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INSIDE A PSS DESIGN PROCESS: INSIGHTS THROUGH PROTOCOL ANALYSIS

Tomohiko Sakao[1], Svante Paulsson[1], and Hajime Mizuyama[2]
(1) Linköping University, Sweden (2) Aoyama Gakuin University, Japan

ABSTRACT
Product/Service Systems (PSS) has been addressed as an interesting research target in the engineering design community. Yet, an understanding of PSS design processes is scarce. Motivated by this gap, this paper aims to analyze, through a *descriptive* study, the details of the entire process of a PSS design case, and thus contribute to a better understanding of PSS design processes. To do so, an example of PSS design was conducted by three people working as a group using a modelling scheme called PSS Layer Method. Then, this design episode was analysed through protocol analysis. The results of the analysis include two reasonable hypotheses. First, PSS design follows a general process of problem solving. Second, it begins with need and value for a customer, addresses mainly lifecycle activities for solutions, and ends back with value. In addition, lifecycle activities might be given a central role within PSS design. However, it should be emphasized that the analysis of PSS design needs to be carried out further with more cases in order to create more robust knowledge.

Keywords: Product/Service System, descriptive study, PSS Layer Method, lifecycle activity, need, value

1 INTRODUCTION
In the much of the manufacturing industry today, numerous companies' business offerings are a combination of physical products and services. In fact, over 50% of the companies in the USA and Finland provide both physical products and services [1]. Service here includes operation, maintenance, repair, upgrade, take-back, and consultation. Some manufacturing firms are even strategically shifting from being a "product seller" towards becoming a "service provider" [2]. In response to this trend, new concepts have been developed, including Product/Service Systems (PSS), which is "a marketable set of products and services capable of jointly fulfilling a user's needs" [3]. In addition to this definition, Tukker and Tischner [4] regard PSS as a value proposition, including its network and infrastructure.
Importantly to the design community, service activity is beginning to be increasingly incorporated into the design space (e.g. see [5, 6]), an area which has been traditionally dominated by physical products in manufacturing industries (see conventional theories for mechanical design; e.g. [7]). However, knowledge on theories in this area is insufficient, as developing such theories has just begun in the last decade. Especially, an understanding of PSS design processes is scarce. In fact, several design guidance procedures have been proposed and applied to cases in different sectors (e.g. [8-12]). Yet, very little research has been carried out on how PSS is actually designed. The processes of PSS design are not really understood scientifically in detail; what, for example, is happening inside the design processes? This has been a challenge in design research in general (e.g. [13]). Thus, systematizing knowledge of PSS design is demanded.
Motivated by this gap, this paper aims to analyze, through a descriptive study [14], the details of the entire process of a PSS design case, and thus contribute to a better understanding of PSS design processes.
To do so, an instance of PSS design was first conducted and recorded to improve a given PSS offering existing in the marketplace. The PSS design was carried out by three people working as a group. Then, this design episode was structured based on a coding scheme proposed by Gero and Mc Neill [15] and analysed to capture some salient characteristics of PSS design.
The remainder of the paper consists of the following: Section 2 reviews existing literature about PSS design and grounds our research motivation; Section 3 describes the adopted methods, including

protocol analysis; Section 4 shows the results of the analysis; Section 5 discusses the results; and Section 6 concludes the paper.

2 PSS DESIGN – EXISITNG INSIGHTS AND RESAERCH MOTIVATION

In PSS research in general, thus far there has been relatively more work with the analytical approach (e.g. [16]), and less work with PSS synthesis. This is quite natural, since PSS researches have been initially approached from the environmental viewpoint. In the PSS design research area, some methods useful for design have been proposed. For instance, designing Total Care Products (Functional Products) [11, 12], which comprises combinations of hardware and support services, has been proposed. Several methods for designing PSS have also been proposed (e.g. [8, 9, 17-19]). In addition, a method for producing specifications for products from PSS architectures was also proposed [20]. Furthermore, CAD (computer-aided design) software for PSS design has been proposed [21, 22]. Most such methods and tools have been developed based on theories and methodologies for conventional product design (e.g. [7, 23]), and extended through logical reasoning of what extension and modification is needed for integrating services to products. It is surprising that no research of developing PSS design methods has come out explicitly from a descriptive study of an actual PSS design process.

