therefore is suitable for supporting the engineering design process. The four proposed characteristics attempt to describe PSSs by their potential value to customers, the interdependencies between the existing and new elements, the type and degree of internal and external connections and their structural configurations. Where product and service are referred to, a clear definition is followed to avoid confusion. These four PSS characteristics encourage development team members to think through the future impacts of all human and non-human actors in the operating environment on the customer value creation process. By doing so, team members gain additional clarity on PSS design specification, which includes the following aspects:

- Product and service features
- Stakeholder involvement
- Conditions of the relevant environmental factors

In conclusion, the four PSS characteristics proposed here for engineering design contribute to literature relating to PSS definitions and classifications.

7.4.2 Extending the theory of technical systems

The PSS characterisation approach transforms information from new PSS ideas to clarified design specifications, which is similar to how Hubka and Eder (1987) have applied the theory of technical systems to the engineering design process of mechanical systems. The top portion of Figure 7-5 shows Hubka & Eder's (1988) application of the theory of technical systems to mechanical system design activities. The bottom portion of this figure shows the extension of the application of this theory to the PSS characterisation approach in the bottom.

Furthermore, the PSS characterisation approach decomposes a system of functions into partial functions, and partial functions further into elementary functions. This is the property of decomposability, which is one of the properties proposed by Hubka and Eder (1988) for technical systems (see chapter 2 section 2.3).

Therefore, the PSS characterisation approach extends the application of Hubka and Eder's (1988) theory of technical systems from the engineering design of mechanical systems to instruments supporting the engineering design process.

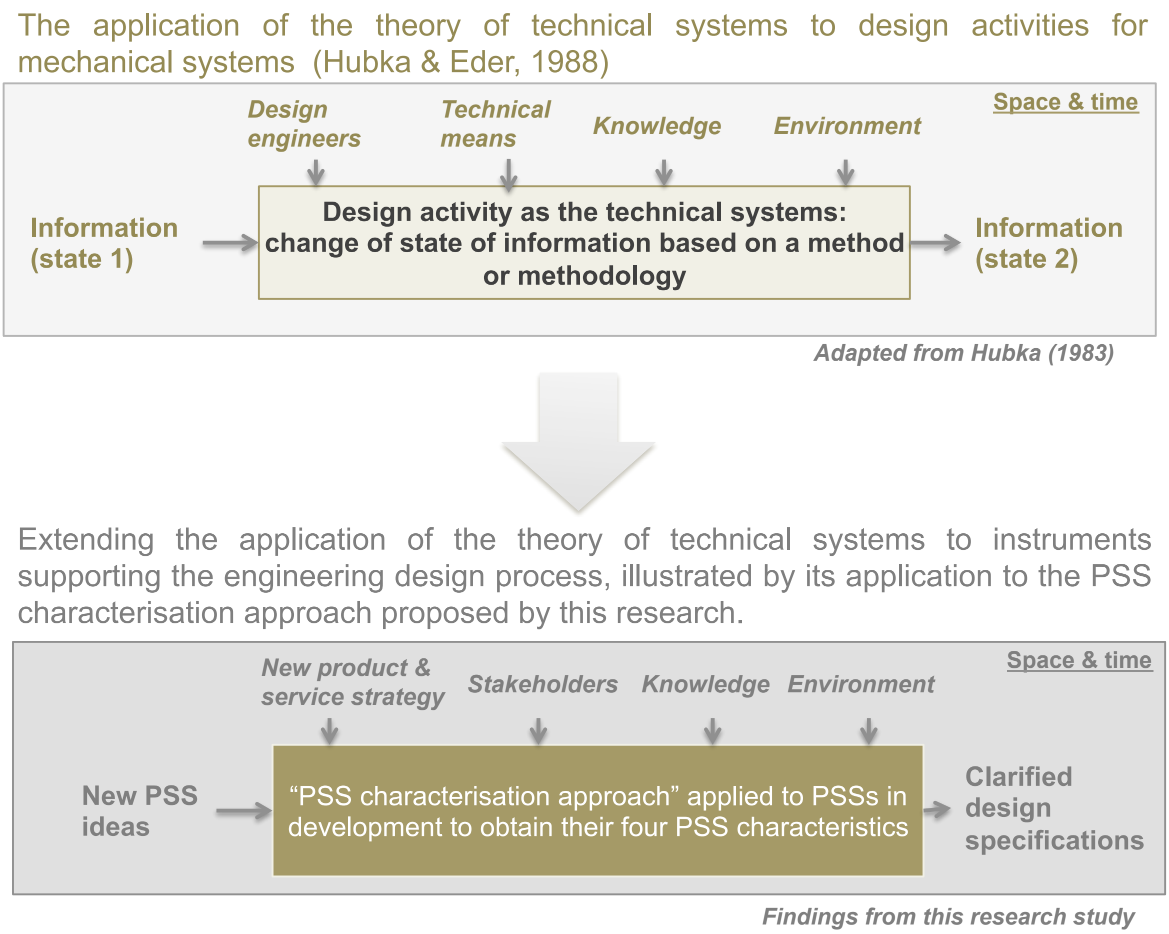


Figure 7-5 Extending the application of the theory of technical systems (Hubka & Eder, 1988) to instruments supporting the engineering design process

7.5 Practical contributions

Learning from the workshops conducted in Phase II, the application of the PSS characterisation scheme appears to be a useful way for new development team members to analyse PSSs under development, and also to analyse a commercially successful PSS for its physical/data and process connectivity and configuration. The PSS characterisation approach developed to support this research is one way to systematically apply the characterisation scheme to PSSs in a facilitated workshop environment. There may be other ways to consistently identify the four characteristics of PSSs.

The practical contribution of this research is a facilitated workshop method, called the PSS characterisation approach, by which manufacturers in different industries may characterise new PSSs in the engineering design process. The five steps of the PSS characterisation approach and the optional step of stakeholder identification, when packaged into a workshop led by a trained facilitator, is a practical method for manufacturers to clarify their PSS design specifications. The diagrammatic output of each step provides a means for the workshop participants to discuss and debate their assumptions as well as the features of the new PSS. The observations and feedback obtained during this research have provided initial support that this approach is practical and useful to practitioners.

7.6 Research limitations

As with all research studies, there are limitations to the findings. First of all, the PSS characteristics for engineering design that have emerged from Phase I were based on individuals' opinions collected through interviews. Although attention has been paid to include more than one stakeholder in each case study where possible, the information obtained cannot be considered the full picture of the PSS development projects. Another limitation is that participants of failed development projects declined to discuss their development. Therefore, all the collected data comes from successful new PSS development projects, or projects that the company's management have evaluated as satisfactory to proceed with their development. As a result, the proposed PSS characteristics may only apply to successful PSSs.

When exploring the influences of the PSS characterisation scheme on PSS design specifications, action research was the chosen methodology. As only one facilitator, that is the researcher, has been involved in all the Phase II workshops, her facilitation skills have directly impacted the data collection process. Moreover, apart from one workshop, all workshops have been without the benefit of an independent observer, so the researcher's observations could not be independently verified. Furthermore, the interpretation of the workshop findings may be biased by the researcher's culture, background and knowledge of the PSSs in discussion. The workshop participants' emotional state and availability on the day of the workshop may have also impacted their contributions, and therefore impacted the validity of the findings.

One other limitation is that Phase I focused solely on healthcare and Phase II involved only four additional industries: environmental protection, defence, financial investment and executive education. The findings of this research may be generalisable, but further work is needed to confirm.

7.7 Future research directions

To minimise the bias introduced by the facilitator, future workshops could involve an independent observer, or be video-recorded for an independent researcher's analysis. Facilitators can also be trained for the PSS characterisation approach, so that different facilitators can be used to conduct future workshops. This will strengthen the data collection and analysis processes, as well as make the PSS characterisation approach repeatable by different facilitators. Furthermore, a survey can be introduced to gather participant's feedback. This will enhance understanding of the influences of the PSS characterisation scheme on the design specification of new PSSs.

Given the limitations discussed in the previous section, more workshops are necessary to apply the PSS characterisation approach for analysing different new PSSs in development. The following types of PSSs could be targeted:

- PSSs from companies of different sizes
- PSSs from companies of different countries

- PSSs from different industries

With more data, analysis on the influences of the PSS characterisation scheme on the PSS design specification can be performed with respect to company size, country of origin and industry.

The new data can also be used to further define the fourth PSS characteristic, the PSS configuration type. Currently, the way in which PSS configuration types are assessed has shown that there can be much disagreement within the development team before a configuration type is agreed upon. However, the other three characteristics are objectively derived from the PSS representation diagram. While discussions among the workshop participants may add clarity to the PSS design specifications, the identification of PSS configuration type can also be further developed in order to be more objectively determined. One benefit of having all four characteristics obtained objectively is that different combinations of the PSS characteristics could become different PSS types in an unambiguous PSS classification scheme for engineering design.

Finally, as a longer-term research direction, the impact of a PSS classification scheme that is formed from the four proposed PSS characteristics on PSS development costs and success could be considered. For example, companies that have participated in PSS characterisation workshops could be surveyed to see whether the PSSs have been commercialised, how their development costs compare to other similar developments that have not been characterised and classified with this scheme, and whether these PSSs have been evaluated as successful offerings by the companies and by their customers. Alternatively, retrospective analysis of post-launched PSSs can be considered to explore the utility of the PSS characterisation in examining commercially successful and failed PSSs. This will move this research toward the investigation of success factors of new PSS development and innovation management, and enable new theoretical propositions to be generated.

7.8 Final conclusion

The engineering design process is important. Through this process, stakeholders' needs and desires are transformed to PSS design specifications, which manufacturers develop into new PSS offerings. When customers use the PSSs they want, value is realised. A clear PSS design specification is crucial to achieve the value potential of a new PSS and a useful PSS classification could help to produce unambiguous design specifications. However, a useful PSS classification for engineering design is missing. This research confronts this problem by identifying a PSS characterisation scheme of four characteristics that are useful for clarifying PSS design specification. The research has also shown the potential generalisability of its findings. The findings form the foundation of future studies to propose PSS classification for engineering design, and contribute to the PSS classification literature.

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Appendices

Appendix 01 Summary of stakeholder analysis tools

The following table summarises some examples of stakeholder identification and analysis tools, grouped according to their main purposes.

Table A 1 Stakeholder identification and analysis tools

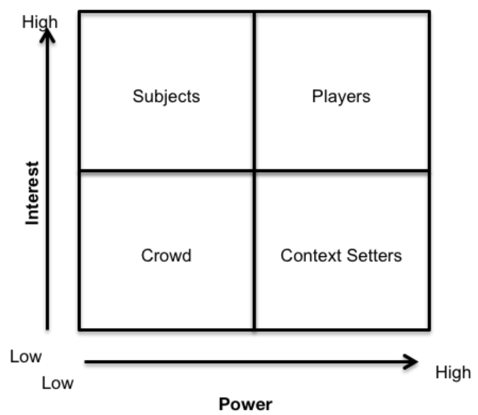
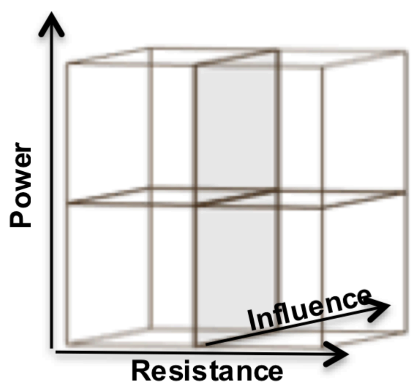
Purpose: Identify and categorise stakeholders	
Format of tool: two dimensional, each axis is a continuous scale	 (adapted from Bryson, 2003, p. 34 Figure 1)
Format of tool: three dimensional, each axis is a continuous scale	 (adapted from Kipley & Lewis, 2008, p. 119 Figure 5)

Table A 1 ***(continued)***

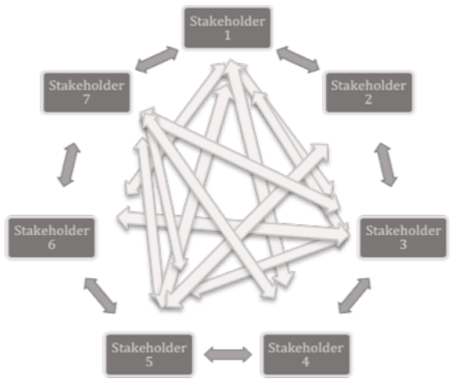
Purpose: Identify stakeholders and analyse sources & direction of influence

Format of tool: two dimensional, each axis has discrete categories

Stake \ Power	Formal/Voting	Economic	Political
Equity	e.g. stockholders		e.g. stockholders
Economic		e.g. suppliers, customers	e.g. unions
Influencers	e.g. regulators	e.g. EHS	e.g. trade association

(adapted from Freeman, 1984, p. 63 Exhibit 3.7)

Format of tool: map showing "interconnectedness"



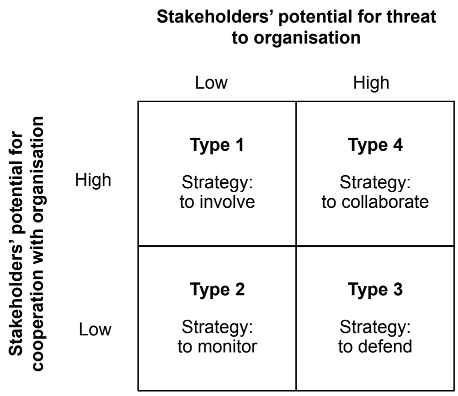
Multi-Rater Feedback Model

(adapted Kipley & Lewis, 2008, p. 109 Figure 2)

Table A 1 ***(continued)***

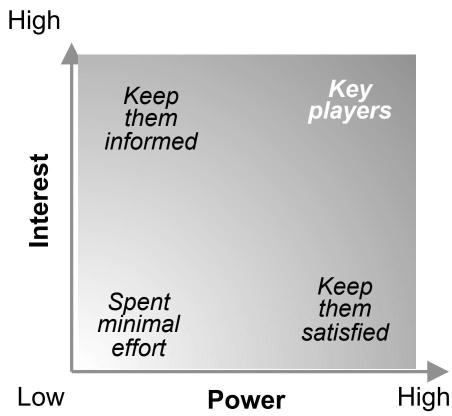
Purpose: Identify stakeholders and guide strategy formulation

Format of tool: two dimensional, each axis has discrete categories



(adapted from Savage, Nix, Whitehead, & Blair, 1991, p. 65 Exhibit 2)

Format of tool: two dimensional, each axis is a continuous scale



(adapted from Williams & Lewis, 2008, p. 659 Figure 2)

Appendix 02 Stakeholder identification framework

Table A 2 The stakeholder identification framework (Yip & Juhola, 2014)

Stakeholder level	Stakeholder group	Company's perspective	Code
Environment – those in the industry, business, government	Industry interest groups	External	E-Ind
	Government quality and regulatory agencies or department	External	E-Aut
	Law & legislation	External	E-Law
	Quality standard & guidance	External	E-Std
	Domain experts or industry experts (can be external or internal to the company, but not involved in the development)	External	E-Dom
	Media	External	E-Med
System/Offering – those in the organisations involved in the development / operations of the system	Customer's management	External	O-CuM
	Company's management	Internal	O-CoM
	Company's sales	Internal	O-Sal
	Company's marketing	Internal	O-Mkt
	Company's engineering/technical development	Internal	O-CoT
	Company's quality & regulatory	Internal	O-CoQ
	Company's industry/government relationship awareness	Internal	O-Spe
	Supplier	External	O-Sup
	Partner (external & internal partners)	External	O-Par
	Business networks	External	O-Net
	Competitors	External	O-Cpt
	Resellers / distributors	External	O-Dis
Product – those in the departments who manage & operate the product	Customer's product maintenance	External	P-CuR
	Company's product maintenance	Internal	P-CoR
	Customer's IT support	External	P-CuS
	Company's IT support	Internal	P-CoS
	Company's product manufacturing	Internal	P-Mfg
	Company's service parts logistics	Internal	P-CoL
	Customer's end users (using product)	External	P-CuU
	Company's service delivery (using product)	Internal	P-CoU
Service delivery – those who deliver the service or are impacted by the service	Company's service delivery (not using product)	Internal	S-CoD
	Customer's service delivery (not using product)	External	S-CuD
	Patients / exercisers	External	S-Ben
	Patient's family / exerciser's family	External	S-Fam
	Care-giving organisations	External	S-CaO
	Patient's organisations / charities	External	S-Cha

Appendix 03 Exploring environmental factors – the business strategy perspective

Chapter 2 section 2.6 has provided an evaluation of the literature about contextual factors and their potential influence on engineering designs. Two frameworks from the business strategy perspectives have been reviewed. They are the 'diamond framework' (Porter, 1990a) and the 'value chain framework' (Porter, 1985).

Figure A 1 shows how the 'diamond framework' could be used to identify contextual factors that may influence a new healthcare PSS development.

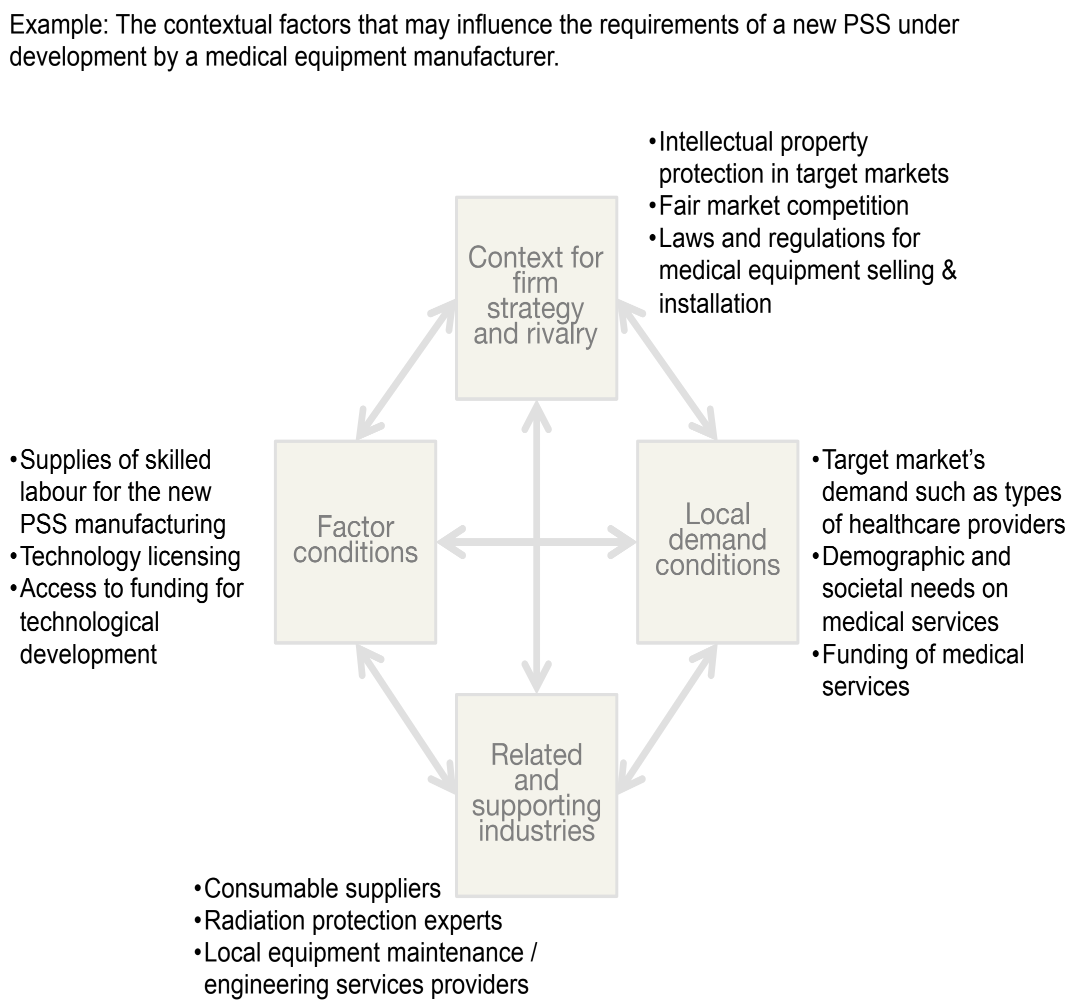


Figure A 1 Potential factors impacting the requirements of a new PSS (based on Porter & Kramer, 2002, p. 60)

Figure A 2 shows an example of how the 'value chain framework' could be used to identify contextual factors for a new healthcare PSS.

