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EARLY STAGE NEW PRODUCT AND SERVICE DESIGN PROCESS - THE USE OF GRAPHICAL REPRESENTATIONS

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ABSTRACT

This paper summarises the initial results from a study that translates a research instrument into a business application that supports the early stage of new product-service system development, with the objective of clarifying design specifications. The business approach, called system design characterisation (SDC), contains five different graphical representations. Following the method of procedural action research, the feasibility, usability and utility of the graphical representations used in SDC are tested. Drawing from literature of multiple disciplines - engineering, design and cognitive science – how SDC may bridge the gap of design techniques that use multiple representations to manage complex information is discussed in this paper. The result of this study intend to contribute to the on-going discussions in the research community of design research or design methodology, as well as that of research methodology in terms of the use of procedural action research for business application development.

INTRODUCTION

The new product development process is one of the riskiest business activities. Early attention to risk, right from the early stages of development, can significantly reduce cost and time to market (Goffin & Mitchell, 2005). The new product or service development 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 (Cooper, 1988). This study focuses on the early stage development of systems of products and services – product-service systems (PSSs), and in particular, it explores the use of graphical representations in a design approach that supports this development stage.

The study of the effects of external representations in problem solving is not new in cognitive science (Zhang, 1997). However, for new product and service development, where the problem to solve concerns the effectiveness of transforming complex information into artefact(s) of value that is context dependent (Simon, 1969), there are limited studies on the use of graphical representations.

An earlier study proposed a research instrument called PSS Characterisation Approach (PSSCA), which has the objective to clarify design specifications in the early stage development process. This instrument was built for data collection with case companies in action research workshops. PSSCA utilises five types of graphical representations.

This study is to further develop this research instrument for business settings. The business application is called System Design Characterisation (SDC), which is described as a design approach to clarify design specifications. The study uses procedural action research (PAR) method to build, improve and stabilise this design approach (Maslen & Lewis, 1994). SDC, once stabilises, contributes to the design research or design methodology (Cross, 2001) of PSS in terms of the usage of graphical representations to support engineering design.

LITERATURE REVIEW

This section first highlights the theories and research methods for engineering design. Then, it provides the definition of product, service and product-service systems adopted from literature. This is then followed by a review of new product/service/PSS development (NPD/NSD/NPSSD) models and tools, especially from the perspective of incorporating multiple stakeholders' requirements. The literature review concludes that there is a need for better process and tool with graphical representations to support NPSSD.

Theories and research methods for engineering design

In the problem-solving paradigm (Simon, 1969), there are prescriptive and descriptive theories for engineering design (Finger & Dixon, 1989). Within prescriptive theories, there are prescriptive design process and prescriptive artefact theories. The former assumes that design moves from abstract to concrete, and complex problems can be approached by dividing them into sub-problems for sub-solutions generation, before synthesising into an overall solution. The latter assumes a design starts with reasonably complete functional specifications for standard methods to produce artefact specifications (Konda, Monarch, Sargent, & Subrahmanian, 1992). The assumption behind prescriptive process theories is that the designer would arrive at a better design if they follow the process (Finger & Dixon, 1989). Within prescriptive process theories, the theory of technical systems proposed by Hubka and Eder (1988) can support the PSS engineering design process – the PSS engineering design process is the technical system that transforms complex information into design specifications.

Design science research, or design research, which is popular in the information systems (IS) field, is a paradigm that proposes knowledge creation through construction and rigorous evaluation of designed artefacts. These designed artefacts solve relevant problems in the environment (Hevner, 2007; Hevner, March, Park, & Ram, 2004). Recently, there is a new design method proposed within the design science research paradigm called action design research. It combines action research and design research (Sein, Henfridsson, Purao, Rossi, & Lindgren, 2011).

In terms of the usage of graphical representation to support the engineering design process, the theories underpinning previous investigations appeared to be mainly from outside of engineering. For example, the interaction between human actors, nonhuman actors (e.g. external representations) and their environment has been explored in researches that are based on actor-network theory (Latour, 2005; Law, 1992). The usage of external representations to help people in solving problems has been investigated in cognitive psychology (Zhang, 1997). Seven ways of using external representations to think more "powerfully" have been proposed, suggesting external representations can help coordinate thoughts by making thinking more sharable, persistent, referable and re-representable. The use of multiple representations have also been put forward to facilitate inferential reasoning and complex information management (Kirsh, 2010).