In addition, application of a design process to a real case in industry has been also reported (e.g. [8-10]). However, existing literature about application of PSS design methods shows the outcomes of design, i.e. design solutions, and the information about the processes is qualitatively written and limited. Therefore, few insights about PSS design processes are available from such literature. As Isaksson et al. [24] point out, how PSS is being developed in industry is less clear.

Thus, a review of existing relevant literature reveals a lack of deep insight into PSS design processes. This gap motivates us to conduct this research in order to understand more about PSS design processes in detail, corresponding to a descriptive study [14].

3 RESEARCH METHOD

3.1 Protocol analysis

This research adopts protocol analysis in order to describe, structure and analyse the process of a PSS design episode. It has been, based on the "think aloud" method introduced by Ericsson and Simon [25] and further developed by van Someren et al. [26], developed by Gero and his colleagues [15, 27] to analyze a process of technical problem solving. Protocol analysis facilitates detailed inspection of all the protocol data in a given process that has rich information of what is happening in a process (see other research of protocol analysis in different fields in [28-33]). In addition, it derives quantitative and objective information across the temporal dimension, because it can follow a certain predefined framework that captures how a designer confronts and handles a problem [15, 27]. Therefore, it is a powerful tool for the purpose of this research. This feature cannot be obtained by other methods such as an interview.

However, there has been little attempt to apply protocol analysis to PSS design. In some existing research of physical product design [15, 27], Function, Behaviour, and Structure were adopted to code an aspect of the problems addressed in the protocol, which is interpreted as identification of elements of a design object. This is an issue to apply protocol analysis in this research, because a design object to be addressed in PSS design is expanded from the conventional product design [22]. The solution adopted in this research is described in the next section.

3.2 PSS Layer Method

It is natural that a design object in the case of PSS design is expanded from product design, because PSS includes service in addition to a physical product [22]. The question is which set of parameters in the case of PSS should be indispensible parameters of a design object. Although the design community doesn't seem to agree to it, an initiative of consolidating notions of PSS based on of the PSS Layer Method [34] can be found in [35]. This research employs the nine dimensions of this model.

This model adopts the nine dimensions by reflecting divergent viewpoints of different actors involved in PSS, as well as various aspects not only about the physical product but also the business model. The nine dimensions include the following. Needs (dim. 1) are satisfied by Customer Value (dim. 2), which a customer perceives. Such value has to be created by Deliverables (dim. 3), which have value for the customer. The deliverables are result of delivery processes, i.e. Lifecycle Activities (dim. 4). To implement a lifecycle activity chain, resources are needed. Actors (dim. 5), Core Products (dim. 6) and Periphery (like IT infrastructure or public transport systems) (dim. 7) are such resources. Contract Elements (dim. 8) frame the entire value creation process, including Finance (dim. 9), offerings, and finally the entire business model. See details in [34].

