Environment-Based Design (EBD) Approach to Formalize Product-Service Systems (PSS) Design Process

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Abstract

Environment-Based Design (EBD) Approach

to Formalize Product-Service Systems (PSS) Design Process

Yuyang Shi

In the past decade, Product-Service Systems (PSS) have been adopted by companies as a business model that can fulfill customers' needs better, enhance market competitiveness and achieve sustainability. PSS integrates tangible product and intangible service in different ratio, which makes its design process complicated. However, in the design discipline, there has not been enough discussion for the methodological implications of PSS design, even though design components play a critical role in the development of PSS. In this thesis, a systematic approach — Environment Based Design (EBD) methodology is applied to formalize the PSS design process, focuses on analyzing the environment components and their relationships. The comparison between EBD and the conventional PSS design methodologies are conducted. A PSS life cycle model generated according to the EBD analysis is proposed in order to help designers respond quickly to changes from the environment along the whole life cycle. The benefits resulted from EBD based PSS design process are discovered. A case study of elevator PSS design reveals the effectiveness, efficiency and the benefits of EBD methodology.

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Chapter 1

Introduction

1.1 Background and Motivation

In today's competitive business environment, industries need to improve their strategy in order to attract and retain customers. The manufacturing industries regard services as vitally important for improving market acceptance and market share in global competition. The concept of Product-Service Systems (PSS) (Baines et al., 2007; Goedkoop et al., 1999; Manzini et al., 2001; Mont, 2002) is a combination of physical products and non-physical services, has increasingly motivated by both manufacturers and customers because it is growing into a dominating economic factor for many companies while fulfils customer needs more than with traditional processes.

Since the markets for many types of consumer goods are saturated, companies increasingly use services to differentiate themselves from competitors. Pre-use, use, and post-use services accompany the product on its life-cycle, and deliver benefit as well as increased value to customers (Sakao and Lindahl, 2009).

The field of PSS research is not fully mature and industries require support in terms of tools, techniques and methods. In literature, several methodologies have been proposed to support them. But still, most PSSs in the market today are developed conventionally, adding services to an already existing physical product. This, of course, creates value, but the benefits for customers and producers mostly remain modest, since the full potential of integrated PSS development is seldom realized. In addition, current PSS development is carried out conventionally, which means intuitively and often more on a trial-and-error basis than with a structured approach. To design and develop PSS efficiently and effectively, the way companies design and develop must be changed (Sakao and Lindahl, 2009).

Environment-Based Design (EBD) was a generic design methodology developed and proposed by Zeng (2011, 2004), is based on the foundation of the recursive logic of design, according to which design is a recursive process that iterates between design requirements and solutions until the final solution is found (Zeng and Cheng, 1991). EBD is considered to be capable of guiding designers through the fuzziness and the ambiguity of raw requirements given by customers, finding and asking the right questions about the environment of the target product, then identifying real requirements that are explicit enough to represent customer expectations correctly. Using EBD approach to formalize and guide the PSS design process should have a good effect that can improve the effectiveness and efficiency of the design stage and save time and cost for the design team.

1.2 Objective

As described in the background, we can see that there is a need for a systematic design methodology for guiding the PSS design. The first objective of this thesis is to apply EBD approach to formalize and guide PSS design process by analyzing the environment of the PSS and identifying the environment components of it. Comparison between EBD and former PSS design methodologies is conducted and benefits of EBD based PSS design process are summarized. The second objective is to propose a life cycle model for PSS, since there is no existing life cycle models accepted by the majority, and only few of them isolate services from products. The proposed EBD based PSS life cycle model can help designers respond quickly to changes from the environment along the whole life cycle.

1.3 Contributions

This thesis contains the following contributions:

1. Applied EBD approach to formalize and guide PSS design process and understand the environment of PSS.
2. Proposed a PSS life cycle model based on EBD methodology that distinguish services from products.
3. Conducted a case study by applying EBD approach and the proposed life cycle model.

1.4 Thesis outline

The rest of the thesis are organized as follows:

Chapter 2 is the literature review of Product-Service System and Environment-Based Deign.

Chapter 3 provides the process of applying EBD approach to design a PSS step by step, from environment analysis to conflicts identification and solution generation, including the detail questions generated during the process. A PSS life cycle model is proposed at the end of this chapter based on EBD.

Chapter 4 contains an elevator company case study. Previous works in Chapter 3 help ease the process a lot. It proves the effectiveness and efficiency of EBD approach as well as the proposed life cycle model.

Chapter 5 contains the conclusion which summarizes the findings in this thesis and the discussion that contains suggestions for the application and future development and at last the future work.

Chapter 2

Literature Review

2.1 Product-Service System (PSS)

2.1.1 Definition and Development

PSS has its origin in Northern Europe in the late 1990s, principally in Netherlands and Scandinavia (Baines et al., 2007), stemmed from a field of service-product related concepts.

Though there were several related definition presented earlier, the first formal definition of a product-service system was provided by Goedkoop et al. (1999). It was defined as “a marketable set of products and services capable of jointly fulfilling a user’s need.” Since then, researchers successively proposed more definitions based on different emphasis. Among all, the most referenced one was given by Mont (2002), which was “a system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models”. Mont further interpreted PSSs from perspectives of two actors: for consumers, instead of products only, PSSs offer services and system solutions that are possible to reduce the environmental impacts while fulfilling their needs; for producers and service providers, PSSs require them to take a higher degree of responsibility for the product’s whole life cycle, consumers’ participation in early stages, and the design of the system. In summary, PSSs focus more on the use phase (consumer stage), compared with previous product systems.

The evolution of PSS leads the thinking of development strategy and value targets of manufacturing enterprises. The traditional product-oriented pattern is shifted towards the service-oriented pattern. Customer values receive more attention during the development of PSS.

In recent years, the perspective Sustainable Product-Service System (SPSS) has been put forward, since the practical effect PSS brings to the environment has been questioned (Annarelli et al., 2016; Doualle et al., 2016). SPSS is inherently based on a Triple Bottom Line perspective of sustainability. It offers a win-win situation that can achieve environmentally, socio-ethically and economically sustainable at the same time (Vezzoli et al., 2015, 2012).