Definitions of products, service and product-service system

There are many different understanding of the words product, service and product-service system. A review of literature has revealed that many researchers used the properties IHIP - intangible, heterogeneous, inseparable and perishable – to differentiate between products and services (Gummesson, 2007; Vargo & Lusch, 2004). IHIP can be traced back to Adam Smith and Jean-Baptiste Say in the 18th century (Gummesson, 2007; Hill, 1999) and has worked well as a definition for services until digital technology enables intangible products. An example of an intangible product is an audiobook available for purchase online (not heterogeneous) and listen to in people's own time (not inseparable), as many times as they want (not perishable). *Intangibility* has become out-dated as a definition. Therefore, in this study, the properties of *separable* and *stock-able* are used for identifying products from services (Hill, 1999).

This study adopts the definition of product-service system (PSS) proposed by Goedkoop, van Halen, te Riele and others (1999): product-service system is a system of products and services that jointly fulfil customers' needs (Goedkoop, van Halen, te Riele, & Rommens, 1999, p. 111). The constituent product(s) and service(s) of a PSS work together, or one element supporting the other, to generate values for the customers, the companies, and other stakeholders in society (Baines et al., 2007; Shostack, 1977; Tukker & Tischner, 2006).

NPD, NSD and NPSSD models and tools

Summarising the reviewed NPD and NSD models, there were proposals to incorporate stakeholders' needs through involving lead-users, depicting employee-user interactions and engaging different functions early in product and service development (Hull, 2004; Lee, 1992; Shimomura, Hara, & Arai, 2009; Shostack, 1984; Takeuchi & Nonaka, 1986; Von Hippel, 1976). In the recent years, NPSSD models were extended to a wider set of stakeholders, including the external environment (e.g. Rondini, Pirola, Pezzotta, Ouertani, & Pinto, 2015; Yip, Phaal, & Probert, 2014).

External representations have gained more attention as means to support the NPD/NSD/NPSSD process. Lim, Kim, Hong and others (2012) summarised the tools for visualising PSS into three groups: PSS process, relational network of PSS stakeholders, and others. PSS process includes Shostack's Service Blueprint (Shostack, 1984) and blueprints that were adapted from her original proposal. Relational network of PSS stakeholders includes maps and models that depict where stakeholders are involved in generating value while using the PSS (e.g. Morelli, 2006). The last group includes functional block diagram (Maussang, Zwolinski, & Brissaud, 2009) that shows the relationships between the product and service components of a PSS and their external environment, and technology roadmap that depicts the roles of technologies in developing sets of products and services to support company's innovation strategy (Phaal, Farrukh, & Probert, 2004).

In terms of tools, Design for Environment (DFE) (Ramani et al., 2010) was proposed to incorporate multiple stakeholders' interest. There are also proposals that put on the same diagram the interactions between stakeholders and the products and services within an infrastructure (Lim, Kim, Hong, & Park, 2012). A review of the structural representations proposed since the 1980s (e.g. Gallouj & Weinstein, 1997; Hubka & Eder, 1988; Shishko & Aster, 1995; Shostack, 1982) revealed that although there are various proposals for visualising PSS, only Hubka & Eder's organ structure depicts the structure of the PSS, the connections between the components within a PSS, and that with its environment. A more recent research in service design inquired into the benefits of using external representations, which reported a gap in service design technique – one that uses multiple representations to deal with complex information (Blomkvist & Segelstrom, 2014).

In summary, there is a need to investigate the usage of graphical representations in prescriptive engineering design process.

APPROACH

The philosophical position of this study is that a prescriptive approach to PSS engineering design will result in a better specification for detailed design. To develop a design approach that is useful for practitioners, knowledge needs to be created jointly between researchers and practitioners. Therefore, action research (Lewin, 1946), in particular procedural action research (PAR) (Maslen & Lewis, 1994), is selected as the method, to guide the researchers and practitioners to test conjectured knowledge through planned actions and evaluate the outcomes through reflection. The knowledge created is situational and bound by context. The tests here refer to the use of the business application SDC in different workshops for different new PSS developments, with the evaluation criteria of *feasibility*, *usability* and *utility* of SDC (Platts, Mills, & Bourne, 1998; Reason & Bradbury, 2001). Feasibility is about the degree to which the process laid out for the workshop participants can be followed. Usability relates to the ease of following the SDC approach. Utility focuses on whether the approach achieved its intended benefits for the participants, that is, to clarify PSS design specifications.

The observed benefits and difficulties arise from using the multiple graphical representations in SDC in clarifying the design specifications are reflected for further planned actions (changes) to the SDC before subsequent application. The number of changes and the magnitude of the changes on SDC resulted from observations and reflections are to be tracked for its building and refinement (Maslen & Lewis, 1994; Platts, 1993). Table 1 provides a definition of the magnitude of change.