Table 1. Categories for the micro strategies

Name	*Abbr.*	*Example*
Introducing Problem	**I**	
Discovering a Problem	ID	"I think this is a problem..."
Clarifying a Problem	ICL	"...this is because of..."
Correcting a Problem	ICO	"Wouldn't this rather be the real reason to the problem?".
Retracting a Previous Problem	IR	"This isn't really an issue that needs to be investigated."
Making a Problem Design Decision	IM	"Let's go this direction with the problem…"
Analyzing Problem	**Z**	
Analyzing a Problem	ZAZ	"What is the problem leading to..."
Questioning a Problem	ZQ	"Is that really a part of the problem?"
Justifying a Problem	ZJ	"This is a problem because of..."
Agreeing to a Problem	ZAG	"I agree with you that that is an issue."
Disagreeing to a Problem	ZD	"I don't think that is a problem."
Evaluating a Problem	ZE	"That's an important requirement..."
Postponing Analysis of the Problem	ZP	"I can find that out later."
Proposing Solution	**P**	
Proposing a Solution	PS	"The way to solve that is..."
Clarifying a Solution	PCL	"This is a good solution because of..."
Correcting a Solution	PCS	"This is has to be changed."
Retracting a Previous Solution	PR	"That approach is no good, what of we..."
Making a Solution Design Decision	PM	"OK. We'll go with that one…"
Analyzing Solution	**A**	
Analyzing a Proposed Solution	AAZ	"That will work like this..."
Questioning a Proposed Solution	AQ	"Why is that good?"
Justifying a Proposed Solution	AJ	"This is the way to go because…"
Agreeing to a Proposed Solution	AAG	"I agree with that solution."
Disagreeing to a Proposed Solution	AD	"I don't agree on that part."
Postponing Analysis of a Proposed Solution	AP	"We'll need to do work that out later."
Evaluating a Proposed Solution	AE	"This is faster, cheaper etc…"
General Strategies	**G**	
Consulting External Information	GC	"What are my options…?"
Postponing a Design Action	GP	"I need to do…later."
Looking Ahead	GA	"These things will be trivial to do."
Looking Back	GB	"Can I improve this solution?"
Discussion Strategies	**D**	
Permission Request	DPR	"Can I say something?"
Confirmation Request	DCO	"Does everyone understand?"
Understanding Request	DU	"Is that a good idea?"
Clarification Request	DCL	"Can you describe that part further in detail?"
Affirmative Response	DAR	"Yes."
Negative Response	DNR	"No."
Explicit Strategies	**E**	
Referring to Application Knowledge	EA	"In this environment it will need to be…"
Referring to Domain Knowledge	EK	"I know that these components are…"
Referring to Design Strategy	ES	"I'm doing this the hard way…"

3.3 Adopted method

This section describes the method adopted for this research based on [15] and [34] with focus on the adjustment. The coding scheme is adjusted from cases in the literature [15, 27], where the scheme was based on designing a physical product. Thus, the nine dimensions of the PSS Layer Method [34] (as shown in Table 3 with abbreviations used in the paper) are substituted to the set of Function, Behaviour, and Structure in the existing cases [15, 27].

The same macro strategies are used as in the existing cases [15, 27] (see Table 2). Note that Top-Down is interpreted in the PSS-design context as a process of elaborating need/value and identifying product/service (Bottom-Up for reasoning on the opposite direction). On the other hand, the micro strategies shown in Table 1 are used after modification of the existing cases [15, 27]. Introducing Problem, General Strategies, and Discussion Strategies are newly introduced groups of categories at a higher level. There are two reasons for this addition. First, the PSS design process is characterized to be a zigzag process between the problem space and the solution space (e.g. [8]), while a traditional product design process focuses more on exploration in the solution space. Therefore, the group of categories, Introducing Problem, was foreseen to be useful. Second, the PSS design to be analyzed is conducted by multiple people, and thus it is more likely to have sentences questioning or attempting to agree with other people in the design episode. Thus, the groups of categories, General Strategies and Discussion Strategies, were added.

In sum, the procedure to structure the transcribed dialogues of the design episode is as follows.

1. Segmentation of dialogues
   Segmentation is the process of dividing the protocol into utterances.
2. Encoding of each segment
   This is done from three aspects, i.e. the PSS dimension, the micro strategy, and the macro strategy. The alternatives are shown in Tables 1, 2, and 3. This is done independently by two people. Then, coding consistency is checked through comparing the two different protocols to derive the final protocol by the two people. This aims to increase the robustness of the final protocol. Note that an alternative, “no dimension applied”, was possible to be chosen for the PSS dimension.

Table 2. Categories for the macro strategies

Name	*Abbr.*
Top-Down	TD
Bottom-Up	BU
Decomposing Problem	DE
Backtracking	BT
Opportunistic	OP

Table 3. Categories for the PSS dimensions

Name	*Abbr.*
Need	N
Value	V
Deliverables	D
Lifecycle Activities	L
Actors	A
Core Products	CP
Periphery	P
Contract Elements	CE
Finance	F
No dimension applied	X

4 ANALYSIS OF A PSS DESIGN EPISODE

4.1 Addressed PSS offering

The company develops, manufactures and delivers drilling equipment for e.g. construction business. Training, spare parts delivery and maintenance, repair and overhaul are part of the company’s service portfolio. The motivation of this company to provide PSS is to create higher value for customers/users. The PSS offering investigated was among their major services provided. Instead of selling a physical product alone, i.e. a drilling machine, the company also delivers warranty of quality, original spare parts in time, early information on the next MRO (maintenance, repair and overhaul) activities, grease and oil in adequate quality, cleaning equipment, and a service binder. Lifecycle Activities are early fault detection, MRO prognostics and execution including scheduling, transport of spares to the field and take back of rotatable and broken parts. See details of the offering described by the PSS Layer Method in [36].