Other typical unique type of PSS is Smart PSS, which aims to fulfill customers' needs via smart connected product (SCP) as the media and tool, to generate various e-services as a bundle (Valencia Cardona et al., 2015).

2.1.2 Categorization and Application

Three main categories below are generally acknowledged by researchers among various classifications in this field (e.g. Tischner, Verkuijl, and Tukker 2002; Tukker 2004; Baines et al. 2007; Yang et al. 2009).

Product-oriented: the core principle of this type of PSS is still to sell the product after all, but some additional services are provided to the customer, such as maintenance, repairs, upgrades and other after-sales service to insure that the customer can use the product better and longer. Minimizing costs for designing a long-lasting, well-functioning product is the motivation for a company to bring a PSS (Baines et al., 2007).

Use-oriented: in this second main category, the product still plays a central role, but it is owned by the service provider who sells the use and functions of the product. Sometimes the product can be shared by a couple of users. Typical examples include leasing, renting, sharing and pooling (Tukker, 2004). The motivation of the company to apply a PSS in this situation is to maximize the product use and extend its lifespan (Baines et al., 2007).

Result-oriented: the product is no longer the expected outcome here, instead, a specific result is what providers sell to customers. For example, web information replacing directories, selling laundered clothes instead of a washing machine. Companies provide services that the provider still maintains ownership of the product while the customer affords the prearranged results (Baines et al., 2007).

Based on this classification, some subcategories were subdivided from the system, shown in Figure 1.

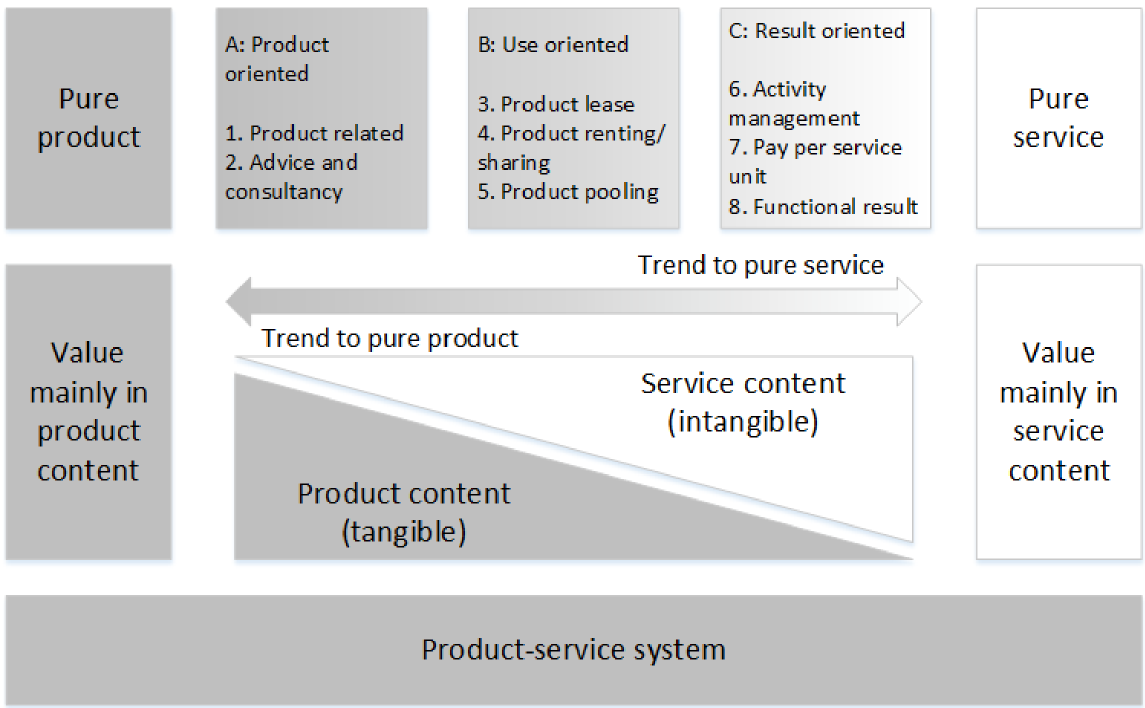


Figure 1 Three main categories of PSS (Tukker, 2004)

Hundreds of cases have been introduced in the literature. The application field is broader, involving farming, printing, automobile, materials and so on. Several successful cases of PSS applications are given below (Baines et al., 2007):

Xerox International as one of the PSS leaders, sell their remanufacturing photocopiers with fixed but much lower price for each copy which gives them larger profits than those from newly-produced machines.

Parkersell (a UK lighting company) have been offering an integrated PSS lighting system solution to Sainsbury's (a UK supermarket), by providing maintenance including renewal and repairs of the luminaires instead of just simply purchasing new lamps. What's more, they have been innovating and developing for environmental improvement.

Mobility (a Switzerland Car Sharing Company) have 1400 cars at 850 locations in 350 communities for 37000 customers to form their vehicle sharing group. Customers are only required to pay a membership fee to get access to a series of vehicles, and it's cheaper than owning a car when driving less than 1500km per year.

2.1.3 PSS design methodologies

To design PSS that can satisfy customers' changing needs better, a variety of methodologies have been proposed by researchers.

Bullinger et al. (2003) presented an approach to attempt to organize services systematically and discuss applying the experience of product development into the service section.

Aurich et al. (2006) enlarged the scope of traditional product engineering methodologies by integrating the design processes of physical products and non physical services to exploit the potential interrelationships between them.

Sakao and Shimomura (2007) proposed a methodology of modeling and designing services in parallel with products, and a computer-aided design tool called Service Explorer. They followed the discipline of service engineering (SE) to add more value to PSS.

Welp et al., (2008) developed a IPS2 concept modeling approach that abolishes established and mostly diffuse borders between products and services to assess systems behavior.

