# Effects of a design support on practitioners designing a Product/Service System – a case study

Abhijna Neramballi[1], Tomohiko Sakao[1], John S Gero[2]

*[1] Linköping University, Sweden*
*Department of Management and Engineering*

*[2] University of North Carolina at Charlotte, USA*

## Abstract

This paper presents empirical evidence on which to ground the understanding of effects of a design support on Product/Service Systems (PSS) designing. The effects are measured by the extent of application of a systems perspective and level of integration of product and service elements during PSS designing. Protocol analyses of a control team and an experiment team, involving experienced practitioners performing an identical PSS design task are conducted. Only the experiment team is provided with the design support. The Function–Behavior–Structure ontology and a scheme for the systems perspective are utilized to code the data. Results show preliminary insight into the influence of a design support. The focus on systems level abstraction shows a three-fold increase, the cognitive effort spent on behavior of structure is halved and the effort on design description is more than doubled, in the experiment team.

*Keywords: Product/Service Systems design, Function-Behavior-Structure Ontology, Protocol analysis, Design support*

## 1 Introduction

There is an extensive literature on studying designing, and on studying design cognition in particular [1], There is increasing interest in researching more foundational questions about designing. One such growing body of research is that of Product/Service System (PSS), which 'consists of a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs' [2]. As customers are increasingly demanding solutions for their needs rather than specific products, companies are increasingly exploring the prospect of developing and offering PSS [3]. Design is considered to be a critical aspect during the development and delivery of PSS as it determines the quality and characteristics of the final offering [4]. The process of designing a PSS is expected to inherently differ from designing its individual product or service part as the activity is conceptually characterized by the integration of the physical and intangible aspects [5], and application of a systems perspective [6, 7]. The differences may be so significant that PSS development is reported to potentially require a dedicated design approach [8, 9], in contrast to the widespread view in academia that suggests that, the fundamental issues and processes in designing are not unique to the nature of the domain [10, 11]. However, this is not examined in this research reported in this paper and it is assumed that the fundamental design cognition of designing PSS matches that of designing generally [10].

Two of the main objectives of research in design are to increase understanding of designing as an activity and to develop tools to aid designers [12]. PSS design research regarding the latter is developing, mainly due to the industrial demand for design support in the form of tools, methods or techniques [13]. The effectiveness of these advancements could be questioned, as they are mainly based on conceptual understanding of the characteristics of PSS designing with limited empirical evidence.  To develop an empirically-grounded understanding of design, it is necessary to obtain reliable empirical insights from the activity of designing and one such way of achieving that is through the study of design cognition [11]. The empirical insights into how designers design products [14, 15] and the influence of design support on product designing [16] is established in academia. However, similar research regarding PSS designing as an activity, is still in its infancy with only a few studies [17, 18]. One such study is a recent explorative work by the authors, that provided preliminary empirical insight into what practitioners discuss during the design of a PSS in terms of distributions of design issues and processes [18]. It provided early indications of design issue distribution differences between other domains of design and PSS design, reporting increased focus on function in the latter. This research demonstrated that PSS designing could be described in the same way at product design. However, there is no similar research that provides empirical insight regarding how the use of a design support influences PSS designing. This lack of knowledge could lead to the ineffective development of PSS design support.

## 1.1 Aim and Research Question

This research aims to provide preliminary empirical insight into the influence of a design support on PSS designing activities with an explorative case study. The results can potentially be utilized as a basis for hypothesis generation. The resulting knowledge from these hypotheses, when tested with statistically reliable data sets can then be utilized by researchers to support the development of effective design support for practitioners [19]. The following research question will be addressed through this case study:

> How do the characteristics of PSS designing vary with and without the use of a design support?

Characteristics of PSS design activities in this research refers to its distribution of design issues and processes, extent of application of a systems perspective and level of integration of product, service and other elements within PSS design. A design support in the form of a set of recommendations for PSS design is adopted from a separate work of the authors [20]. The following sections will describe the research approach, results, discussions and conclusions.

# 2 Research approach

An exploratory case study approach involving two design experiments was conducted with experienced industrial practitioners in a controlled laboratory setting, to investigate the research question. The participants were provided with a conceptual PSS redesign task and were instructed to carry it out in teams of two. A conceptual design task was chosen as it allows the exchangeability of product and service aspects, which is vital for PSS design [21]. The participants were all instructed to engage in a think-aloud protocol [22]. The corresponding data was collected as recordings in both audio and visual formats and was later transcribed. Each pair included a product and a service designer. The teams were assigned to one of two distinct groups: control and experiment group. The experiment group was provided with the design support. The control group was not provided with any such support. The following sections will describe the case, the design support and the methods of analysis.