4.2 Conducted design

Task of design

The task of this design was to find several rational improvement options of this offering and represent them on the PSS Layer Method approximately within one hour. This was conducted by a group of three designers in a collaborative manner.

Preconditions of designers

Three designers were nominated from masters students majoring in mechanical engineering at Kyoto University, Japan. They had basic knowledge about industrial economics on top of knowledge in mechanical engineering.

Preparation of design

Before conducting the design, the designers accomplished the following in this order.

1. Understanding the background for interest in PSS by industry in general
2. Understanding the PSS Layer Method as a method
3. Understanding the addressed offering through studying materials (brochure, etc.) from the company, and by visiting a tunnel construction site, where similar services and the same core product of the PSS offering were provided by the company, located in Kumano, Japan.
4. Creating individually one or two improvement ideas based on the current offering described in the PSS Layer Method by a developer and an expert of the method.
5. Reviewing feedback about the description from the PSS Layer Method expert in order to correct misunderstandings and to stimulate more ideas.
6. Understanding how the design should be conducted, e.g. by thinking aloud.

Each designer spent around 14 hours for the activities above, excluding the visit to the site. Note that the designers were not allowed to exchange information about the design with the others in order to prevent any co-development in advance of the design.
It should be noted that the designers did not learn any particular methods for PSS design in order not to influence the design process.

Environments of design

The design episode was created in the form of group discussion in the Japanese language, the mother tongue of the three designers. The execution of the design took place on October, 2010. A poster-sized paper was used to describe information via post-its for the nine dimensions. In addition, a whiteboard and pens were used for complementary means. Besides the three designers, two people were present during the design. One of them, who had more information about the offering and the company, accompanied them with the aim of ensuring that everything went according to plan. This person also worked as a consultant with external sources during the design. This person, as well as the other attendant, were transcribers and encoders of the protocols to get the best possible insight into the design activities.

Method of recording

The equipment used for both audio and video recording was two video cameras with mobile microphones to give the best possible sound recording. A couple of extra sound recorders were used as a backup.

4.3 Results of the analysis

Outcome – Generated ideas for improvement

The two encoders abstracted distinguishable ideas generated during the design for improving the offering as follows.

1. Have an on-site service technician for enabling quicker service and sharing more information on machine operation.
2. Provide more information about the provider's costs with a customer for more transparency of the cost structure.
3. Estimate economic costs of services, particularly for a concerned customer.
4. Introduce an IT System for the different actors to share the current status of a machine and their needs.
5. Introduce a *kaizen* system at the site to facilitate machine operation more efficiently.
6. Improve safety for machine operators (usually not from the PSS provider).
7. Introduce qualification skills for machine operators to assure their properness of operation.
8. Make the charging scheme of services easier for a customer to project its economic cost by.
9. Support the customer's CSR (corporate social responsibility) activities at the construction site.

Segmentation and encoding

The design episode lasted for 1 hour 13 minutes and 29 seconds, and was transcribed into 1,449 segments. Table 4 is an example of a part of the segmented protocols, which has been translated from

Table 4. A part of segmented protocols

Time	*PSS*	*Mi*	*Ma*	*D*	*Dialogue*
00:09:27	N	ID	TD	2	So, it's a fact that the workers' skills are not enough.
00:09:29	N	ZAG	TD	1	That's right.
00:09:30	N	ZAZ	TD	2	So, the method of solving that is...
00:09:32	N	ID	TD	1	Their skills aren't enough... but we can't really measure that...
00:09:36	N	ZQ	TD	2	Their skill levels are unclear?
00:09:38	N	ZAZ	TD	1	Unclear.
00:09:40	N	ID	DE	3	We can't measure it... So the problem is that we can't know how skilful each worker is?
00:09:46	N	ZAG	DE	1	Right...
00:09:48	N	ID	DE	3	Or is it really? Isn't the problem that they don't have enough skills?
00:09:52	N	ID	DE	1	Well, no but... Simply put the problem I thought about was that you would like to be able to use the product for a longer time…
00:10:02	N	ZAG	DE	2	Right.
00:10:03	N	ZAZ	DE	1	And , well, the most important factor there is...
00:10:07	N	ZAG	DE	2	Yeah...
00:10:08	N	ZAZ	DE	1	That the workers skills are quite low, so... well...
00:10:14	N	ZAZ	DE	2	They're focusing on the wrong parts.
00:10:15	N	ID	DE	1	Focusing on the wrong parts, right...
00:10:18	N	ZAZ	DE	2	I see, the workers' overall skills are too low.
00:10:20	N	ZAG	DE	1	Yes.
00:10:21	N	ZAZ	DE	2	Well, I'm not personally sure about it but let's go with that for the moment.
00:10:23	N	ZAG	DE	3	Ok.
00:10:25	N	ZAG	DE	2	Low skills... right
00:10:29	N	ZAZ	DE	1	Right, so the next step is...