Komoto and Tomiyama (2008) proposed ISCL, Integrated Service CAD and Life cycle simulator, to design business models that promote economic and environmental performances of PSS. Komoto (2009) further improved the method to increase eco-efficiency with more value addition and decreased environmental impacts from a systemic perspective.

2.1.4 PSS life cycle models

In general, four categories of PSS life cycle could be found from the literatures: product life cycle with service association, interrelated product life cycle and service life cycle, integrated PSS life cycle and service dominant PSS life cycle.

Product life cycle with service association: this kind of PSS life cycle just simply extend traditional product life cycle. Service in this model plays an add-on role for the product, such as free delivery service and free repair service. Since product is almost dominant in this type of PSS life model, it can be regarded as an upgrading product life cycle (Sundin, 2009).

Interrelated product life cycle and service life cycle: service plays a more important role in this kind of model, even more important than product in a PSS. PSS life cycle in this case is divided into two branches: product life cycle and service life cycle. However, they are not isolated from each other but interrelated (Goedkoop et al., 1999).

Integrated PSS life cycle: PSS is regarded as an integration rather than a product with some services or the sum of products and services. PSS life cycle also targets the PSS as a holistic solution rather than a simple extension of product life cycle or the interacted product life cycle and service life cycle (Wiesner et al., 2015).

Service dominant PSS life cycle: in this case, service obviously holds the dominant position, while product is a platform of a specific service provision (Zanetti et al., 2016).

2.1.5 Research gaps

A host of researchers identified issues and pointed out in literature that the field of PSS design methodologies is not fully mature.

The way these methodologies define service are diverse, which make them weak and too general for them to design PSS (Komoto and Tomiyama, 2008). Plenty of PSS solutions are proposed, but few are fully designed from a life cycle perspective (Mont, 2002). There exists a separation (Sakao and Shimomura, 2007) and insufficient consideration of mutual influences between the design of products and services which result in unnecessary cost, due to the fact that service design processes are unavailable or unimplemented (Aurich et al., 2006). Currently, there is no integrated, modeling approach to support designers to generate PSS concepts clearly (Welp et al., 2008), since identifying and differentiating products and services is a challenge stressed by most researchers.

Most PSSs in the market today are developed conventionally, adding services to an already existing physical product. The process is carried out intuitively and often based on a trial-and-error method instead of a structured approach (Sakao and Lindahl, 2009). To design and develop PSS efficiently and effectively, there has to be a design methodology applied to formalize the PSS design process.

Existing PSS life cycle model were mostly proposed based on the specific field the author was in, so there is rarely one model that can be accepted by the majority. As a good PSS life cycle model, products and services should be considered independently from each other, since they are quite different from design prospective.

2.2 Environment-Based Design (EBD)

2.2.1 Origin and Development

Environment-Based Design (EBD) was a generic design methodology developed and proposed by Zeng (2011, 2004) Three interdependent activities are included in EBD: environment analysis, conflict identification and solution generation. Their relations are shown in Figure 2.

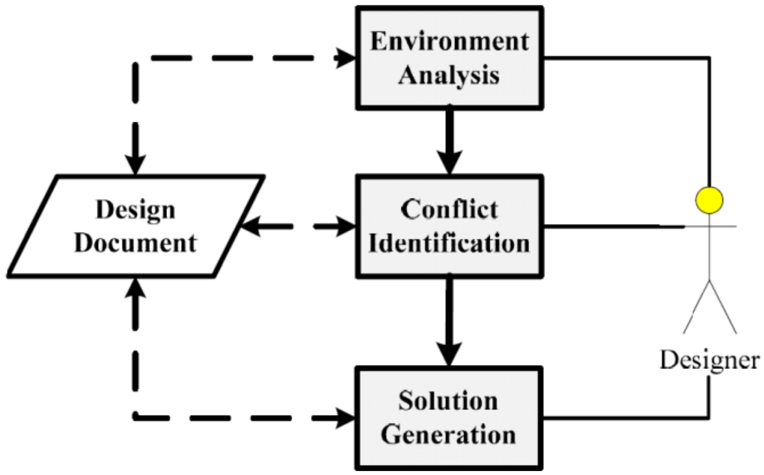


Figure 2 Environment-Based Design: Process Flow (Zeng, 2011, 2004)

Zeng and Cheng (1991) pointed out that the logic of design is recursive, *the conclusion of the reasoning is recursively dependent on the major premise of the reasoning*, as an early foundation to build EBD. EBD was logically derived from the research of the axiomatic theory of design modeling, which established an approach based on two axioms to investigate design activities: axioms of objects defined the universe, while axioms of human thought identify the nature of human thinking (Zeng, 2002). This is its mathematical foundation. Recursive Object Model (ROM), proposed following the previous study of Chen and Zeng (2006) on product requirements, is a tool for modeling natural language used in engineering, and also the third foundation of EBD (Zeng, 2008). Another significant part of EBD is the question asking process in environment analysis, formalized by Wang and Zeng (2009). Based on the three foundations, Zeng summarized all the definitions, components and processes to formalize and officially propose EBD (Zeng, 2011).

2.2.2 Application

Since EBD is a generic design methodology, it is quite effective and efficient in analyzing design problems. A few applications applying EBD from different fields have made success.

To deal with the complexity of medical device functionality, EBD was applied to analyze medical devices design requirements and ended up with a systematic approach to manage the requirements (Chen et al., 2005).

Liu and Zeng (2009) developed a comprehensive conceptual model for the Design Chain Management (DCM) by applying EBD to identify and remove unacceptable conflicts between DCM environment components. Following this work, Sun et al. (2013) made further efforts to formalize the DCM conceptual model in the context of product lifecycle management (PLM) from the natural language description of the DCM.

Sun et al. (2011) created a quality manual with a data processing tool to guide the development of Quality Management System (QMS). EBD was adopted to cope with the imprecise content in the beginning of the project, by clarifying the goals and direction for the project members.