Following the ideal model of procedure development in PAR (Maslen & Lewis, 1994), it is 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 than secondary changes, and the number of tertiary changes would then taper off. More contextual conditions for the SDC usage would more likely be identified with the maturity of the business application development, that is the last phase, "Refine". Until the application development has reached the phase "Refine", additional cases would be identified.

Table 1 Definition of the magnitude of change

Magnitude of change	Descriptions
Primary	Change of the core content of a step. Add or remove main steps or sub-steps. Change the order of main steps. Add or reduce the number of symbols used in the tool Change the shape or color of symbols used in the tool.
Secondary	Change the order of the sub-steps. Add instructions into a sub-step. Digitalising a main step or sub-step.
Tertiary	Clarify the wordings of an instruction or keys to symbols used in diagrams.

THE GRPAHICAL REPRESENTATIONS IN THE ORIGINAL RESEARCH INSTRUMENT

A previous study has proposed a procedure called the PSS Characterisation Approach (PSSCA) (Yip, 2015) that utilises five types of graphical representations to systematically analyse PSS for NPSSD in a research setting. This study further develops this procedure for a business setting. The business application is called System Design Characterisation (SDC).

The PSSCA (Figure 1) was applied in company case studies using a workshop approach, and was stabilised as a research instrument following the PAR method. During each workshop, five types of graphical representations were used to systematically analyse PSS for NPSSD. Each workshop began with the company's new product and service strategy already defined. Before carrying out step 1 (PSS Depiction), the company could choose to go through the optional step of *stakeholder identification* especially if it had not already identified the stakeholders of the new PSS. Figure 1 shows the five steps of PSSCA - *depiction, abstraction, decomposition, representation and characterization*.

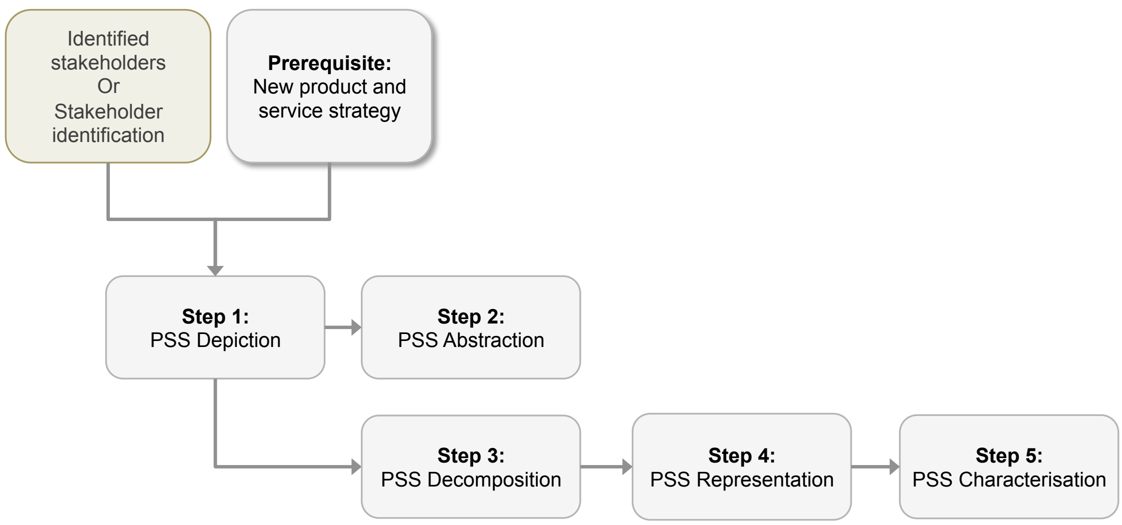


Figure 1 The PSS Characterisation Approach (PSSCA) for analysing PSS ideas in research settings

