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Abstract: Since the 1970s, marketing and innovation management communities have been investigating how to incorporate customer-desired functions into new product and service designs. These wide-ranging enquiries have shed light on the impact of lead-user engagement in new product development, demonstrated ways to examine service production and delivery, such as the use of 'line of visibility' in service blueprints and the modelling of 'service encounters', and have created new terms such as 'value co-creation'. Despite these efforts, recent reviews have identified the lack of an holistic approach to new product-service system (PSS) development. This deficiency needs to be rectified, especially for complex PSS developments in regulated industries such as healthcare, as often there are multiple stakeholders posing conflicting priorities to the development team.
This paper describes a novel PSS characterisation approach that supports the early-stage new PSS development process. The approach is originated from eleven healthcare case studies, involving twenty-five new products, services and PSSs. Following the methodology of action research, further cases are selected for the application of the approach to a new product, service or PSS concept in facilitated workshops. Initial implications of employing this approach in three cases are discussed in this paper.

***Title Page (WITH Author Identifiers)**

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Vitae

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Characterising product-service systems in the healthcare industry

Abstract

Since the 1970s, marketing and innovation management communities have been investigating how to incorporate customer-desired functions into new product and service designs. These wide-ranging enquiries have shed light on the impact of lead-user engagement in new product development, demonstrated ways to examine service production and delivery, such as the use of 'line of visibility' in service blueprints and the modelling of 'service encounters', and have created new terms such as 'value co-creation'. Despite these efforts, recent reviews have identified the lack of an holistic approach to new product-service system (PSS) development. This deficiency needs to be rectified, especially for complex PSS developments in regulated industries such as healthcare, as often there are multiple stakeholders posing conflicting priorities to the development team.

This paper describes a novel PSS characterisation approach that supports the early-stage new PSS development process. The approach is originated from eleven healthcare case studies, involving twenty-five new products, services and PSSs. Following the methodology of action research, further cases are selected for the application of the approach to a new product, service or PSS concept in facilitated workshops. Initial implications of employing this approach in three cases are discussed in this paper.

Keywords: Product-service system, healthcare, characteristic, design, development

1 INTRODUCTION

The aging population is an unprecedented, enduring, and pervasive global phenomenon, affecting economic, social, and political aspects of life [1]. On the one hand, the healthcare industry is facing a growing demand for new medical technologies from healthcare service providers. On the other hand, there is a trend that governments are reducing their health spend [2]. There have also been studies and debates about preventive care as a potential remedy, and how preventive care can be implemented at a national level through policy and

technology [e.g. 3,4,5]. Healthcare equipment manufacturers and service providers may be able to help by developing and delivering suitable products and services that are valued by customers. In this paper, 'healthcare' industry refers to the healthcare equipment, device and software, healthcare professional services, and physical and mental fitness services, while 'companies' refers to both manufacturers and service providers.

The healthcare industry involves multiple stakeholders who regularly have conflicting interests. Companies often have to innovate in a constrained environment: governed by multiple regulations, laws, and quality standards, and impacted or confined by existing infrastructure and established work procedures of the customer or end-user environment. Given the increased interest in healthcare service effectiveness, how healthcare companies develop new products and services is an important area for investigation, especially at the early stage of the development process where a large proportion of the product-service system (PSS) life-cycle cost is not yet committed [6].

Set against this context, this research is being undertaken to explore how healthcare PSSs can be characterised with the contextual factors in mind, for the early stage of the new PSS development (NPSSD) process. Furthermore, the impact of this characterisation on the definition of the new PSS is explored.

This paper describes the PSS characterisation approach that is a new tool developed with industry practitioners to support the early-stage new PSS development process. Its application to three healthcare PSSs, and the implications on the NPSSD and PSS definitions, are also discussed. A brief overview of the methodology is presented in Section 2, which is then followed by a literature review in Section 3. Section 4 describes the PSS characterisation approach, and Section 5 gives a description of the setting of the workshops for applying the PSS characterisation approach. Section 6 discusses the findings, Section 7 concludes the paper, and Section 8 discusses the limitations of the findings.

2 RESEARCH METHODOLOGY

This research intends to contribute novel theories in PSS characterisation for the early stage of the NPSSD process. There are two phases in this research: the first explores how to characterise PSS in a way that is useful

for the early stage of the NPSSD process; the second builds a repeatable process to characterise PSS and explore the implications of the method on the PSS definition.

In the first phase, a case study research methodology has been selected. The unit of analysis is a new product, service, or PSS under development. The reasons for selecting a multiple-case/single unit of analysis design [7] are: (1) building theory from cases is more likely to generate a testable and empirically valid novel theory [8]; (2) the boundary of the phenomenon of interest, the internal and contextual factors of a PSS when it is in-use and how these factors impact a new PSS definition, is unclear [7].

A conceptual framework with potential variables developed from literature review has been revised after pilot interviews involving 14 stakeholder groups. The use of *potential* variables minimises bias and limitations from prior theoretical perspectives [8]. Data collection and analysis are designed to be overlapping to allow changes of data collection instrument if found to be necessary upon reflection [8]. The degrees of data and process connectivity have emerged as the case selection criteria upon preliminary data analysis. Eleven cases involving 25 commercial offerings have been completed. Four variables have been identified to be useful to characterise PSS for NPSSD, forming the novel PSS characterisation scheme. From the data analysis of the first phase, a systematic approach to apply this novel PSS characterisation scheme has been developed.

In the second phase, action research [9] has been selected as the method to build, test and refine the PSS characterisation approach to support the early stage of the NPSSD process. Action research was selected because it develops knowledge through application, collaborating with practitioners (company employees) who have a personal interest in the result [10]. New PSS ideas or concepts are the subject of analysis for the PSS characterisation approach, using a facilitated workshop approach with selected new PSS development team members from the participating companies. Both healthcare and non-healthcare new PSS ideas have been targeted to investigate how the approach works in different contexts. The workshops have been facilitated by the same researcher for consistency [11], until the PSS characterisation approach has reached a stabilised form. The number of workshops was not fixed in advance, as the objective was to reach procedural stability [12]. To ensure validity of the findings from the workshops, the research process of preparing and conducting the workshops, the setting of the workshops, the context of the participating companies and individuals, and the assumptions about the participants and the facilitator were documented [11,13].

Three assessment criteria on the PSS characterisation approach have been adapted from the evaluation of manufacturing strategy formation process proposed by Platts [9]: feasibility, usability and utility. 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. The implications of the PSS characterisation approach on the PSS definition result directly from the reflection on the discussions regarding utility.

To minimise the possible adverse impact of the newly developed PSS characterisation approach on a NPSSD project, the first workshop analysed an existing PSS that has been launched within the last two years, instead of a new to-be-developed PSS. Three cases in the healthcare industry, including the initial post-launch case, are discussed in this paper.

3 LITERATURE REVIEW

This section is divided into three sub-sections. The first summarises a review of the existing literature on the definitions and classifications for product, service, and PSS, which has led to a realisation that existing PSS classifications are not complete or useful for new PSS development. The second sub-section summarises a review of engineering design theories that provides the theoretical foundation for new product development (NPD), new service development (NSD) and new PSS development (NPSSD) process models. This sub-section shows the need of an holistic approach to new PSS development. To explore the contextual factors that are potentially significant for NPSSD, a literature review covering actor-network theory and value-in-use is summarised in the third sub-section.

3.1 PRODUCT, SERVICE, AND PRODUCT-SERVICE SYSTEM

The economics and marketing communities have provided a number of definitions and classifications for products and services. In fact, some commonly quoted characteristics of products and services have their origins in concepts proposed by Adam Smith and Jean-Baptiste Say in the 18th century, Nassau Senior in the 19th

century and Joan Robinson in the 20th century [14–16]. Since the 1960s, a common perspective adopted by scholars is that products are tangible, and services are intangible, heterogeneous, inseparable, and perishable [17]. Another perspective to separate services from products is that a product is a tradable object [18], while a service is an act performed [19–21] to change the state of objects and/or people [21–24].

Tangibility has been a useful characteristic for the marketing community, as it allows product classifications such as: durable / nondurable, industrialised / customised, and differentiated / commoditised to be developed and applied [25,26]. More than 30 service classifications have been proposed since the 1960s [27]. Some examples are: whether the service provision involves a product and who owns the product [20,28]; whether the service impacts people or objects [18,23]; and whether the impact created by the service is temporary / permanent, reversible / irreversible [22], or tangible / intangible [23]. With the advancement of digital technology, the use of tangibility as a demarcation of products and services has created confusion. For example, is a digital sound track that one can buy online, which is intangible, a product or service? More recently, Vargo and Lusch have defined a service as "the application of specialised competences (knowledge and skills) through deeds, processes, and performances for the benefit of another entity or the entity itself" [29]. This broad concept is not dissimilar to Levitt's viewpoint that a product is "a tool to solve [customers'] problems" [30].

As a result, the definition proposed by Hill [18] is considered to be more suitable and is adopted for this research. Hill's proposal is that a product "exists independently of its owner and preserves its identity through time" [18]; and a service cannot be stocked without losing its identity and requires both producer and consumer, and hence is constrained by time and location [18].

PSS is a more recently defined terminology. Baines et al. [19] suggest that PSS was first formally defined in 1999 by Goedkoop, van Halen, te Riele and Rommens [31] as "a marketable set of products and services capable of jointly fulfilling a user's need". However, the idea of customers buying bundles of products and services was proposed 30 years earlier by Levitt [25]. The concept of a product-service continuum was also proposed in the 1970s [21]. More recently, [19] added to the definitions that a PSS offers "the opportunity to decouple economic success from material consumption".

In terms of PSS classification schemes, there are three frequently used classifications in the reviewed PSS literature: product-oriented, use-oriented and result-oriented PSS. These were first proposed by Hockerts and

Weaver in 2002 [cited in 32], and were later extended to include integration-oriented and service-oriented [19]. From the examples given to illustrate the proposed classification of PSS, it appears that authors such as Goedkoop, van Halen, te Reile and Rommens [31], Mont [33] and Neely [32], have built their proposed classification schemes upon the previously discussed condition of 'tangibility' [34]. Moreover, there seems to be a concern with the ownership of the product, which may be of more importance to decisions pertaining to business strategy and business model, rather than for NPSSD at an operational level. Table 1 uses the PSS classifications proposed by Neely in 2009 [32] to illustrate where intangible products may be confused with services, and why the classification scheme is not useful for NPSSD.

TABLE 1: DISCUSSION ON NEELY'S [32] PSS CLASSIFICATION

Insert Table 1.

3.2 THEORIES AND PROCESS MODELS FOR THE EARLY-STAGE NEW DEVELOPMENT PROCESS

The early stage of the new development process can be mapped to the engineering design process. The NPD and NSD processes usually begin with idea generation and business assessment, continue with conceptual and detailed design and development, and end with testing and commercialisation [35–38]. The beginning portion of the new development process contains activities in the engineering design process. They are (1) classification of the task; (2) conceptual design; (3) embodiment design; and (4) detailed design [39–45]. Therefore, theories of engineering design are first reviewed in this sub-section.

Engineering design theories can be classified by whether they focus on the design process or artefact, and/or whether the theories are prescriptive or descriptive [e.g. 39,45]. The assumption behind prescriptive process theories is that the designer would be able to arrive at a better design if he or she follows the process [39]. Prescriptive artefact theories, on the other hand, assume that universal methods exist to produce the final artefact

specifications from a set of reasonably complete functional specifications [45]. The prescriptive engineering design theory has provided a relevant theoretical foundation for NPSSD process models. In particular, a group of theories that considers the engineering design process as one of systematic transformation, such as the VDI 2222 guidelines (1973, 1993) provided by the Association of German Engineers (VDI) [46], the systematic approach proposed by Pahl and Beitz (1977) [43], and the theories of technical systems proposed by Hubka & Eder (1988) [47], are found to be relevant to this research. Hubka and Eder proposed that *"engineering design is a process …which information in the form of requirements is converted into information in the form of descriptions of technical systems..."* [48], and had applied the theory to the engineering design for mechanical systems. However, this theory may potentially be extended to engineering design tools that convert user requirements into design specifications.

The investigation of NPD/NSD has been a popular research area since the 1950s. The findings that successful new product introductions were infrequent and that most failures are preventable [35], drew the attention of business managers and researchers in the 1960s and 1970s. Having a standard process has been suggested to be a remedy. Booz, Allen, and Hamilton proposed a NPD model in the 1960s – in its revised format, the 7-step model [35] 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. NSD is often seen as more ad hoc than NPD [20,49] because of the service characteristics [49]. While some of the proposed NSD models resemble Booz, Allen, and Hamilton's NPD model [e.g. 50], other models consider the process of producing, delivering, and receiving services [e.g. 15,20,24]. Many new PSS development process models proposals in the 2000s are built upon the earlier NPD and NSD models. As observed by Maussang, Zwoliski, and Brissaud [51], many approaches have a product-focus [e.g. 52,53] or a service-focus [e.g. 15,20]. Otherwise, the models are either at a business strategy level [e.g. 54,55], or lack an holistic approach [e.g. 56]. One exception is the proposal by Maussang, Zwoliski & Brissaud [51], which tackles the product and service design holistically, including technical details.

3.3 CONTEXTUAL FACTORS

The external environment is an important aspect in the design of a new offering, as it influences the product design, the customer experience [15,51,57], the interests and concerns of stakeholder in society [58], and the social and ethical priorities for the design [59]. The urge for companies to focus on customer value has been promoted through the introduction of the Service-Dominant Logic (S-D logic) by Vargo & Lusch [29]. The concept of the business ecosystem boundary can also help to describe the requirements on stakeholders of the new PSS to be developed.