Japanese into English. The Time column shows what time the specific segment starts. PSS is an abbreviation for a dimension for the PSS Layer Method. The Mi and Ma columns specify which type of micro and macro strategies are used, respectively. The D column, for designer, specifies which designer out of the three (labelled 1, 2, and 3) spoke the dialogue. In the Dialogue column, the designer's words are transcribed. In this column, short pauses are represented by '…' in the text.

Coding consistency

Coding consistency was checked through comparing the two different protocols to reach the final coding. The results are shown in Table 5, where the first column shows agreement between two encoders. The second and the third columns show agreement within Encoder A and Encoder B, respectively. For example, in categorizing the PSS dimensions, two encoders agreed with 67% of their first codings, while the first coding by Encoder A was different from the final one with 8%. The ratio of agreement between the encoders in the micro strategies (Mi) was the lowest, 28%.

Table 5. Agreement between codings

	Between the first codings by Encoders A and B	Between the first coding by Encoder A and the final one	Between the first coding by Encoder B and the final one
PSS	67%	92%	74%
Mi	28%	72%	42%
Ma	42%	75%	60%

Overall trend along the timeline

Figure 1 shows the transitions of dialogues of the whole PSS design along the timeline in terms of micro strategies, macro strategies, and PSS dimensions (from the top). Note that micro strategies are categorized into a higher level and limited to the four groups.

Figure 1 shows, for instance, that the PSS dimensions begin with the customer view, take a descent through the dimensions to return to the customer view later. After around 27 minutes, the graph for the PSS dimensions shows a focus change from the customer view to the Lifecycle Activity, and then other dimensions. Note that discontinuous parts of each graph mean no appropriate category assigned to the corresponding segment.