## 2.1 Description of case and design support

There were two pairs of individuals as participants one in the control group and one in the experiment group. The participants are experienced industrial practitioners based in Sweden. The aim of the design task given to the participants was to conceptually redesign the product and service aspects of an existing PSS (an office use coffee machine), to increase its resource efficiency. A design brief that details information regarding the PSS offering, the provider, customers, and main users, was provided to the participants (see [18]). The same design task was given to the participants in the previous work [18] of the authors. The participants in the experiment group were asked to perform the same task with the use of the design support [20]. The design support is a set of recommendations in the form of a procedure to follow, that is consolidated from the state of the art of PSS design literature (see [20] and the authors' ResearchGate pages as a supplement for the full description). It suggests the designers systematically assign a functional unit for the offering being designed, explore the various stakeholders involved, their potential requirements and value propositions, criteria for potential evaluations, identification of product, service or other elements that address requirements and value propositions, examine balance between the elements from a systems perspective, before selecting feasible combinations of these elements to synthesizing the solutions.

## 2.2 Methods of analysis

Protocol analysis, a highly developed, well accepted rigorous methodology for interpreting verbal data of thought sequences as a valid source of information on cognition [11, 23], is utilized to analyse the empirical data collected. It was chosen over other methods of analysis as it provides both quantitative and qualitative information regarding the protocol data. It has been widely utilized in similar design related research as reported in a recent review of protocol studies by Hay et al. [1], further motivating its use in this context. During the application of the methodology, the protocols are segmented, the following coding schemes are applied, and the segments are categorized accordingly.

### 2.2.1 Function – Behavior – Structure (FBS) ontology

FBS ontology [12] is utilized in this research as one of the coding schemes to interpret and describe the thinking process of the designers during PSS designing. It has been utilized widely in protocol studies as it is independent of the design task, experience of the designers and the settings in which they operate within, allowing the possibilities for comparative assessments of the results

[11], thus justifying its use in this context. This ontology provides a unifying framework for representing the design issues and processes with high level design semantics. The basis for this framework is formed around the following three classes of variables that describe the various aspects of the design object [24]: i) Function (F): describes the purpose of the design object; ii) Structure (S): describes the components of the design object and their relationships; iii) Behavior : describes the behavior expected (Be) or behavior derived (Bs) from the structure. Design requirements (R) represent the requirements the design object is expected to satisfy, and design descriptions (D) represents drawings or written information regarding the design. Since both requirements and descriptions are expressible in terms of either function, behavior or structure, no additional classes of variables are needed to describe them. Through the lens of this framework, the overarching objective of the activity of designing is to transform a set of functions (F) derived from the design requirements (R) into detailed descriptions of the design (D). The transitions between these design issues are design processes and are represented by the eight design processes of: F→Be: Formulation, Be→S: Synthesis, S→Bs: Analysis, Be – Bs: Evaluation, S→D: Documentation, S→S: Reformulation 1, S→Be: Reformulation 2, S→F: Reformulation 3, see [12]. The design issues R, F and Be fall under the problem space of design ($P_s$), and the design issues S, Bs and D fall under the solution space of design ($S_s$) [25, 26]. The P-S index is calculated by taking the ratio of total occurrence of $P_s$ and of $S_s$. An illustration of how this scheme will be applied is given in Table 1.

Table 1. Illustration of FBS coding scheme

| Segment from Protocol data | Design issue | ($P_s$)-($S_s$) |
|---|---|---|
| ”Let us discuss about the heating coil” | S | $S_s$ |
| “It should heat the water” | F | $P_s$ |
| “Up to x degrees” | Be | $P_s$ |
| “It will consume x watts of electricity” | Bs | $S_s$ |
| “The machine needs to be resource efficient” | R | $P_s$ |

### 2.2.2 Coding scheme to capture level of systems perspective and integration

The following coding scheme is proposed and applied to capture level of systems perspective within the protocol data. It is inspired from the work of Gero and Mc Neill [19], originally developed to investigate the hierarchical or systems aspects of the process of designing. In this research, it is contextualized to analyse the levels of application of systems perspective and the level of interaction between the various elements of the system during PSS designing by experienced practitioners, with and without the use of the simple design support. The proposed scheme has three primary levels of design abstraction: i) discrete elements (D): designers focus on a discrete element in a segment (ex. product or service or stakeholders (ex. suppliers, environment, users etc.) or other elements); ii) interactions (I): designers focus on an interaction between two or more discrete elements; iii) systems (S): designers address problems / solutions as an integral system (ex. PSS) involving various discrete elements to provide value, meet requirements (ex. resource or cost efficiency). An illustration of the coding scheme is presented in Table 2.