One of the ten foundational premises (FP9[1]) of S-D logic has also proposed that all social and economic actors are resource integrators, which implies that the context of value creation is network of networks [60]. This S-D logic proposition has some similarities to the actor-network approach in sociology that encourages researchers to look at the social effects of the agents and devices if they want to answer the "how" questions about structure and organisation [61]. According to Law [61], an organisation is an achievement, a process, a consequence, and a precarious effect. Applying this rationale to a new PSS, a new PSS can be understood as a precarious effect of human and non-human actors [62] that belong to different levels in a business ecosystem. Therefore, the actor-network theory provides a sound theoretical basis to allow the connections among actors to be brought out and examined, through "flattening" levels and putting actors from different levels side by side [62].

In terms of fulfilling customer needs and experience, customer-focus in service design has been an on-going theme in the field of management [e.g. 63,64,65]. However, S-D logic has stimulated discussions on how to deliver value-in-use, and what companies need to provide to assist value co-creation with customers [16]. Within this literature, roles in value creation are clarified: companies can offer values propositions and only customers can specify what value is [29,60]. Value is also described as "idiosyncratic, experiential, contextual, and meaning laden" [60]. Outcome-based contracting, such as Rolls Royce's 'Power-by-the-hour®', has also been proposed to measure value-in-use [66].

The business ecosystem, actor-network theory and value-in-use literature has provided insights in potential PSS classification dimensions for NPSSD.

[1] FP 9 referred to the ninth "foundational premise" proposed by Vargo and Lusch in 2008 [60]

4 THE PSS CHARACTERISATION APPROACH

The PSS characterisation approach is a new way to characterise a PSS systematically in terms of four parameters. It provides greater clarity for specifying the PSS to-be-developed. Identifying characteristics that can clarify PSS specification is a step towards identifying a PSS classification scheme for NPSSD. The PSS characterisation approach is originated on the basis of 11 case studies involving 25 commercial offerings in the healthcare industry, and is built and refined with industry participants who were engaged in new PSS development projects. The prerequisite of the approach is clarity of the company's strategy on new products and services. Depending on the level of awareness the company has about the stakeholders of the PSS of interest, the approach may or may not include Step 0 – Stakeholder Identification. With the company's new product and service strategy and a list of potential stakeholders, the company can choose one or more new product / service / PSS ideas that are in the early stage of the development process for characterisation. The 'early stage' of the development process is explained to the company as the activities that come after the company's strategy formation and before detail and/or technical development begins. Fig. 1 shows the high level PSS characterisation approach.

Insert Fig. 1.

Fig. 1: The PSS Characterisation Approach (source: authors)

Two questions that the company needs to clarify before Step 1 are:

- What problem(s) the company is attempting to tackle with this new PSS
- What values the new PSS aims to bring to the company's customers and their customers' customers

4.1 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) 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

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. Fig. 2 shows an example of a PSS depiction and its elements identification table.

Insert Fig. 2.

Fig. 2: PSS Depiction Diagram and Elements Identification Table

4.2 STEP 2: PSS ABSTRACTION

PSS abstraction aims to produce an abstract diagram that represents what the focus of the new development(s) is/are about. It fosters discussions within the development team on a number of topics: what the main PSS development is and what is supplementary; 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 stakeholders on what the NPSSD project is about. 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

Potential meanings include relative value to customers, physical interactions between product and service, dependencies between product and service, and relative development cost and effort.

Basic shapes to use in the PSS abstract diagram are (see Fig. 3):

- Rectangle to represent the operating environment
- Dotted line circle to represent the PSS
- Pink and blue (light and dark grey) circles/rings to represent product and elements respectively

Insert Fig. 3

Fig. 3: PSS Abstraction - some examples of PSS abstract diagrams

4.3 STEP 3: PSS DECOMPOSITION

PSS decomposition involves progressively building a series of grids during the analysis of the constituent parts of the PSS. This step decomposes the element(s) that potentially provide(s) the ultimate customer value, to infrastructural elements that the PSS is built upon. The decomposition diagram requires the relationships among the identified elements to be identified and exhibited. The element that potentially provides the ultimate customer value may be part of the new PSS to be analysed, or an existing commercial offering that the company has. The concept and design of PSS decomposition is inspired by quality function deployment (QFD), a technique for developing a solution that translates customer demands into design targets and quality assurance points throughout the production process [67].

The product and service elements identified in Step 1 are captured on sticky notes. Each product element is captured on a pink note (light grey in Fig. 4 and 5 if printed in black and white). Each service element is captured on a blue sticky note (dark grey in Fig. 4 and 5 if printed in black and white). A red (grey if printed in black and white) dot is put on each sticky note of a new element to be developed.

As illustrated in Fig. 4, the first grid (labelled 'Top grid') in a PSS decomposition process contains the elements that intend to provide the ultimate customer value in the top/horizontal row (labelled 'Top level'). When 'Top level' elements are in operation or in use, they interact directly with some other elements. These elements are listed vertically ('Top-1 level'), forming the right-hand side of the top grid. The 'Top-1 level' elements then cascade down to form the top row of the second grid ('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'. Once again (see Fig. 5), these vertically listed elements in the 'Top-2 level' are cascaded down to form the top row of the third grid ('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 as the 'Last grid'. Infrastructural elements are facilities and operations for which the company can assume existence, or have no business interest in developing. Examples of infrastructural elements are floor and operations of the building that the new products will be used in and/or the new services will take place. Green sticky notes are used for capturing infrastructural elements (appearing as strips on light grey in Fig. 4 and 5 when printed in black and white).

After forming the series of grids, the relationships among the elements within the grids are to be identified. The 'squares' inside each grid in the PSS decomposition are used to denote the relationships between the elements in adjacent levels (inter-level relationships). Elements from the same level can also interact with each other. These are the intra-level relationships, and are captured in the external 'squares' between two adjacent grids (see Fig. 4 and 5). Relationships are represented by an 'X' inside the grids or on the outside between two adjacent grids. A relationship means one element directly impacts another element, or is dependent on another element.

Insert Fig. 4.

Fig. 4: PSS Decomposition – building the grids (Part 1)

Insert Fig. 5.

Fig. 5: PSS Decomposition – building the grids (Part 2)

After all the relationships are 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 towards element B. If element A's functionality is dependent on element B, an arrow is placed pointing towards element A. Where element A and B impact each other, then two arrows are placed between them in opposite directions. Fig. 6 illustrates the concept.

Insert Fig. 6.

Fig. 6: Identifying the impact directions

After the direction(s) of impact is/are identified for each relationship, the relationships between existing and new elements are further highlighted. If a new element impacts an existing element, the relationship arrow in between them is coloured black. If a new element is impacted by an existing element, the relationship arrow is striped. The arrows for relationships between two new or two existing elements are left white. Fig. 7 illustrates the concept.

Insert Fig. 7.

Fig. 7: Visualising the nature of the relationship between elements

4.4 STEP 4: PSS REPRESENTATION

PSS representation involves developing a structured-diagram (see Fig. 8) to represent the elements and the relationships identified in 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. This design is inspired by the organ structure proposed by Hubka & Eder [47], which shows the connections among sub-systems and components within the technical system, as well as the connections between the technical system and its operating environment. 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 shape of the diagram is impacted by the number of elements that have multiple relationships with different elements. 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.

The outer rim of the PSS representation (shaded area) represents the intended operating environment of the PSS. The dotted line represents the boundary of the PSS and the area within the PSS operating environment. The infrastructural elements are the base of the PSS representation diagram. 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. Fig. 8 gives an example of a PSS representation diagram.

Insert Fig. 8.

Fig. 8: PSS Representation Diagram

4.5 STEP 5: PSS CHARACTERISATION

The PSS characterisation step determines the ‘value’ of the four PSS characteristics: (1) the potential customer perceived value level; (2) the type and degree of connectivity; (3) the connectivity number of the PSS; and (4) the PSS configuration type.

4.5.1 Potential customer perceived value level

The perceived potential customer value level is represented by the height, or the number of levels, of the PSS representation diagram. The infrastructural level in the PSS representation diagram is level 0.

4.5.2 Type and degree of connectivity

To determine the type and degree of connectivity, the numbers of black and striped arrows within a PSS representation are counted. Moreover, the number of arrows going into a product sticky note and the number of arrows going into a service sticky note are counted separately. The degree of connectivity associated with product elements is called physical/data connectivity, because they can be either touching each other physically or intangibly at a data exchange level. The degree of connectivity associated with service elements is called process connectivity, because service involves activities that change the state of people and/or objects [21–24]. Each type of connectivity can be assessed in terms of three degrees: incorporated, linked, or independent. Table 2 explains how to determine the degree of connectivity.

TABLE 2: DETERMINING THE DEGREE OF CONNECTIVITY

Insert Table 2.

4.5.3 Connectivity number

The formula proposed to calculate the connectivity number is:

Connectivity number = 2 x (total number of black arrows) + total number of striped arrows

The argument behind multiplying the number of black arrows by two is that more attention in the design specification is required if the new PSS impacts the existing systems in the operating environment. If there are no black or striped arrows in the PSS representation, it implies no connectivity between the new and existing elements within the intended operating environment is expected, and the connectivity number is zero. If the new PSS heavily impacts or is dependent on the existing systems within the intended operating environment, a very high connectivity number will result. The proposition is that the higher the connectivity number, the higher the number of constraints there are, and more attention is required for the new development. The connectivity number can hence be viewed as an expression of complexity of the development.

4.5.4 PSS configuration type

Five PSS configuration types (A, B, C, D, E), each divided into two sub-types, are also proposed as one of the PSS characteristics. Fig. 9 shows the ten configuration types and Table 3 highlights their differentiating features.

Insert Fig. 9.

Fig. 9: The Proposed PSS Configuration Types

Insert Table 3.

Fig. 10 is an example of how the four PSS characteristics are calculated and concluded from a PSS representation diagram.

Insert Fig. 10.

Fig. 10: An example of how to determine the four PSS characteristics

5 THE SETTING OF THE WORKSHOPS

The PSS characterisation approach has been developed and tested in facilitated workshops with industry participants. Drawing on this experience, a number of requirements for the setting of each workshop have been identified as important for success:

- The workshop participants should be selected for their knowledge and experience, and their current or expected participation in the new PSS development:
    - One or more participants must have market knowledge and technical development / engineering knowledge.
    - Other participants can be from functions such as quality assurance, service delivery, manufacturing, or distribution.
- The number of participants should be kept below six for more effective facilitation.
- There should be at least one pre-workshop meeting with the key participant(s) to understand the company and the development team's expectation from the workshop, to agree the duration of the workshop, and for the facilitator to brief the key participant(s) on the purpose and potential outcomes of the workshop.
- The participants may need to do some work before the workshop. Depending on the requirements of the participating company, pre-work can include one or more of the followings:
    - Clarify, align understanding, or to confirm the company's new product and service strategy
    - Make a shortlist of the new PSS ideas to be analysed

    - Think about what the problem is that the new PSS is intended to solve, and who the customers and customers' customers are for the new PSS
    - Identify key stakeholders for the new PSS
    - Read through the guidance notes on the PSS characterisation approach
- The facilitator should bring all necessary workshop materials to the workshop venue.
- The facilitator should distribute a standard feedback collection form to each participant after the workshop.
- The workshop should be audio-recorded for data analysis purpose.
- Where the participating companies require, non-disclosure agreements should be signed before the workshop.

Table 4 provides the background information of the three workshops from which the findings are discussed in the following section.

Insert Table 4.

Table 5 describes the new PSS that is analysed in each workshop and the objectives of the workshops as agreed with the participants.

Insert Table 5.

As seen in Table 4 and 5, the three workshops were very different in terms of company background, the product and service content and their dependencies within the PSS. The diversity of these three cases has provided rich data for exploring the implications of the PSS characterisation approach on the PSS definition, and the applicability of the approach in different contexts.

6 FINDINGS AND DISCUSSION

The findings are presented and discussed in two sub-sections: implications of applying the PSS characterisation approach on the PSS definition, and the applicability of the PSS characterisation approach in supporting the early stage of the NPSSD process.

6.1 IMPLICATIONS ON PSS DEFINITION

In all three workshops, additional understanding and insight on the new PSS was reported by participating organisations as a result of the PSS characterisation workshop. Table 6 summarises the implications in the PSS definition in terms of five perspectives: customer value, environmental impact, product and service content, strategy for NPSSD, and the process for NPSSD. The source of each implication is indicated in brackets in Table 6 by the short name of the workshop(s) (see Table 5).

Insert Table 6.

6.2 APPLICABILITY OF THE APPROACH AND ITS CONTRIBUTION

Apart from exploring the implications of PSS definitions, another aim of testing the PSS characterisation approach in the format of facilitated workshops is to determine whether the approach provides a practical and repeatable way of characterising PSS to support the early stage of the NPSSD process [9]. As explained in Section 2, the feasibility, usability, and utility of the approach are assessed. This is summarised in Table 7, with the source of each finding indicated in brackets by the short name of the workshop(s) (see Table 5).

Insert Table 7.

To summarise, in terms of feasibility, only the stakeholder identification step and the PSS abstraction step could possibly be completed without a trained facilitator; the other steps would need a trained facilitator. In terms of usability, although the approach has found to be in need of further refinement, it is robust enough to be applied in the different scenarios.

The PSS characterisation approach is essentially a tool that supports the transformation of information from user requirements of a new PSS to design specifications. It also displays the properties of a technical system as defined by Hubka & Eder [47] and therefore contributes to extend the theory of technical systems from mechanical systems to tools supporting NPSSD.

7 CONCLUSION

This paper has presented a novel approach, the PSS characterisation approach, which was developed on the basis of 11 case studies involving 25 new products, services, and PSSs in the healthcare industry. Four characteristics are proposed to usefully characterise PSS for the early stage of the NPSSD: (1) the perceived potential customer value level, (2) the type and degree of connectivity, (3) the connectivity number, and (4) the

PSS configuration type. This way of characterising PSS is different from the existing PSS classification schemes, and therefore potentially contributes to the classification of PSS in the marketing and innovation management communities.

The proposed PSS characterisation approach allows the four PSS characteristics to be obtained in a systematic and repeatable manner. The feasibility, usability and utility of the approach as a tool to support the early stage of the NPSSD are discussed in this paper. This approach contributes to the process model discussions in NPD, NSD, and NPSSD, extends the application of the theory of technical systems to tools supporting the engineering design process for PSS, and also to the study of innovation using an actor-network-like approach.