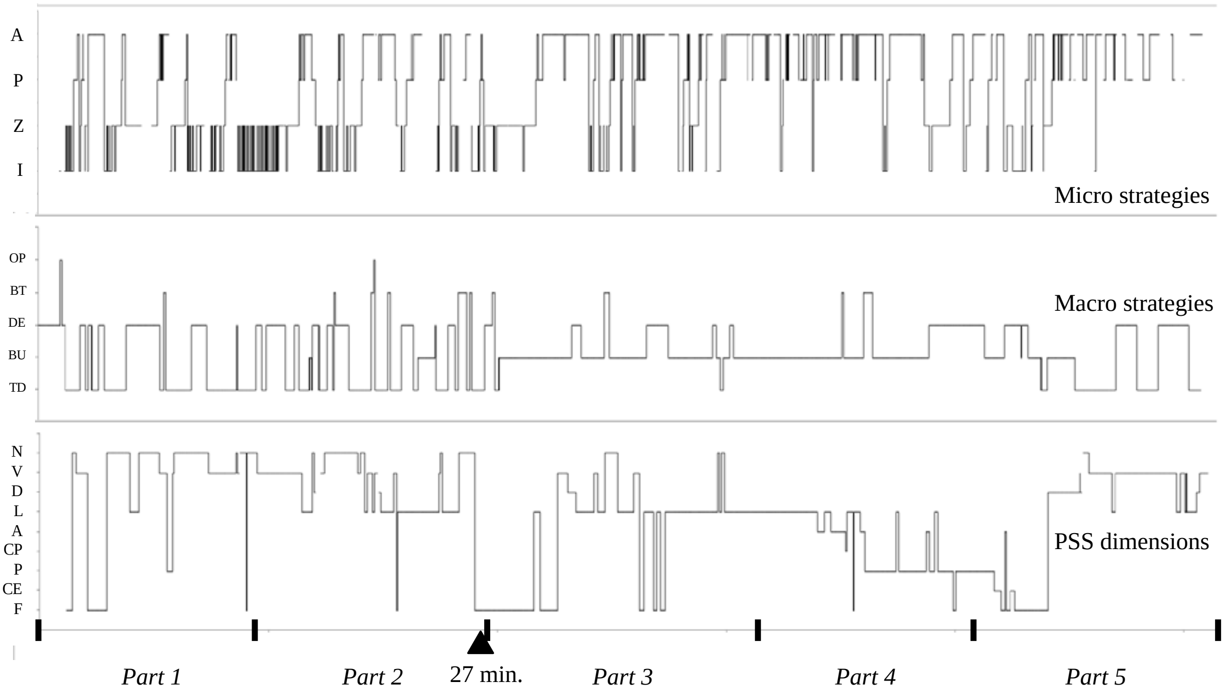

Figure 1. Transitions of dialogues along the timeline

Analysis by divided parts

To make the results easier to understand, the design episode has been divided into five parts. Part 1 stands for the first 300 segments (about 15 minutes) of the design episode, while Parts 2, 3, 4, and 5 stand for 301-600, 601-900, 901-1200, and 1200-1449, respectively. Tables 6 and 7 show time lengths of each micro/macro strategy used and those of each PSS dimension discussed, respectively. All the numbers in these tables are in percentage of the length of the whole PSS design; 100, for instance, means 100% and corresponds to 4,409 seconds (1 hour 13 minutes and 29 seconds). The numbers in bold on shaded cells are above the average.

Table 6 (a) shows that two micro strategies, Introducing Problem (I) and Analyzing Problem (Z), are used in earlier parts, while the strategy Analyzing Solution (A) is used later. Actually, Introducing Problem (I) and Analyzing Problem (Z) accounted for 51% within Parts 1 and 2. Table 6 (b) shows a clear shift of the macro strategies used in Parts 1/2 and Parts 3/4/5, from Top-Down (TD) to Bottom-Up (BU).

Table 7 shows that the customer view, i.e. Need and Value, are discussed 12% (8% and 4% each) in Part 1 and 10% in Part 2. Actually, 60% of the time in Part 1 and Part 2 was spent in these two dimensions. In Part 3 and Part 4, the Lifecycle activity rose to 51%, while the customer view fell to 8%. In the last part, Value is heavily discussed (8/22 (actually 37%) within Part 5). All these numbers support the qualitative observation mentioned previously. In addition, the dimension with the highest frequency was Lifecycle Activities with 30% of the total time, followed by Value (20%). Furthermore, noticeable from the other dimensions is that Core Products (CP) is almost nonexistent. Table 7 shows that Parts 1 and 2 are dominant in the time for Need and Value to be discussed (66%).

Table 6. Length (in percentage) of each strategy used along the timeline

(a) Length of the micro strategies used

Part \ Mi	I	Z	P	A	G	D	E	Total
Part 1	**5**	**6**	1	**3**	0	1	2	19
Part 2	**5**	**4**	3	**5**	1	1	1	20
Part 3	2	**5**	**3**	**10**	0	0	0	21
Part 4	1	2	2	**12**	0	1	0	19
Part 5	2	2	**3**	**10**	0	1	**3**	22
Total	15	19	13	40	2	4	8	100

(b) Length the macro strategies used

Part \ Ma	TD	BU	DE	BT	OP	Total
Part 1	**11**	0	**8**	0	0	19
Part 2	**10**	2	**7**	1	0	20
Part 3	1	**16**	4	1	0	21
Part 4	0	**16**	2	1	0	19
Part 5	**7**	**5**	**10**	0	0	22
Total	28	39	30	3	0	100

Table 7. Length (in percentage) of each PSS dimension being discussed along the timeline