Table 2: Coding scheme to capture hierarchy

| Segment from Protocol data | Criteria |
|---|---|
| "Let us discuss about the coffee machine" | D |
| "The coffee machine should remotely indicate when it needs to be serviced" | I |
| "A regularly maintained coffee machine can increase resource efficiency" | S |

# 3 Results

## 3.1 FBS Results

Two independent coders were used to generate the coded protocol. They have an average agreement ratio of 81% with the third independent arbitrator, with a standard deviation of 5.52% for this coding scheme. The results of the distribution of the FBS design issues from the control and experiment group are reported in Table 3.

Table 3: Design issue distributions

| | Control group (G1) | Experiment group (G2) | Ratio (G2/G1) | G1 without 'D' | G2 without 'D' | Ratio (G2/G1) |
|---|---|---|---|---|---|---|
| Requirement (R) | 1% | 1% | 1.00 | 1% | 2% | 2.00 |
| Function (F) | 22% | 26% | 1.18 | 24% | 32% | 1.33 |
| Expected Behavior (Be) | 20% | 17% | 0.85 | 22% | 21% | 0.95 |
| Behavior of structure (Bs) | 31% | 16% | 0.51 | 34% | 20% | 0.58 |
| Structure (S) | 18% | 20% | 1.11 | 20% | 25% | 1.25 |
| Design description (D) | 8% | 20% | 2.50 | | | |

The results indicate that there are noticeable changes in Bs and D between the experiment and control groups. Frequency of occurrence of Bs has almost halved and D has increased by around two fold in the experiment group compared to the control group. F and S also show small levels of increase in frequency in the experiment group. The results of distributions of the design issues considered without the frequency of occurrence of D, show the highest increase in occurrence of F, closely followed by S and the design issue with the lowest frequency as Bs. The P-S index of the control group is 0.75, while the P-S index of the experiment group is 0.78. These are very close to each other.

The graphical representation of the dynamic design issues of the control and experiment groups are presented in Images 1 and 2, respectively. These figures are generated using LINKODER a publicly available software (see linkoder.com).

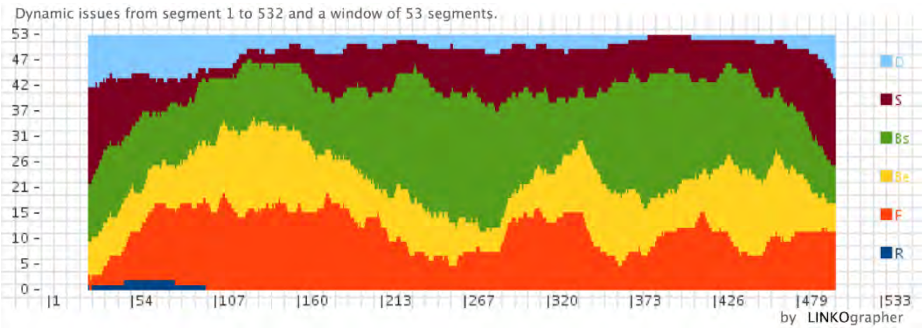


Image 1. Moving average of cognitive effort expended on design issues, control group

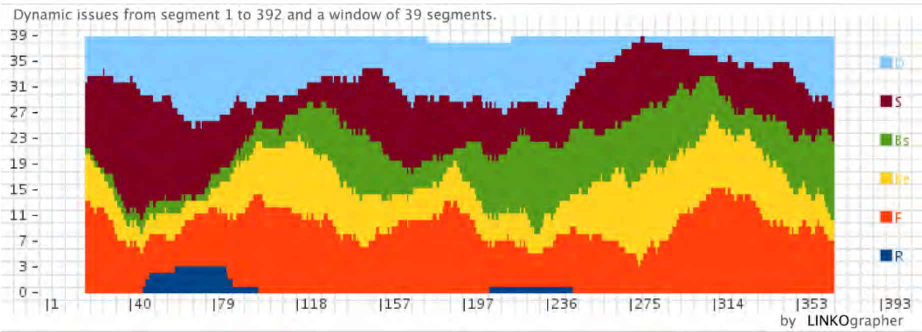


Image 2. Moving average of cognitive effort expended on design issues, experiment group

The results of the distribution of dynamic design processes of the control and experiment group are presented in Table 4.