Initial implications of the PSS characterisation approach are also reported in this paper. The implications are grouped into five perspectives: customer value, environmental impact, product and service content, strategy for NPSSD, process for NPSSD. In summary, the overall approach is found to be capable of informing the company's NPSSD strategy in terms of the complexity of each potential new PSS idea, and where to focus in the NPSSD process. The participants in the workshops have found the approach helpful in elucidating and visualising which part of the PSS is of higher potential customer value. The participants have also realised how the new PSS will interact with the operating environment, including the key stakeholders in the environment. The approach has also enabled the participants to detect whether there is a particular product or service element that is a key building block of the PSS.

8 LIMITATIONS

The PSS characteristics proposed in this paper are generated from healthcare cases, and may be limited to NPSSD in the healthcare industry only. Moreover, the assessment of the PSS characterisation approach and its implications of PSS definition presented are limited by the fact that only three workshop results are included in this paper. Furthermore, as action research is used as the methodology to test the approach, the feasibility of the approach is influenced by the facilitation skills of the researcher who performed the facilitation. The interpretation of the workshop findings is biased by the researcher's culture, background, and knowledge of the PSSs in discussion.

As the next step of this research, more workshops targeting new PSS ideas in both healthcare and non-healthcare industries are to be performed to further test and refine the approach, and to explore the implications of the approach for PSS definition. To minimise the influence of the facilitator on the application of the approach, other trained facilitators can be used in the future. An independent observer will also be introduced in future workshops to enrich the assessment of the approach.

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Figure 1
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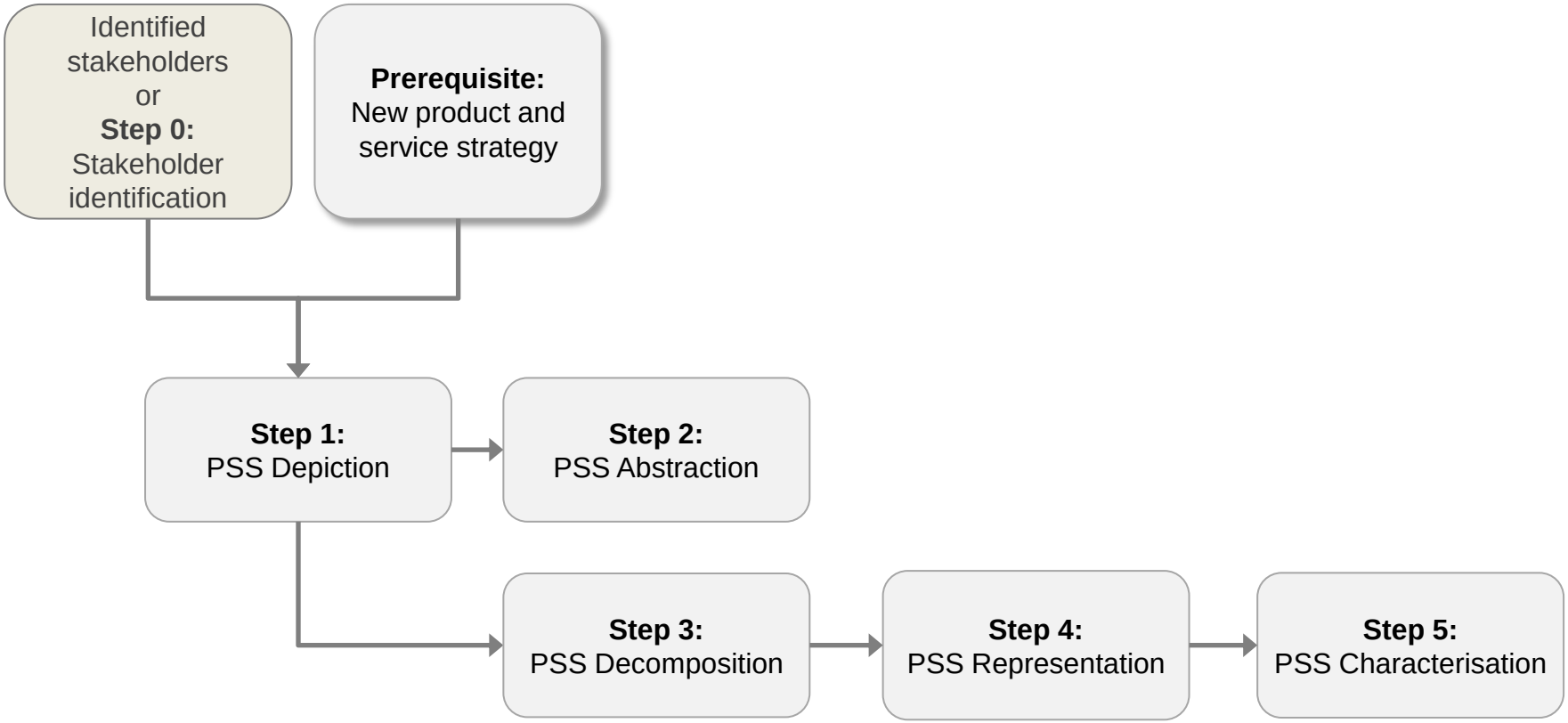

Fig. 1: The PSS Characterisation Approach (source: authors)

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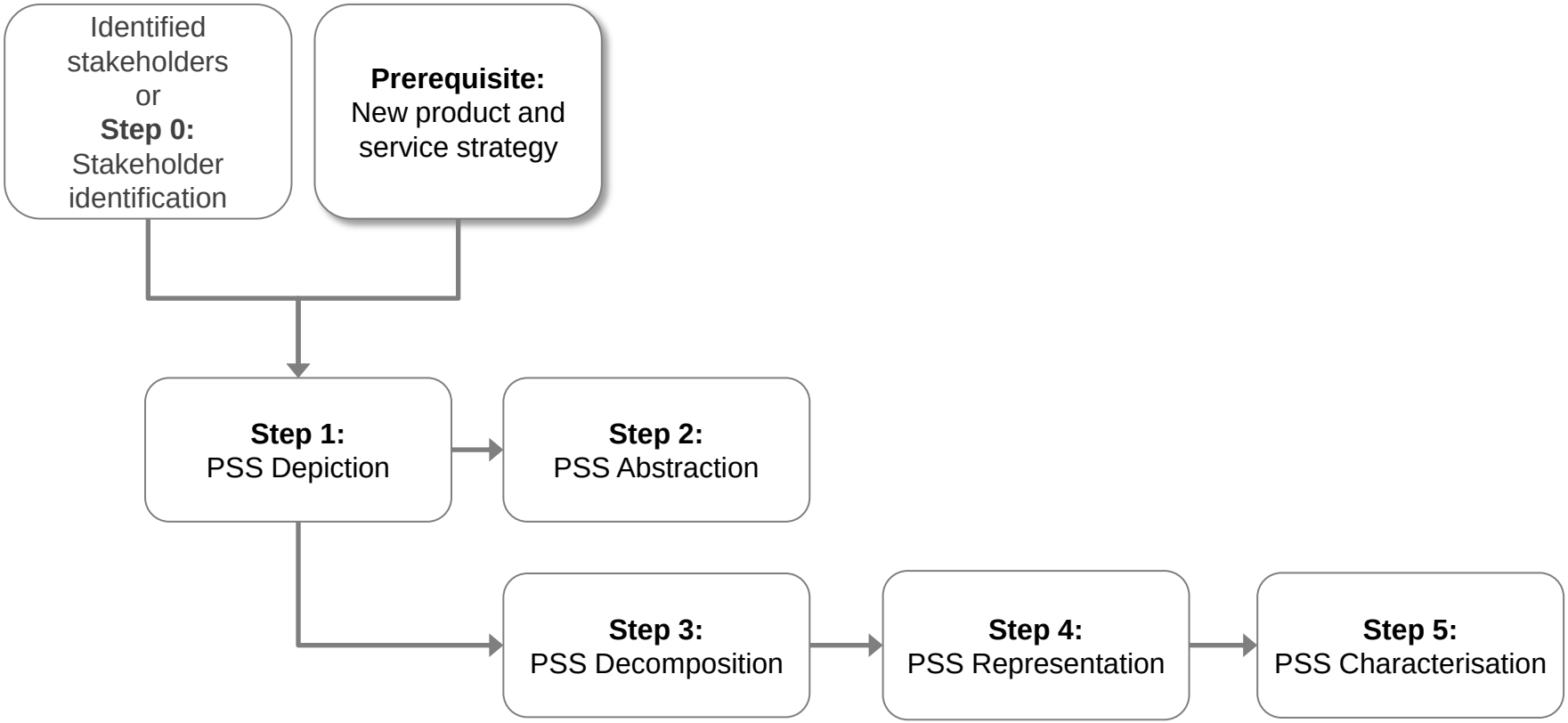

Fig. 1: The PSS Characterisation Approach (source: authors)

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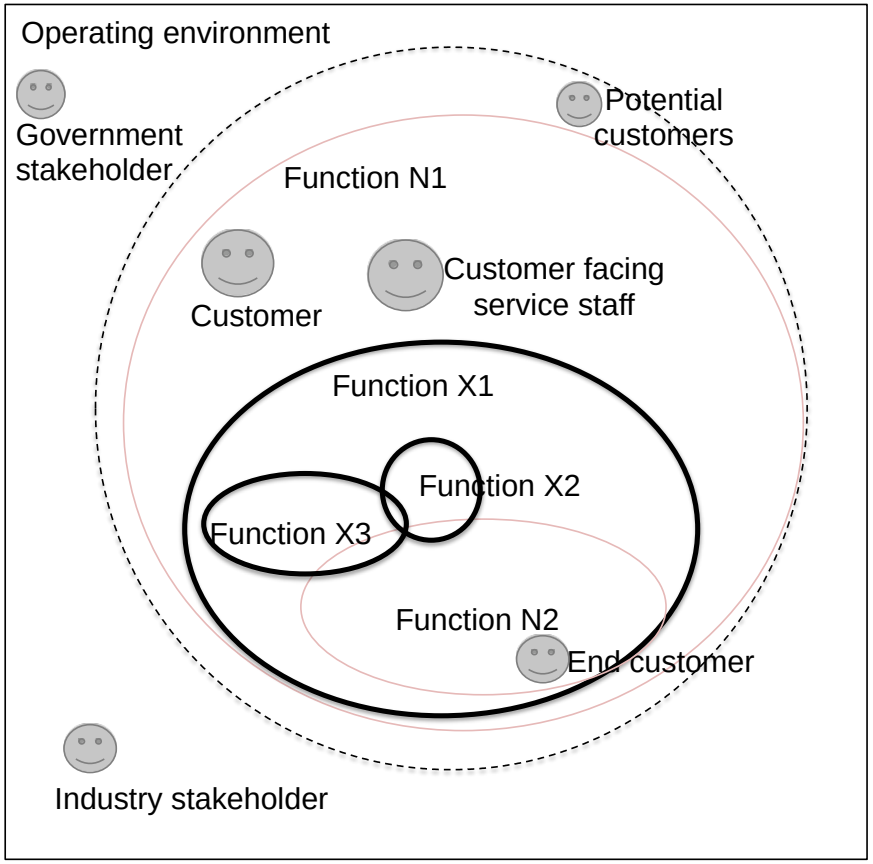

New Functions	Elements for delivering the functions	New (N) or Existing (X)	Product (P) or Service (S)
Function N1	Software X	X	P
	Hardware Y	X	P
Function N2	Site survey	N	S
	Installation	X	S
	Configuration	N	S
	E-Learning module	N	P

Legend:

Operating environment of new PSS
Existing functions to be offered
Key stakeholders
Boundary of the PSS
New functions to be offered

Fig. 2: PSS Depiction Diagram and Elements Identification Table

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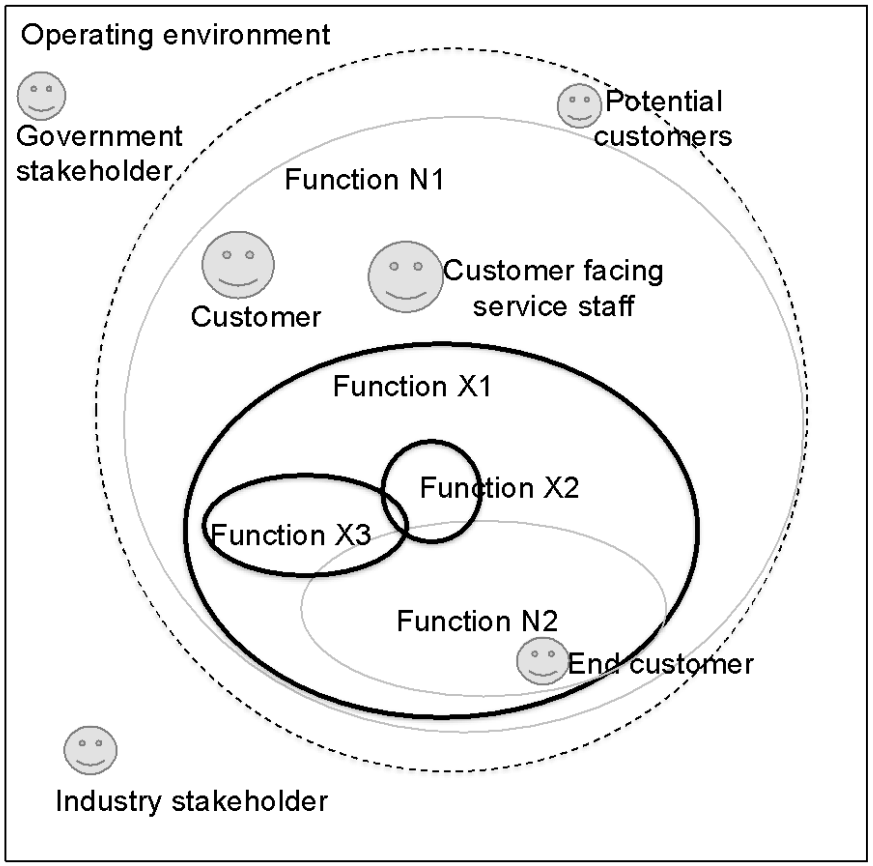