Part \ PSS	N	V	D	L	A	CP	P	CE	F	X	Total
Part 1	**8**	**4**	0	1	0	0	1	0	**2**	**2**	19
Part 2	**5**	**5**	0	**7**	0	0	0	0	1	1	20
Part 3	2	2	1	**11**	0	0	0	0	**6**	0	21
Part 4	0	0	0	**9**	**2**	0	**7**	0	0	0	19
Part 5	0	**8**	**3**	2	0	0	**3**	1	**4**	0	22
Total	16	20	4	30	3	0	11	1	14	3	100

Table 8. Length (in percentage) of each PSS dimension being discussed

(a) Length related to the micro strategies

PSS \ Mi	I	Z	P	A	G	D	E	Total
N	**5**	**5**	1	**2**	1	0	1	16
V	**4**	**3**	**3**	**7**	0	1	**3**	20
D	0	1	1	**2**	0	0	0	4
L	**1**	**3**	**5**	**16**	1	1	**3**	30
A	0	0	1	1	0	1	0	3
CP	0	0	0	0	0	0	0	0
P	1	**2**	1	**7**	0	0	0	11
CE	0	0	0	0	0	0	0	1
F	**3**	**4**	1	**5**	0	0	0	14
X	0	0	0	0	0	1	1	3
Total	15	19	13	40	2	4	8	100

(b) Length related to the macro strategies

PSS \ Ma	TD	BU	DE	BT	OP	Total
N	**8**	1	**5**	1	0	16
V	**11**	2	**7**	0	0	20
D	1	**3**	0	0	0	4
L	**5**	**18**	**6**	0	0	30
A	0	**3**	0	0	0	3
CP	0	0	0	0	0	0
P	0	**5**	**4**	1	0	11
CE	0	1	0	0	0	1
F	**3**	**6**	**4**	0	0	14
X	0	0	**3**	0	0	3
Total	28	39	30	3	0	100

Analysis of combination between strategies and PSS dimensions

Table 8 shows time lengths of each PSS dimension discussed in combination with micro/macro strategies. The numbers in bold in the shaded cells are above the average in these tables as well. All the numbers are in percentage in the same manner as Tables 6 and 7; 100 means 100% and corresponds to 4,409 seconds. For example, the time for Lifecycle Activities (L) to be discussed with the micro strategy Analyzing Solution (A) accounts for 16% of the whole design, as shown in Table 8 (a). In the same way, Table 8 (b) shows the time for Value (V) to be discussed, with the macro strategies Top Down (TD) and Decomposing Problem (DE) accounting for 11% and 7%, respectively.

The customer view, i.e. Needs and Value, shares highly in Introducing Problem (I) - 63%. This means that most problems were introduced when discussing Needs and Value of the customer. In addition, for the customer view, i.e. Needs and Value, Top Down (TD) and Decomposing (DE) strategies were dominant to be combined, with 84% for Needs and 90% for Value. On the other hand, Lifecycle Activities (L) were combined 16% with Top Down (TD) and 61% with Decomposing (DE), as well as 22% with Bottom Up (BU).

The highest percentages were taken out from Table 8 (a) and (b) into Table 9 (a) and (b), respectively. Table 9 (a)/(b) shows combinations of a PSS dimension and a micro/macro strategy that are addressed most frequently.

Table 9. Ranking of length of discussed combination

(a) PSS dimension with the micro strategies

1: Lifecycle Activities – Analyzing Solution	16%
2: Value – Analyzing Solution	7%
3: Periphery – Analyzing Solution	7%
4: Need – Analyzing Problem	5%
5: Need – Introducing Problem	5%
6: Lifecycle Activities – Proposing Solution	5%

(b) PSS dimension with the macro strategies

1: Lifecycle Activities – Bottom Up	18%
2: Value – Top Down	11%
3: Need – Top Down	8%
4: Value – Decomposing Problem	7%
5: Lifecycle Activities– Decomposing Problem	6%
6: Finance – Bottom Up	6%

5 DISCUSSION

As explained at Table 6, as a general trend for the used macro strategies, the whole design episode began with Top Down and Decomposing Problem, went through Bottom Up, and ended with all of the three. Regarding the micro strategies, it started with Introducing Problem, Analyzing Problem, and Analyzing Solution, went in the middle through more Analyzing Solution, and finished with Analyzing Solution. These general trends observed in this particular PSS design follow the characteristics of a problem solving process in general. Regarding micro strategies, similarity like high percentage of time spent on Analyzing Solution can be found in the previous analysis of designing a physical product [15].