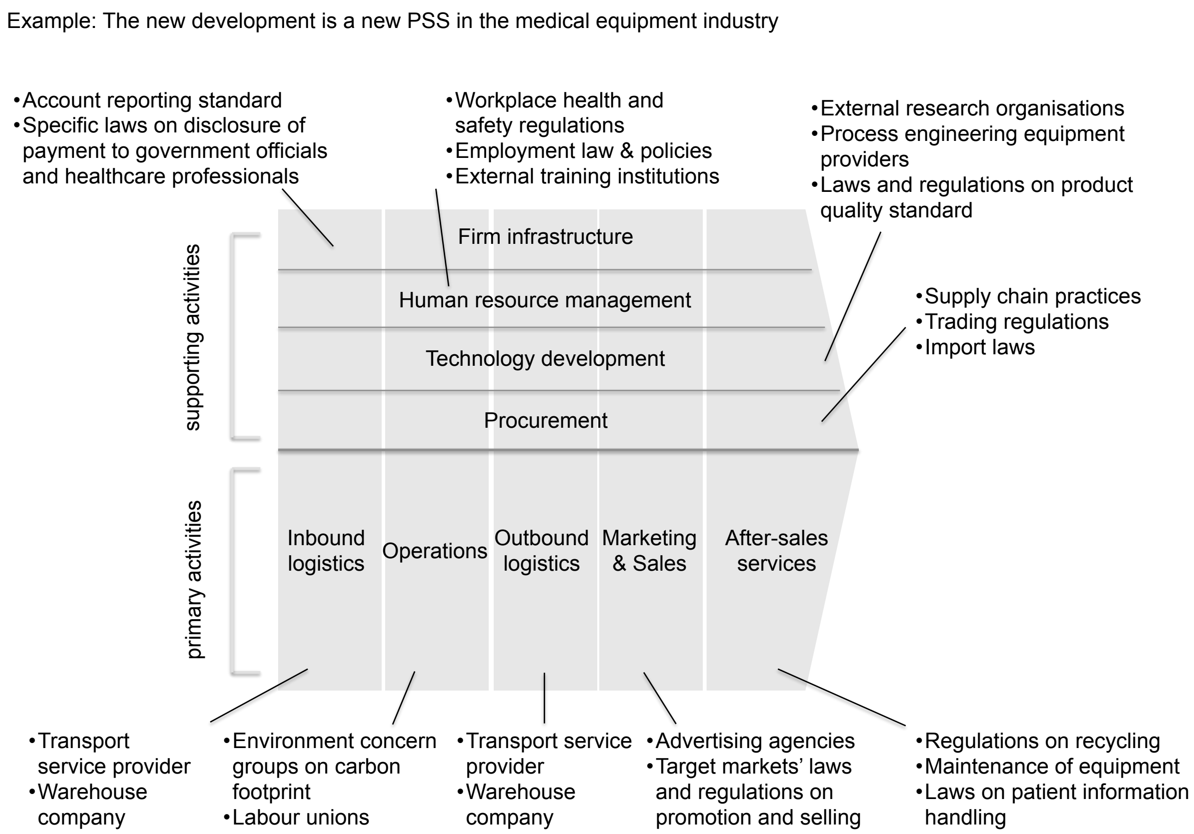


Figure A 2 Identification of contextual factors using the 'value chain framework' (adapted from Porter & Kramer, 2006, p. 85)

Appendix 04 Developing the PSS Characterisation Approach

Background

A PSS characterisation scheme for new PSS engineering design was proposed based on the Phase I completed case studies (see chapter 5). This scheme consists of four characteristics: (1) the customer perceived value level; (2) the ‘connectivity number’; (3) the type and degree of connectivity; and (4) the PSS configuration type. A way to systematically obtain these four PSS characteristics was subsequently proposed, called the PSS characterisation approach. This approach was used as the data collection instrument in Phase II. This appendix describes the development of this approach as a research instrument.

Method

As explained in chapter 3, action research was selected as an appropriate approach to develop this research instrument (Platts, 1993). New PSS ideas or concepts were the subject of analysis for the PSS characterisation approach. The researcher facilitated PSS characterisation workshop (called “the workshop” hereafter) with selected participants who were directly involved in the development project. The number of workshop was not fixed in advance, as the objective was to reach procedural stability. The initial cases developed the instrument while later cases tested it (Maslen & Lewis, 1994).

As described in Table 6-4, there are three types of changes:

- Primary changes – changing the core content of a step, adding or removing main steps or sub-steps, changing the order of main steps, reducing the number of symbols used and changing the shape of symbols used.
- Secondary changes – changing the order of sub-steps and adding instructions into a sub-step.
- Tertiary changes – clarifying the wordings in an instrument and clarifying the key to the symbols used.

Following the ideal model of procedure development proposed by Maslen and Lewis (1994), it was anticipated that the proposed number of primary changes would increase sharply during the first phase, "Build", and would then decrease with an increase number of secondary changes in the following phase, "Improve". The third phase, "Stabilise", would have more tertiary instead of secondary changes, and the number of tertiary changes would then taper off. More contextual conditions for the instrument application would more likely be identified with the maturity of the instrument development, that is the last phase, "Refine". Until the instrument development has reached the phase "Refine", additional cases would be identified.

Nine workshops (workshop O to W) were used to develop the PSS characterisation approach. A description of the cases was shown in Figure 3-3.

Instrument development

In the following sub-sections, the context of each workshop is given and the proposed changes to the instrument are listed and colour-coded. Primary changes are in **red** (and in bold font), secondary changes in orange (and underlined) and tertiary changes are in yellow (and underlined with a dotted line). Contextual conditions to the instrument are in *italics*.

Build

Two workshops were involved in the "Build" phase. Workshop O was a hypothetical example in the confectionary industry and the participants were PhD students of the Institute for Manufacturing at the University of Cambridge who had professional product design experience or an interest in service and/or innovation management. Workshop P was about a commercialised healthcare PSS and the participant was a senior technical development engineer who had knowledge of the market needs. Comments were collected during the workshops and the following changes to the instrument were implemented. The changes are listed by the order of their step in the PSS characterisation approach. The contextual conditions are also identified and listed.

- Overall:
  - Provide a key to the shapes and symbols used in the workshop and a guideline to participants for reference.
- PSS depiction:
  - **Add a sub-step to identify functions that the PSS is to fulfil before identifying the product/service elements needed.**
  - **Instead of drawing the product and service elements with pink and blue circles, the diagram needs to focus on the new functions that the manufacturer thinks of introducing (red circles) and existing systems that relate to these new functions (black circles).**
  - **Add a sub-step to draw a table that allows participants to identify all relevant elements to be developed. This table is called the table of elements identification. The table captures the functions to be developed, the elements within the functions, whether the elements are new or existing, and whether they are product or service in nature.**
  - **Add a sub-step to ask the participants to immediately write three copies on blue and pink sticky-notes, the identified products and services in the PSS. Blue sticky-notes are to be used for services and pink stick-notes to be used for products.**
  - **For elements that are new, instead of asking the participants to write "new" on top of the sticky-note, use a red dot instead to make them visually stand out.**
- PSS abstraction:
  - **Add a discussion sub-step on the size of circle used for the product and service elements, whether size represents effort, cost or revenue**
- *PSS depiction and PSS abstraction steps could be useful for generating concept before business model generation, with a feedback loop from business models back to concept generation.*

- PSS decomposition:
  - **Instead of identifying the type of relationships among the elements that directly interact with each other in one step, the elements that directly interact with each other are to be marked with an X and form the series of grids.**
  - Encourage the participants to check that the Xs are marked correctly. This is to avoid marking Xs where the elements are not directly interacting with one another. Mistakes made at this sub-step, if not corrected, would require the participants to restructure the decomposition.
  - **The triangle symbol representing 'depends on' is to be eliminated. The relationships are limited to 'impacting' and 'impacted by'. 'Depends on' is understood as a type of 'impacted by' relationship.**
  - **The relationships of 'impacting' and 'impacted by' are represented by arrows pointing from the impacting element to the impacted element.**
  - **The right-angled arrow shapes are to be replaced by straight arrow sticky notes or low-adhesiveness stickers to eliminate the need to use a glue stick.**
  - The colouring of the arrows (solid black / stripped) is to be added on only after the directions of impact were identified.
  - The wordings "customer facing elements" in the guidelines are to be clarified as "what the customers potentially value the most".
  - **Add a sub-step to discuss whether the PSS decomposition diagram can be linked to roles in the operations.**
- PSS characterisation:
  - *PSS configuration type is more useful when the instrument is used as a post-launch audit.*

In summary, the total number of changes to the instrument from the "Build" phase and the number of contextual condition identified are:

- Primary: 11

- Secondary: 1
- Tertiary: 3
- Contextual condition identified: 2

Improve

Two workshops were involved in the "Improve" phase. Workshop Q and R were from the defence and healthcare industry respectively. The changes implemented to the instrument and the contextual conditions identified are listed below.

- PSS depiction:
  - **Use stakeholder identification framework if needed before the participants start drawing the PSS depiction diagram.**
  - *When the participating company is unclear of its product and service strategy, this step can help the participants to identify suitable choices.*
- PSS decomposition:
  - Only further decompose an infrastructural element if it is important to identify the interdependencies among the lower-level infrastructural elements, or the lower-level infrastructural elements are unique to the PSS.
  - When there are many infrastructural elements, consider having a separate decomposition diagram for the infrastructural elements.
- PSS representation:
  - If required, consider using one PSS representation diagram for every selected product/service element.
  - If required consider combining some infrastructural elements where there is no interest in understanding their interdependencies, or the lower-level infrastructural elements are not unique to the PSS in discussion.
  - **Consider skipping the PSS representation step if many inter-connections are identified.**
  - Be flexible on other additional use of the PSS representation diagram, such as overlaying it with stakeholders to show the potential influence of stakeholders to the development of different elements within the PSS.

- PSS characterisation:
  - **Make the last sub-step of PSS configuration type identification optional.**
  - Consider identifying the connectivity type and degree, and calculate the connectivity number directly from the PSS decomposition diagram instead of using the PSS representation diagram.
  - *The connectivity number may not mean a lot if there is only one PSS to analyse.*

In summary, the total number of changes to the instrument from the "Improve" phase and the number of contextual condition identified are:

- Primary: 3
- Secondary: 6
- Tertiary: 0
- Contextual condition identified: 2

Stabilise

Three workshops were involved in the "Stabilise" phase. Workshop U, S and T were from the financial investment, environmental protection and healthcare industry respectively. The changes implemented to the instrument and the contextual conditions identified are listed below.

- PSS depiction:
  - Be flexible in terms of the timing within this step to have the element identification table.
  - *This step does not need to limit the participating company to one specific industry or market, it can work for a PSS offering that targets multiple industries / markets.*
- PSS decomposition:
  - *This step does not work too well when the new offering is a just-conceived concept that is to be further developed.*

- PSS representation:
  - Combine elements where relationships are shared to reduce the complexity of the PSS representation diagram.
  - *Consider building an alternative PSS representation diagram when it is necessary to draw attention to one particular element in the PSS.*
- PSS characterisation:
  - *For a relatively simple new PSS development, where the relationships among the PSS and the operating environment are simple, the PSS characterisation step may not be of much utility.*

In summary, the total number of changes to the instrument from the "Stabilise" phase and the number of contextual condition identified are:

- Primary: 0
- Secondary: 2
- Tertiary: 0
- Contextual condition identified: 4

Refine

Two workshops were involved in the "Refine" phase. Workshop V and W were from the executive education and healthcare industry respectively. The changes implemented to the instrument and the contextual conditions identified are listed below.

- PSS depiction:
  - The *operating environment may be narrowed-down to a specific location, if the PSS is customised for a certain operating environment*
  - *The PSS depiction diagram works well to represent how different new and existing systems relate to each other and to their stakeholders*
- PSS abstraction:
  - The shape used in the PSS abstraction diagram for product (P) and service (S) can be extended from circle and rings if the participants agree.

- PSS decomposition:
  - *Knowledge of the new product/service to be developed is the key to build a complete PSS decomposition diagram. If the person who knows about the lower-level elements of the PSS was not available for the workshop, the participants could also choose to stop at the lowest level they could manage to decompose to.*
  - *When the new PSS is directly impacted by different existing programmes at a national level, products and service elements are best to be summarised as infrastructural elements.*

In summary, the total number of changes to the instrument from the "Refine" phase and the number of contextual condition identified are:

- Primary: 0
- Secondary: 0
- Tertiary: 1
- Contextual condition identified: 4

<u>Tracking the development progress</u>

The total number of changes proposed to the instrument in each workshop can be effectively tracked through the visualisation of the increase and decrease of each type of change and contextual condition. Figure A 3 shows the cumulative number of changes and contextual conditions identified. The increment of primary changes stopped after the "Improve" phase. The number of secondary changes rose significantly during the last workshop in the "Improve" phase, and stopped growing during the "Stabilise" phase. The number of tertiary changes only started to increase during the last phase of "Refine". The number of contextual conditions identified increased faster during the last two phases of "Stabilise" and "Refine" than during the initial two phases of "Build" and "Improve".

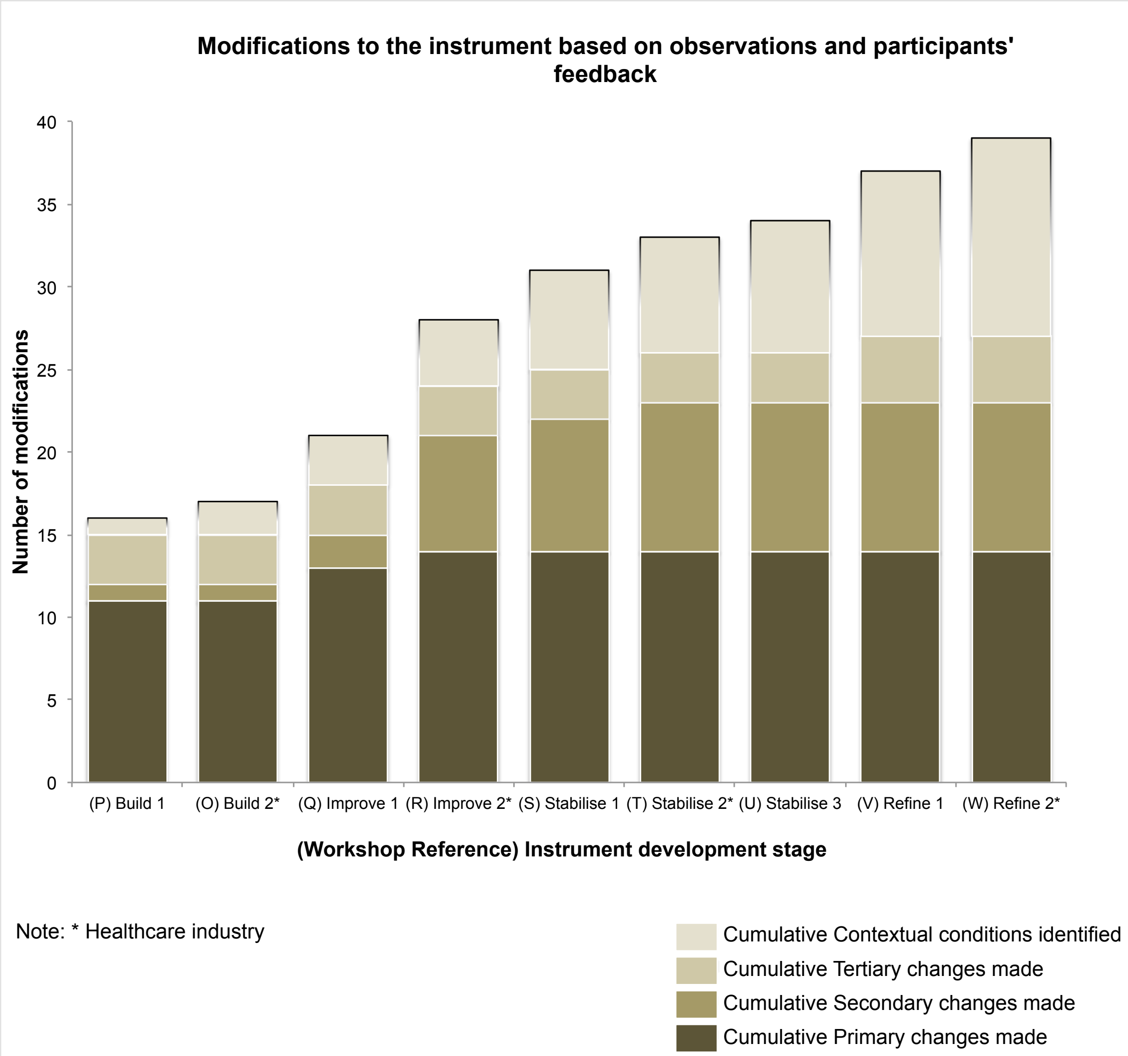


Figure A 3 Modifications to the PSS characterisation approach

As seen in Figure A 3, it appears that the PSS characterisation approach is stabilised as an instrument to support the engineering design process.

Appendix 05 Pilot study interview protocol

The pilot study interview protocol and its introductory notes for the confirmed interviewees are extracted below.

Interview questions (version August 18, 2011)

Introduction

This document explains in brief the research interest, the purpose of the exploratory interview, and how the interviews responses could be used in the research project. All information collected would be anonymised and interviewee would be reminded not to disclose any commercially sensitive information during the interview.

About the research

The conceptual framework below (Figure 1) is an attempt to depict the research interest. Through the exploratory interviews, the elements in the framework, as well as the interactions among the elements would be investigated.

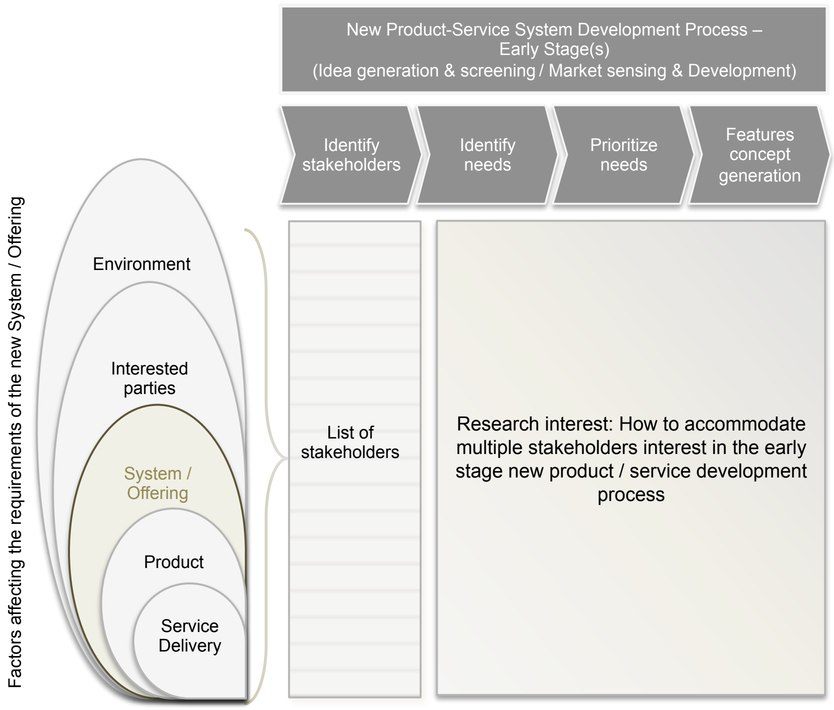


Figure 1: Conceptual framework of the research interest (adapted from Alam & Perry, 2002; Kindström & Kowalkowski, 2009; Moore, 1996; Webster & Wind, 1972)

APPENDIX 05

Pilot interview format

The interview is semi-structured. Open-ended questions are asked. Each interview is estimated to last for 60 minutes. The responses are recorded in the interview-recording sheet in Figure 2. The open-ended questions set can be found in the appendix.