By considering Enterprise Applications Integration (EAI) as a design problem, EBD theory was employed to resolve EAI problems. With the help of ROM, requirements were easily clarified and understood, and designers could generate better solutions during the whole product life cycle (Tan et al., 2012).

An algorithm is proposed to transform a ROM diagram into a Function-Behaviour-State (FBS) model (Wang et al., 2013).

Barklon et al. (2014) introduced EBD to conduct the environment analysis to find out the key component and the relationship between them, so that this helped improve the efficiency of recruiting in a staffing agency.

Chapter 3

EBD Approach to Formalize PSS Design Process

3.1 Introduction

Today, services are regarded as extremely significant for the market competition of manufacturing industries. As the markets for many types of consumer goods are getting saturated, more and more companies start depending on services to stand out from competitors. Product-service system, as a concept that combines physical products and non-physical services, has increasingly gained attention and is keep growing into a successful business model for many companies.

However, most PSSs in the market today are developed conventionally, adding services to an already existing physical product. The process is carried out intuitively and often based on a trial-and-error method instead of a structured approach. To design and develop PSS efficiently and effectively, there has to be a design methodology applied to formalize the PSS design process.

Environment-Based Design (Zeng, 2011), as a generic and systematic design methodology, is capable of guiding designers through the fuzziness and the ambiguity of raw requirements given by customers, finding and asking the right questions about the environment of the target product, then identifying real requirements that are explicit enough to represent customer expectations correctly. Using EBD approach to formalize and guide the PSS design process can improve the effectiveness and efficiency of the design stage and save time and cost for the design team.

EBD is based on the foundation of the recursive logic of design, according to which design is a recursive process that iterates between design requirements and solutions until the final solution is found (Zeng and Cheng, 1991). The design process in EBD consists of three main activities: environment analysis, conflict identification and solution generation (Figure 3). In each iteration, these three activities should be conducted.

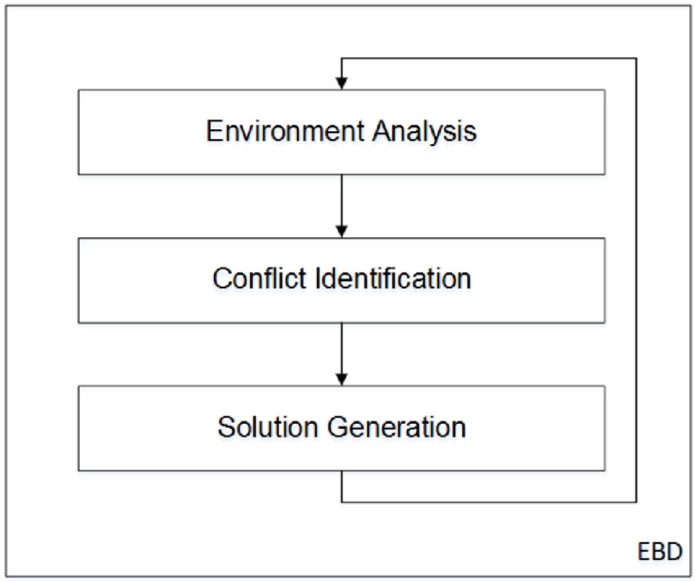


Figure 3 Design Process

3.2 EBD methodology for PSS design

3.2.1 Environment analysis

Environment

Theoretically, when designing a product, the environment means everything except the product itself (Zeng, 2004, 2002; Zeng and Cheng, 1991). Design starts from the environment, functions for the environment, and brings changes to the environment (Zeng, 2011).

There are three kinds of environment: natural, built, and human. The natural environment is the nature without human beings. The built environment includes all the artefacts built or created by human beings. The human environment refers to all the human being involved in the life cycle of the product (Zeng, 2004).

Environment analysis

Environment analysis is the first step in EBD which aims to identify environment components and relationships between them. By understanding the environment, requirements can be clarified, especially the hidden ones which are not given explicitly, and those which customers even have no awareness of (Zeng, 2004).

Since all product requirements come from its environment, identifying environment components clearly and accurately is vitally critical for a successful design, and it is the objective of environment analysis (Zeng, 2011).

To analyze the environment, a ROM diagram of the initial problem description should be built as the first step. It is the basis for the following process. The core process for the environment analysis is the question asking procedures, which help designers to understand the environment and the product step by step.

Environment analysis provides a foundation for the next two activities: conflict identification and solution generation.

3.2.1.1 Problem statement

In EBD theory:

The requirements stated by customers are diverse in the level of detail: obvious and clear ones are relatively simple for designers to understand; some are hidden requirements when customers actually want more than they required; sometimes customers do not even know what they want exactly.

During the design planning phase, designers aim to dig out real customer requirements through the analysis and the communication with customers. In other words, the input of the planning phase is a design task and the output is a requirement list respectively. A problem statement or a product description in plain text form containing the design objectives and other limited information is usually given to designers as a design task. How designers analyze the design task and communicate with the customer play a critical role during the design process by ensuring they are on the right way.

For PSS design:

Suppose a fuzziest situation, the customer mentions only the product, without any additional requirement at the beginning, as:

Design a Product-Service System.

Requirement identification shall start with this problem statement and be expanded using EBD.

3.2.1.2 ROM

In EBD theory:

Recursive logic

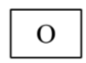
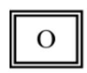
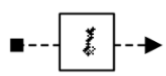
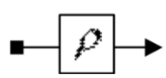
The logic of design is mainly different from other three basic logics: deduction, induction and abduction in that the minor premise, the major premise, and the conclusion of the reasoning are recursively dependent (Zeng and Cheng, 1991). Hence, the logic of design is the recursive logic.

Recursive Object Model (ROM)

ROM was proposed as a graphical linguistic tool to build connections between natural language and structured modeling language (Zeng, 2008, 2004).

ROM facilitates EBD process based on two axioms from the axiomatic theory of design modeling: “everything in the universe is an object” and “there are relations between objects”. Hence, the ROM introduces two kinds of objects: each word is considered as an object, at least two words form a compound object to represent complex objects. There are also three kinds of relations between objects: constraints, connection and predicate, as shown in Table 1.