As explained at Table 7, simply put the entire design episode spent major time on Need and Value in the beginning, shifted to focus mainly on Lifecycle Activities with addressing Periphery and Finance, and closed with a focus on Value. High frequencies of Periphery and Finance are caused by the improvement options derived from this particular design. If the discussed improvement options were about the PSS' core products, the frequency of Core Products (CP) might have been as high as Periphery or Finance in this case.

Described in the previous two paragraphs is a description of the whole design episode containing nine different design solutions shown in Section 4.3. This paper did not discover how these nine solutions were generated; e.g., if they were derived in parallel or in a sequence on the time line. Therefore, there is risk of identifying general patterns like those mentioned before. However, it is reasonable to make two hypotheses: H1) PSS design follows a general process of problem solving; and H2) PSS design begins with Need and Value, addresses mainly Lifecycle Activities with particular dimensions addressed for solutions, and ends with Value.

As mentioned with Table 7, Lifecycle Activities was the most frequently discussed dimension. In addition, the combination between Lifecycle Activities and Analyzing Solution was ranked at the top in terms of frequency as shown in Table 9 (a). These facts in this design may give a central role to Lifecycle Activities.

In more detail, investigating the frequency of the combinations between a PSS dimension and a micro/macro strategy in each Part would be also interesting to calculate in the future. This data would make even clearer what is happening in a PSS design process.

From the viewpoint of developing methods/tools to support PSS design, developing the methods/tools supporting the combinations in Table 9 is implied to be more focused on than other combinations. It would be of interest to question to the research community if, for instance, the process of analyzing solution at the level of lifecycle activities (with the highest ratio in Table 9 (a)) has been the target of research sufficiently or that process deserves more attention. Yet, it should be emphasized that this ranking needs to be investigated with more cases.

As shown in Table 7, Core Products (CP) was virtually untouched at all in this PSS design. This is due to the fact that all the improvement options were not directly about the core product. The reason for this can be caused by relatively less information that designers had about the core product. On the other hand, the designers could and did reason about the Finance, e.g. by referring to offerings in other sectors. This implies that the time spent in each dimension is dependent on the competence of the designers, as well as the type of offering and sector.

Furthermore, the capacity and skills of the designers are interesting factors that influence on the outcomes and the process of the design. This design episode was created by master course students. They do not have all the knowledge and experiences that experienced designers in the example company ought to have. There is a possibility that the created design solutions are less realistic and it was due to their lack of knowledge and experiences. However, the fact that they are not bound by certain routines of design at the example company or the industry is expected to have brought more neutral results.

Verifying the encoding, Table 5 clearly shows the difficulty of encoding the micro strategies. The high number of categories made it harder to come up with the same alternatives between the two encoders. In addition, it can be hard to discriminate among these categories. For instance, it is hard to determine exactly when the switch took place between Introducing Problem and Analyzing Problem.

6 CONCLUSION AND FUTURE WORK

This paper conducted in-depth analysis of the entire process of a design episode to improve a PSS offering in the marketplace as a first attempt within the engineering design community. The adopted methods were protocol analysis with extension by the authors and the PSS Layer Method. The insights gained through this research include reasonable hypotheses that PSS design follows a general process of problem solving, and that PSS design begins with Need and Value, addresses mainly Lifecycle Activities with particular dimensions addressed for solutions, and ends with Value. In addition, Lifecycle Activities seems to play a central role in design. Although this paper contributed to a greater understanding of a PSS design process scientifically and in quantitative terms, more research is needed to draw general conclusions. Yet, this paper presented preliminary results of investigating what is happening inside a PSS design process.

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Contact: Tomohiko Sakao
Environmental Technology and Management,
Department of Management and Engineering, Linköping Institute of Technology,
Linköping University
581 83 Linköping
Sweden
Tel: Int +46 13 282287
Email: tomohiko.sakao@liu.se
URL: www.iei.liu.se/envtech/om-oss/tomohiko_sakao

Tom is Professor of IPSE (Integrated Product Service Engineering) and Ecodesign (Environmentally conscious design). His focus at present is environmental and economic sustainability in manufacturing industries (from perspectives of both suppliers and purchasers) in the matured economy.