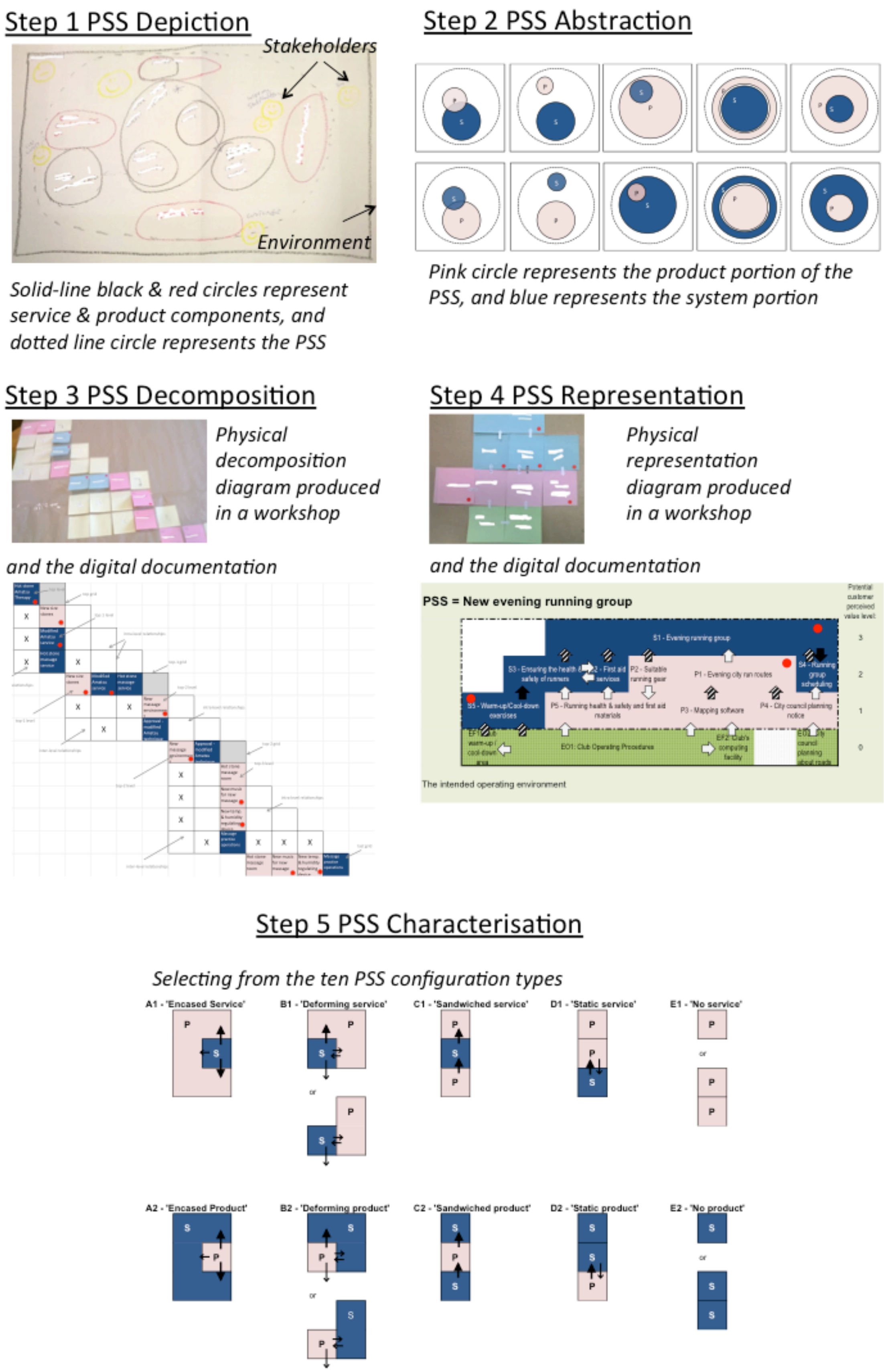


Figure 2 The five types of graphical representations of PSSCA

In step 1, the participants are guided to draw a diagram to depict the key components, subsystems, and stakeholders of the new PSS in the environment that it is to be used (see step 1 of Figure 2). In step 2, the participants are asked to choose a representation that best represented the PSS in discussion (see step 2 of Figure 2). In step 3, the participants decompose the new PSS systematically based on how the customer-facing elements interact with other elements of the PSS and with the operating environment. This step starts with a blank canvas (at least four pieces of A0 paper taped together), and requires three colour sticky-notes (pink, blue and green) to denote whether an element is a product, service or an environmental element; three styles of arrows (white, black and striped) to denote whether the dependencies are between two new or two existing elements, a new element impacting an existing element, or an existing element impacting a new element; and red dot-stickers to mark all new elements. Following a specific procedure, the PSS decomposition diagram is built layer by layer (see step 3 of Figure 2). In step 4, the participants are requested to construct a block-diagram from the PSS decomposition diagram (see step 4 of Figure 2). Another blank canvas is used for sticking the colour sticky-notes, arrows and dots to build the PSS representation diagram (see step 4 of Figure 2). In step 5, the participants are requested to choose from five pairs of PSS configuration types, which are structural archetypes of PSS configurations, that the PSS in discussion resembles the most (see step 5 of Figure 2).

In each step, the facilitators ask the participants questions when they see potential doubt, excitement, or disagreement between the participants. For example, the facilitators may ask why an element of a sub-system was singled out in a diagram (relevant to step 1, 3, 4); why one participant has a different choice of an abstraction (step 2) or configuration type (step 5); why an element is difficult to place in the decomposition diagram (step 3); or why it is difficult to build the representation diagram (step 4). Through these probing questions, the facilitators encourage the participants to discuss their opinions on the design, and ultimately aim at clarifying the design specifications.