New Functions	Elements for delivering the functions	New (N) or Existing (X)	Product (P) or Service (S)
Function N1	Software X	X	P
	Hardware Y	X	P
Function N2	Site survey	N	S
	Installation	X	S
	Configuration	N	S
	E-Learning module	N	P

Legend:

Operating environment of new PSS

Existing functions to be offered

Key stakeholders

Boundary of the PSS

New functions to be offered

Fig. 2: PSS Depiction Diagram and Elements Identification Table

Figure 3
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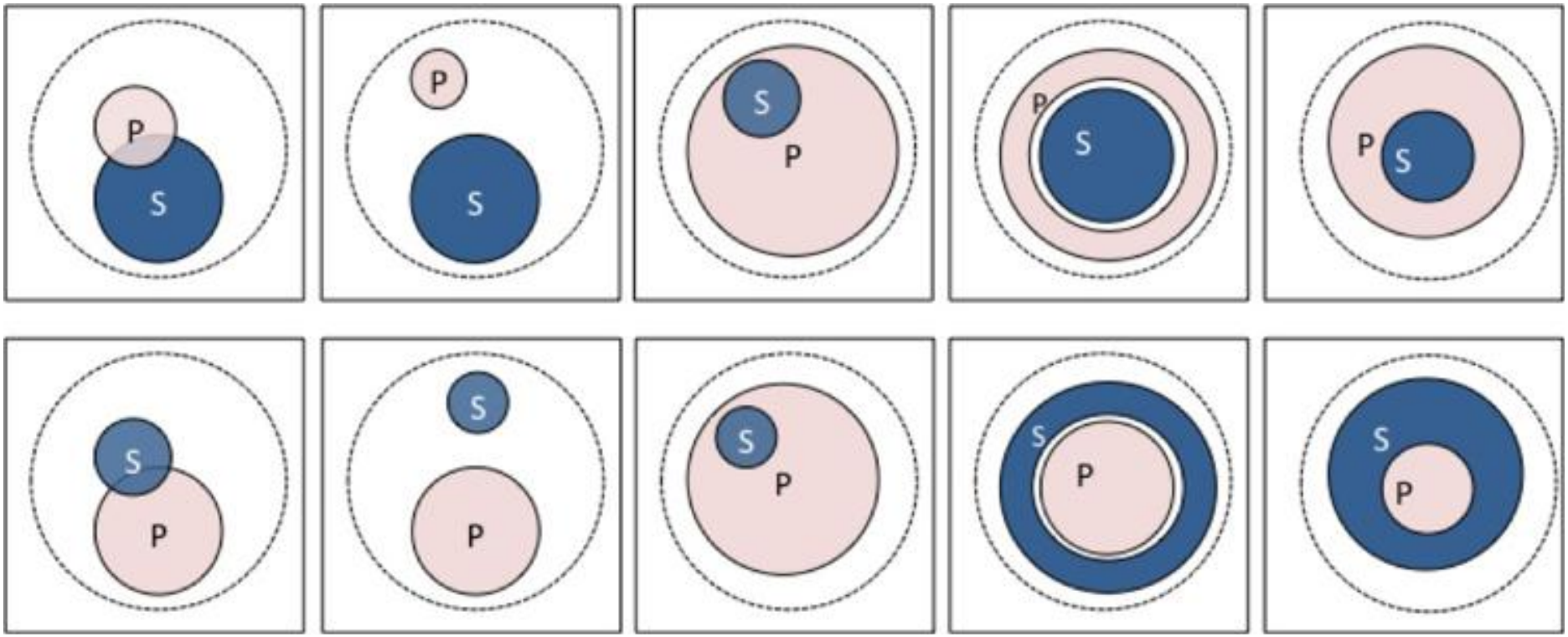

Fig. 3: PSS Abstraction - some examples of PSS abstract diagrams

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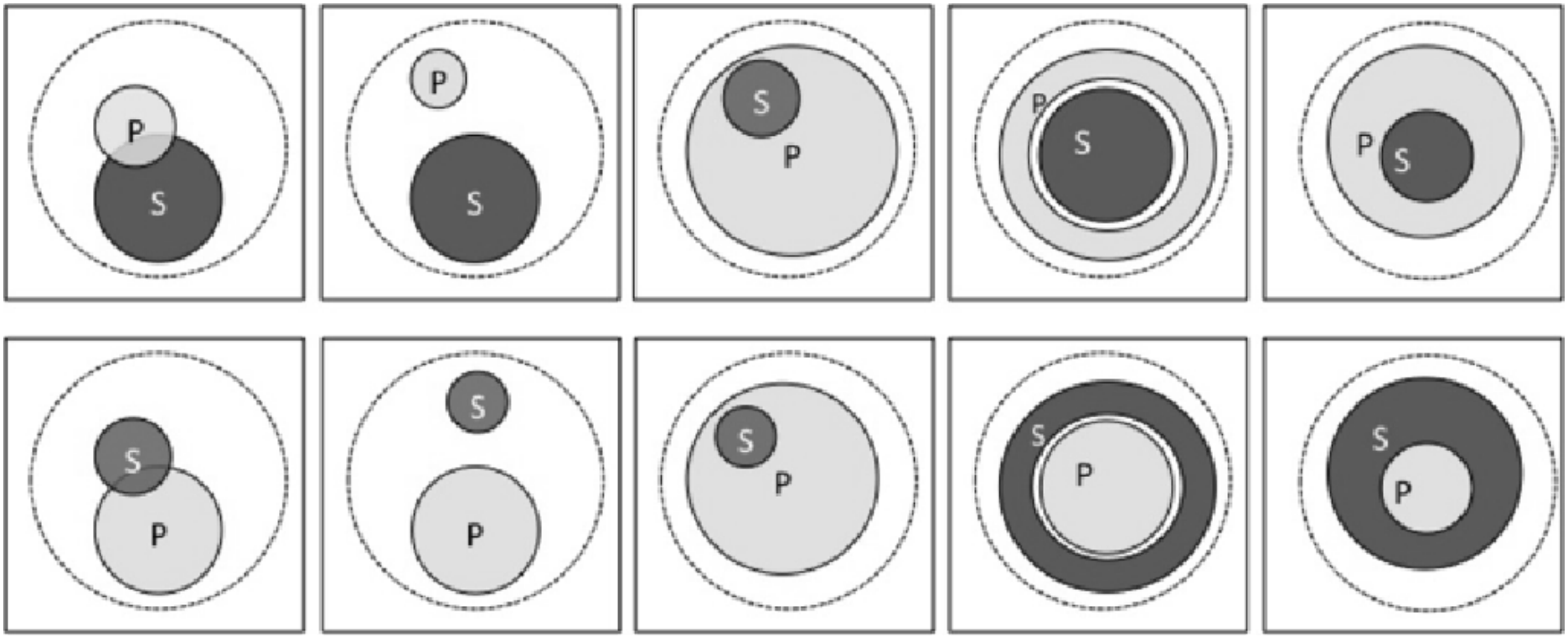

Fig. 3: PSS Abstraction - some examples of PSS abstract diagrams

Figure 4
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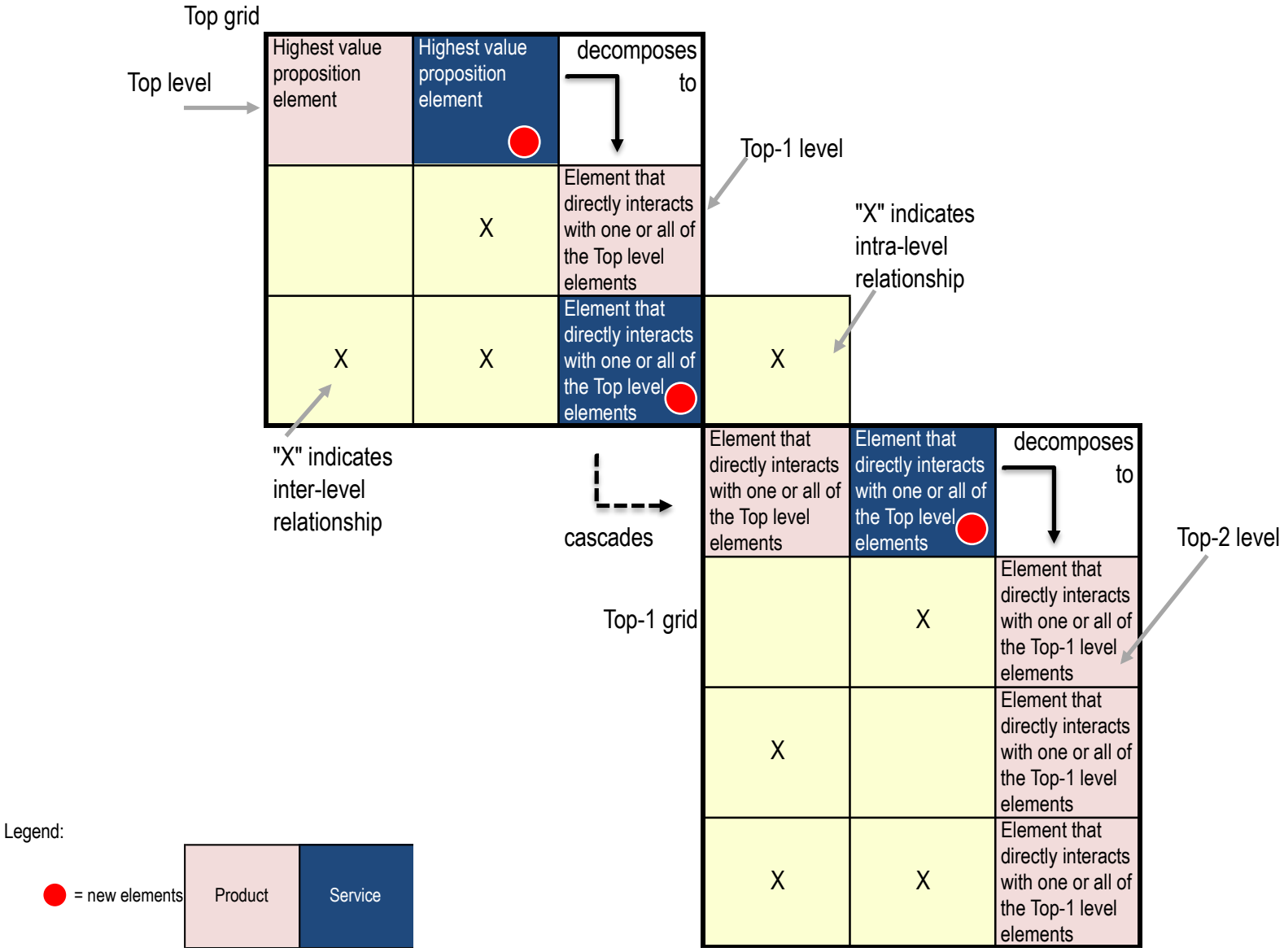

Fig. 4: PSS Decomposition – building the grids (Part 1)

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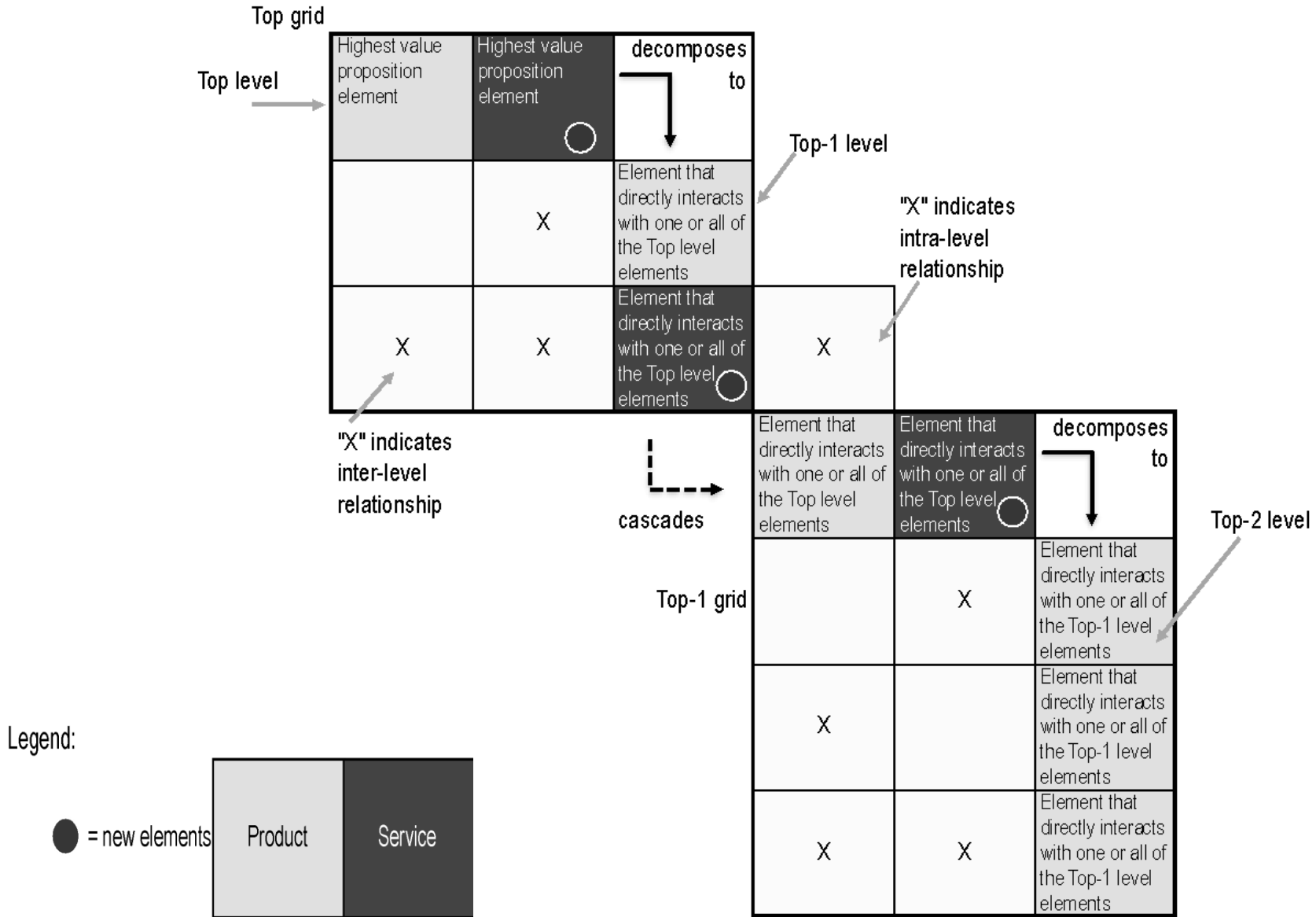