Interview date:

Interview time:

Respondent info:

(Name)

(Company)

(Title)

High-level Process from idea to launch (Typical process? Y/N)

New product-service system development process – early stage(s)

Capture respondent's sub-steps here:

Identify stakeholders → Identify needs → Prioritise needs → Features concept

Project mechanism: (circle mandatory meetings)

	Stakeholders:	*Describe their involvement:*
Environment Industry: Gov't:		
Other Interested parties		
System / Offering Describe the solution:		
Product Equipment:		
Service Delivery Operator(s):		

Figure 2: Interview-recording sheet

Open-ended questions

1) Characteristics of the product-service system:

    a) What is the last new product development project you participated in and when was it? Would you like to discuss this project or would you rather choose another project for the rest of this interview?

    b) Was this project successful in your opinion and why?

    c) What is the problem that this solution intends to solve? Who are the customers? Who operates the equipment? Who provides services?

2) Descriptions of the new product / service development process:

    a) What triggered this development project? How long was the project?

    b) How many phases / stages were there in the development process for this project? Was this process typical in your company?

    c) From which point to which point in the process would you consider as the "early stage(s)" of the development process? Does this depend on the product being developed?

3) Categories of influence:

    a) How would you describe your role in this project?

    b) Did you also represent other stakeholder interest (e.g. customer, supplier and regulator)?

    c) What are the external and internal constraints or preconditions for the successful usage of this new product-service system?

4) Interaction between roles and sub-process steps:

    a) Could you give me some examples of the project mechanism? Which of these did you participate in? Were these mandatory?

b) If you were to participate in a similar development project, would you participate in the same way (in terms of timing and intensity of your involvement)? Or would you like to change something?

c) Who were the other roles involved in the early stage(s)? Were they part of the development project team?

d) Are there any other roles that you believe should have been involved in the early stage(s) of this development? What are they and why?

Appendix 06 Pilot study – consolidated interview report for Project A

Background

The purpose of pilot study is to examine an initial conceptual framework drafted for the research interest as seen in Figure A 4. This conceptual framework is based on literature. The responses from the pilot study interviews bring valuable experience, which may support or contradict the drafted framework. The pilot study's results help to focus the research on the problem that is most relevant to practitioners. In this research, recent new product-service system (PSS) development projects are identified and stakeholders involved in the development are target interviewees.

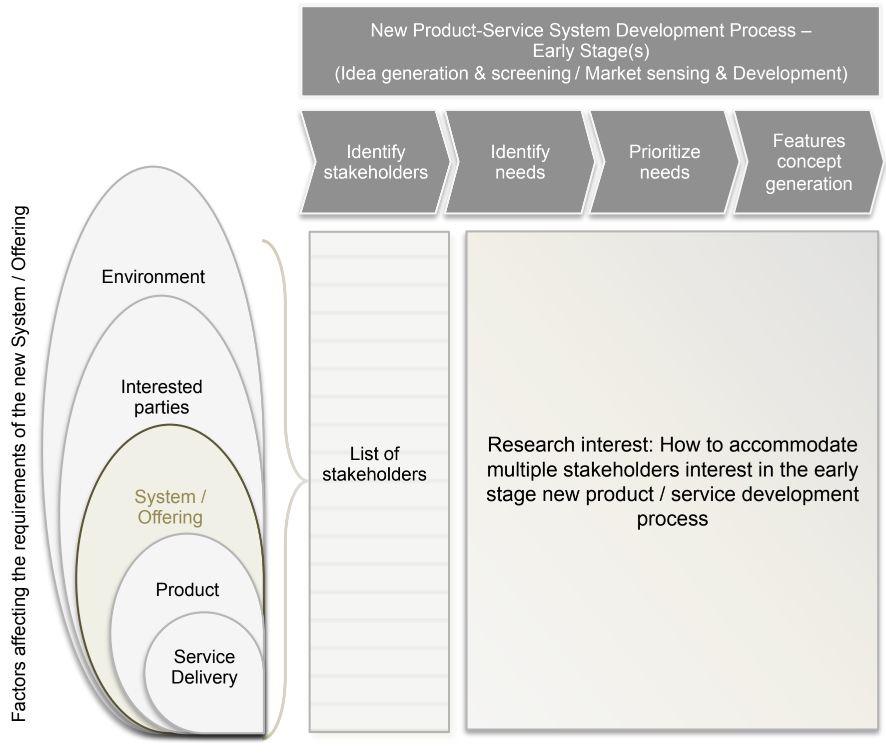


Figure A 4 The initial conceptual framework for the research interest (adapted from Alam & Perry, 2002; Kindström & Kowalkowski, 2009; Moore, 1996; Webster & Wind, 1972)

Introduction

Four people who had been directly involved in a recent new development in the medical device industry were invited to participate in a pilot study interview. The interviewees, in general, referred to this new offering as a new service. This new development was called Project A (not the real name).

The pilot study interviews were carried out between August 29th 2011 and September 9th 2011. The interviews were conducted over the phone, and the duration of each interview was about one hour to one hour and fifteen minutes. The initial conceptual framework (Figure A 4) and the open-ended questions (see Appendix 05) were sent to the interviewees in advance for their reference.

The interviewees

The four interviewees worked in different functions of a global medical device manufacturer and service provider. Their typical customers were hospitals. Table A 3 provided the details of the function the interviewees worked in, their roles in the company and their roles in this development project.

Table A 3 Information on the interviewees of Project A

Function	Role in the company	Role in the new development project	Other notes
Modality[1] technical service operations	Technical service director. Responsible for the remote service delivery of this modality.	Originated the new service concept for this modality. Secured support and resources in the company for this development	He also had experience in manufacturing, product development and service development.
Global service technology	Chief engineer. Responsible for the setting technical strategy for service.	Heavily involved in the proof of concept of this development. Also responsible for the development of service delivery process toward service launch.	This function was responsible for the development of the software back-end of the new service.
Modality service operations	One of the two team-leaders in the modality service operations.	Responsible for the development of the proof of concept of the new service.	He had experience in product engineering, manufacturing, field services and online service support. He used to create software to measure performance of equipment[2].
Modality product engineering	Engineering manager. Responsible for the design and development of the equipment[2].	As the system manager for a development program, which this new service development belonged to.	

Note: 1 'Modality' here refers to a type of medical diagnostic imaging equipment
2 'Equipment' here refers to a medical diagnostic imaging equipment

The development project – duration, team size, motivation and results

The interviewees had different views on the development project duration and team size. This could be because they represented different elements of the PSS.

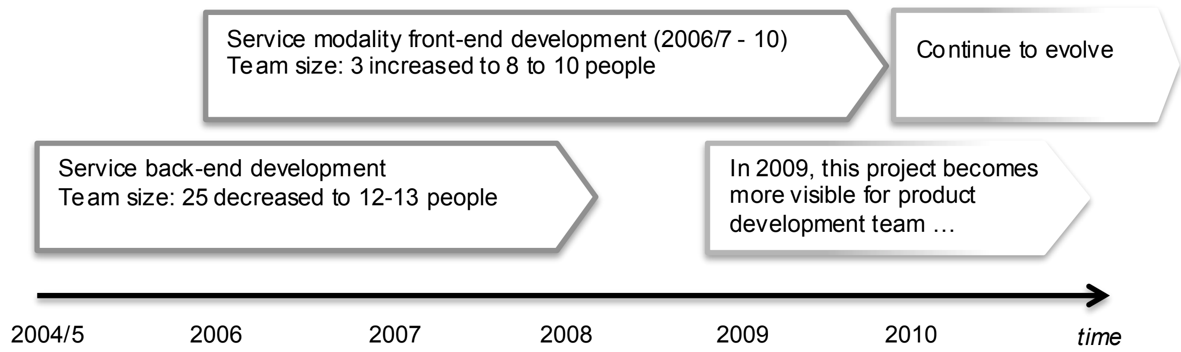


Figure A 5 Project timeline and team size (rationalised from interview responses)

Various reasons were given to explain why the company embarked on this project:

- To differentiate from competitors or to keep up with competitors
- To meet an identified customer need
- As a service strategy or marketing strategy
- To realise internal productivity gain
- To take advantage of a proven internal capability

In general, the interviewees believed that the new service was a success or a partial success. Each interviewee defined success differently. The various perspectives mentioned were:

- Benefits to the company: productivity gain and new avenue for future revenue
- Value to customer: whether the new service brought value to the customer now and/or could potentially bring more value in the future
- Recognition by customer: whether the service was recognized by existing customers

- Technology of the new service: superiority of technology compared to the technology offered by competitors
- Operational success in the new solution implementation

More than once, it was mentioned that the customers would not be getting the full value of this new service until a certain proportion of their equipment had this new service offering implemented.

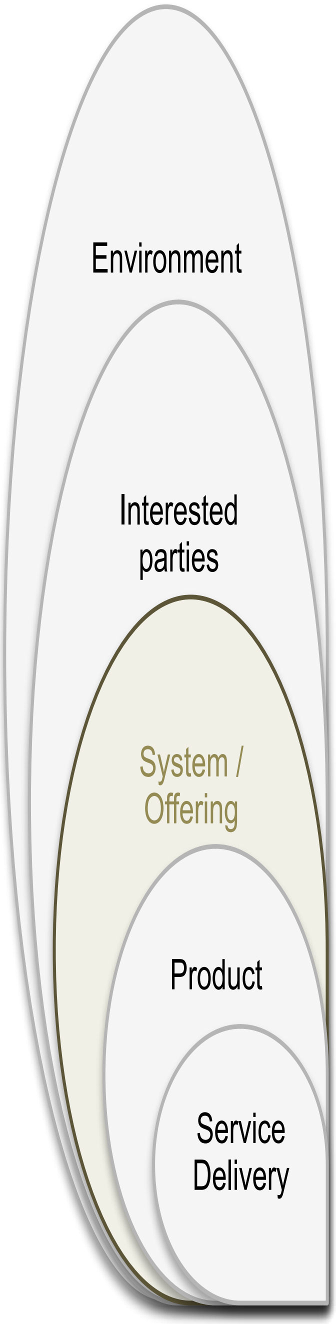
The purpose of the new offering

The aim of this offering was described in the following ways:

- Enabled the customers to have minimal interruptions to their capacity to serve patients.
- Alleviated the two main problems the customers faced – workflow interruptions and issues with image quality.
- Increased the availability and capability of the equipment.
- Proactively serviced the system before it would break down and affect the customers.
- Reduced the materials and labour required to maintain the equipment for both customers and the manufacturer.

Generalising from the responses, the ultimate aim of this offering was to increase the capacity of the customers (hospitals) to serve their customers (patients) in a cost effective and quality manner.

About the PSS that this new service belonged to



Environment: Medical equipment industry
Stakeholders in this environment: Body for accreditation, quality and regulatory bodies.

Interested parties other than customers and development team (% of interviewees who had mentioned a certain party):

Internal

- Field / Online service team (100%)
- Service upper management (100%)
- Marketing / Service marketing (50%)
- Sales (25%)
- Intellectual property right expert (25%)
- Quality expert (25%)
- Legal (25%)
- Global IT (25%)

External

- Hospital administration (25%)
- Radiology department administration (25%)

The system / offering:
A software / feature / service that would take data from the equipment in-use in hospitals, apply an algorithm to analyse the status of equipment and trigger alerts to field service engineers about the pending problems with a recommended fix.
The customer of this system / offering (% of interviewees who had mentioned this party):

- Operator of the equipment (50%)
- Medical diagnostic manager / radiology director (50%)
- Radiologist in the hospital (50%)

The product in this system:

- Equipment (average price: USD1.5 to 2.2 millions^)

The operator of this product:

- Technician of equipment

The service delivered to the end customer:

- Enabled the customer to provide service to end customers

The end customer:

- Patients who required medical diagnostic scanning service

^ Information from the Internet

Figure A 6 The product-service system and its stakeholders

The development process

Combining the responses from the interviewees, the development process of this new service could be depicted as in Figure A 7. Most interviewees believed that this process was typical in the company for this type of development.

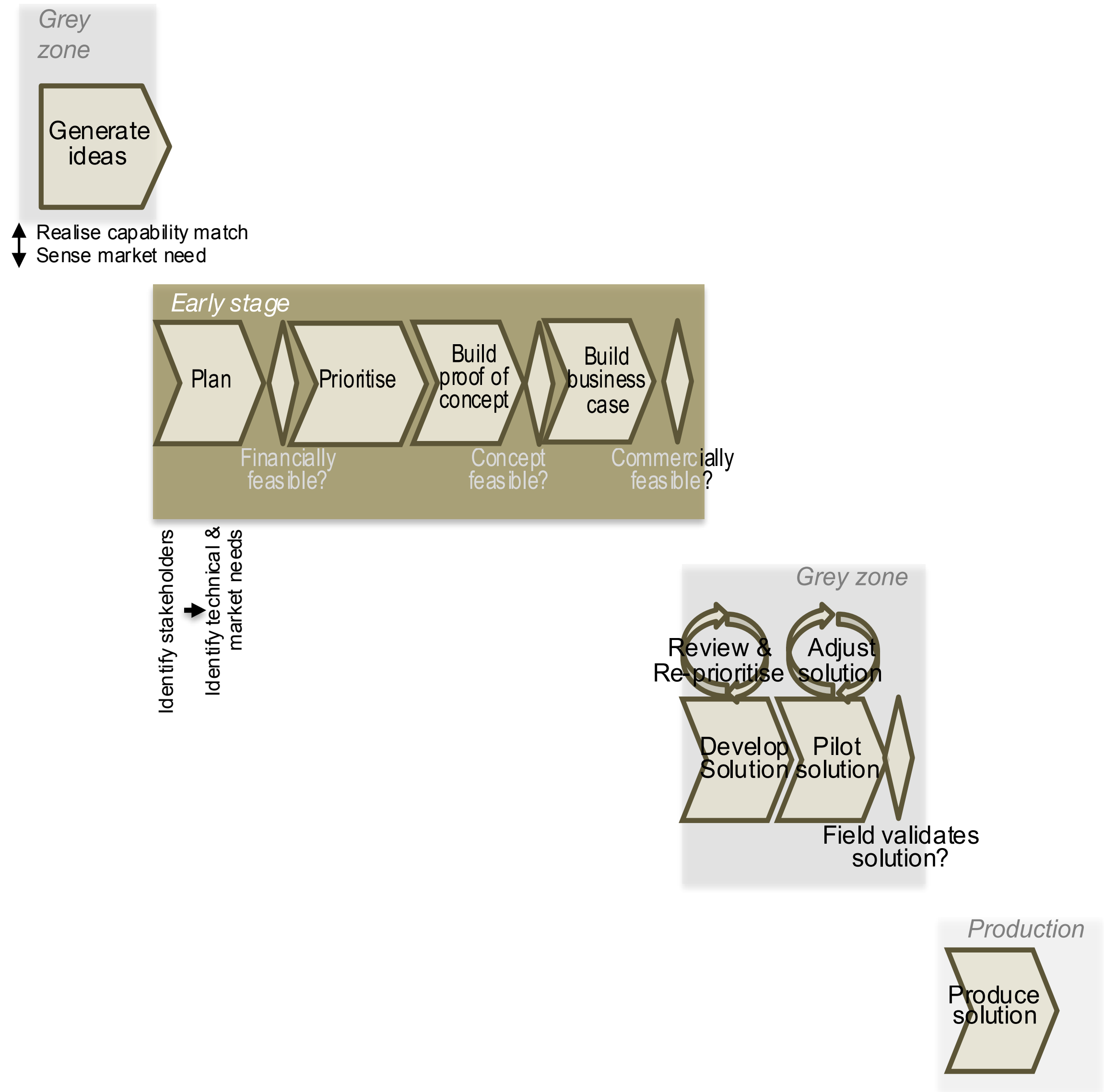


Figure A 7 The high-level idea to launch process for the described new service development

There were two activities within the step of "Generate ideas":

- To realise that there is an internal capability that can be exploited
- To sense that there is a customer need

The sensing of market needs could come from the feedback from field employees, customer contacts and competitors' advertisements. Ideas of matching the internal capability to external market need would be generated in this step.

In the "Plan" step, two sequential sub-steps could be listed:

- To identify stakeholders of the new offering
- To identify technical and market needs, including:
    - Technical – to identify the equipment failure modes
    - Market – to characterise the customer needs through market research techniques such as survey, in order to understand what can interrupt their daily activities in delivering the service to the end customers

At the end of the "Plan" step, a decision would be made with regards to whether the development should continue. This decision would be based on whether the idea is financially feasible for the company.

In the "Prioritise" step, the technical failure modes would be prioritised based on the frequency of occurrence, and the impact on customers according to the market research findings. This would form the prioritised feature list for the new development. Afterwards, a "Proof of concept" would be built.

In the "Build proof of concept" step, four sequential sub-steps could be listed:

- To pull together people with the capability to build the proof of concept
- To perform a technical feasibility check to see whether there is enough data to fulfil the analytic requirements of the new service concept

- To develop rules and algorithms according to the new service concept
- To verify the rules and algorithms with relevant technical experts

For this development, the last sub-step of the “Build proof of concept” step involved the field service and online service engineers who diagnosed and repaired the equipment to verify the rules and algorithms.

Once the concept was proven to be feasible, the next step of “Build business case” would follow. This was the step where information collected so far would be put together to show to the senior management team that the new service was commercially feasibility. Once the senior management team had approved the business case, the development project would proceed onto the development phase, with resources committed to the development.

The step that followed would be “Develop solution”, during which constant reviews would take place, new feature requirements would be proposed and reviewed. Some of the newly proposed features would be incorporated into the new solution. At the end of the “Develop solution” step, a prototype would be ready for evaluation in the “Pilot solution” step.

During the “Pilot solution” step, adjustments to the solution would be made and re-evaluated. At the end of this step, the solution would be validated by the field service team that the new offering was capable to perform what it was designed to perform. Afterwards, the solution would be put into production.

The interviewees had different opinions as to which steps were within the boundary of the early stage of the development process, that is the engineering design process. In Figure A 7, the steps from “Plan” to the checkpoint of “Commercially feasible?” were marked as within the boundary of the early stage of the development process, as all the interviewees had mentioned these sub-steps in their definition of the early stage of the development. The "Generate ideas" step, "Develop solution" and "Pilot solution" steps were shaded as the "grey zone" in Figure A 7, because some interviewees considered these steps as within the early-stage, or some interviewees were not too sure whether they were within the early-stage or not.

<u>The development project management – operating mechanism</u>

During the development, there were many standard and *ad hoc* meetings to manage the progress of the development. The development mechanism was depicted in Figure A 8.

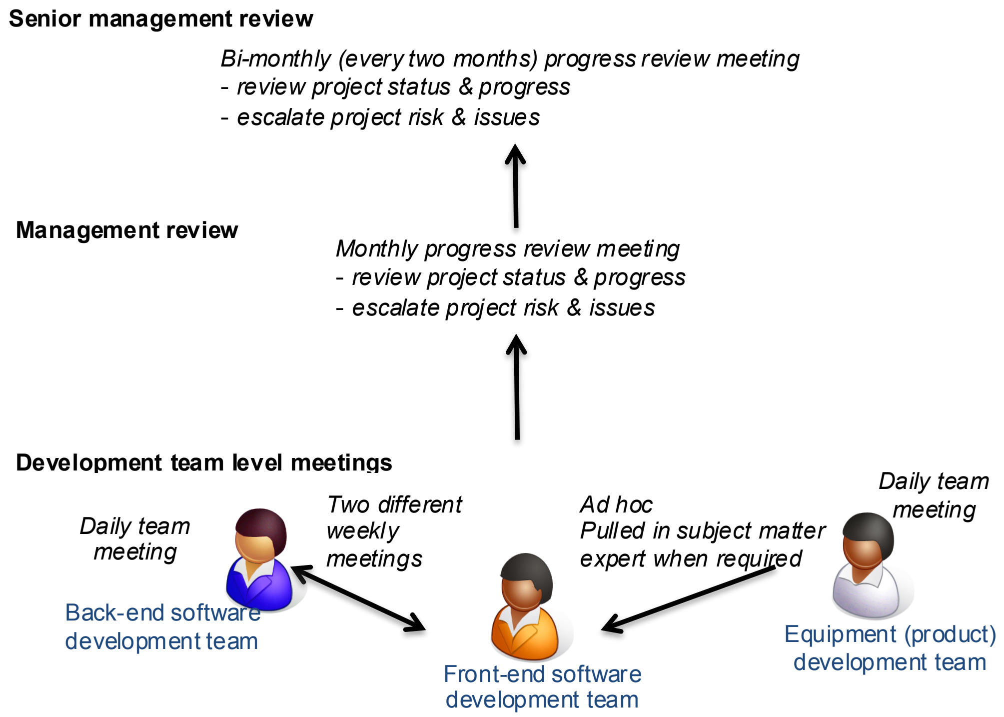


Figure A 8 The operating mechanism for the described new service development

Generally speaking, the interviewees believed that the number of meetings and frequency of meetings were required, given the complexity of the development.