Table 4: Syntactic design process distribution

| | Control group (G1) | Experiment group (G2) | Ratio (G2/G1) |
|---|---|---|---|
| F→Be: Formulation | 10.8% | 13.8% | 1.27 |
| Be→S: Synthesis | 9.0% | 9.4% | 1.04 |
| S→Bs: Analysis | 12.2% | 10.1% | 0.82 |
| Be – Bs: Evaluation | 36.9% | 18.8% | 0.50 |
| S→D: Documentation | 8.1% | 13.0% | 1.60 |
| S→S: Reformulation 1 | 8.1% | 13.0% | 1.60 |
| S→Be: Reformulation 2 | 5.9% | 10.1% | 1.71 |
| S→F: Reformulation 3 | 9.0% | 11.6% | 1.28 |

## 3.2 Results from systems coding scheme

The two independent coders have an average agreement ratio of 87.3% with the third independent arbitrator, with a standard deviation of 3.49% for this coding scheme. The systems coding results from the control and experiment group are presented in Table 5.

Table 5: Distribution of design criteria of systems coding scheme

| | Control group (G1) | Experiment group (G2) | Ratio (G2/G1) |
|---|---|---|---|
| Discrete (D) | 54% | 37% | 0.65 |
| Interactions (I) | 38% | 36% | 0.94 |
| Systems (S) | 8% | 27% | 3.37 |

The results indicate that there is around a 3-fold increase in the occurrence of systems level abstraction, with balanced distribution of focus on discrete elements and the interactions between them, in the experiment group.

# 4 Discussion and conclusion

The results are utilized to answer the research question "How do the characteristics of PSS designing vary with and without the use of a design support?". Three main characteristics that are expected to be specific to PSS designing are investigated in this research: design issue and design process distributions, extent of systems perspective and level of integration of the elements within the system. The design support provided to the experiment group is a set of procedural recommendations consolidated from the state of the art of PSS design methods. Among other things, the support suggests designers assign functional unit at the begining of the design, to identify and integrate various elements that fulfill the requirements and corresponding functions, and to balance them from the systems perspective. As expected, the results of the experiment group reported a significantly higher degree of systems level abstraction and a balanced focus on discrete elements and the interaction between them. The earlier work of the authors [18] reported that almost half of the cognitive effort spent by designers during PSS designing is on behavior and high degree of effort on evaluation. The current results indicate a noticeable reduction in behavior of structure and evaluation, as a result of the application of the design support. It also shows an increase in the occurrence of design description, with small increases in function, structure and the majority of the design processes. The major changes could potentially be attributed to the increase in systems level abstraction and resulting in the balanced focus on discrete elements and their interactions within the system being designed, potentially caused by the introduction of the design support.

The results of this exploratory case study, provide an early indication regarding the effects of the design support on the characteristics of PSS designing. It suggests that the use of a design support can increase systems level abstraction and modify the focus on discrete elements and their interactions, while potentially reducing the cognitive effort spent on behavior, which otherwise is a dominant design issue in PSS designing. This preliminary insight can be used as a basis for generating hypothesis. However, this study is based on minimal data, thus limiting the external reliability of the results. The immediate future work of the authors will involve hypothesis building and the corresponding testing with statistically significant data sets and the use of a higher level of granularity for the proposed systems coding scheme to obtain richer data.

## Acknowledgements

This research is supported in part by the Mistra REES (Resource Efficient and Effective Solutions) program funded by Mistra (The Swedish Foundation for Strategic Environmental Research) (grant number DIA 2014/16). It is also supported in part by grants from the US National Science Foundation to the third author, Grant Nos. 1463873 and 1762415.

## References

[1] Hay, L., A.H.B. Duffy, C. McTeague, L.M. Pidgeon, T. Vuletic, and M. Grealy, *A systematic review of protocol studies on conceptual design cognition: Design as search and exploration.* Design Science, 2017. **3**: p. 1-36.

[2] Tukker, A. and U. Tischner, *Product-services as a research field: past, present and future. Reflections from a decade of research.* Journal of Cleaner Production, 2006. 14(17): p. 1552-1556

[3] Boehm, M. and O. Thomas, *Looking beyond the rim of one's teacup: A multidisciplinary literature review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design.* Journal of Cleaner Production, 2013. 51: p. 245-260.

[4] Geum, Y. and Y. Park, *Designing the sustainable product-service integration: a product-service blueprint approach.* Journal of Cleaner Production, 2011. 19: p. 1601-1614.

[5] Mont, O.K., *Clarifying the concept of product–service system.* Journal of Cleaner Production, 2002. 10(3): p. 237-245.