SYSTEM DESIGN CHARACTERISAITON – DEVELOPING THE BUSINESS APPLICATION

The PSSCA was first adapted for a business setting, by reflecting on its most significant academic contribution. It was identified that the PSS configuration type (see step 5 of Figure 2) was the most significant academic contribution. As a result, step 5 was moved up to become the first mandatory step after the optional step 0 of stakeholder identification (see Figure 1). The intention was to focus the workshop participants to a particular PSS configuration type to design, by requiring them to choose a type upfront. The original step 2 of PSS abstraction was moved to become the last step, as this step was often referred back to at the end of the workshop during the use of PSSCA in research setting. To give more visual guidance to the participants, A0 size pages printed with gridlines and legends were prepared as the blank canvas for the PSS decomposition and PSS representation steps.

The researchers expected that the first business application would encounter many primary changes (see Table 1 for the definition of the magnitude of change). To avoid any adverse impact to a commercial offering, it was decided that the first application outside of academic settings would be a business case about a hypothetical company developing a new PSS. The business case should be complex enough to test the feasibility, usability and utility of SDC. The business case was about a local running club developing a new weekday run group. The new run group would be a new PSS, developed by the running club to align with its strategy of connecting local people. Four roles were involved in the business case: the running club manager, the running group leader, the marketing clerk and the procurement clerk. These four roles represented the interests of management, technical experts, market needs and operational needs respectively.

Four management consultants from a local consulting firm that is linked to an academic institution, who had an interest in new product/service development, were recruited as workshop participants. Each of them has between 20 and 35 years of industry experience before joining the consulting firm, and have held roles in general management, business development, marketing, new product development, manufacturing management, and project management. The participants were provided with the business case to read one week before the workshop and were asked to select their preferred role in the running club business case.

In summary, this first adaptation for business setting includes the same five graphical representations as the PSSCA, but used in a slightly different order - PSS configuration diagram being used in the first step and PSS abstraction diagram being used in the last step. The method to develop SDC into a business application is shown in Figure 3.