Table 1 ROM relations (Zeng, 2008)

Type		**Graphic Representation**	**Definition**
Object	Object		Everything in the universe is an object.
	Compound Object		It is an object that includes at least two other objects in it.
Relations	Constraint		It is a descriptive, limiting, or particularizing relation of one object to another.
	Connection		It is to connect two objects that do not constrain each other.
	Predicate		It describes an act of an object on another or that describes the states of an object.

In reality, designers usually understand the design problem statement with their capabilities and experience which could deviate from the intention. In EBD methodologies, this process is assisted by conducting ROM analysis which transforms the design problem statement into a ROM diagram.

For PSS design:

To analyze a problem statement, building its initial ROM diagram is the first step before the following processes can proceed. For our problem statement *Design a Product-Service System*, its corresponding initial ROM diagram is shown in Figure 4.

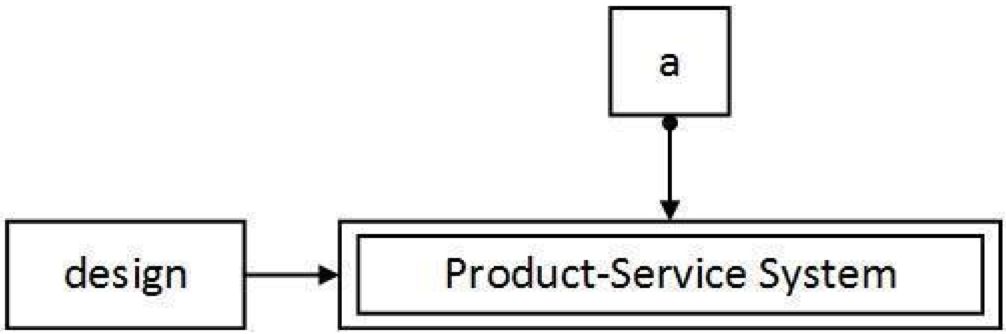


Figure 4 Initial ROM Diagram

3.2.1.3 Question asking and answering

In EBD theory:

Question asking, as the key process of environment analysis and the critical part of EBD, aims to guide designers to analyze the environment step by step. Asking right questions generated from ROM diagrams, and answering them following a guideline are actually defining and refining the design problem as well as the knowledge and information that designers have regarding to this problem, so that it can help designers obtain a better understanding on the design problem, and also a better vision on the direction in which they should pursue.

During this process, ROM analysis should be conducted before questions are asked following the rules and definitions provided by (Zeng, 2008). Generic questions are asked first, in order to find definitions, objectives and some other concrete answers. Then domain specific questions are asked to help designers get to know implicit properties behind the product which can hardly be realized by customers.

Figure 5 illustrates the whole question asking and answering process.

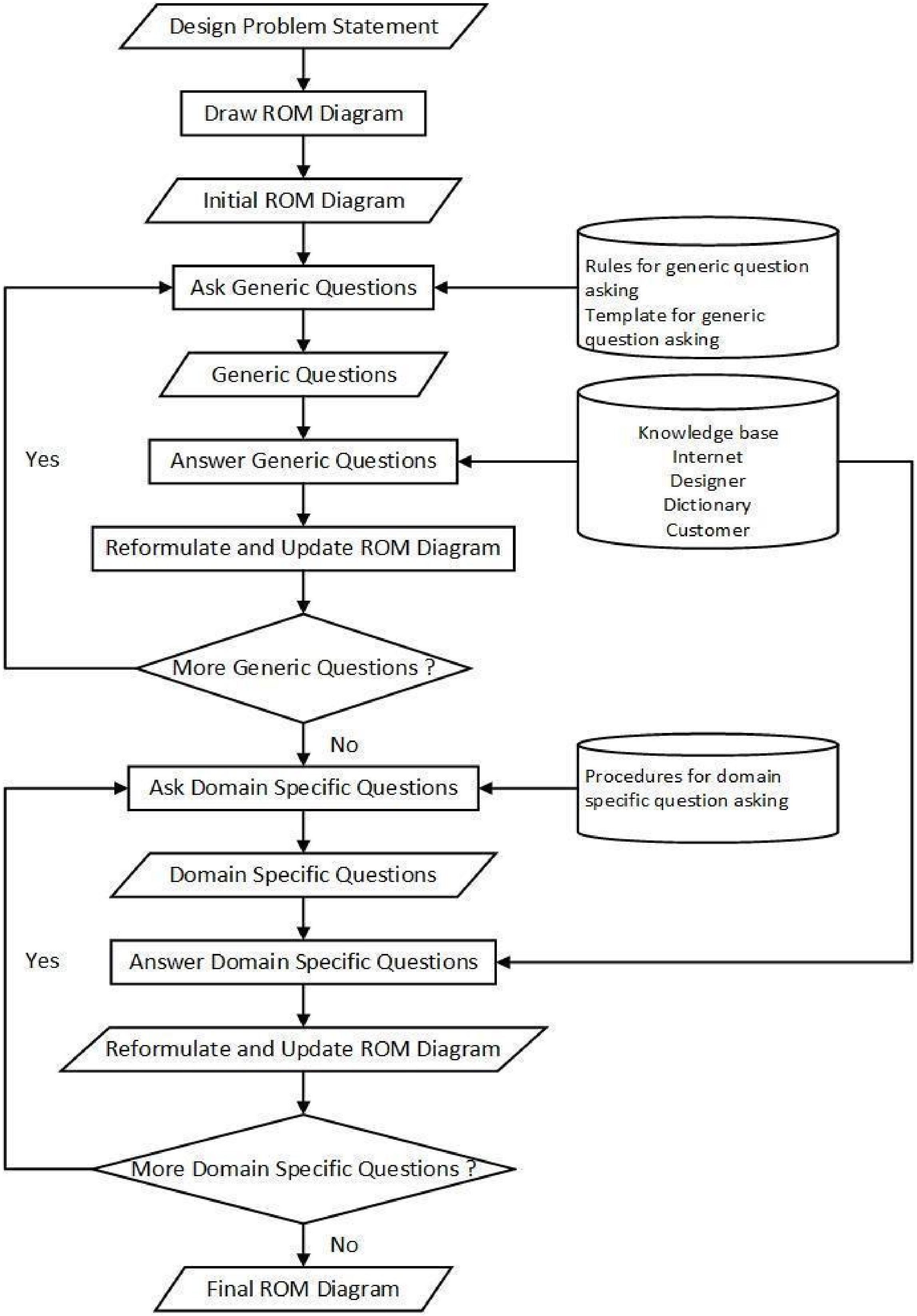


Figure 5 Question Asking and Answering Process (Wang and Zeng, 2009)