Fig. 4: PSS Decomposition – building the grids (Part 1)

Figure 5
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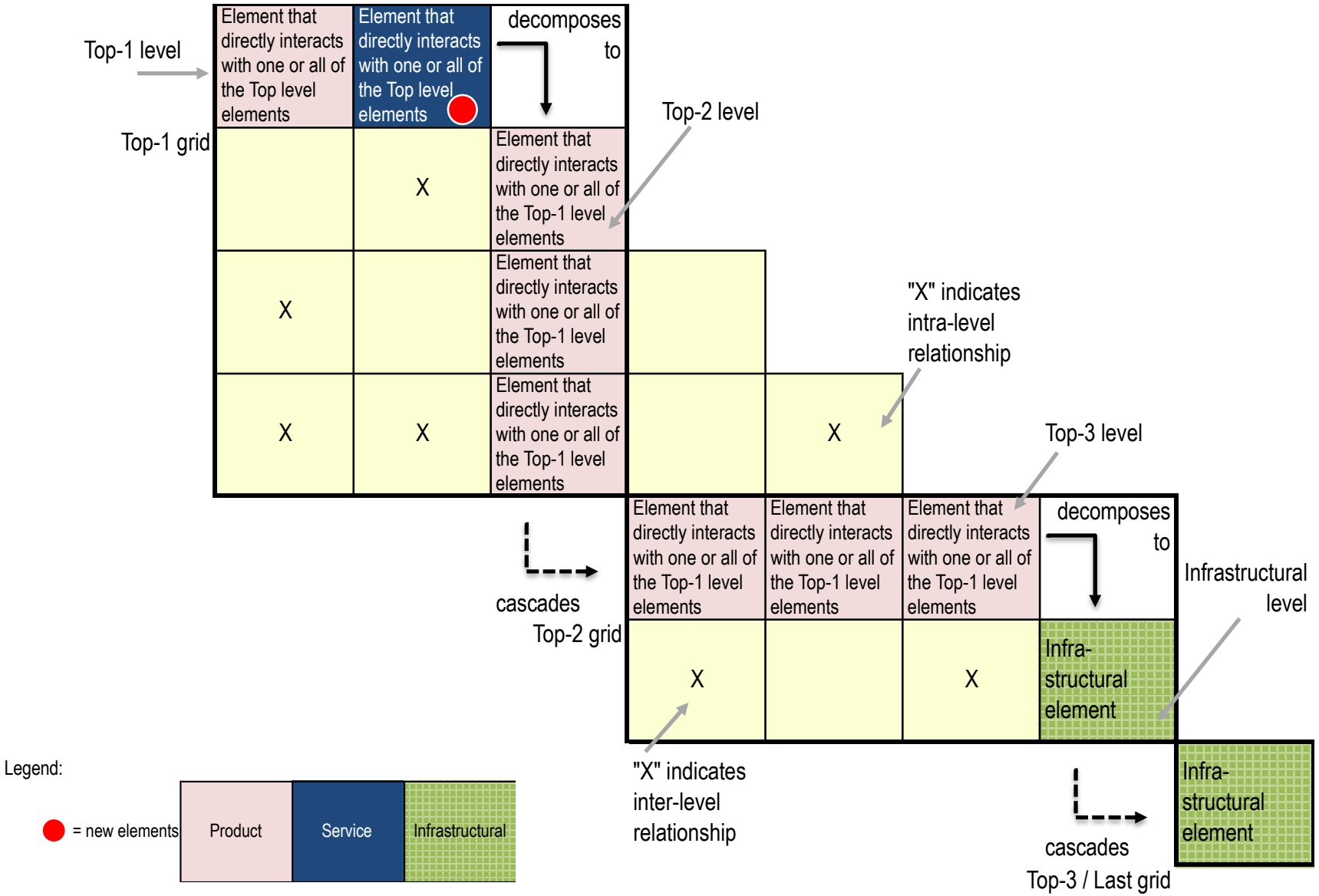

Fig. 5: PSS Decomposition – building the grids (Part 2)

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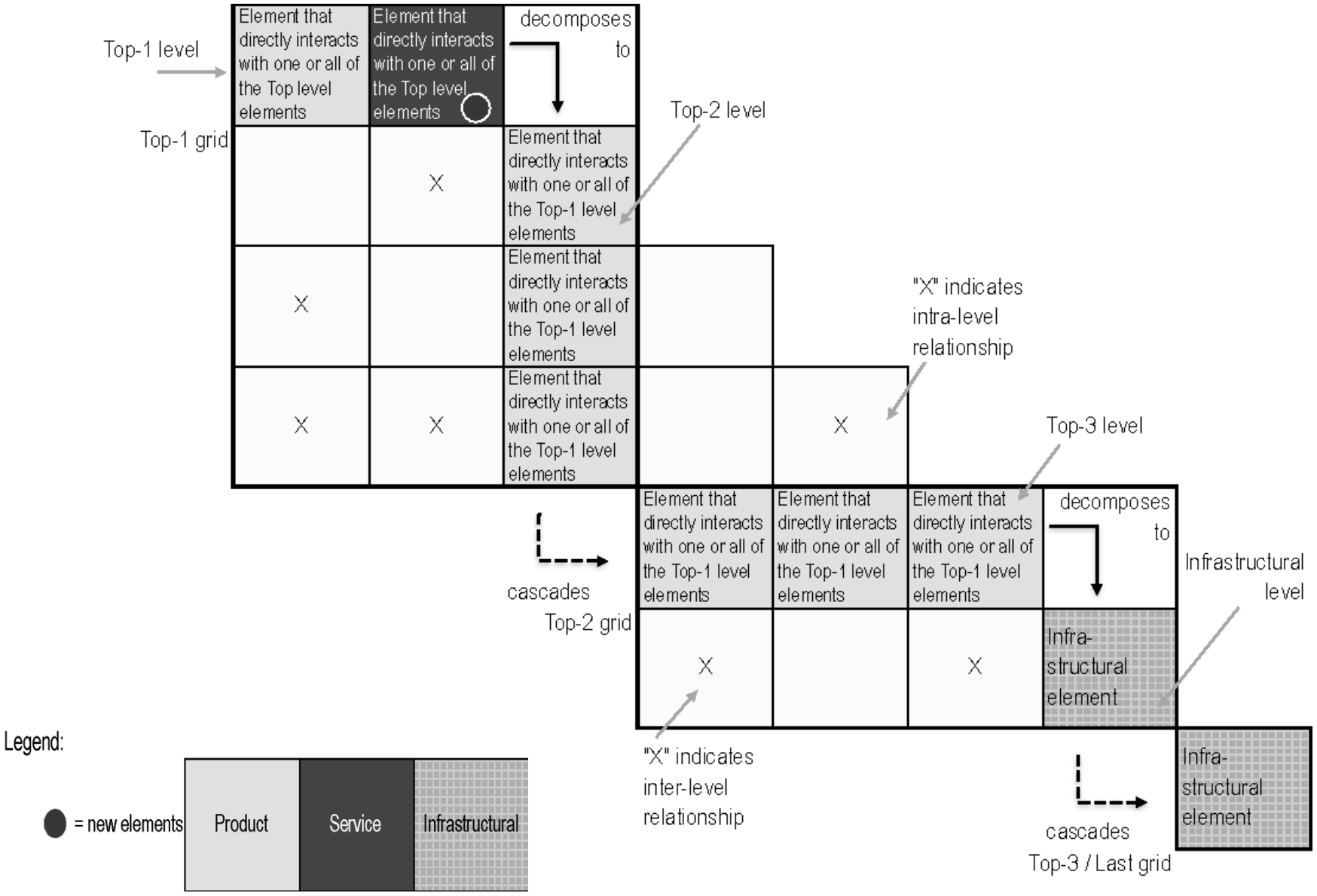

Fig. 5: PSS Decomposition – building the grids (Part 2)

Figure 6
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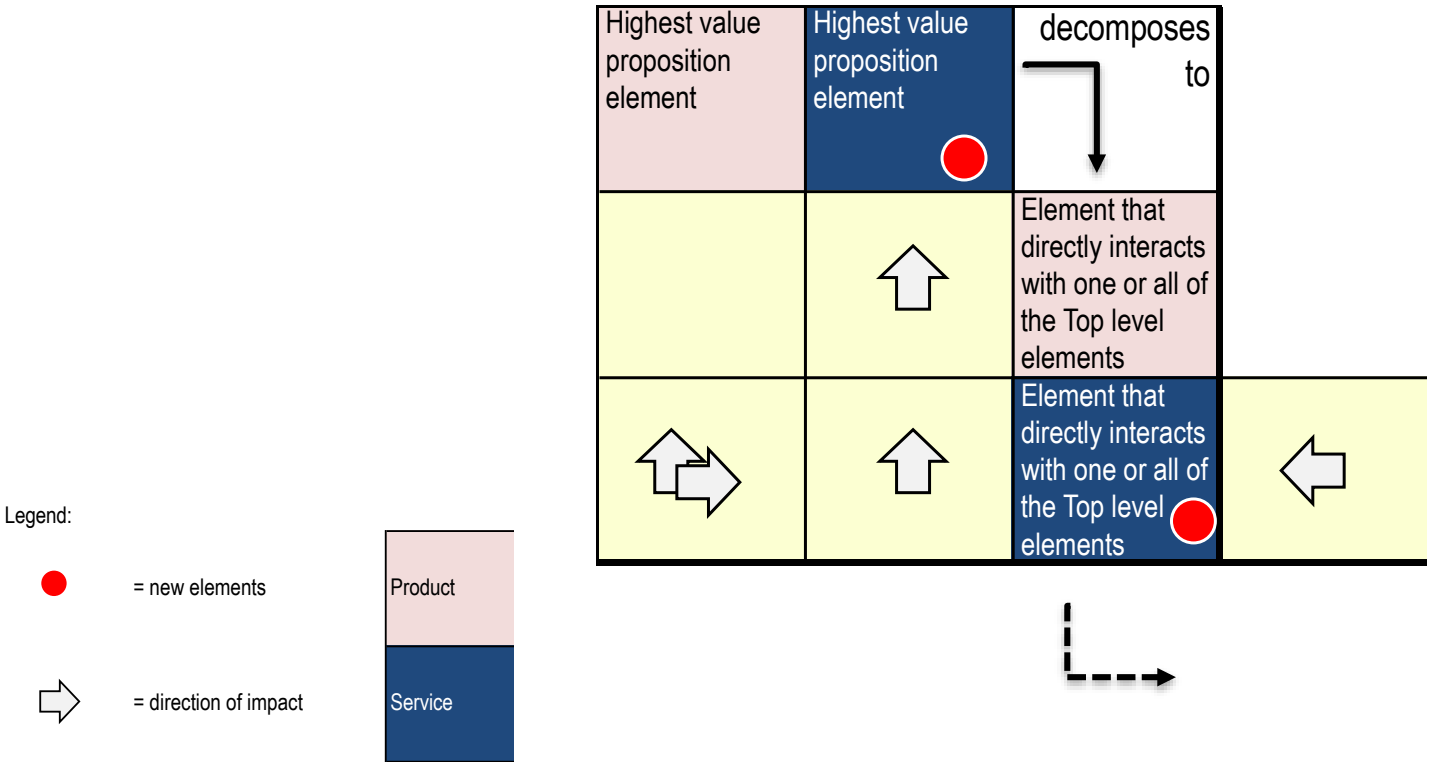