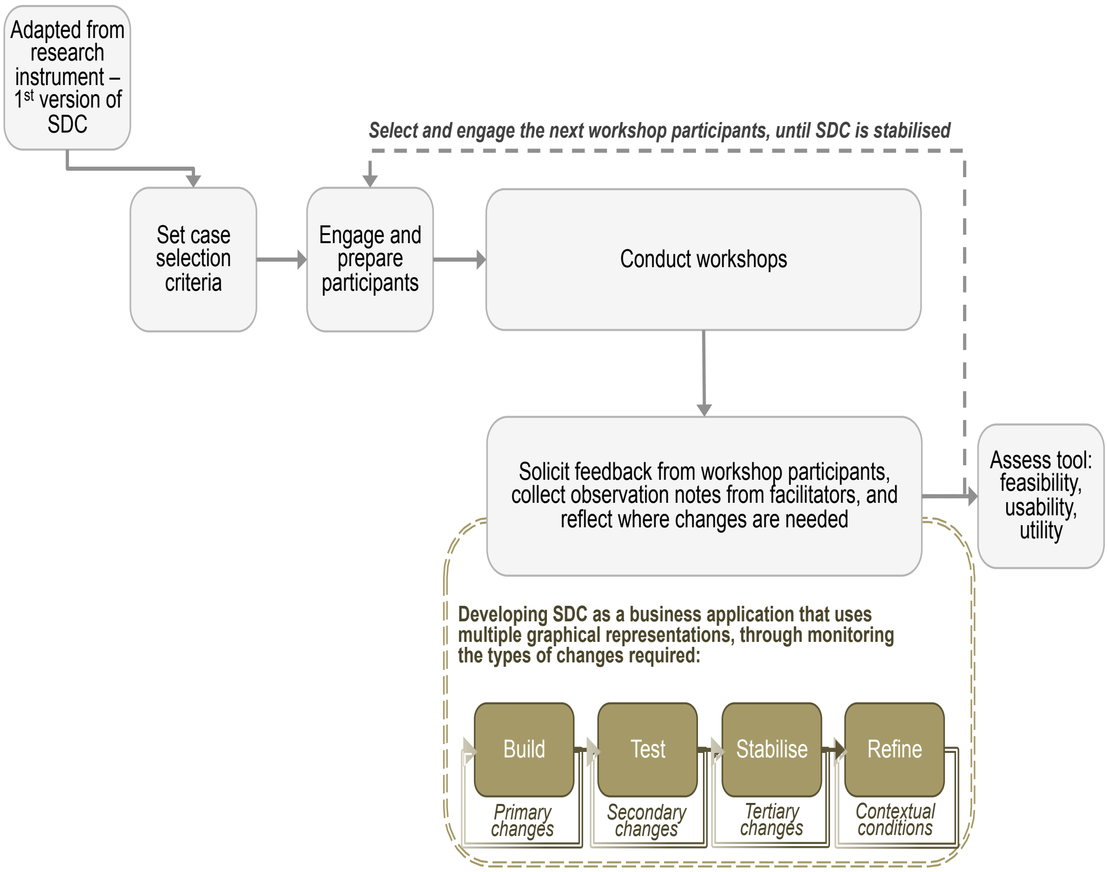


Figure 3 The method to develop SDC as a business application

The following section reports the findings of how the participants find the usage of these graphical representations to support NPSSD.

FINDINGS

At the time of writing, three workshops, including the hypothetical business case were completed. Nineteen primary and eight secondary modifications were adopted. There were no tertiary modifications suggested yet, but four contextual conditions were identified in the second and third workshop. According to PAR, SDC would be in the "Improve" phase as there was a drop of primary changes identified since the second workshop and the number of secondary changes increased.

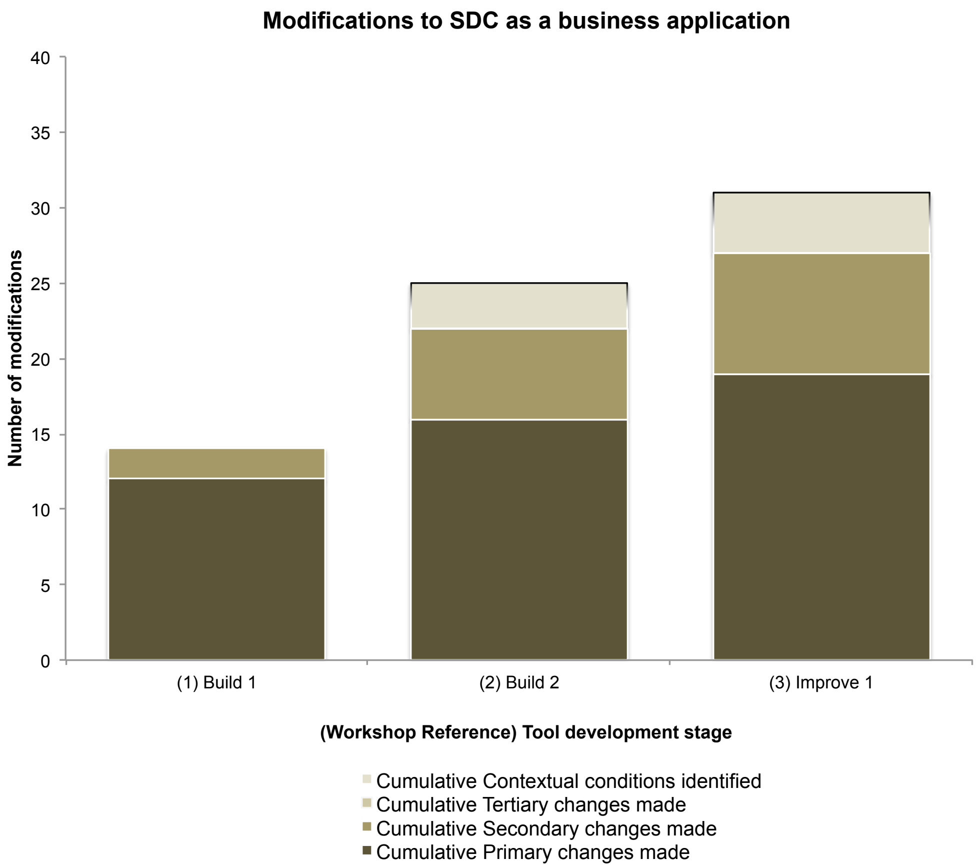


Figure 4 SDC development – number of types of changes to the business application

The number of changes proposed for the graphical representations are summarised in Table 2. No change is required for the PSS abstraction diagram so far, and the total number of changes on the PSS representation diagram is the highest among the five graphical representations in SDC. However, two of the five graphical representations, PSS configuration types and PSS depiction diagram, have been removed from SDC after the first workshop.