The stakeholders and their involvement in the process

The percentage of involvement of various stakeholder groups in the sub-steps within the early stage or the development process was shown in Figure A 9. Where a stakeholder was directly involved in a development sub-step, the area(s) corresponding to the stakeholder and the step(s) was/were shaded. The checked-pattern shading represented the indirect involvement of stakeholders, that is, the development team represented the interests of these stakeholders. The development team: the global service technology team for the software back-end development, modality technical service operations for the software front-end development, and product (equipment) engineering were listed in Figure A 9 in addition to the stakeholders captured in Figure A 6.

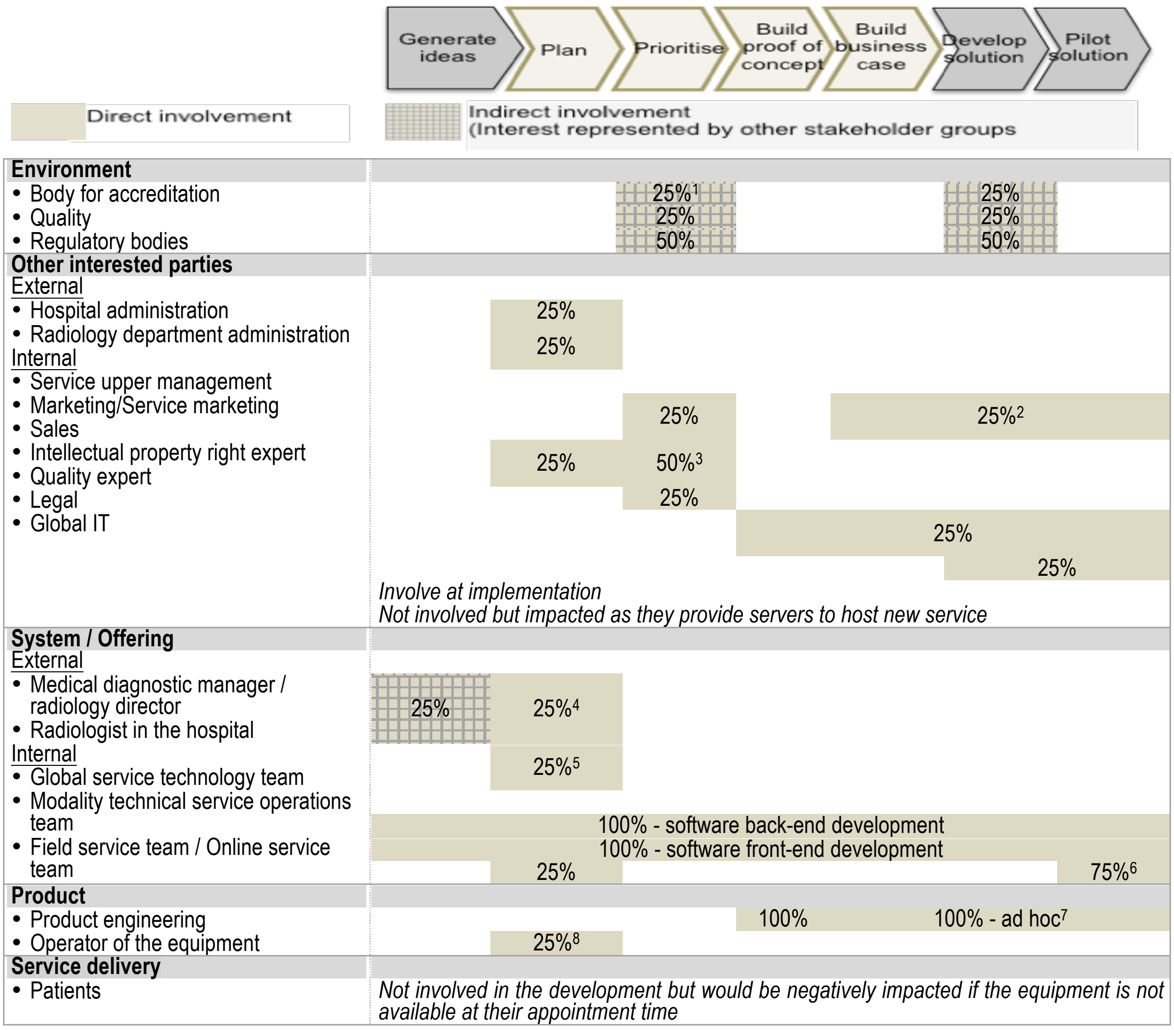


Figure A 9 Stakeholder involvement in early stage new service development

Notes to Figure A 9:

[1] percentage of interviewees who had this point

[2] 25% of the interviewees mentioned the involvement was in "Plan" step and another 25% said the involvement was from after "Proof of concept" onwards. The other 50% said that management was interested in the result, but not actively involved in the development.

[3] 25% of the interviewees mentioned marketing involvement in characterising customer needs during the "Plan" step. 50% of the interviewees mentioned that marketing's interests in having a sellable product in the portfolio, which the researcher interpreted as an involvement during the "Prioritise" step.

[4] 50% of the interviewees mentioned medical diagnostic manager / radiology director as stakeholders, but 25% believed that their interests could be represented by the development team, and 25% believed that they were directly involved by marketing in the "Plan" step.

[5] 50% of the interviewees mentioned radiologists as stakeholders, but only 25% said that they were directly involved by marketing in the "Plan" step.

[6] 100% of the interviewees mentioned field service / online service engineers as stakeholders. 75% said they were involved in the "Pilot solution" step to validate the prototype, 25% said that their comments would be called upon during the "Plan" step to identify needs.

[7] 100% of the interviewees mentioned product engineering team's involvement was important, as the new service would be taking data from the equipment. However, most of the time this team's involvement was pulled in as subject matter experts in an ad hoc manner. Therefore the involvement was shown as "ad hoc".

[8] 75% of the interviewees mentioned the equipment operators as stakeholders. 50% mentioned that the equipment operators were the customers of this new service. 25% said that they were directly involved by marketing in the "Plan" step.

The interviewees mentioned the difficulty of getting product engineering resource during the development process. Half of the interviewees believed that the product engineering team should have been involved earlier, deeper, or taken a more proactively role in the development rather than being pulled-in as subject matter experts in an *ad hoc* manner. Twenty-five percent of the interviewees said that the global service technology team should have involved the modality service operations team earlier so that the vision of the new service between the software front-end team and back-end team could be aligned from the beginning. Twenty-five percent of the interviewees also said that field service / online service teams should have been involved earlier in the "Plan" step so that the resistance to the new way of delivering service could be lower, making the roll-out of the solution in the "Production" phase easier.

Interview analysis

The interviews had raised several questions on the early-stage development process drafted in the initial research conceptual framework as seen in Figure A 10.

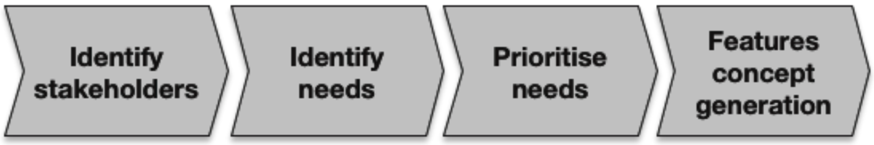


Figure A 10 Early-stage development process in draft research conceptual framework

From the responses, it was clear that some other activities needed to occur before the step "Identify stakeholders". For this new service development project, the concept of providing proactive service to customers was conceived before stakeholders were identified for collecting their needs. The needs were then prioritised and formed a feature list for the development. Hence, in Figure A 7, the first step of the process was "Generate ideas".

There were two other steps that were mentioned by all interviewees and were not in the draft research conceptual framework: the development of a "Proof of concept", and the building of a "business case" for management approval and resources commitment for the new development.

The boundary of the early stage of the development process, or the engineering design process, was also found to be difficult to be clearly defined. Therefore, as seen in Figure A 7, there were a couple of steps in the "grey zones", where either some of the interviewees considered these steps are within the process boundary, or some of the interviewees were not sure whether they are within the boundary or not.

Another aspect that had emerged from the interviews as an area that would benefit from clarification was the definition of 'service'. The interviewees had referred to the offering of Project A as a service, software, an algorithm, or a feature in a product development program. It seemed that the general recognition of the development being a new service came from the fact that the development was initiated by the service organisation in the company, and it required changes in the company's service delivery processes. However, when the interviewees were describing the offering, most interviewees used the word "software" and "algorithm".

Almost all the interviewees mentioned the difficulty of getting support from the product engineering team during the development, even though this development was a top-down management-driven project to execute the new service strategy. The service team needed to show how the new service features would benefit the product quality and reliability, before the product engineering team started to pay more attention to the requests for supporting the new service features development.

One of the interviewees pointed out that there was a misalignment of the performance measurement of the product engineering team and the service strategy. Product engineering's primary concern was time to market and not lifecycle cost of the product. If product lifecycle cost were a performance measure, the product engineering team would have an incentive to work on service features such as Project A, which would lower the on-going product maintenance cost.

In summary, these interviews revealed that the initial conceptual framework of the sub-steps involved in the engineering design process needed to be modified. The interviews also exposed the lack of clarity in the term "early stage" and what a service was. Furthermore, the interviews showed that there was room for improvement in terms of the identification of who should be involved in the engineering design process. The lack of support from product engineering as well as the lack of a common understanding of the goal of the new offering between the software back-end and front-end teams had supported one of identified literature gap that there was a need for an holistic approach for the new PSS development.

Appendix 07 Pilot study – stakeholder involvement engineering design

From the pilot study, it has been found that the following stakeholder groups are involved in the engineering design process (see Table A 4).

Table A 4 Stakeholders involved in the engineering design process

Proximity to final value creation for ultimate beneficiaries	Stakeholder groups	Involvement in the engineering design process
Environment	Law & Legislation	Interests should have been represented
	Domain experts or industry experts (can be external or internal to the company, but not involved in the development)	Involved
Interested party	Industry interest groups	Interests represented by company's employees
	Government Quality and Regulatory Agencies or Department	Interests represented by company's employees
System/Offering	Customer's management	Involved
	Company's management	Involved
	Company's sales	Involved
	Company's marketing	Involved
	Company's engineering/technical development	Involved
	Company's quality & regulatory	Involved
	Company's industry/government relationship awareness	Involved
	Supplier including contractors	Involved
	Partner (external & internal partners)	Involved
Product	Company's product maintenance	Involved
	Customer's IT support	Should have been involved
	Company's IT support	Should have been involved
	Customer's end users (using product)	Involved
	Company's service delivery (using the product)	Involved
Service delivery	Patients	Interests represented by customers

Appendix 08 Phase I interview protocols

Four main versions of interview protocols have been used in the Phase I case studies, three for the three iterations in Phase I, and one for collecting newly required data from previous cases. The four main versions are Version 1.2, Version 2.1, Version 3.0 and Version 3.1b. Version 1.2, 2,1 and 3.0 are included in this appendix.

Version 1.2 Interview questions (extracted from interview protocol version 1.2)

Please be reminded that commercially sensitive information is not to be given to the research student. The information collected from this interview will be anonymised.

Background information

About the interviewee

Role in the development project: ______________________________________

Duration of involvement (in terms of the development process) in the project: ____

About the development project

The new service / product-service system (PSS) we are discussing today was started in ____ (month/year) and has passed the early stage of the development process in ____(month/year).

The problem that this new service / new PSS intends to solve, or *the value(s) this new service / new PSS intends to provide to the customers:* _________________________ ____

The new service / PSS is perceived as successful? ____________________________

Questions

There are fifteen questions, divided into five topics.

1 Stakeholder identification

Stakeholders are defined as the parties or functions that have an interest in the requirements of the new service / PSS or are potentially impacted by the new service /

PSS. The two questions here identify who are the stakeholders and how they could be classified.

1.1 In your opinion, in the process of developing this new service/PSS:

- Which parties or functions had an interest on its requirements?
- Which parties or functions were identified as potentially impacted by it?
- Which parties or functions had eventually input to its requirements?
- Which parties or functions should have ideally been involved in deciding on its requirements? Why?
- Which parties or functions should not be involved? Why?

Use Figure 1 to help remembering the parties or functions related to this development.

1.2 Based on the stakeholders you have named, would you say you group them by: ____

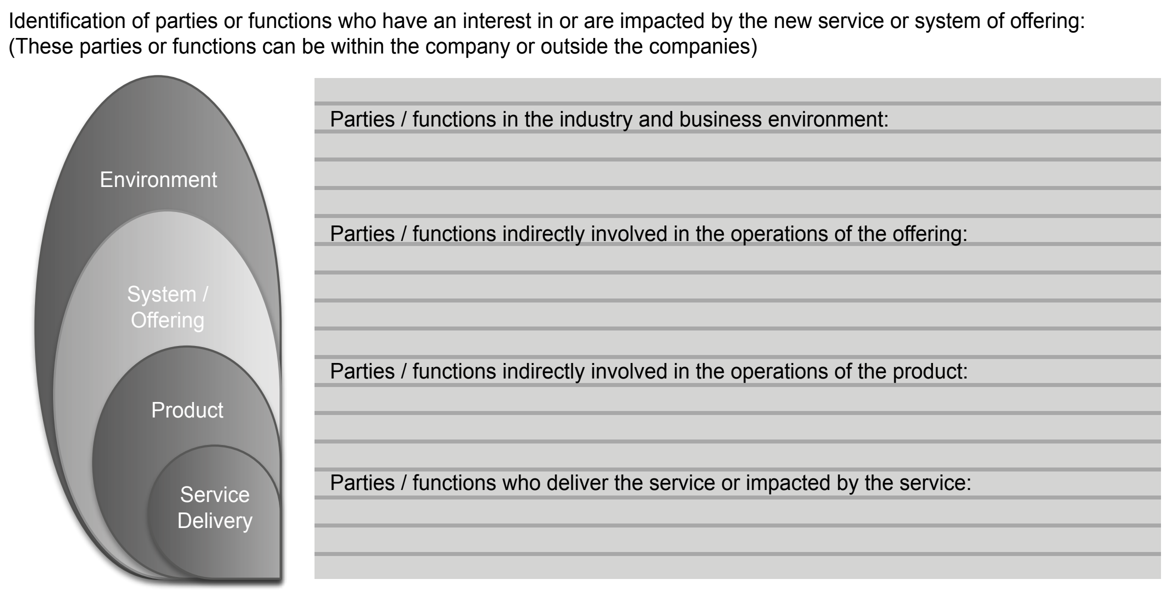


Figure 1: Identification of stakeholders

2 Product-service system (PSS) classification

In this research, PSS is defined as a commercial offering consisting of a collection of elements of products and/or services that fulfil a customer's needs.

The following five questions are about the product and service element of this new development or PSS that it belongs to.

2.1 How would you describe when and where this new PSS / the PSS that this new system is part of is used?

2.2 What are the product elements of this PSS? (Note: Product includes software)

2.3 What are the service elements of this PSS?

2.4 Which of the four "systems" in this diagram would best describe it? Please feel free to draw a new diagram to describe this PSS. Where about in the Product/Service content gradient would you place this PSS?

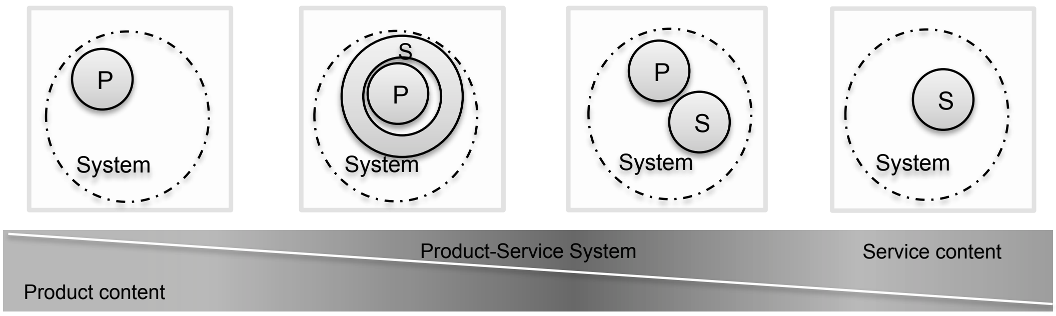


Figure 2: A proposed classification of PSS (source: author)

2.5 Apart from using product/service content to classify PSS, what other aspects would you use?

3 Stakeholders' engagement in the development process

The four questions below are about when and who were involved in the development process.

3.1 When were the stakeholders identified in Question 1 involved in the development? Indicate using the process map in Figure 3.

Figure 3: A proposed new PSS development process (source: author)

3.2 When should they be involved for a better outcome? Indicate using a different colour pen on the same process map.

3.3 What are the "start" and "end" points of the early stage of the new development? Indicate on the same process map.

3.4 Which stakeholders are salient in the early stage and why? Circled these stakeholders on the same process map.

4 The "newness" of the development

The two questions below are about how to define how new a development is, and whether the degree of "newness" impact who are involved and when they are involved in the development process.

4.1 How would you classify "newness" of a new development? Or how many types of "newness" are there?

4.2 How would you define this new development against the above "newness" classifications?

<u>5 Others</u>

5.1 Any other contextual factors that impact who and how different parties / functions are to be involved in the new development process?

Use the models in the following page to help generating more thoughts.