[6] Maussang, N., P. Zwolinski, and D. Brissaud, *Product-service system design methodology: from the PSS architecture design to the products specifications.* Journal of Engineering Design, 2009. 20(4): p. 349-366.

[7] Baines, T.S., H.W. Lightfoot, S. Evans, A. Neely, R. Greenough, J. Peppard, R. Roy, E. Shehab, A. Braganza, A. Tiwari, J.R. Alcock, J.P. Angus, M. Bastl, A. Cousens, P. Irving, M. Johnson, J. Kingston, H. Lockett, V. Martinez, P. Michele, D. Tranfield, I.M. Walton, and H. Wilson, *State-of-the-art in product-service systems.* Proceedings of the Institution of Mechanical Engineers - B, 2007. 221: p. 1543-1552.

[8] Vezzoli, C., F. Ceschin, J.C. Diehl, and C. Kohtala, *New design challenges to widely implement 'Sustainable Product–Service Systems'.* Journal of Cleaner Production, 2015. 97: p. 1-12.

[9] Matschewsky, J., M.L. Kambanou, and T. Sakao, *Designing and providing integrated productservice systems – challenges, opportunities and solutions resulting from prescriptive approaches in two industrial companies.* International Journal of Production Research, 2018. 56(6): p. 2150-2168.

[10] Kannengiesser, U. and J.S. Gero, *Is Designing Independent of Domain? Comparing Models of Engineering, Software and Service Design.* Research in Engineering Design, 2015. 26: p. 253-275.

[11] Gero, J.S. *Generalizing design cognition research*. in *DTRS8: Interpreting Design Thinking, DAB documents*. 2010. Sydney.

[12] Gero, J.S., *Design Prototypes: A Knowledge Representation Schema for Design.* AI Magazine, 1990. 11(4): p. 26-36.

[13] Vasantha, G.V.A., R. Roy, A. Lelah, and D. Brissaud, *A review of product–service systems design methodologies.* Journal of Engineering Design, 2012. 23(9): p. 635-659.

[14] Mc Neill, T., J.S. Gero, and J. Warren, *Understanding conceptual electronic design using protocol analysis.* Research in Engineering Design, 1998. 10(3): p. 129-140.

[15] Song, T., K. Becker, J. Gero, S. DeBerard, O. Lawanto, and E. Reeve, *Problem Decomposition and Recomposition in Engineering Design: A*

*Comparison of Design Behavior Between Professional Engineers, Engineering Seniors, and Engineering Freshmen.* Journal of Technology Education, 2016. 27(2): p. 37-56.

[16] Kannengiesser, U. and J.S. Gero, *Can Pahl and Beitz' systematic approach be a predictive model of designing?* Design Science, 2017. 3: p. e24.

[17] Sakao, T., S. Paulsson, and H. Mizuyama. *Inside a PSS Design Process: Insights through Protocol Analysis*. in *International Conference on Engineering Design*. 2011. Copenhagen.

[18] Neramballi, A., T. Sakao, and J.S. Gero. *What do experienced practitioners discuss when designing Product / Service Systems ?* in *Design Computing and Cognition DCC 18'*. 2018.

[19] Gero, J.S. and T.M. Neill, *An approach to the analysis of design protocols.* Design Studies, 1998. 19: p. 21-61.

[20] Sakao, T., Y. Liu, and A. Neramballi, *Enhancing PSS design through big data, IoT and big data analytics*, in *ICED19 22nd International Conference on Engineering Design*. 2019: Delft, in review.

[21] Sakao, T. and M. Lindahl, *A method to improve integrated product service offerings based on life cycle costing.* CIRP Annals - Manufacturing Technology, 2015. 64(1): p. 33-36.

[22] van Someren, M.W., Y.F. Bardard, and J.A.C. Sandberh, *The Think Aloud Method: A Practical Guide to Modelling Cognitive Processes*. 1994, London: Academic Press.

[23] Ericsson, K.A. and H.A. Simon, *Protocol Analysis Verbal Reports as Data*. Revised edition ed. 1993, Cambridge, MA: MIT Press.

[24] Gero, J.S. and U. Kannengiesser, *The situated function-behaviour-structure framework.* Design Studies, 2004. 25: p. 373–391.

[25] Jiang, H., J.S. Gero, and C.C. Yen, *Exploring designing styles using Problem-Solution indexes*, in *Design Computing and Cognition'12*, J.S. Gero, Editor. 2014, Springer. p. 85-101.

[26] Kan, W.T. and J.S. Gero, *Quantitative Methods for Studying Design Protocols*. 2017, Dordrecht: Springer.