Fig. 6: Identifying the impact directions

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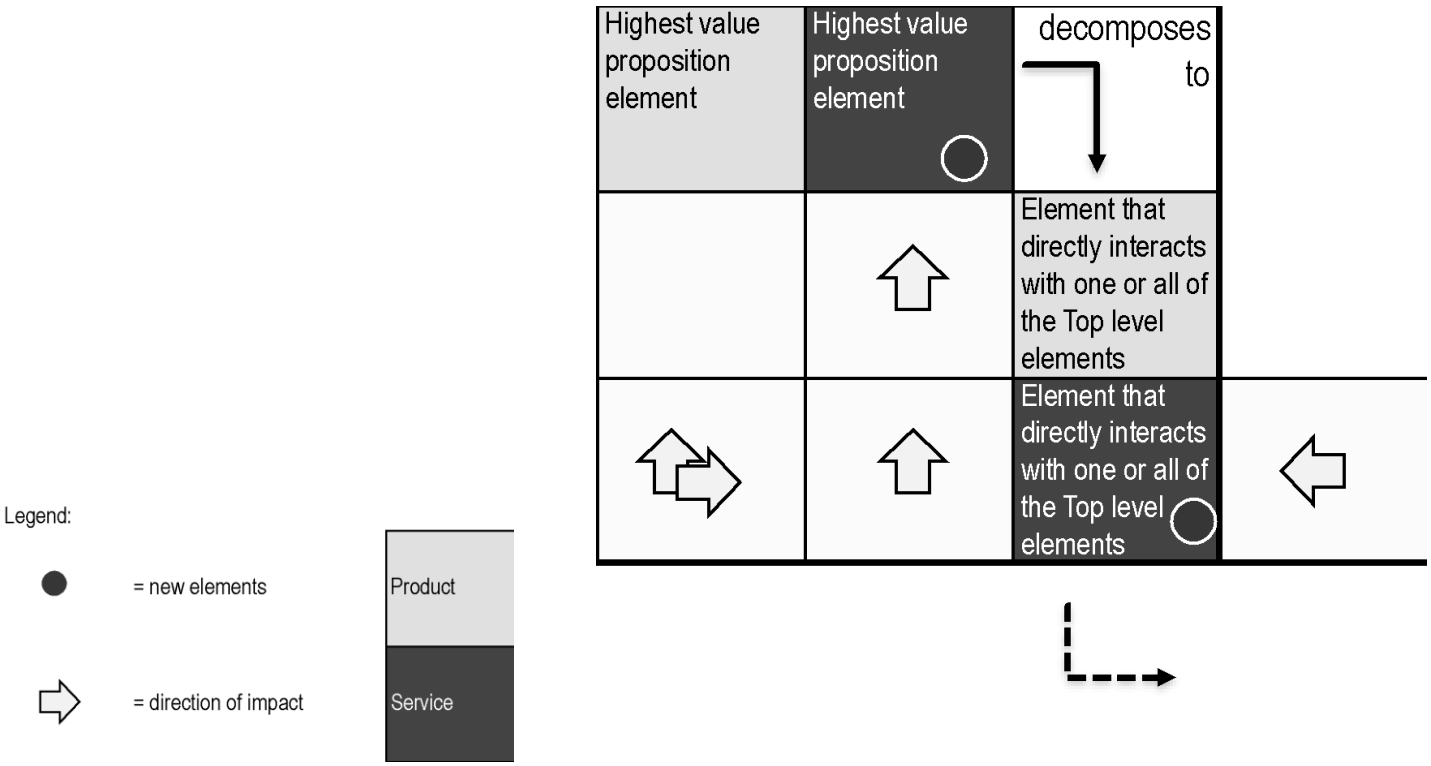

Fig. 6: Identifying the impact directions

Figure 7
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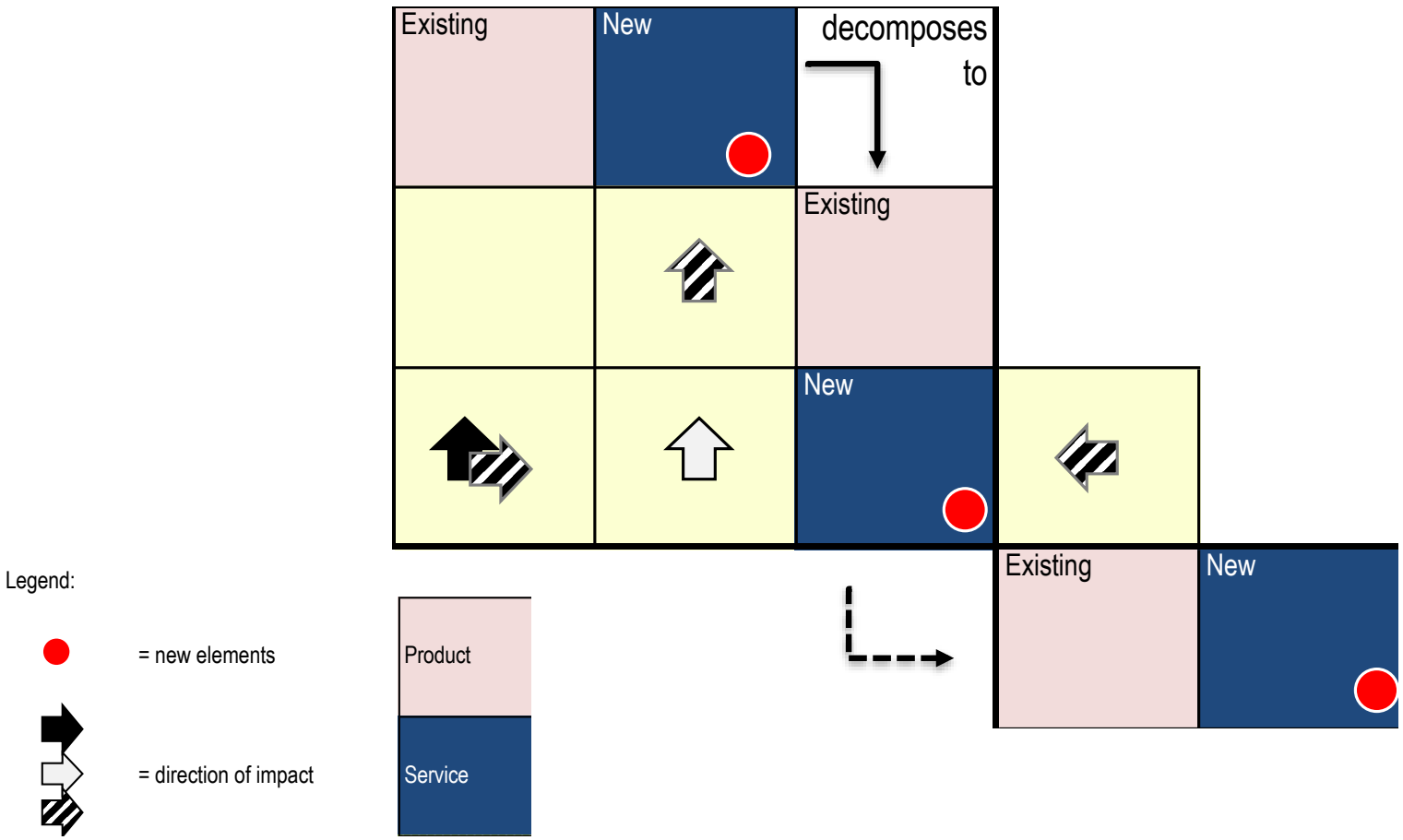

Fig. 7: Visualising the nature of the relationship between elements

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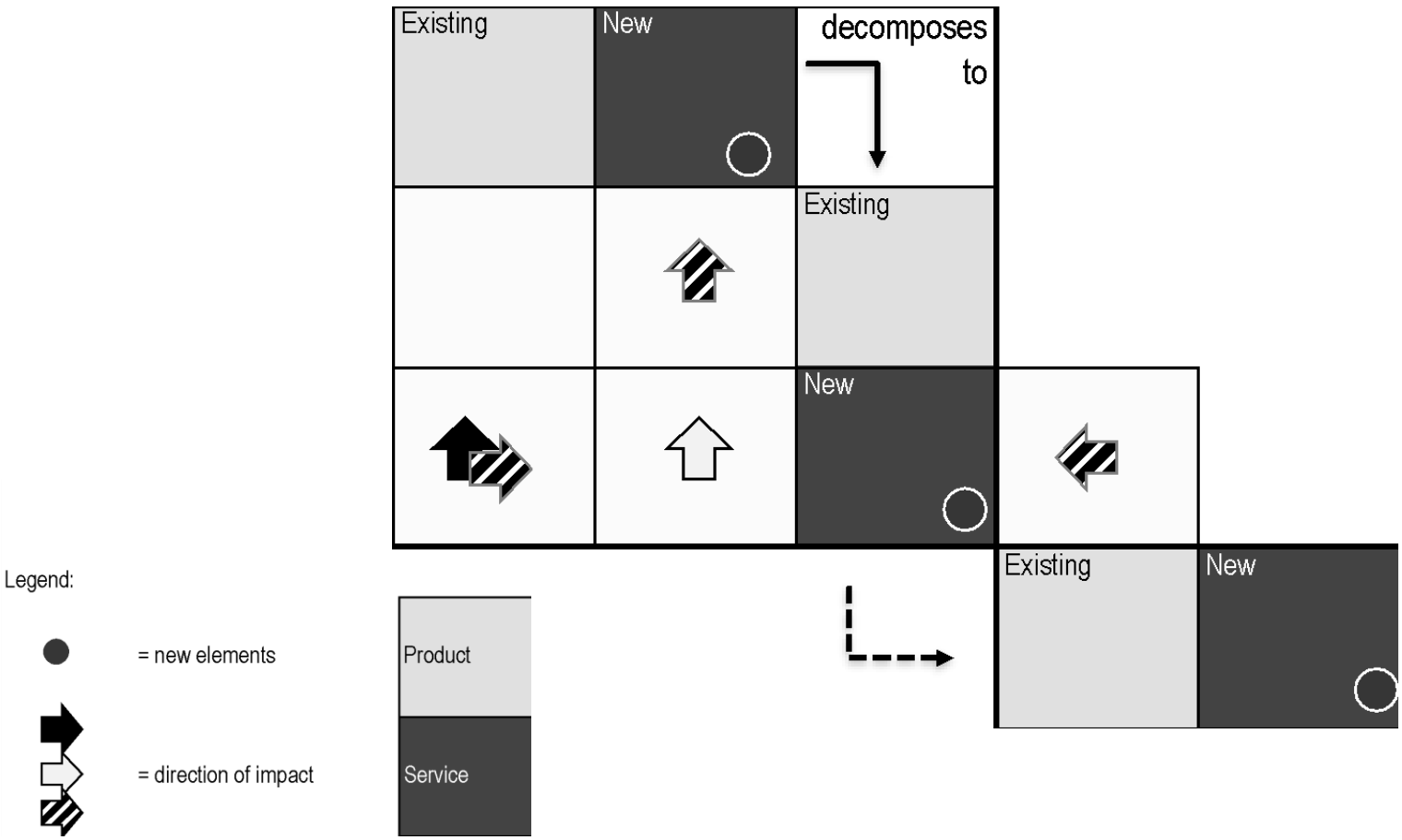

Fig. 7: Visualising the nature of the relationship between elements

Figure 8
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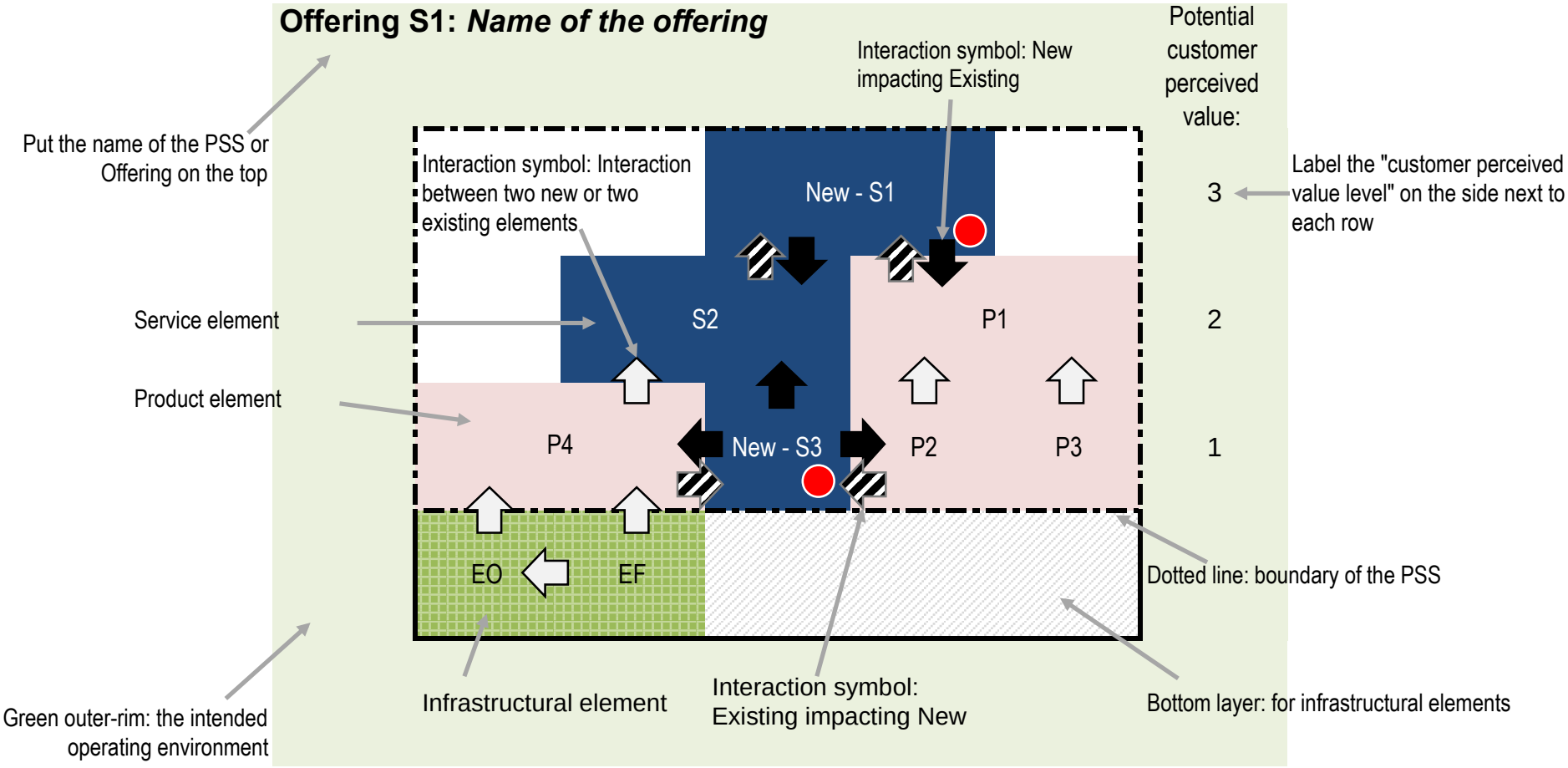