5.2 Any other comments?

Supporting frameworks:

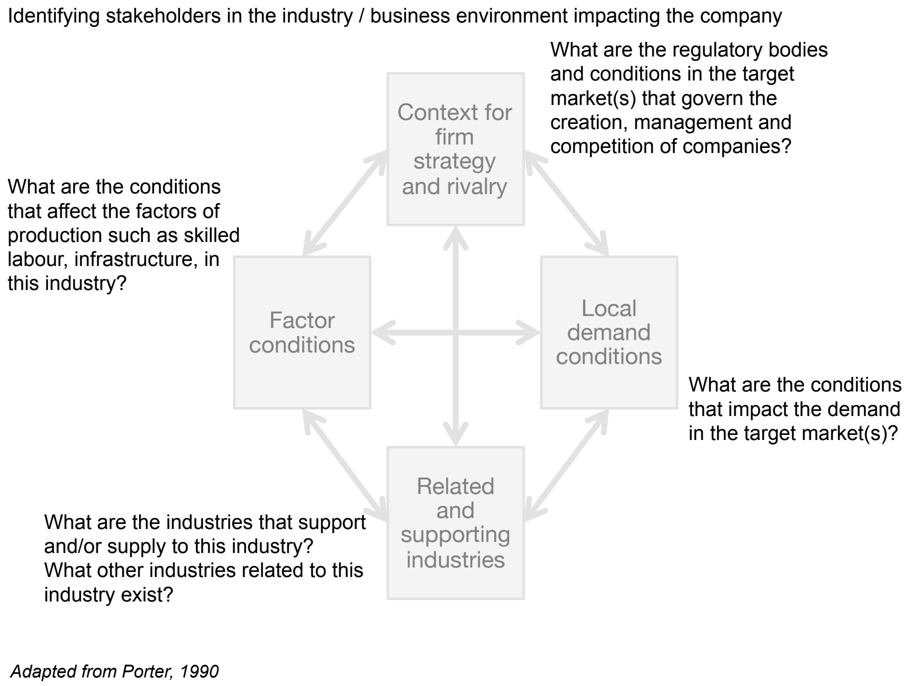


Figure 6: The 'diamond framework' (Adapterd from Porter, 1990b)

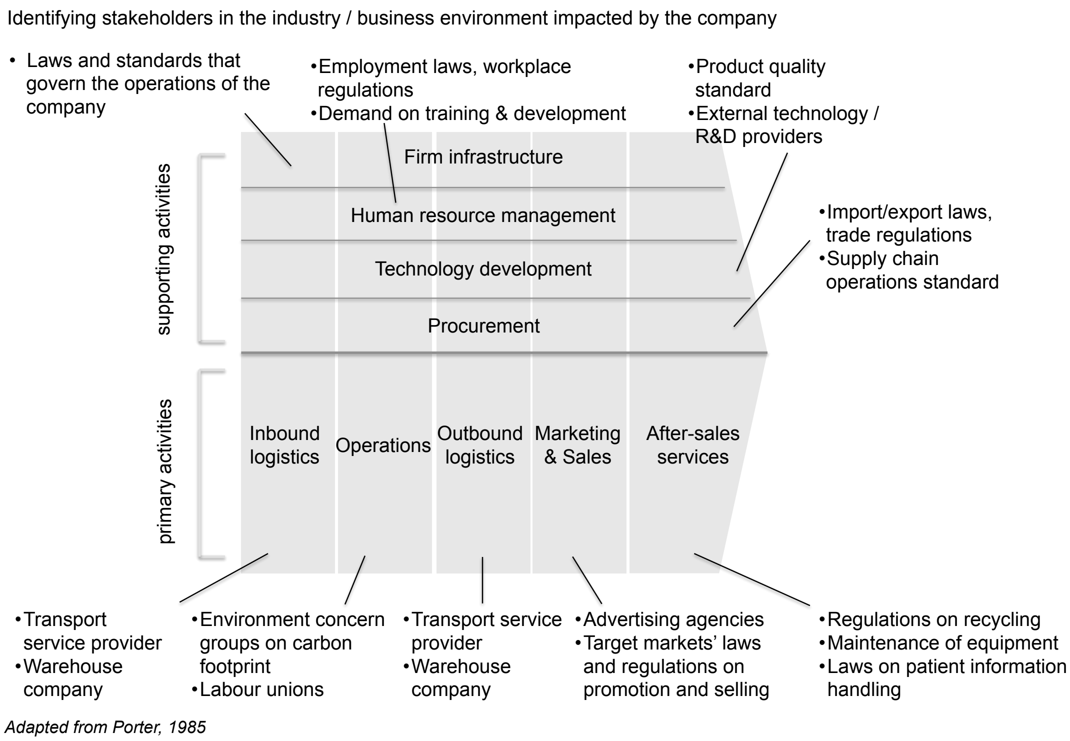


Figure 7: The 'value chain framework' (Adpated from Porter, 1985)

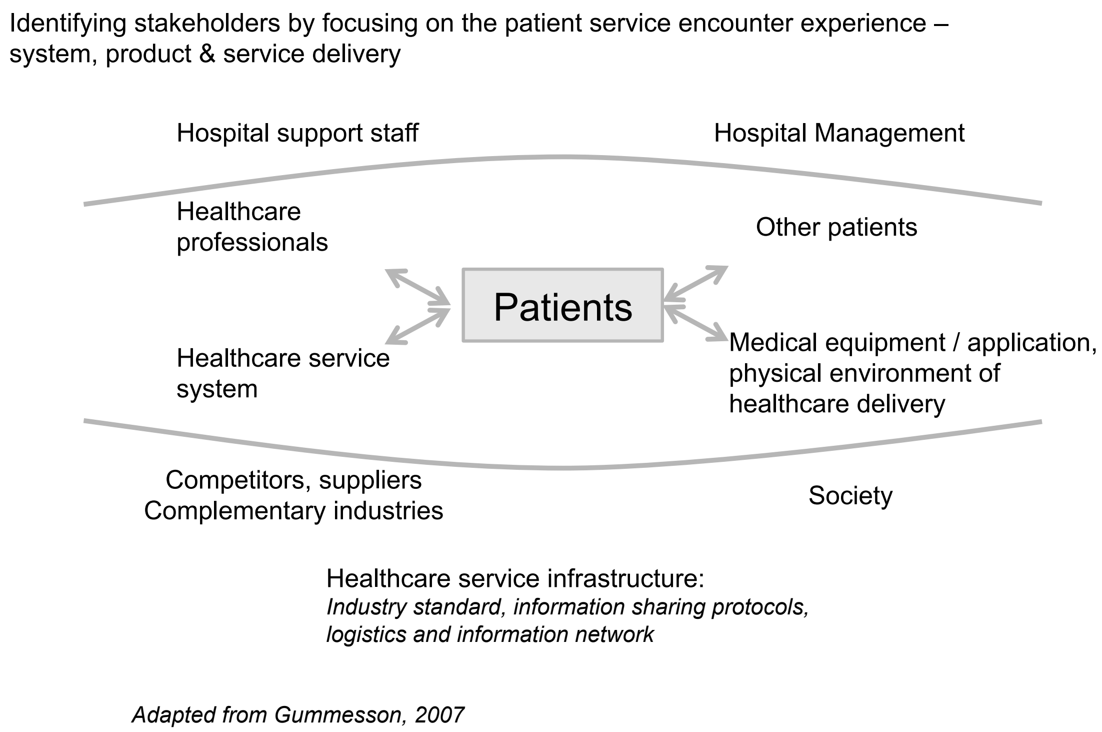


Figure 8: The Service Encounter Framework (Adapted from Gummesson, 2007)

Version 2.1 Interview questions (extracted from interview protocol version 2.1)

Please be reminded that commercially sensitive information is not to be given to the research student. The information collected from this interview will be anonymised.

Background information

<u>About the interviewee</u>

Role in the development project: ____

Duration of involvement (in terms of the development process) in the project: ____

<u>About the development project</u>

The new development we are discussing today was started in ____ (month/year) and has passed the early stage of the development process in ____(month/year).

The problem that this new PSS (note: could be product, service, or combination of product and service) intends to solve, or the value(s) this new PSS intends to provide to the customers*:* ____

____

Is the new PSS perceived as successful? Please explain _________________________

____

Questions

There are twelve questions, divided into six topics.

<u>1 Stakeholder identification</u>

Stakeholders are defined as the parties or functions that have an interest in the requirements of the new service / PSS or are potentially impacted by the new service /

PSS. This question is to identify who are the stakeholders what you think of their level of involvement

1.1 In your opinion, which parties/functions were involved in the process of this new PSS development? What do you think of their level of involvement? Were there party/function who should have been involved and was not involved?

Please use Table 1 to answer the question and add stakeholder groups where needed.

Table 1: Stakeholder identification and level of involvement

Levels	Stakeholder group	Involved? (Yes/No)	Should have been… (e.g. more, less, not involved)
Environment – those in the industry, business, government	Industry interest groups Authority Standards bodies Domain experts		
System/Offering – those in the organisations involved in the development / operations of the system	Customer's management Company's management Company's commercial Company's development Supplier in the development Partner in the development		
Product – those in the departments who manage & operate the product	Customer's IT support Company's service delivery		
Service delivery – those who deliver the service or are impacted by the service	Customer's end users Patients Patient's family Care-giving organisations		

2 Stakeholders' engagement in the early stage development process

The two questions below are about how stakeholders were involved in the early stage development process. Figure 1 shows the early stage development process. The process step could be overlapped or happening simultaneously.

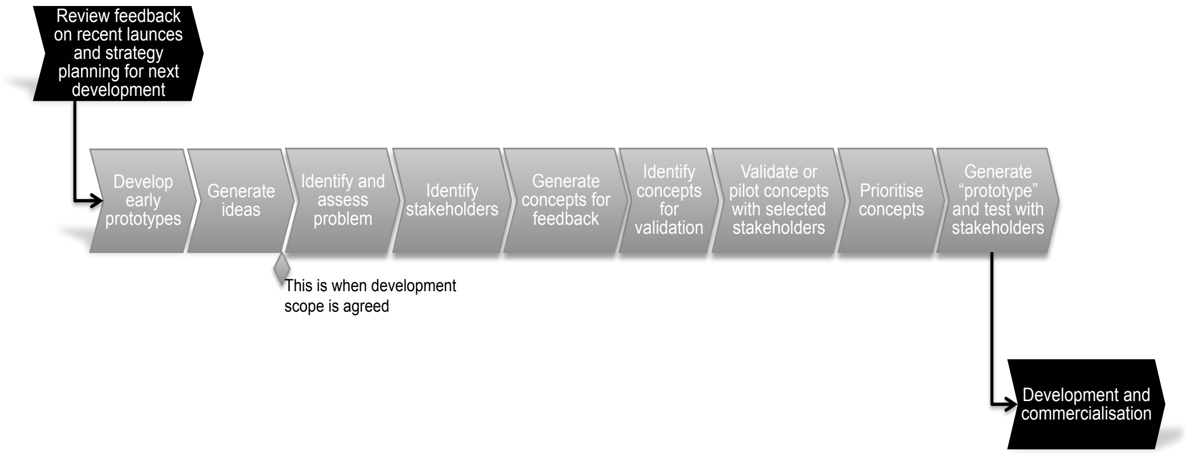


Figure 1: A proposed early stage of new PSS development process (source: author)

2.1 When were the stakeholders identified in Question 1 involved in the early stage of this new PSS development? Table 2 is designed to capture this discussion. Modify the table where needed during the discussion.

Table 2: Stakeholder involvement in the early stage development

Process steps in the early stage	In each process step, stakeholder groups who…		
	were involved	should have been… (e.g. more, less, not involved) for a better outcome	were important
Develop early prototypes			
Generate ideas			
Identify and assess problem			

Table 2 ***(continue)***

Identify stakeholders			
Generate concepts for feedback			
Identify concepts for validation			
Validate or pilot concepts with selected stakeholders			
Prioritise concepts			
Generate "prototype" and test with stakeholders			

2.2 Check point: are there any stakeholder groups identified in Question 1 that were not involved or had no need to be involved in the early stage development process? Why?

3 Product-service system (PSS) classification

In this research, PSS is defined as a commercial offering consisting of a collection of elements of products and/or services that fulfil a customer's needs.

The following six questions are about the product and service element of this new development.

3.1 Where is this product / service / PSS being used? (Or where is it intended to be used if not yet introduced to market)

3.2 When the PSS is being used in the customer's environment, what are the main product and service elements? Please note that for the purpose of this research, product includes software.

3.3 If you were to list the different product and service elements on a catalogue as individual "sellable" options, what would be the product elements and service elements?

3.4 In your opinion, in the scale of "highly valued" to "not valued", how do the customers value the PSS as a whole? Do you think the customers value some of the product/service elements listed in Question 3.3 more than others?

3.5 How do the product and service elements of this PSS interact with the products and / or services in the operating environment? Are there multiple physical locations where these products / services are? How do physical locations impact the development process? Please try to sketch the relationship.

3.6 How would you describe the relationship between the product and service elements in this PSS? Please feel free to draw a diagram to represent the relationship. Some ideas are given in Figure 2, which is a hypothetical example of patient management in a clinic.

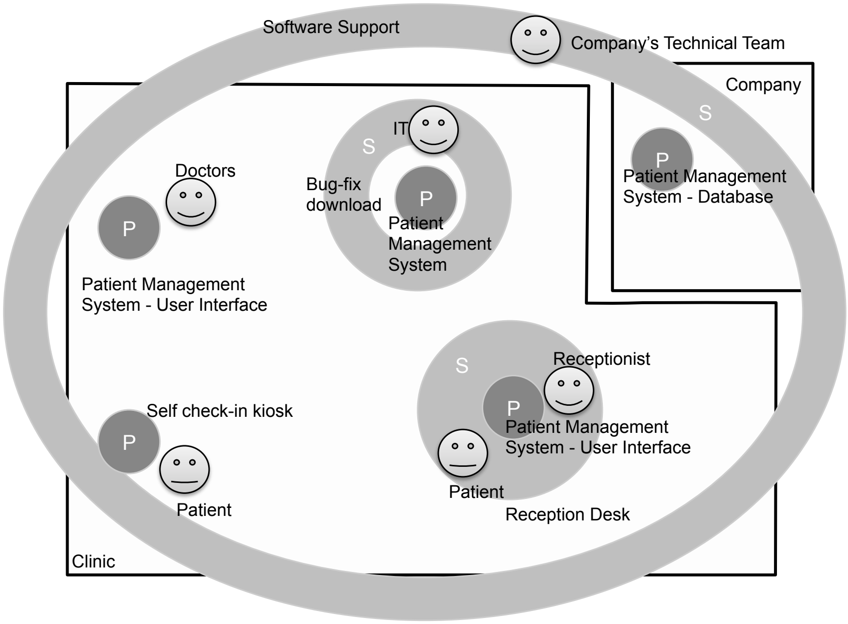


Figure 2: Relationship between product and service elements within the PSS (source: author)

4 The "newness" of the development

4.1 Using Figure 3, what are the types of "newness" in this new development?

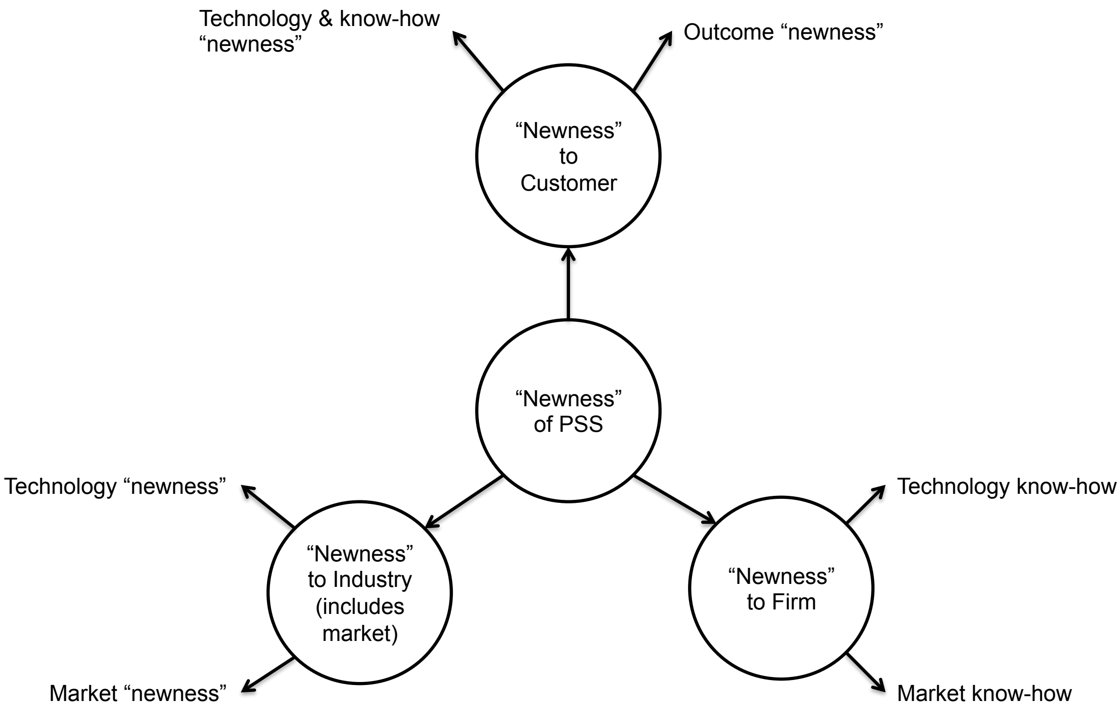


Figure 3: Different type of "newness" aspects (adapted from Garcia & Calantone, 2002)

5 Contextual factors

5.1 What are the key contextual factors to this new PSS development? Table 3 is designed to capture this discussion. Add other contextual factors if needed.

Table 3: Contextual factors identification

Contextual factors – grouped according to The 'diamond framework' (Porter, 1990b) and The Service Encounter Framework (Gummesson, 2007). See next section "Supporting frameworks"	**Impacted the stakeholders involved in this development? How?**	**Impacted the timing of stakeholder involvement in this development? How?**
Factor conditions – conditions that affect the factors of production such as skilled labour, infrastructure in the industry		
Technology – Information sharing protocol, technology that is required to operate the PSS		
Technology – Industry standard / technology that is used in the development of the PSS		
Industry – the availability of labour supply, industry standard, sector domain expertise		
Context for firm strategy and rivalry – regulatory bodies and conditions in the target market(s)		
Government – the law and legislation, regulation, target standards and operation budget or incentives in the countries where the PSS is to be operated in		
Government – the government budget to support the development and of the PSS		
Competition – competitors' merger and acquisition, competitors' market positioning, competitors' product functions and features		
Company – the company's strategy, growth, cash flow, research & development strategy and planning		
Company – the company's norm of stakeholders' roles in the new development process		
Local demand conditions – the conditions that impact the demand in the target market(s)		
Market – the market awareness of the existence of the problem that the PSS intends to solve, the local or customer specific requirements on the PSS		

Table 3 ***(continued)***

Related and supporting industries – the industries that support and / or supply to this industries; industries that are related to this industry		
Supplier and Partner – the product versions of suppliers' or partners' product that this PSS would be interacting with		
Customer's operating environment – actors and other systems in the operating environment of the PSS		
Maintenance and support – the availability of information technology support, product maintenance, service support to users in the operating environment		
Users – the influence of customer's users on the design of the new product, users' willingness to change their ways of working		
End customers / Patients – the experience desired by the end customers / patients who are receiving this service or are in the environment at the same time		
Society – other parties and systems in society that set the expectation on the performance of the PSS		
Impacted organisations – Organisations, e.g. care-giving organisations that are impacted by the quality of the PSS		

6 Others

6.1 Any other comments?

Supporting frameworks:

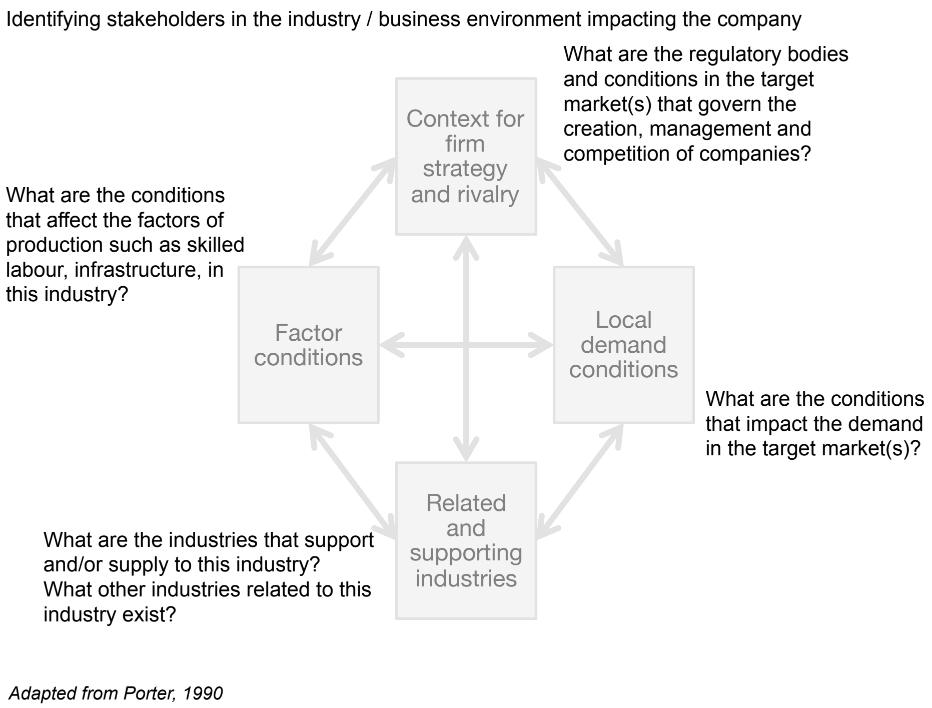


Figure 4: The 'diamond framework' (Adapted from Porter, 1990b)

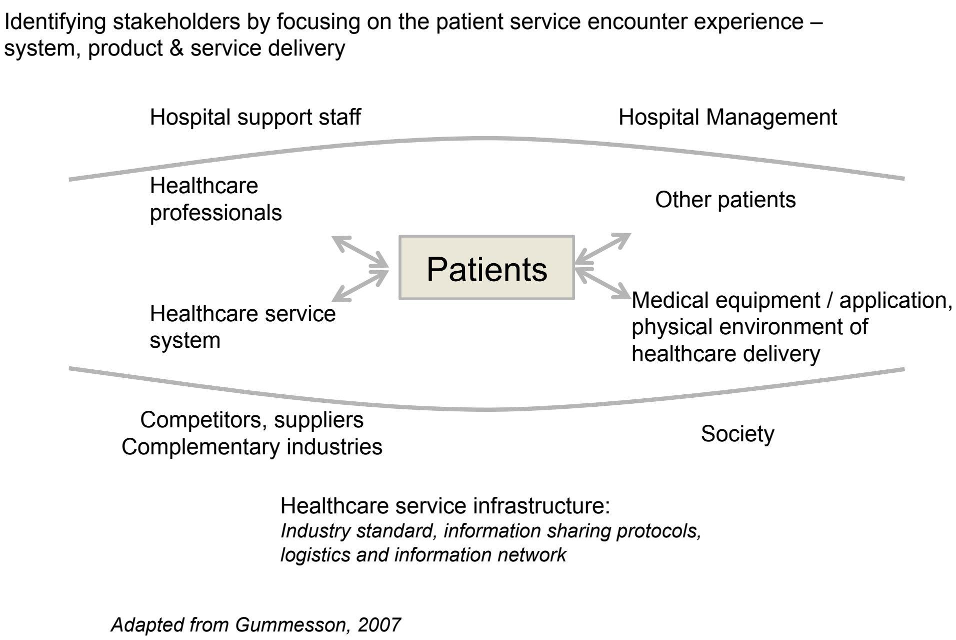


Figure 5: The Service Encounter Framework (adapted from Gummesson, 2007)

Version 3.0 Interview questions (extracted from interview protocol version 3.0)

Please be reminded that commercially sensitive information is not to be given to the research student. The information collected from this interview will be anonymised.