In order to ask right questions, two things should be figured out in advance: which objects need to be questioned and in what sequence these objects are questioned. This process is also known as to define object list for questioning and it is completed in four steps given in Table 2 (Zeng, Unpublished).

Table 2 Steps for defining object list for questioning (Zeng, Unpublished)

Step 1	Code objects in the ROM diagram
Step 2	Construct ROM matrix
Step 3	Rank ROM objects
Step 4	Define object list for questioning

The details of how to perform these four steps are introduced in the second round of generic question asking for PSS design.

Table 3 contains the rules for generic question asking which indicate the recommended sequence of the questions to be asked.

Table 3 Rules for objects analysis (Wang and Zeng, 2009)

Rule 1	Before an object can be further defined, the objects constraining them should be refined.
Rule 2	An object with the most undefined constraints should be considered first.

Since the meaning of the central objects may be refined by their constraints, these constraining objects should be questioned first. The meaning of the central objects with the most relations going toward them should be clarified at last.

Table 4 provides a template for the questions generated for different kinds of objects may occur in a ROM diagram.

Table 4 Templates for generic questions (Wang and Zeng, 2009)

#	Conditions	Question template
T1	For a concrete, proper, or abstract noun object N without any constraint	What/Who is N?
T2	For a concrete, proper, or abstract noun N with an adjective constraint A	What is A N?
T3	For an noun object A constraining an noun object N	What is A? What is/are A N?
T4	For a verb V with its subject N1 and object N2	What do you mean by V in the statement "N1 V N2"? How do/does N1 V N2? Why do/does N1 V N2? When do/does N1 V N2? Where do/does N1 V N2?
T5	For a verb object V constrained by an adverb A with its subject N1 and object N2	What do you mean by V A? Why do/does N1 V A N2? When do/does N1 V A N2? Where do/does N1 V A N2?
T6	For a verb V with an object N, but missing its subject	What/Who V N?

After the generic questions are generated, answers can be collected by consulting a dictionary or knowledge base, searching on the internet or directly gathering information from the customer (Wang and Zeng, 2009).

The answers collected must serve the purposes of environment analysis, which are to provide sufficient and necessary information that can help identify both explicit and implicit components of the environment and the interactions between them, and the interactions between the product and these components. To be sufficient, all the information that can be well defined should be collected; to be necessary, all the information collected comes only deductively from available information and resources (Zeng, Unpublished).

Table 5 provides a guideline for answering questions to serve the objectives of environment analysis as much as possible.

Table 5 Guideline for answering questions (Zeng, Unpublished)

#	Questions	Guideline
G1	What/Who is N? N: a concrete, proper, or abstract noun object What is A N? A: an adjective constraint	If (A)N is the product to be designed, then the answer should address 1) the purpose of (A)N; 2) the definition of (A)N; Else, if N is an environment component of a product, then the answer should define (A)N; Else, the components and attributes of N should be described.
G2	What/Who do/does V N? V: a verb	For N1 that V N, the answer should define the components and attributes of N1 in the context of V.
G3	When do/does N1 V N2?	The answer may assume one of the following two forms:

	When do/does N1 V A N2?	In/On a time, N1 V(A) N2; When/During/While N3 Va N4, N1 V(A) N2.
G4	Where do/does N1 V N2?	The answer may assume one of the following two forms:
	Where do/does N1 V A N2?	In/Along/Through a place, N1 V(A) N2; N3 Va N4, where N1 V(A) N2.
G5	Why do/does N1 V N2?	The answer should be organized as:
	Why do/does N1 V A N2?	To Va Na, N1 V (A) N2.
G6	What do you mean by V?	If the subject (N1) or object (N2) of V is not the product, then the answer should include all activities included in V-ing in the context of N1 and N2;
	What do you mean by V A?	Else, skip the question and leave for solution generation.
	How do/does N1 V N2?	

By following the question asking procedure, answers and information gathered can be transformed and merged with the initial ROM diagram in this iteration. Depending on the complexity of the task, the environment analysis process can go several rounds until designers are clear enough of the requirements and have no more questions to ask. Then the final merged ROM diagram can represent all the requirements of the desired product.

For PSS design:

Table 6 shows the first round of generic question asking and answering generated from the initial ROM diagram (Figure 4).

Considering that the original design problem statement and the corresponding first ROM diagram are too simple, the questions and answers are given directly below in Table 6. The detailed questioning process is shown in the second round of generic question asking and answering.

Table 6 Q & A Round 1

Q1	What is PSS?
	A system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models. (Mont, 2002)
Q2	Who designs a PSS?
	Designers.
Q3	Why design a PSS?
	For companies, stay competitive. For customers, satisfy their needs. For the environment, have lower environmental impact.

According to Table 6, answers are merged to the initial ROM diagram and it is reformulated and updated as in Figure 6.