Table 2 Changes proposed for the graphical representations

Workshop Reference	Number of changes adopted that impact the use of graphical representations in SDC					Description of key changes to the graphical representations
	Configuration	Depiction	Decomposition	Representation	Abstraction	
1	1	1	3	5	0	The use of PSS Configuration Type (see Step 5 in Figure 2) is completely removed from the SDC. The PSS Depiction step is no longer a step that a drawing, PSS Depiction, is produced (see Step 1 in Figure 2). Instead, a table format template is used. The colours sticky-notes and arrows are simplified for the physical and digital version of PSS Decomposition diagram and PSS Representation diagram (see Step 3 and 4 in Figure 2) The PSS Representation diagram is simplified to only showing the elements that are visible to the customers, and the outer boundary that represents the operating environment is removed. The PSS Representation diagram is changed into a digital-only diagram.
2	0	2	2	1	0	The table format template to support PSS Depiction is enhanced to guide the identification of elements within the PSS and to classify them according to importance to customers. A new symbol (circle) is introduced to the PSS Decomposition and PSS Representation diagrams to mark the elements that are of the highest importance to customers. The PSS Decomposition diagram is to be digitalized by the workshop facilitator within the workshop duration, to enable better use of the diagram for support design modification suggestions.
3	0	0	0	1	0	The PSS representation diagram is modified to become the formation of multiple mini representation diagrams for elements that required attention of the PSS development team.

The graphical representations that are removed for their lack of feasibility and utility

The PSS configuration type was moved from the last step to become the first step in the SDC, and it was removed from the SDC procedure due to its infeasibility to be used in a business setting. The participants in the first workshop spent a lot of time trying to understand what they were supposed to do with the PSS configuration types and could not follow the procedure written for this step. It caused lots of frustration and the facilitators had to abandon this graphical representation in order to continue with the rest of the workshop.

The PSS element identification table, a template that was originally designed to support the drawing of the PSS depiction diagram, was found to be very useful in helping participants to think through the important elements of the PSS. The table was enhanced after the first and second workshops and had replaced the PSS depiction drawing completely since the second workshop.

<u>The graphical representations that are simplified for feasibility and usability</u>

The PSS decomposition and representation steps were found to be laborious to use in a business setting. The main reason for using sticky-notes in these steps was to enable participants to reposition them in the decomposition and representation diagrams when discussions pointed to modifications of the PSS design. For the three workshops, the PSS decomposition step took over one-third of a six-hour workshop to complete. The participants also found it difficult to follow the colour scheme and styles of the sticky-notes and arrows used in this step. It was reflected that the colours and styles of the sticky-notes and arrows were to be simplified for this step to be feasible. Moreover, the decomposition diagram would need to be digitalised, or even better, to be supported by custom-built software, to make it easier and less time-consuming to build. Despite the drawback, the observations and feedback showed that the PSS decomposition step was useful to support NPSSD. To further enhance its utility, a new symbol, a circle, was added to mark elements that are associated with customer wants of higher priorities.

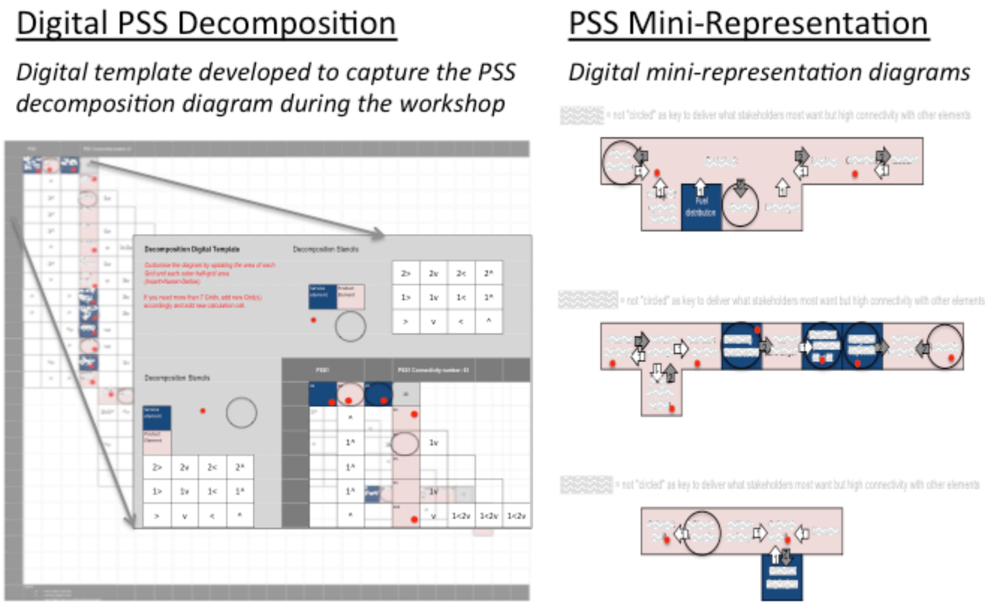
The representation diagram was designed to iterate with the decomposition step in order to visualise the interdependencies of the product and service elements in a PSS design. The PSS representation diagram was built using the information organised in the PSS decomposition diagram. For a complex PSS, such as the PSS design in the second workshop, the size of the physical representation diagram grew to be over 2m x 1.5m, and it became infeasible to complete on a wall. The size of the diagram also prevented the participants to easily identify opportunities to improve the design. The many sticky-notes on a big canvas also, to a certain extent, limited the capability of participations to reposition the sticky-notes in order to learn and communicate the changes proposed through visualisation, defeating the purpose of this graphical representation.