Background information

The interviewee's role in the development project: ________________________

Duration of involvement (in terms of the development process) in the project: ____

The new development we are discussing today was started in ____ (month/year).

If it is commercialised, it was launched in ____(month/year).

The problem that this new development or the PSS that this new development is part of intends to solve, or the value(s) this new PSS intends to provide to the customers: ____

Is the new PSS perceived as successful? Please explain ________________________

Questions

There are twelve questions, divided into six topics.

<u>1 Stakeholder identification</u>

Stakeholders are defined as the parties or functions that have an interest in or are potentially impacted by this new product / service / PSS. This question is to identify who are the stakeholders and the level and timing of their involvement.

1.1 Please indicate in Table 1, along the early stage development process, where:

- The parties/functions who were actually involved in the development (using an X)
- The parties/functions who <u>ideally</u> should have or should not have been involved (using an <u>X</u>)
- In the actual and ideal cases, which parties/functions were important (* next to the X or <u>X</u>)

Table 1: Stakeholder identification and the level and timing of involvement

Early stage development process steps		Generate ideas		Assess problem		Identify stakeholders		Generate concepts		Select concepts		Generate prototype		Test prototype	
Level	Stakeholder group	Actual	Ideal	Actual	Ideal	Actual	Ideal	Actual	Ideal	Actual	Ideal	Actual	Ideal	Actual	Ideal
Environment – those in the industry, business, government	Industry interest groups														
	Government Quality and Regulatory Agencies or Department														
	Law & Legislation														
	Quality standard & Guidance														
	Domain experts or industry experts														
	Media														
Offering – those in the organisations involved in the development / operations of the system	Customer's management														
	Company's management														
	Company's sales														
	Company's marketing														
	Company's engineering/technical development														
	Company's quality & regulatory														
	Company's industry/government relationship awareness														
	Supplier														
	Partner (external & internal partners)														
	Business networks														
	Competitors														
	Resellers / distributors														
Product – those in the departments who manage & operate the product	Customer's product maintenance														
	Company's product maintenance														
	Customer's IT support														
	Company's IT support														
	Company's product manufacturing														
	Company's service parts logistics														
	Customer's end users (using product)														
	Company's service delivery (using the product)														
Service delivery – those who deliver the service or are impacted by it	Company's service delivery (not using product)														
	Customer's service delivery (not using product)														
	Patients / Exercisers														
	Patient's family / Exerciser's family														
	Care-giving organisations														
	Patient's organisations / Charities														

2 Early stage development process

2.1 Did the development project go through these steps? If not, what were the steps? What was the order of the steps or where did they overlap? Ideally, in your opinion, what is the best order of steps for this new development?

Table 2: Early stage development process steps

Phase	Steps (within the early stage)	What happened? (order, overlap)	What is the idea process? (order, overlap)
Beginning	Generate ideas		
Beginning	Assess problem		
Beginning	Identify stakeholders		
Middle	Generate concepts		
Middle	Select concepts		
End	Generate prototype		
End	Test prototype		

3 Product-service system (PSS) configuration

3.1 List the commercial offerings for this new development

3.2 Describe the environment that this PSS is intended to be operating in: what type of facility, what operating procedures of the facility, etc.

3.3 For each of the offering listed in 3.1, what product and/or service elements does it consist of? Please also separately list the existing elements that you know or assume the customers will have for the operations of this new offering.

3.4 Identify the relationship among the above listed elements using: needs, impacts and impacted by.

For example:

If A needs B, then A cannot exist independently without B

If A impacts B, then the operations of A impact the operations of B

If A is impacted by B, then the operations of B impact the operations of A

3.5 In your opinion, in the scale of "highly valued" to "not valued", how do the customers value the PSS as a whole? Do you think the customer value some of the product/service elements listed in Question 3.3 more than others?

3.6 Which of the following diagram best represents the PSS that this new development is / is part of? Please feel free to draw another diagram.

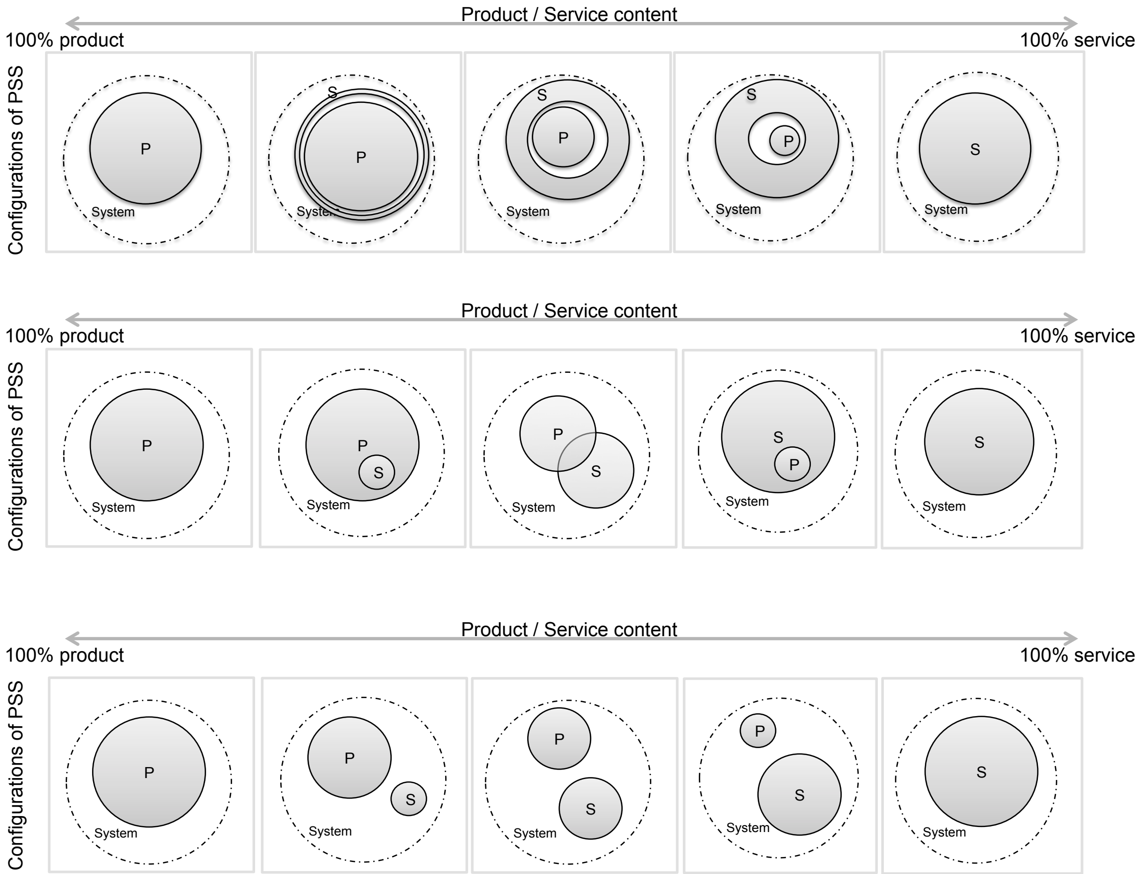


Figure 1: PSS Configurations (source: author)

4 The "newness" of the development

4.1 Using Table 3, please identify the types of "newness" in this new development.

Table 3: Different aspects of "newness"

Main aspects of "Newness"*	**Aspects of "Newness"**	**Rate the new product/service/PSS against each aspect** e.g. New / Not New; Yes / No ; Not Applicable (N/A)
Newness to Customer (include user)	Newness to customers - Technology / Skills:	
	(1) Customers need to acquire new skill in order to operate the new product to deliver the service, or to benefit from the new product/service	(1)
	(2) Customers need new set-up for the existing product	(2)
	Newness to customers - Outcome / Benefits:	
	(1) New benefits	(1)
	(2) Awareness of having new benefits	(2)
Comments:		
Newness to firm	Newness to firm – Technology:	
	(1) The product technology / service approach	(1)
	(2) Technology that is used to produce the product / service	(2)
	Newness to firm – Market:	
	(1) Has no sales in the target market	(1)
	(2) Has no understanding of the target market	(2)
Comments:		
Newness to Industry	Newness to industry – Technology:	
	(1) The product technology / service approach	(1)
	Newness to industry – Market:	
	(1) Competitors have similar product / service	(1)
	(2) Market awareness of product / service	(2)
Comments:		
Overall comments:		

(* adapted from M. Adams et al., 1998; Garcia & Calantone, 2002)

5 Contextual factors

5.1 Using the table below, please capture the key contextual factors that has impacted or will impact on this new development. Identify the relevant factors by putting R in the 'relevance' column. Underline the Rs where the factors must be present for the successful operations of this new product/service.

Table 4: Contextual factors identification

Contextual factors – high level**	Contextual factors - details	Relevance (R = relevant) (R = must have)	Comments: how this fact impacts the stakeholder involvement decision
Factor conditions – conditions for product/service production. e.g. skilled labour, infrastructure	Industry standard / technology standard		
	Availability of labour / skills / domain experts in the industry		
Context for firm strategy and rivalry – regulatory bodies and conditions in the target market(s)	Government law, regulation, incentive		
	Competitor market positioning and product features		
	Company strategy, business planning and operations		
Local demand conditions – conditions that impact the target markets' demand	Market awareness of the problem, local / specific demand		
Related and supporting industries – the industries that support, supply to this industry	Industries that supply to this development		
Customer's operating environment – actors and other systems in the operating environment of the new product/service	Availability and actions of people who maintain or provide user support at customer's location		
	Expectation, perception and behaviours of users of the new product/service		
	Expectation and experience of end customers		
Society – other parties in society that set the expectation on the performance of the new product/service	Other parties in society who are impacted by or benefiting from this new product/service		

(** adapted from Gummesson, 2007; Porter, 1990b)

5.2 How did/do you ensure the presence of the "must have" factors (the underlined factors)?

6 Others

6.1 Any other comments?

Appendix 09 Phase I data collection template

A template in Microsoft Powerpoint format has been used to facilitate the Phase I case interviews. Each page of the template corresponds to a question in the interview protocol. Using the first iteration as an example, Figure A 11 shows the note-taking template and how each page corresponds to the interview protocol version 1.2. This interview protocol can be found in Appendix 08.

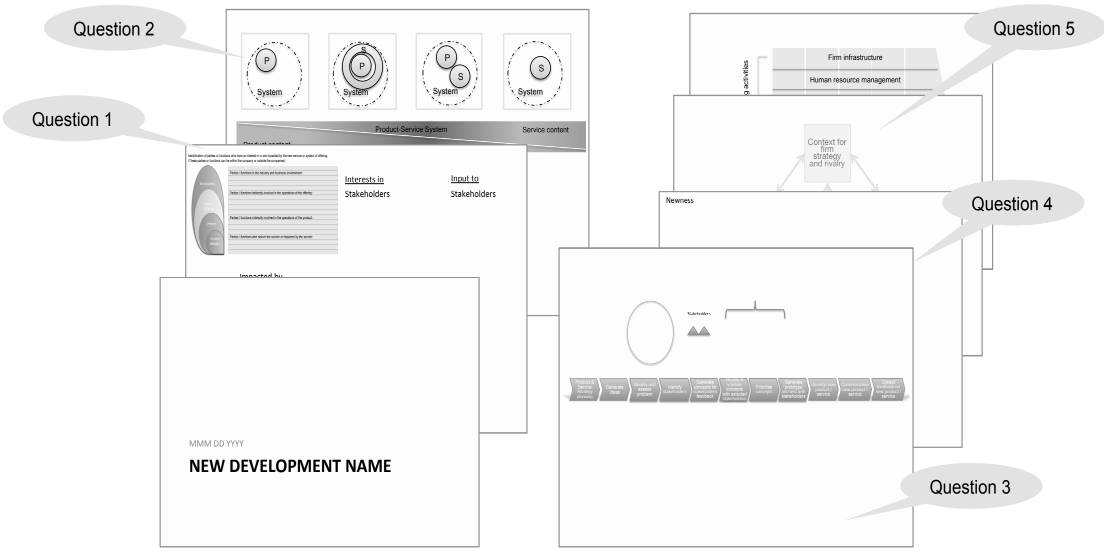


Figure A 11 The note-taking template used for the first iteration case studies

Where the interviews are conducted face-to-face or over the Internet with computer screen sharing (e.g. by using Skype), this file is shared with the interviewees in real-time. This has been found to be an effective way to solicit feedback from the interviewees on the accuracy of data documented and to clarify the points mentioned.

Appendix 10 Phase I data analysis templates

Different templates have been developed to organise the data collected from the case studies for data analysis. For within-case analysis, a framework in the format of Microsoft Excel is used. Figure A 12 is an example. Each worksheet holds the information collected from multiple interviewees in the same case study. This format has enabled the process of within-case analysis. The framework is updated along with the modifications of the interview protocol.

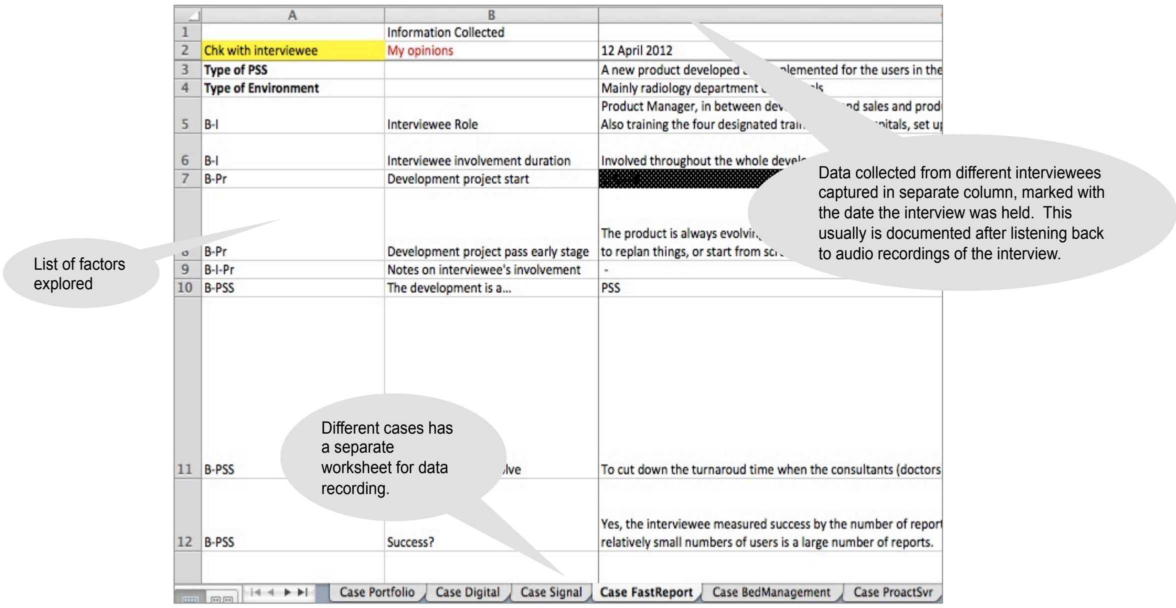


Figure A 12 An example of the framework used for within-case analysis

For cross-case analysis, the templates used for analysis show the potential variables in the first column on the left-hand side of a framework, and list the case names horizontally across the top. A series of framework are used for comparing the differences and similarities of a potential variable across all different cases.

Figure A 13 is an example of cross-case analysis for the potential variable 1.1 "types of stakeholder identified". The top portion of this figure shows the potential variable "types of stakeholder identified" listed in the first column of the framework, and relevant data collected from each case captured under the heading of the respective cases. For potential variable 1.1, there are a number of dimensions that could be used to group stakeholders. These are listed in the first column of the bottom portion of Figure A 13. For each case, if a potential stakeholder group was mentioned in the case interviews, the corresponding case name is marked with an X.

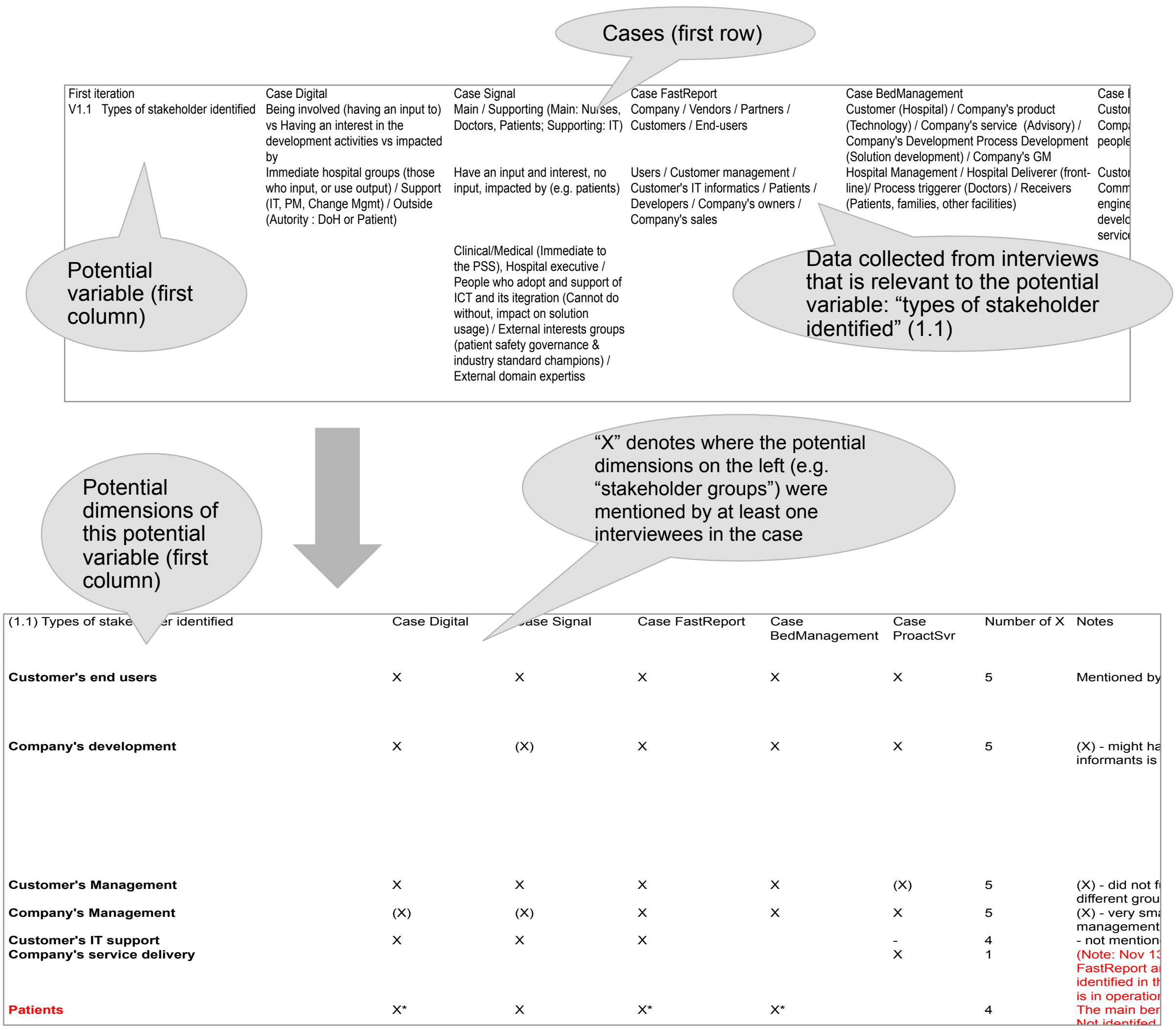


Figure A 13 An example of a series of frameworks used for cross-case analysis

These frameworks helped the systematic analysis of emerging variables from the Phase I case studies.