Fig. 8: PSS Representation Diagram

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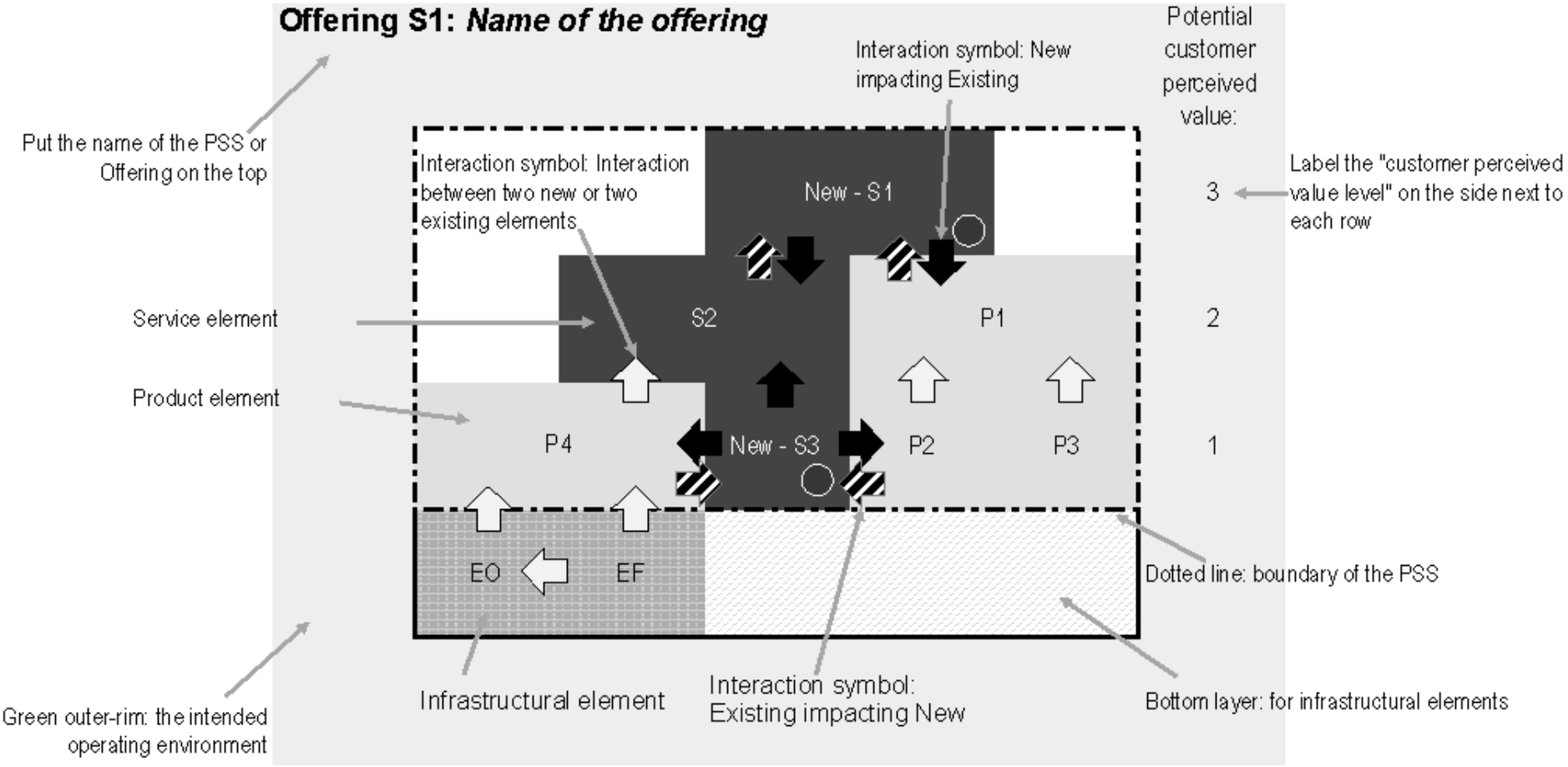

Fig. 8: PSS Representation Diagram

Figure 9
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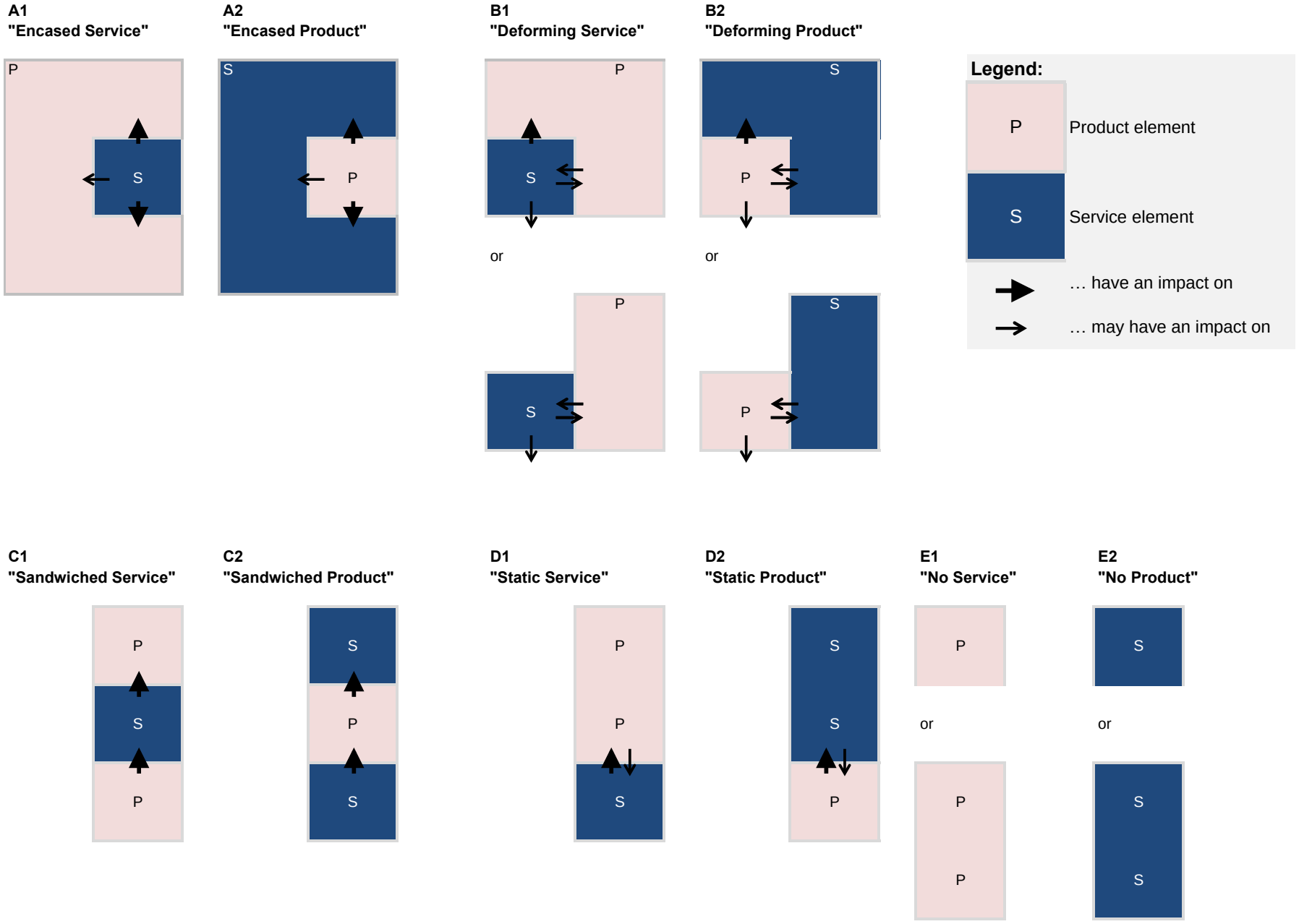

Fig. 9: The Proposed PSS Configuration Types

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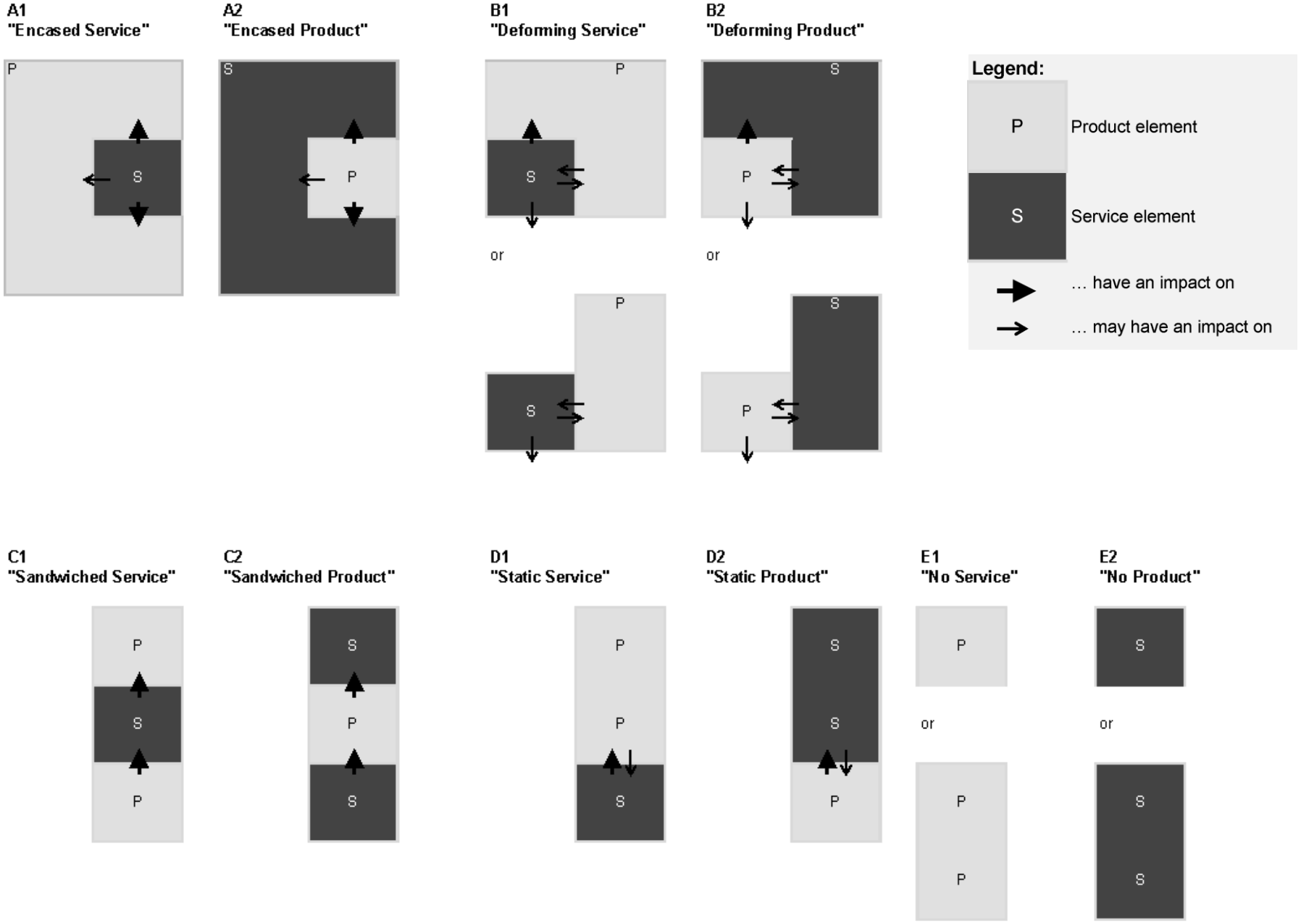

Fig. 9: The Proposed PSS Configuration Types

Figure 10
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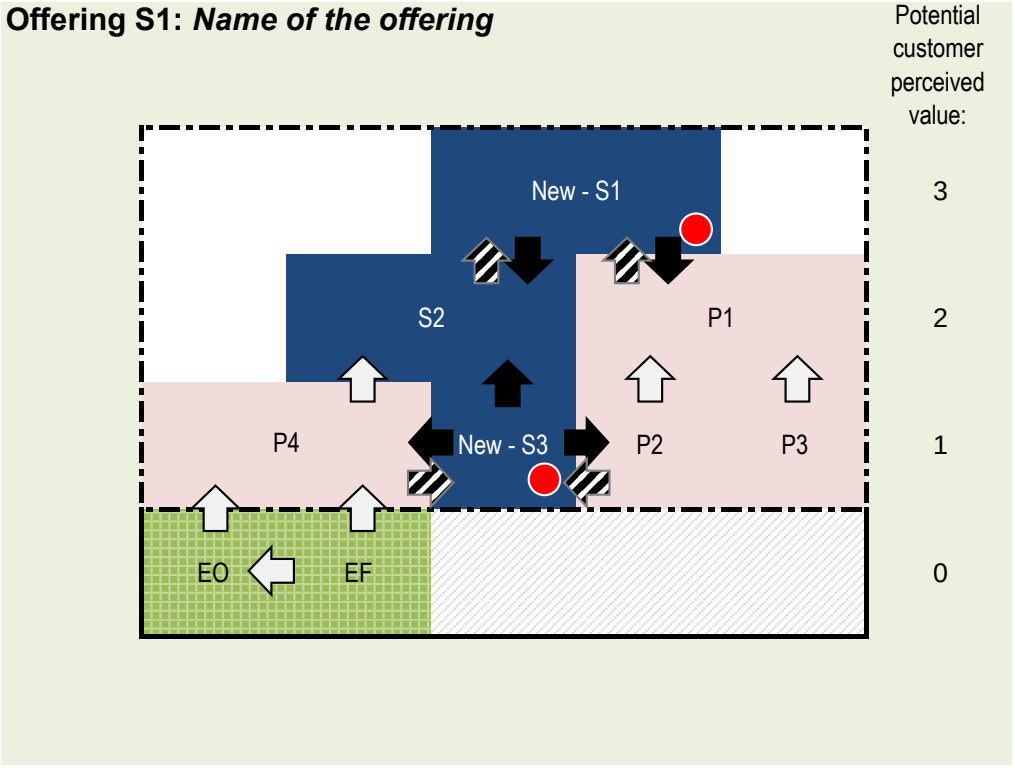