There were six primary and one secondary changes proposed so far for the representation diagram. The primary changes were ways to improve its feasibility and usability to support the design discussion. The secondary change was to digitalise the building of the representation using software. An interesting proposal was created during the third workshop jointly by the facilitators and workshop participants, which was to draw a scaled-down version of representation diagrams using a flip chart, a mini-representation diagram per page. Each mini-diagram focused on an element of interest in the PSS design. Such element could be one that was circled-out as of high importance to potential customers, or one that potentially causes high complexity in the development, usage and maintenance of the PSS. A potentially complex element can be identified in the decomposition diagram by its high dependencies with other elements, shown by the high number arrows going into or out of the sticky-note that represents this element.

In the third workshop, the mini-representation diagrams were found to be very useful in facilitating useful debates that ultimately clarified the design specifications for the participants. It was a stark contrast to the failure of using the full-size representation wall-chart in the second workshop, where time was lost in building the diagram and some participants lost interests in the workshop process.

The resulting graphical representations in SDC

As a result, SDC now contains an elements identification table, which is not counted as a graphical representation, and three graphical representations – PSS decomposition, PSS mini-representations, and PSS abstraction diagrams. Figure 5 shows the digital versions of the modified PSS decomposition diagram and some of the PSS mini-representation diagrams produced in the second workshop.



Real data from the workshop has been redacted for confidentiality.

Figure 5 Digital PSS decomposition diagram and PSS mini-representation diagrams

DISCUSSIONS

Focusing on the external representations in the resulting SDC that are graphical (i.e. diagrams and not tables), the three graphical representations proposed are: PSS decomposition diagram, PSS mini-representation diagrams, and PSS abstraction. The observed gap reported by Blomkvist and Selgelstorm (2014) in service design technique - the use of multiple representations to ease the management of complex information - is potentially bridged by SDC.

The PSS decomposition and PSS mini-representation diagrams demonstrate the benefit of using objects on a canvas to share and re-represent thoughts, and to transform debates in this early stage of development into “persistent referents” (Kirsh, 2010). The PSS abstraction diagram is a different representation of the structure of the PSS, facilitating participants to align their thoughts on the type of system they are designing.

In the three workshops, SDC has passed the initial “Build” phase of the procedural development according to PAR, and is in the phase of “Improve”. More cases are needed to improve and stabilise SDC, to make it more feasible and usable as a design approach for businesses to apply on their new PSS ideas, and to realise the objective of clarifying design specifications.

CONCLUSION AND CONTRIBUTIONS TO THE FIELD

This study has shown the potential of a research instrument to be adapted for business usage. It has also described a design approach that is in its infancy, which uses multiple graphical representations to help new development teams to deal with complex information in the engineering design process.

In the three workshops completed, it was shown that the PSS decomposition and representation diagrams were very useful, but need the most adaptions to become feasible in a business setting. The PSS configuration type and the PSS depiction diagram were found to be not useful in a business setting. The PSS abstraction diagram worked well in both research and business environments.

In terms of academic contributions, first, this study contributes to research methodology by demonstrating the use of PAR to develop a workshop approach that supports a critical business process – new product-service system development. Second, the study contributes to design research / design methodology in terms of the use of standardised graphical representations that involve participants to interact with objects in the process of clarifying design specifications. Although more cases are needed to stabilise SDC as a business application, the resulting design approach and its contingent framework will contribute to PSS development literature.

MANAGERIAL IMPLICATIONS

For practitioners, this study shows that it is fruitful to use a design method that utilises multiple graphical representations. Observations from the three applications of SDC showed that the graphical representations were useful in facilitating the development team members to generate, articulate, evaluate and debate their insights, and to share and maintain their ideas, agreements and disagreements (Blomkvist & Segelstrom, 2014).

The results from this study intend to support new development managers to clarify the required product and service features, the operating environment and the stakeholders of a new PSS. The resulting procedure, once stabilised, will be useful for manufacturers that are adding services, or service providers that are adding products to their offerings, to develop PSS holistically.

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