Appendix 11 Phase I data analysis – variables explored

The potential variables explored in the three iterations of the Phase I study are shown in Figure A 14, listed in a descending order of importance for examination. The potential variables are colour-coded in the figure according to when they were first introduced in the Phase I study. A total of 19 potential variables were explored. Upon reflection, some potential variables were added, modified, combined or dropped during the three iterations of case studies.

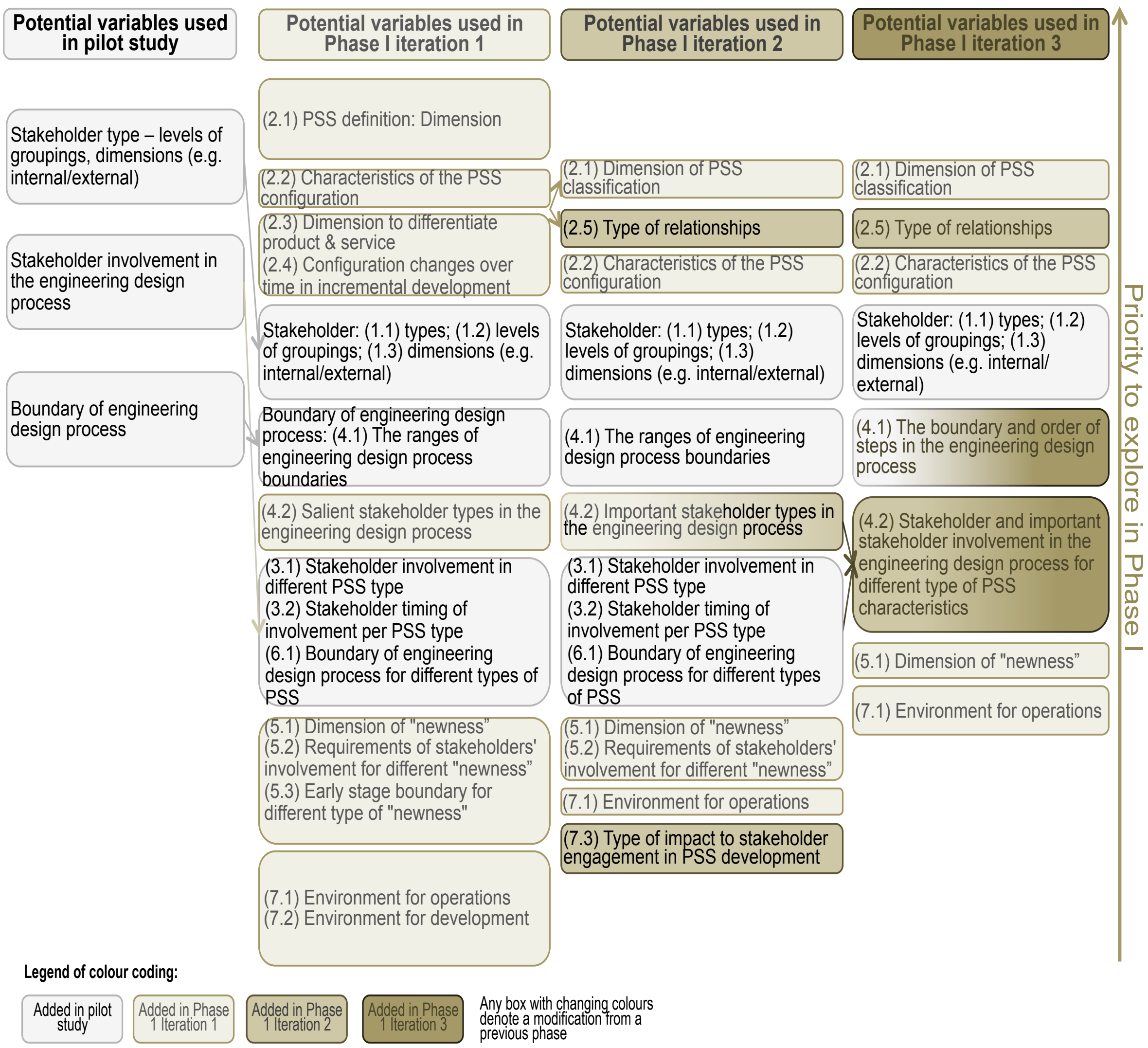


Figure A 14 The convergences of relevant variables for Phase I study

As seen in Figure A 14, potential variables 2.3, 2.4, 5.3 and 7.2 were found to be irrelevant to the study and were dropped. Potential variable 2.1 was split into two, 2.1 and 2.5 in the second iteration, while some others were combined, such as 3.1 and 3.2 were combined into 4.2 in the third iteration. Some potential variables were found to be useful, for example, 1.1, 1.2 and 1.3, and were tested in all iterations in Phase I. Across the three iterations, there was a convergence of relevant variables. The third iteration had further eliminated potential variable 5.1 (see Figure 5-5).

Appendix 12 Phase I – PSS characteristics of the cases involved

Using the PSS characterisation approach describes in chapter 6, the new products, services and PSSs involved in the Phase I case studies are characterised. The following tables show the four PSS characteristics of the commercial offerings involved in Phase I. The first left-hand column of each table shows the reference number of the offering as per Table 5-1.

Table A 5 First PSS characteristic – customer perceived value level

Ref.	Case - Main commercial offerings being developed	Level of potential customer perceived value
	Case Digital	
O1	Digital - Software	2
O2	Digital - Software configuration & training	4
	Case Signal	
O3	Signal - Software	3
O4	Signal - Software support & maintenance	4
O5	Signal - Software implementation & configuration	4
	Case FastReport	
O6	FastReport - Software and user interface	3
O7	FastReport - Train to trainer training	4
O8	FastReport - Integration & configuration	4
	Case BedManagement	
O9	BedManagement - Change Management	3
O10	BedManagement - Training: RFID usage & bed plan / allocate	3
O11	BedManagement - Software & process implementation	2
	Case ProactSvr	
O12	ProactSvr - Proactive Service	3
	Case PredictSvr	
O13	PredictSvr - Dashboard & reports	4
O14	PredictSvr - Predictive proactive service	4
	Case eLearnHospital	
O15	eLearnHospital - Hygiene training	3
O16	eLearnHospital - Outcome measurement set-up	3
	Case eLearnCharity	
O17	eLearnCharity - Training	3
	Case Stent	
O18	Stent - Stent with training on how to use new stent	1
	Case GroupTraining	
O19	GroupTraining - Main module	2
O20	GroupTraining - Small group exercise	3
O21	GroupTraining - Training to gym staff/personal training	2
O22	GroupTraining - Training: how to run effective classes	1
	Case Biomechanics	
O23	Biomechanics - Exercise routine documentation	3
O24	Biomechanics - Monitoring/re-assessment service	3
O25	Biomechanics - Exercise routine design & demo	2

Table A 6 Second PSS characteristic – 'connectivity number'

Ref.	Case - Main commercial offerings being developed	Total number of 'new impacting existing' relationships	Total number of 'existing impacting new' relationships	'Connectivity Number'
	Case Digital			
O1	Digital - Software	0	3	3
O2	Digital - Software configuration & training	0	5	5
	Case Signal			
O3	Signal - Software	0	3	3
O4	Signal - Software support & maintenance	0	3	3
O5	Signal - Software implementation & configuration	0	3	3
	Case FastReport			
O6	FastReport - Software and user interface	0	3	3
O7	FastReport - Train to trainer training	0	3	3
O8	FastReport - Integration & configuration	0	4	4
	Case BedManagement			
O9	BedManagement - Change Management	0	3	3
O10	BedManagement - Training: RFID usage & bed plan / allocate	0	3	3
O11	BedManagement - Software & process implementation	0	3	3
	Case ProactSvr			
O12	ProactSvr - Proactive Service	1	3	5
	Case PredictSvr			
O13	PredictSvr - Dashboard & reports	1	4	6
O14	PredictSvr - Predictive proactive service	3	6	12
	Case eLearnHospital			
O15	eLearnHospital - Hygiene training	1	3	5
O16	eLearnHospital - Outcome measurement set-up	1	2	4
	Case eLearnCharity			
O17	eLearnCharity - Training	0	1	1
	Case Stent			
O18	Stent - Stent with training on how to use new stent	0	0	0
	Case GroupTraining			
O19	GroupTraining - Main module	0	3	3
O20	GroupTraining - Small group exercise	0	5	5
O21	GroupTraining - Training to gym staff/personal training	0	5	5
O22	GroupTraining - Training: how to run effective classes	0	0	0
	Case Biomechanics			
O23	Biomechanics - Exercise routine documentation	1	5	7
O24	Biomechanics - Monitoring/re-assessment service	1	5	7
O25	Biomechanics - Exercise routine design & demo	1	5	7

Table A 7 Third PSS characteristic – type and degree of connectivity

Ref.	Case - Main commercial offerings being developed	Degree of Data/Physical connectivity	Degree of Process Connectivity
	Case Digital		
O1	Digital - Software	Linked	Independent
O2	Digital - Software configuration & training	Linked	Linked
	Case Signal		
O3	Signal - Software	Linked	Linked
O4	Signal - Software support & maintenance	Linked	Linked
O5	Signal - Software implementation & configuration	Linked	Linked
	Case FastReport		
O6	FastReport - Software and user interface	Linked	Independent
O7	FastReport - Train to trainer training	Linked	Independent
O8	FastReport - Integration & configuration	Linked	Linked
	Case BedManagement		
O9	BedManagement - Change Management	Linked	Linked
O10	BedManagement - Training: RFID usage & bed plan / allocate	Linked	Linked
O11	BedManagement - Software & process implementation	Linked	Linked
	Case ProactSvr		
O12	ProactSvr - Proactive Service	Linked	Incorporated
	Case PredictSvr		
O13	PredictSvr - Dashboard & reports	Linked	Incorporated
O14	PredictSvr - Predictive proactive service	Incorporated	Incorporated
	Case eLearnHospital		
O15	eLearnHospital - Hygiene training	Linked	Incorporated
O16	eLearnHospital - Outcome measurement set-up	Linked	Incorporated
	Case eLearnCharity		
O17	eLearnCharity - Training	Independent	Linked
	Case Stent		
O18	Stent - Stent with training on how to use new stent	Independent	Independent
	Case GroupTraining		
O19	GroupTraining - Main module	Linked	Independent
O20	GroupTraining - Small group exercise	Linked	Linked
O21	GroupTraining - Training to gym staff/personal training	Linked	Linked
O22	GroupTraining - Training: how to run effective classes	Independent	Independent
	Case Biomechanics		
O23	Biomechanics - Exercise routine documentation	Independent	Incorporated
O24	Biomechanics - Monitoring/re-assessment service	Independent	Incorporated
O25	Biomechanics - Exercise routine design & demo	Independent	Incorporated

Table A 8 Fourth PSS characteristic – PSS configuration type

		PSS configuration types									
Ref.	**Case - Main commercial offerings being developed**	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2
	Case Digital								**X**		
O1	Digital - Software									X	
O2	Digital - Software configuration & training								X		
	Case Signal						**X**				
O3	Signal - Software							X			
O4	Signal - Software support & maintenance						X				
O5	Signal - Software implementation & configuration						X				
	Case FastReport				**X**						
O6	FastReport - Software and user interface									X	
O7	FastReport - Train to trainer training				X						
O8	FastReport - Integration & configuration				X						
	Case BedManagement				**X**						
O9	BedManagement - Change Management				X						
O10	BedManagement - Training: RFID usage & bed plan / allocate				X						
O11	BedManagement - Software & process implementation				X						
	Case ProactSvr								**X**		
O12	ProactSvr - Proactive Service								X		
	Case PredictSvr		**X**								
O13	PredictSvr - Dashboard & reports									X	
O14	PredictSvr - Predictive proactive service		X								
	Case eLearnHospital								**X**		
O15	eLearnHospital - Hygiene training								X		
O16	eLearnHospital - Outcome measurement set-up								X		
	Case eLearnCharity						**X**				
O17	eLearnCharity - Training						X				
	Case Stent				**X**						
O18	Stent - Stent with training on how to use new stent				X						
	Case GroupTraining								**X**		
O19	GroupTraining - Main module								X		
O20	GroupTraining - Small group exercise								X		
O21	GroupTraining - Training to gym staff/personal training								X		
O22	GroupTraining - Training: how to run effective classes										X
	Case Biomechanics				**X**						
O23	Biomechanics - Exercise routine documentation				X						
O24	Biomechanics - Monitoring/re-assessment service				X						
O25	Biomechanics - Exercise routine design & demo				X						

Appendix 13 Phase I – findings about the engineering design process

From the case studies completed in Phase I, some common steps for the engineering design process have emerged, as shown on the right-hand side of Figure A 15. There are feedback loops going from the later steps to the earlier steps, which are represented by double-headed arrows. The process steps were logically grouped into the beginning, middle and end phases. To compare this engineering design process that has emerged with the generic engineering design process from the literature, the two process flows were placed side-by-side in Figure A 15.

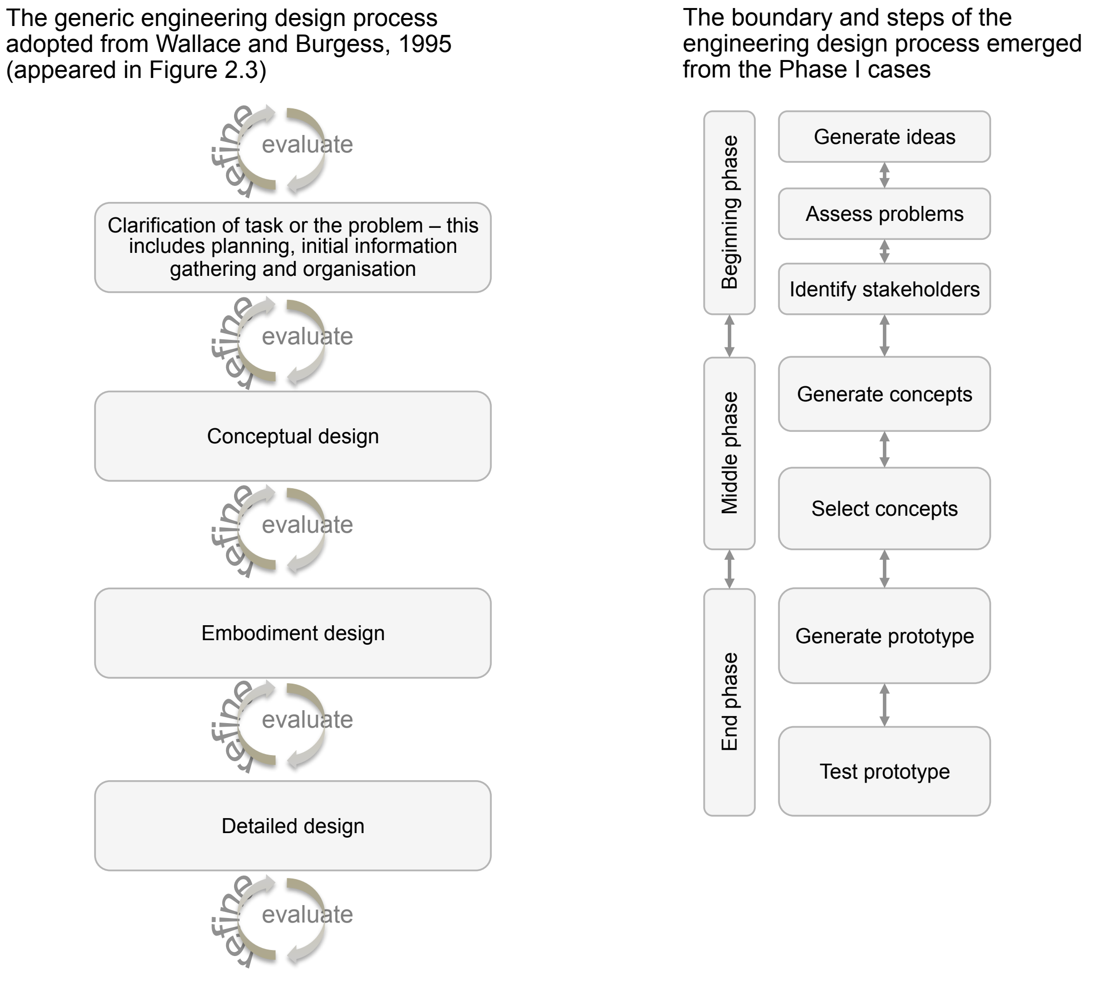


Figure A 15 The engineering design process – findings from literature (left) compare to the findings from the cases (right)

Comparing the generic process adapted from literature (the left-hand side of Figure A 15) and the process emerged from the case studies (the right-hand side of Figure A 15), the process from the case studies can be mapped to a great extent to the process from literature. The emerged steps of the 'beginning phase' achieve the same objectives as the first step in the process from literature, "clarification of task or the problem". The 'middle phase' of generating and selecting concepts fulfil the same aims as the second step of "conceptual design" of the process from literature. However, the 'end phase' which consists of the steps to generate and test prototype, has not spelt out the design activities required for achieving the embodiment and detailed designs. The emerged process appears to have stopped short of the step to finalise the detailed design after prototyping, and may not be able to result in a detailed specification for the purpose of producing the PSS. In conclusion, the process adapted from literature is found to be more complete when compared to the process that has emerged from the Phase I case studies.

Appendix 14 Phase I – findings about the influence of the "newness" of a PSS on stakeholder involvement in engineering design

This appendix presents the high-level findings of how "newness" of a PSS may have influenced the stakeholder involvement requirements of the PSS. In order to explore the influence of the "newness", qualitative comments were collected during the case studies. These comments were transformed into a "newness" score, called the degree of "newness", which enable comparison across different cases. The method used to calculate the degree of "newness" is explained in Table A 9. The degree of "newness" for each type of "newness" of the cases in Phase I is shown in Table A 10, colour-coded to aid data analysis.