The four parameters for PSS characterisation:

i. Potential customer perceived value level = 3

ii. Type of connectivity:

a. Number of black arrow to "product" = 3

b. Number of black arrow to "service" = 2

c. Number of striped arrow to "product" = 0

d. Number of striped arrow to "service" = 4

From a & c: Data/physical = Incorporated

From b & d: Processl = Incorporated

iii. New/Existing connectivity number = 2 x (3+2) + 4 = 14

iv. Type of PSS configuration:

New S1 = B1; New S3 = B1

Fig. 10: An example of how to determine the four PSS characteristics

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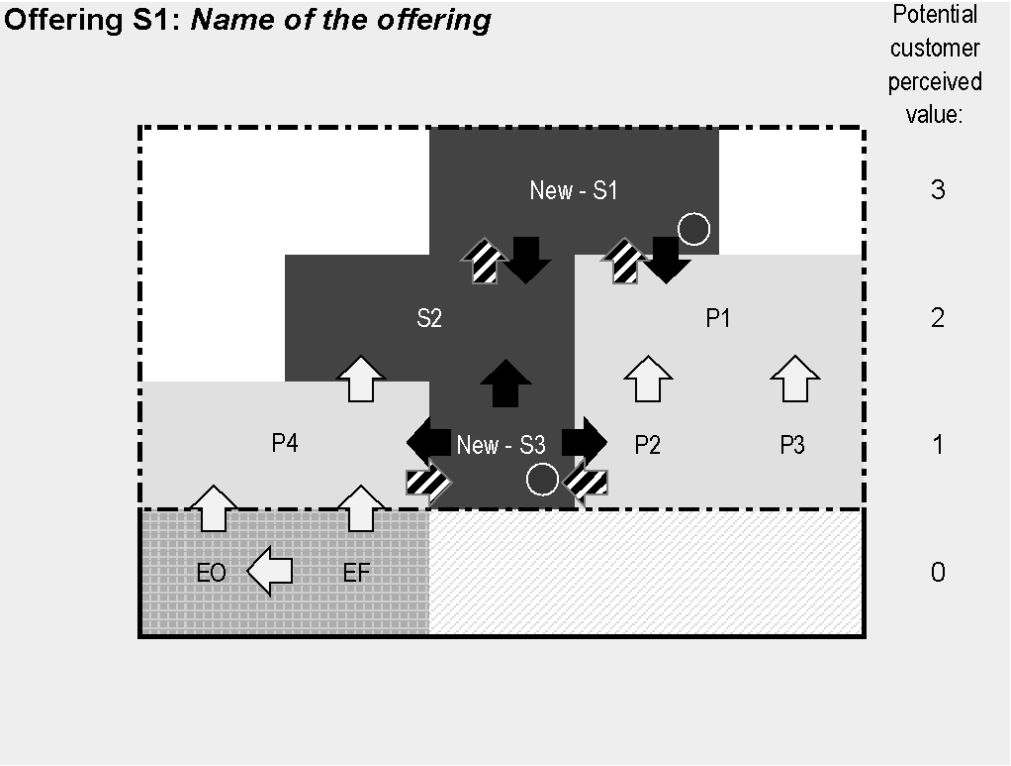

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Fig. 10: An example of how to determine the four PSS characteristics

Table 1

TABLE 1: DISCUSSION ON NEELY'S [32] PSS CLASSIFICATION

Classification and explanation by Neely [32]	**Examples provided by Neely** [32]	**Product or service elements within the PSS, according to Hill's definition** [18]	**Why the classification scheme is not useful for NPSSD**
Product-oriented – products plus product-related services; ownership of tangible product transferred to customer	Design and development services, installation and implementation services, maintenance services	It is a service, because a provider cannot provide, e.g. a design service, without the demand of a customer.	If a manufacturer provides service (e.g. a design service) for a product it does not sell, according to this classification scheme, it would be an integration-oriented PSS. This classification only informs the manufacturer that a service is related to a product, but nothing about the requirements of the service.
Use-oriented – service delivers through a tangible product; often ownership of tangible product retained	Sharing, pooling, leasing	It is about how the product is being accessed. When the user accesses the product, a service is produced.	The ownership of a product is arguably more of a concern for business modelling, than for NPSSD. At best, it reminds the manufacturer to consider the life-cycle cost of the product.
Result-oriented PSS – replaces the product with a service	Voicemail services	Similar to the argument for use-oriented PSS, it is about how a replacement product, probably intangible, is being accessed (e.g. accessing a voicemail recording). If the example was "a personal assistant to take messages replaces an answering machine", it would have better fit the definition of "replaces the product with a service".	This classification is not much different from user-oriented PSS, apart from the tangibility of the product concerned. It is again arguably more of a concern for business modelling than for NPSSD. It does not inform the manufacturer about the specifications of the new product, nor the new service.
Integration-oriented – products plus downstream services; ownership of tangible product transferred to customer	Moving from manufacturing into retail and distribution, financial services, consulting services	It is a service, because a provider cannot provide, e.g. a distribution service, without the demand of a customer.	This classification is not much different from product-oriented PSS; apart from the service concern is not for a product that the manufacturer sells. The vertical integration of a manufacturer impacts the company's business model. However, it does not inform the manufacturer how the service has to be designed.
Service-oriented – a coupled product and value added service; ownership of tangible product transferred to customer	"Health Usage Monitoring Systems", "Intelligence Vehicle Health Management"	It is probably software, which is an intangible product. Software can exist independently with its identity preserved over time.	This classification at best makes the manufacturer aware that it can choose to develop new services such as proactive maintenance. However, it does not inform what are the new service requirements.

Table 2

TABLE 2: 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”

Table 3

TABLE 3: FEATURES OF THE PSS CONFIGURATION TYPE

PSS congiuration type	The element that is at a higher value-level	Key features	Hypothetical example
A1	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 person who makes & sells (service) animal-shaped balloons (higher level product) on a stick (mid-level product) at a fairground retail stand (lower level product).
A2	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 teacher has a chat with her class (lower level service) and got the feedback that they do not understand the concept of the food chain. She then made some animal-shaped balloons (product) that she uses in a game (mid-level service) that helps her to teach (higher level service) the concept.
B1	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	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).
C1	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 golf technique improvement video (product) that is produced by filming a golf instructor correcting the techniques of different students (service) in holding and swinging the golf clubs (lower level product).
C2	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 golf coach who provides golf technique improvement advice (service) uses some specialised video recording devices (product) to record how her clients' stand and swing. These devices are rented (lower level service) from a photography equipment company.
D1	Product	The product elements are using the service mostly as a static input to the product	A forum for gamers of a network video game to exchange tips and tactics on improving gaming techniques (service), gives certificates of different levels of expertise (higher level product) based on users' level of contribution.
D2	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 network game (lower level product) that allows gamers to customise the game for playing on different devices (high level service) such as computer, tablet, and cellular phone.
E1	Product	The product element(s) are standalone product(s)	A recording of a contemporary dance performance that is available online for streaming and/or distributed on DVD.
E2	Service	The service element(s) are standalone service(s)	A live contemporary dance performance at a local theatre.

Table 4

TABLE 4: BACKGROUND INFORMATION OF THE THREE WORKSHOPS

Workshop name (short name)	**Company description**	**Number of participants (excluding facilitator)**	**Type of participants (functional experience & role in NPSSD)**	**Workshop location**	**Workshop duration**	**Notes**
Healthcare IT (HIT)	Large multinational, with headquarter in Germany	1	Software design, marketing awareness, service design, service delivery	Participant's office in Germany	2 hours	Participant's first language is German. During the workshop, sometimes he found it difficult to find the right English word.
Fitness (F)	Entrepreneur, based in the United Kingdom serving local market only	1	Technical design, sales & marketing, service delivery	Participant's office in the United Kingdom	4 hours	The workshop was conducted under a lot of time pressure. The participant had a client coming in at the planned workshop end time.
Psychology Counselling (PC)	Medium local counselling service company based in Hong Kong	1	Solution design, sales, service delivery	A borrowed conference room in Hong Kong, outside participant's / facilitator's office	2.5 hours	The workshop was conducted in Cantonese, but the workshop materials were in English.

Table 5

Table 5: The Three PSS Analysed

Workshop name (short name)	Stage of new PSS idea	Description of the product and service content within the PSS	Workshop objectives agreed with participants prior to the workshop
Healthcare IT (HIT)	Post-launch, second year in the market	A software product that was designed and developed to work with existing products, and has triggered a new configuration service to be developed. The new software product was sold with the configuration service.	The main focus was to characterise the PSS that the newly developed software product belonged to, and to discuss why it was a successful product according to the participant.
Fitness (F)	Initial ideas formed, developer was unsure which one to develop	New exercises to be added in small group fitness classes that are delivered in the gym. The exercises are services that require the usage of products (gym equipment) to delivery the services.	To help the participant to focus his development effort on fewer ideas.
Psychology Counselling (PC)	Customer requirements obtained. Developer had some rough ideas about what elements would be needed for the new PSS	Customised workshop that teaches public and special needs audience selected psychology theories and the application of these theories to their situations. It is a service that can be delivered with or without the support of products.	To help the participant to improve the design of future workshops of a particular theme. The participant was to select an up-coming workshop of this theme to be analysed in the PSS characterisation approach.

Table 6

Table 6: Implications of PSS Characterisation Approach to PSS Definition

Implications	**Overall approach**	**Step 0: Stakeholder identification**	**Step 1: PSS depiction**	**Step 2: PSS abstraction**	**Step 3: PSS decomposition**	**Step 4: PSS representation**	**Step 5: PSS characterisation**
Customer value				What is of higher customer value within the PSS, and where the development focus should be (PC)	Whether the PSS will be successful in customers' eyes as a result of the product or service element (F)		
Environmental impact		Who are the stakeholders and which part of the PSS they are interested in (HIT, F, PC)			What are the environmental factors, including skills of stakeholders, that will impact the functioning of the PSS (HIT, F, PC)	How much interaction there is between the elements within the PSS and its operating environment (F)	
Product and service content			What are the product and service elements for the PSS (PC, F)		How product & service elements within the PSS interact (HIT, F, PC)	Which element is the most fundamental in the PSS (PC)	Whether there is a product or service that is a building block of the new PSS (HIT, PC)
Strategy for NPSSD	Which PSS is a less complex solution among various potential solutions (HIT, F) What new skill is crucial to the success of delivering the new PSS (HIT)						Where complexity of development potentially comes from (F)
Process for NPSSD				What is the main focus, and what is supplementary (PC)			

Table 7

Table 7: The feasibility, usability, and utility of the PSS characterisation approach to support early stage NPSSD

Assessment criteria	Step 0: Stakeholder identification	Step 1: PSS depiction	Step 2: PSS abstraction	Step 3: PSS decomposition	Step 4: PSS representation	Step 5: PSS characterisation
Feasibility	The participants found the instruction notes easy to follow (HIT, F, PC).	Not easy to follow. Made mistakes or constantly needed confirmation on whether the step was done correctly (F, PC).	Participants found the instruction notes easy to follow (HIT, PC), or was able to follow with some more explanation given by the facilitator (F).	Needed the facilitator to clarify the printed instructions and to explain in a step-by-step manner what needed to be done (F, PC).	The participant found the instruction notes easy to follow (HIT). The participant could follow the step when the facilitator was taking the lead to execute the step (F, PC).	The facilitator took the lead to execute this step with the participants providing feedback from time to time (HIT, PC). The participant found the instruction notes easy to follow (F).
Usability	There was confusion on one of the stakeholder groups, better explanation would be needed (HIT); otherwise no problem was encountered (F, PC).	Needed to draw outside the boundary of the diagram (HIT). Step flexible enough to handle multiple PSS to be drawn on the same diagram (F)	The participant would like to use more than one circle to represent the products in the PSS (HIT). The participant found it difficult to accommodate all PSS possibilities in the abstract diagram (F).	The usage of repositionable sticky notes facilitated the ease of re-doing the diagram (HIT, F, PC.) The facilitator had to ask the participant to just focus on one PSS idea for the step (F).	No problem was encountered (HIT). Some elements that had the same interactions with other elements were combined to reduce the complexity and the width of the diagram: some infrastructural elements were combined (F); two product elements were combined (PC).	No problem was encountered, and the participant was able to identify the configuration type very quickly (HIT). There was one mistake in counting the number of arrows due to the combining of infrastructural elements in the PSS representation step. The participant found it easier to do this step directly from the PSS decomposition diagram instead of the PSS representation diagram (F). The participant thought the PSS configuration type was for evaluating whether product or service was more important, which was not this step's purpose (PC).
Utility	Useful for identifying stakeholders and which part of the PSS they are interested in (HIT, F, PC).	All product & service elements were drawn, with stakeholder placed next to the relevant elements. (HIT, F, PC). Triggered brainstorming of the relevant existing and new product & service elements for the new PSS. (PC).	Was able to show the goal & focus of the PSS (HIT). Encouraged the participant to think about which element in the PSS was of more potential customer value (F, PC). Was able to meaningfully show how the product and service elements interact within the PSS (HIT, PC).	Triggered meaningful discussions on how the PSS should behave, how it would impact or would be dependent on other factors in the operating environment (HIT) Was able to identify all the product and service elements, and their environmental constraints. (F, PC). Highlighted which new product element was shared by multiple new service element (F).	The participant questioned the utility of the step (HIT). The participant was not aware of the high degree of the connectivity between the new PSS and its environment until this step (F). The step highlighted which element was the most fundamental in the new PSS (PC).	The low connectivity number had confirmed the participant's goal in this PSS development was to have no requirement on existing product, due to low engineering resources available on existing product modification (HIT). It also showed in the configuration type that the PSS has a "static product" with the configuration service being different for every customer (HIT). The high connectivity number had triggered a discussion that encouraged the participant to see the new exercises from the perspective of how it is to link to its operating environment, and what type of product elements it requires (F). The participant did not find the connectivity number useful, but she agreed that the PSS configuration type had correctly shown product as the foundation of the service (PC).