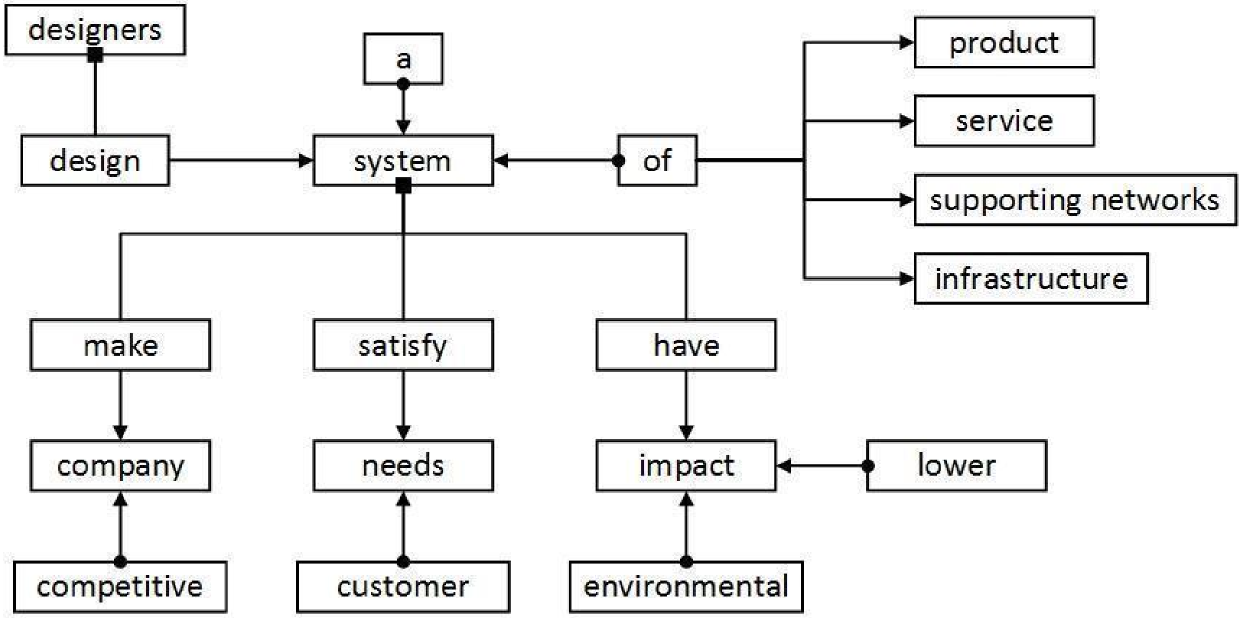


Figure 6 ROM Diagram 2.0

Since it is still not clear enough for designers to understand the design problem, the second round of generic question asking and answering is conducted, starting from defining object list for questioning following the steps introduced in Table 2, respectively.

1) Code objects in the ROM diagram

Each object in the ROM diagram is assigned a number consecutively. Accordingly, for the ROM diagram in Figure 6, its coded ROM diagram is shown in Figure 7.

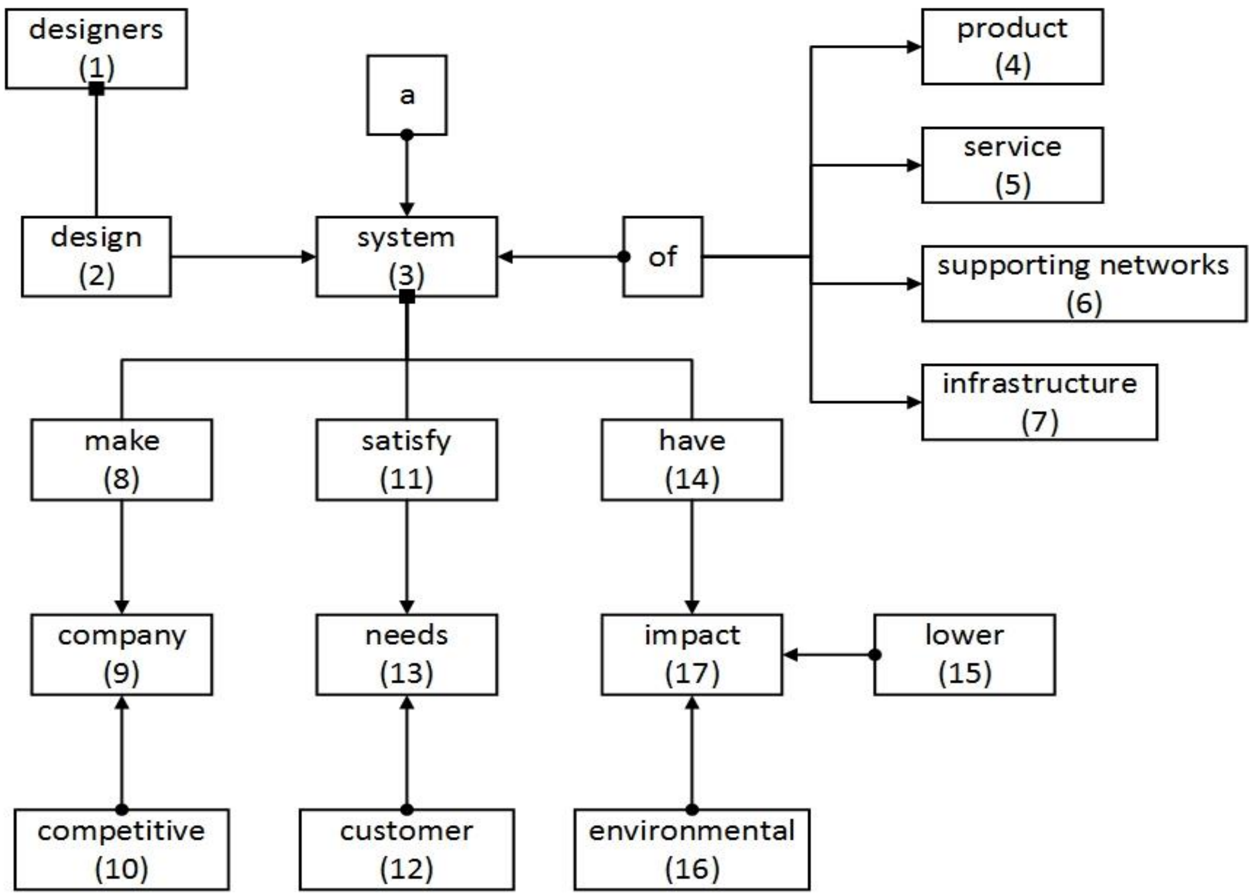


Figure 7 Coded ROM diagram 2.0

2) Construct ROM matrix

A coded ROM diagram can be transformed into a ROM matrix by assigning numbers based on the relation between each pair of objects. According to the equation below proposed by Zeng (Unpublished), the ROM matrix of the coded ROM diagram (Figure 7) is presented in Table 7. By default, the number for a relation is 0.