Table A 9 Illustration of how to calculate the degree of "newness" for each case

Main aspect of "newness" – Customer	Interviewee 1	Score 1	Interviewee 2	Score 2
Technology	New	1	Not new	0
Outcome	New	1	New	1
Total score		**2**		**1**
Highest possible score		**2**		**2**
Degree of "newness" (%) of this main aspect	= sum of total score / sum of highest possible score = (2+1)/(2+2) = 75%			

Table A 10 Degree of "newness" of the cases in Phase I

The "newness" aspects	Case Digital	Case Signal	Case FastReport	Case BedManagement	Case ProactSvr	Case PredictSvr	Case eLearnHospital	Case eLearnCharity	Case Stent	Case GroupTraining	Case Biomechanics
New to the Customer – Outcome (CO)	50%	75%	100%	100%	100%	100%	100%	100%	100%	100%	100%
New to the Customer – Technology (CT)	50%	67%	100%	50%	0%	100%	33%	67%	33%	100%	100%
New to the Firm – Market (FM)	50%	50%	100%	0%	50%	0%	50%	100%	50%	0%	0%
New to the Firm – Technology (FT)	50%	50%	50%	0%	0%	0%	50%	50%	50%	0%	100%
New to the Industry – Market (IM)	50%	75%	0%	100%	100%	25%	0%	50%	75%	25%	100%
New to the Industry – Technology (IT)	25%	50%	0%	0%	100%	100%	0%	100%	0%	0%	100%

To investigate the role of "newness" in PSS characterisation for the engineering design process, the requirement of stakeholder involvement were analysed across the cases by: (a) paring cases with similar degrees "newness" in different "newness" aspects (Table A 11); (b) grouping cases with similar type and degree of connectivity as per sub-section 5.4.1 (Table A 12); and (c) grouping cases of the same PSS configuration types as described in Table 5-3 (Table A 13).

Table A 11 Pair-wise comparison of stakeholder involvement by newness aspect

Comparison scenario **Note: refer to Table A 10 for the short form of the "newness" aspect**	**Case Digital**	**Case Signal**	**Case FastReport**	**Case BedManagement**	**Case ProactSvr**	**Case PredictSvr**	**Case eLearnHospital**	**Case eLearnCharity**	**Case Stent**	**Case GroupTraining**	**Case Biomechanics**
Comparison scenario A – different CO, CT, IM, IT	X	X									
Comparison scenario B – different CT, FM			X				X				
Comparison scenario C – different CT, IM				X						X	
Comparison scenario D – different CT, FM, IT				X	X						
Comparison scenario E – different CT, FM, IM					X	X					
Comparison scenario F – different IT						X				X	
Comparison scenario G – different FM, IM						X					X
Comparison scenario H – different IM							X		X		
Comparison scenario I – different CT, IM, IT			X					X			
Comparison scenario J – different CO, CT, IT		X							X		

Table A 12 Comparison by stakeholder involvement by "newness" and PSS connectivity type and degree

Physical/Data Connectivity	**Process Connectivity**	**Case Digital**	**Case Signal**	**Case FastReport**	**Case BedManagement**	**Case ProactSvr**	**Case PredictSvr**	**Case eLearnHospital**	**Case eLearnCharity**	**Case Stent**	**Case GroupTraining**	**Case Biomechanics**
Independent	Incorporated								X			X
Linked	Linked	X	X	X	X						X	
Incorporated	Linked					X		X				
Incorporated	Incorporated						X			X		

Note: degree of connectivity of the overall PSS is used, as the "newness" data was collected at the project level

Table A 13 Comparison by PSS configuration type

PSS Configuration type	Case Digital	Case Signal	Case FastReport	Case BedManagement	Case ProactSvr	Case PredictSvr	Case eLearnHospital	Case eLearnCharity	Case Stent	Case GroupTraining	Case Biomechanics
B2 – Deforming product			X	X					X		X
D2 – Static product	X				X		X			X	

Note: PSS configuration type of the overall PSS is used as the "newness" data was collected at the project level

The analyses showed some contradicting observations, but also some patterns had emerged. For example, in comparison scenario F (Table A 11) where only the aspect of "newness to industry – technology" were different, it appeared that the stakeholders in the environmental level did not need to be involved in Case GroupTraining, but were required by Case PredictSvr. As for the comparison by connectivity type (Table A 12), for the scenario when both the physical/data and process connectivity were 'linked', it appeared that the service delivery stakeholders were needed in the engineering design process when the PSS was not new to the firm and its technology was not new to the industry, but the PSS had a completely new outcome for customer.

An example of the PSS configuration type comparison (Table A 13) was for the configuration type B2. Case Biomechanics of PSS configuration type B2 needed both external and internal stakeholders to be involved, which could be because it had the highest degree of "newness" across all the "newness" aspects. However, Case Stent and Case FastReport, both of B2 PSS configuration type, seemed to require two of the four levels of stakeholders to be involved in the engineering design process, although Case FastReport had more "newness" aspects being completely (100%) new. It appeared that other contextual factors of the PSS developments might have influenced the stakeholder involvement in addition to or instead of the influence of "newness".

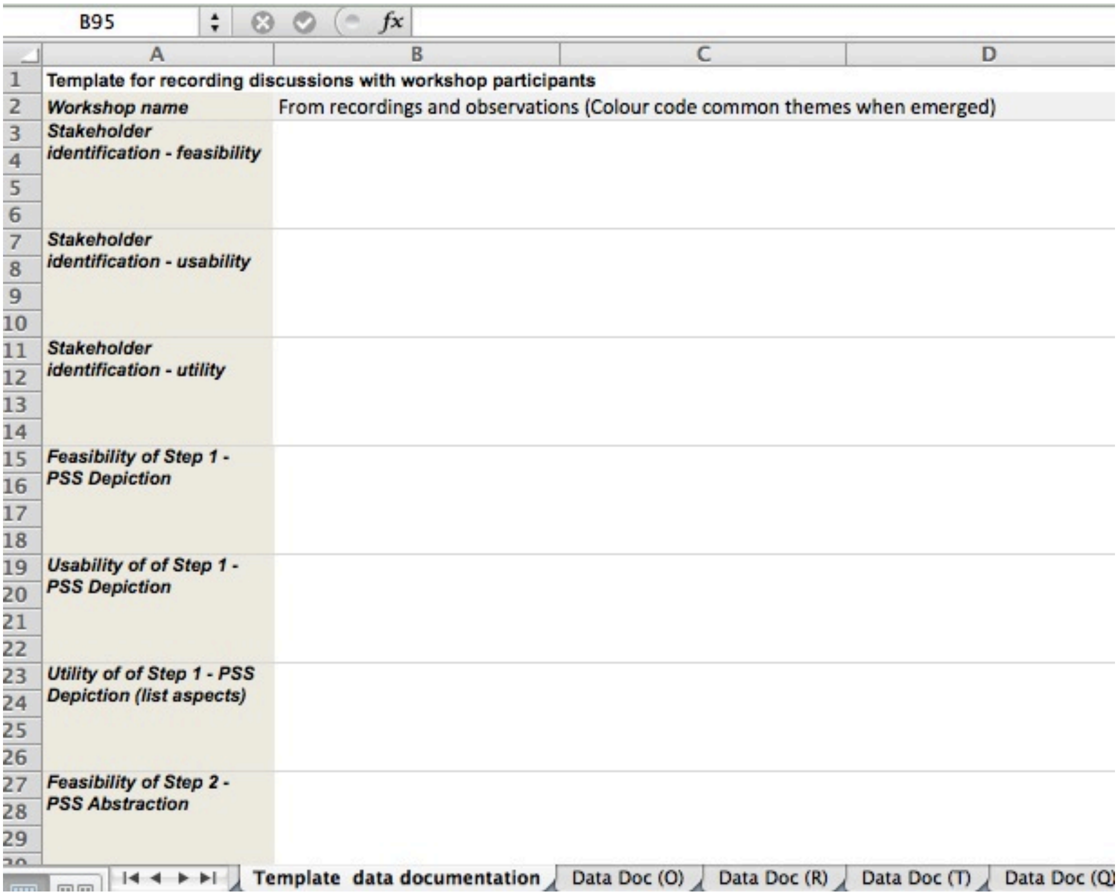
In conclusion, although the interviewees could comment on the “newness” of a PSS according to the six “newness” aspects (see Table A 10), on its own and when combined with PSS connectivity or PSS configuration type, “newness” was not capable to characterise PSSs in the engineering design process when examined by means of its stakeholder involvement requirement in the process.

Appendix 15 Phase II workshop control points

Three control points in the workshop process were described in chapter 6 section 6.2.2. The control points employed were workshop qualification, preparation and workshop facilitation. The criteria for workshop qualification were described in chapter 6. For workshop preparation, Figure A 16 shows the set-up of some workshops.

Figure A 16 Workshop set-up

Figure A 17 is a screenshot of the data table template that was used to record the data collected during the facilitated workshops.



B95

	A	B	C	D
1	Template for recording discussions with workshop participants			
2	*Workshop name*	From recordings and observations (Colour code common themes when emerged)		
3–6	*Stakeholder identification - feasibility*			
7–10	*Stakeholder identification - usability*			
11–14	*Stakeholder identification - utility*			
15–18	*Feasibility of Step 1 - PSS Depiction*			
19–22	*Usability of of Step 1 - PSS Depiction*			
23–26	*Utility of of Step 1 - PSS Depiction (list aspects)*			
27–29	*Feasibility of Step 2 - PSS Abstraction*			

Template data documentation | Data Doc (O) | Data Doc (R) | Data Doc (T) | Data Doc (Q)

Figure A 17 Data documentation template

This data collection template enhanced the consistency of data recording in Phase II.

Appendix 16 PSS Decomposition of a new running group

Figure A 18 shows the full PSS decomposition diagram of the new running group example which was used to illustrate the PSS characterisation approach in chapter 6.

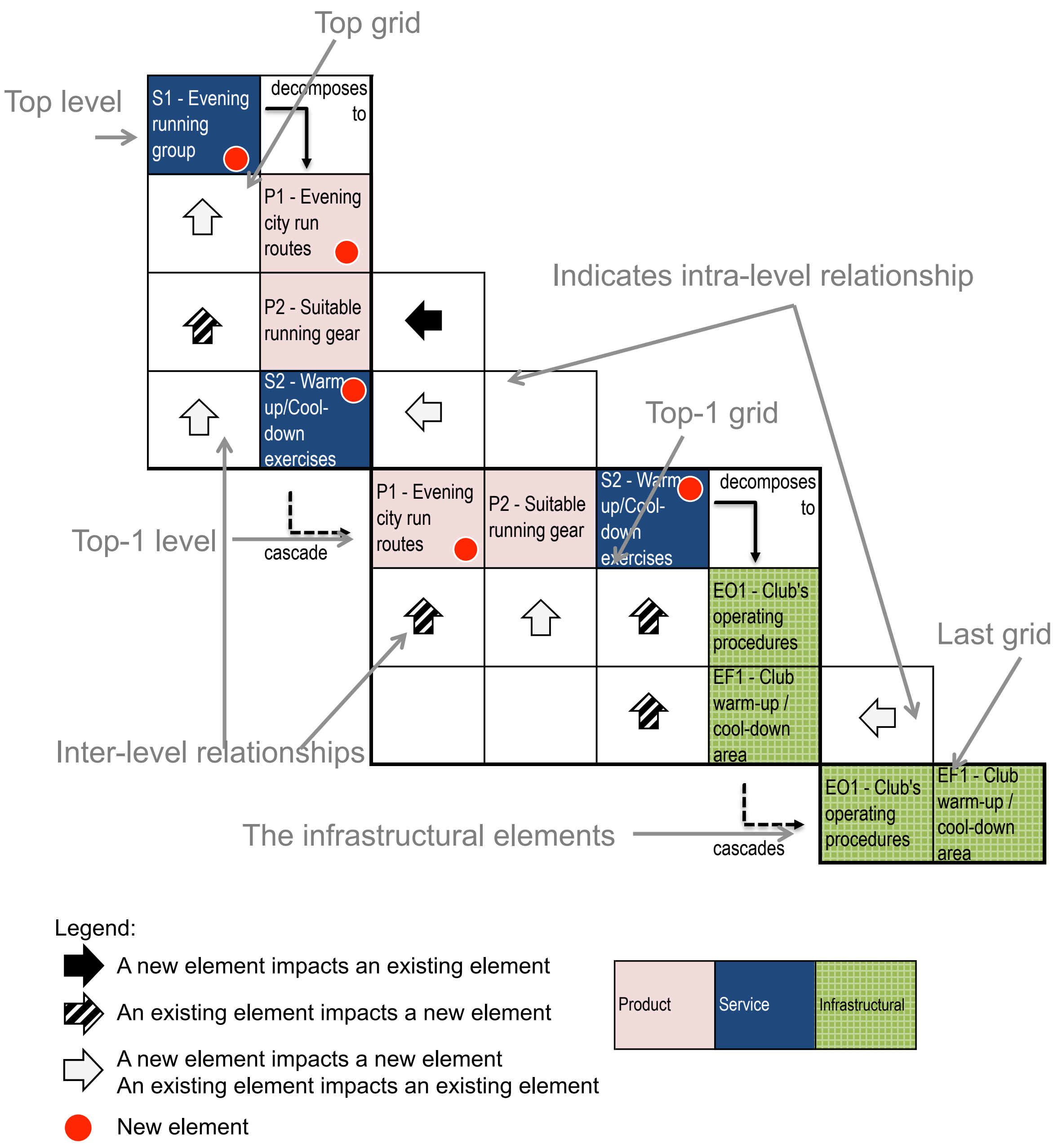


Figure A 18 An example of the PSS decomposition diagram

Appendix 17 PSS characterisation approach - feasibility, usability, utility

Three assessment criteria on the PSS characterisation approach were adapted from the evaluation of manufacturing strategy formation process proposed by Platts (1993): feasibility, usability, and utility. Feasibility concerns the degree to which the process laid out for the workshop participants can be followed. Observations on how well the participants comprehend the process, the types of questions asked during each step, and the level of guidance the facilitator needed to provide to the participants, were made. Usability relates to the ease of following the approach. Observations on whether the facilitator or participants encountered any problem at each stage of the approach, and how each step within the approach could be refined or improved, were noted. Utility focuses on whether the approach achieved its intended benefits for the participants, that is to clarify PSS design specifications.

Comments and observations about the feasibility, usability and utility of the PSS characterisation approach were captured from seven of the nine workshops conducted with manufacturers of the selected PSSs. The two workshops (Workshop O and P) from the "Build" phase of the instrument development process were not included in this summary as the PSS characterisation approach was intended to be used for analysing PSSs in the engineering design process and these two workshops were not real development projects that are in the engineering design process.

Table A 14 shows the data collected for each step of the PSS characterisation approach. Against each comment/observation note, the workshop(s) where the comment/observation was from was noted in brackets, e.g. (T) for workshop T. The workshop reference can be found in Figure 3-3. In the cases where the comment/observation was seen in all workshops, the reference "(All)" was used. In some cases, the exact saying from a participant was quoted against a comment/observation. The audio file of the quote was noted as reference.

Table A 14 Feasibility, usability and utility of the PSS characterisation approach

Assessment criteria	Step 1: PSS depiction	Step 2: PSS abstraction	Step 3: PSS decomposition	Step 4: PSS representation	Step 5: PSS characterisation
Feasibility	• Not easy to follow, mistakes were made (R, T). • Required explanations of what the development was by one participant or there were discussions within the group before this step could begin (V, W). • Required clarifications of the meaning of "operating environment" (Q, R, S, T, V). Once clarified, found this step easy or "make sense" (Q, S [3rd audio 02:01:08], U, V, W). • Required explanations of "system" and "function" (U).	• Found the instructions in the guidance notes easy to follow (T, U). • Were able to proceed after the facilitator asked the participants to decide on the meaning of the size of the shapes representing the product and service within the PSS (Q, R, S, W). • Did not have agreement among all workshop participants with the research's original product definition and required to change the definition to "knowledge" before consensus was reached among the participants and this step could begin (V).	• Needed the facilitator to clarify the instructions in the guidance notes and to explain in a step-by-step manner. The facilitator guided the discussions, at least in the beginning of this step, of the impacts and dependencies among the elements and whether the impacts and dependencies were direct or indirect via other elements (All). • Needed a common/daily-life example (example given was about an oven developed to be sold to a household) before the concept of decomposition was understood (U).	• Found the verbal instructions given by the facilitator easy to follow (Q, S, U, V). • Found the verbal instructions given by the facilitator difficult to follow (W). • Quick to complete: Workshop U's participant built an alternative diagram which needed only 5 minutes without any guidance from the facilitator (U). • Could only follow this step (R, T). • Found this step difficult to follow without a facilitator (V).	• The facilitator needed to take the lead to execute this step with the participants providing feedback (T). • Found the instructions in the guidance notes easy to follow (Q, R, S, U, V, W). • For Workshops U, V and W, the instructions in the guidance notes were first changed to match the arrows' colours of the arrows used in the PSS representation diagram, in order to avoid potential confusions (U, V, W).

Table A 14 ***(continued)***

Assessment criteria	Step 1: PSS depiction	Step 2: PSS abstraction	Step 3: PSS decomposition	Step 4: PSS representation	Step 5: PSS characterisation
Usability	• Needed to use two circles to represent the intercepting constraints that exist in the operating environment (Q). • Found it difficult to draw all the lines in right place to represent the linkages among the functions, systems and stakeholders (R). • Flexible enough to draw multiple PSSs or multiple offerings that belong to one PSS in one diagram (R, S, V). • Did not encounter any problem in this step (S, T, U, V, W).	• Found it challenging in the beginning to accommodate all PSS possibilities in the abstract diagram (R, S). • Needed to use a shape other than a circle or a ring to represent product and service (V). • Did not encounter any problem in this step (Q, S, T, U, W).	• The usage of repositionable notes (sticky-notes) made it very easy for the participants to re-do or modify the diagram during the discussion (All). • Not an intuitive step (Q, S, W). • The facilitator intervened to ask participants to consider breaking down an element into new and existing aspects of that element (T, U). • Had problems understanding what the infrastructural elements were in the context of their PSSs (S). • Found it technically difficult because of the number of dependencies within the PSS (R, S). • Did not have enough knowledge to decompose the PSS into its infrastructural level and the participants had agreed to stop at the lowest level they knew about (V).	• Some elements that showed the same interactions with some other elements were combined to reduce the complexity and the width of the diagram: ○ Some infrastructural elements were combined (R). ○ Some product elements were combined (S, T). • Did not encounter any problem in this step, apart from building an alternative PSS representation diagram for the purpose of comparison (U). • Repeatedly made mistake in the beginning; the participants seemed to be not having the understanding that the PSS representation diagram was the PSS decomposition diagram in a different format, and were placing the elements in a different level from what had been agreed in the previous step (W).	• Did not encounter any problem in this step (Q, S, T, U, V, W), but some workshops had skipped the sub-step to identify PSS configuration type (Q, S). • Able to identify the PSS configuration type very quickly (V, W). • There were mistakes in counting the number of arrows due to the combining of some elements in the PSS representation step, and crosschecking with the PSS decomposition diagram was needed (R, S). • Found it easier to do this step directly from the PSS decomposition diagram instead of the PSS representation diagram as per the instructions in the guidance notes (R).

Table A 14 ***(continued)***

Assessment criteria	Step 1: PSS depiction	Step 2: PSS abstraction	Step 3: PSS decomposition	Step 4: PSS representation	Step 5: PSS characterisation
Utility	• Flexible enough to include more than one new offering in the same diagram (R, V). • Flexible enough to allow multiple target markets to be represented (S, V).	• Represented the company strategy, and was used to communicate the company strategy for new products and services (S). • Represented the results of a debate on the value, focus, timing, and definition of the new development (Q, S, V). • Capable to represent complex PSS (Q, S, W).	• The diagram was not found to be an easy tool to explain to colleagues who did not participate in the workshop (Q, W). • This step was difficult, but once completed, had made the next two steps useful (W). • Was used by a participant to explain to another colleague who was not in the workshop the purpose of the workshop (V). • Very detailed, but found it easy to understand (R, S).	• Found to be the most useful step in the PSS characterisation approach, as it compressed information in a semi-quantitative manner, and allowed direct examination on the relationships among the elements within the PSS (W). • Questioned this step's utility (R). • Found this step complicated and confusing, and therefore not too useful when many elements shared relationships with common elements in adjacent levels (R, S, V). • Colours and patterns of the arrows might have drawn unnecessary attention to one element within the PSS (U).	• Explored relationships among the new and existing elements of the PSS (All). • Explored the relationships among the product and service elements of the PSS (V). • Highlighted the technical specification requirements of the PSS (e.g. The quality of the image resolution required for the new medical diagnostic device) (W). • Did not find this step useful (Q, S, T, V). • Unsure about the validity of the formula used to calculate the 'connectivity number' (Q).