$$r_{ij} = \begin{cases} 1 & \text{objects } i \text{ and } j \text{ have a subject} - \text{verb relation} \\ -1 & \text{objects } j \text{ and } i \text{ have a subject} - \text{verb relation} \\ 2 & \text{objects } i \text{ and } j \text{ have a verb} - \text{object relation} \\ -2 & \text{objects } j \text{ and } i \text{ have a verb} - \text{object relation} \\ 3 & \text{there is a constraint relation from object } i \text{ to object } j \\ 0 & \text{otherwise} \end{cases}$$

Table 7 Relations for the coded ROM diagram in Figure 7: Column = Object i, Row = Object j

Object	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	-1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	-2	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0
4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	-1	0	0	0	0	0	2	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	-2	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
11	0	0	-1	0	0	0	0	0	0	0	0	0	2	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	-2	0	0	0	0	0	0
14	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
17	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	0	0

3) Rank ROM objects

The total number of the constraint ($r_{ij} = 3$) and predicate ($r_{ij} = \pm 1, \pm 2$) relations on each object in the coded ROM diagram given in Figure 7 is counted from Table 7 and presented in Table 8.

Table 8 Number of constraint and predicate relations on an object

Number of relations	8	3	2	1
Object	3	17	2,8,9,11,13,14	1

It can be easily seen that object 3, which is “system”, is the central object in this ROM diagram since it has the most relations with other objects.

Figure 8 illustrates the hierarchical relations between the objects with a structure tree, according to the constraint and predicate relations obtained from the coded ROM diagram in Figure 7, which takes the central object as the trunk and the other objects as branches around it.

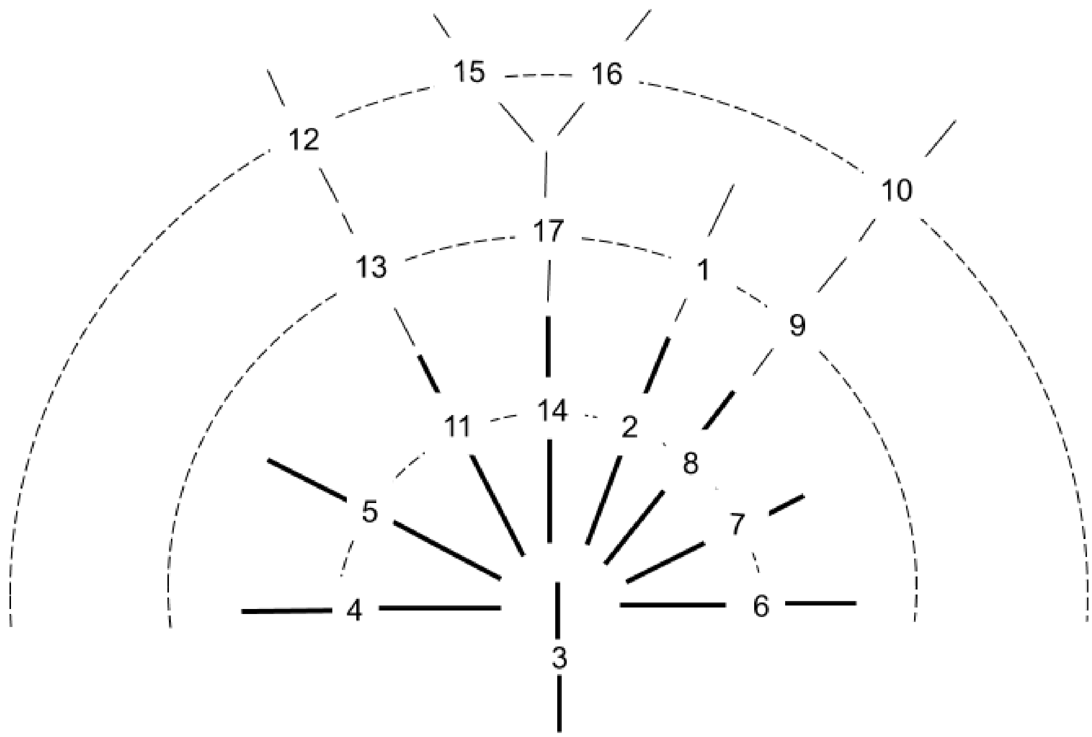


Figure 8 Structure tree of constrain and prediction relations of objects

4) Define object list for questioning

The structure tree shown in Figure 8 indicates that the constraints and predicates are arranged around the central object based on two dimensions: in depth for which objects are strung along each branch of the tree; in width for which objects are distributed on the same layer away from the central object. The object list for questioning can be generated with the information in Table 8 and rules in Table 3, following the principle of the width first (Zeng, Unpublished).

For the coded ROM diagram in Figure 7, an object list for questioning is given in Table 9.

Table 9 Object list to be questioned

Number of relations	8	3	2	1
Object	3	17	2,8,9,11,13,14	1
Questioning object list	(4, 5, 6, 7), (15, 16), (10, 12), 1, (9, 13), 17, 2, (8, 11), 14, 3			

The process of generating the questioning object list is given in Table 10.

Table 10 Process to generate questioning object list for the coded ROM diagram in Figure 7

Rules	Action	Questioning objects
Rule 1 to the ROM	Processing order: 3	
Rule 2 to Object 3	Processing Object: 2,4,5,6,7, 8,11,14	
Rule 1 to Object 2,4,5,6, 7,8,11,14	Processing order: 14, (8, 11), 2	(4, 5, 6, 7)
Rule 2 to Object 14	Processing Object: 17	
Rule 1 to Object 17	Processing order: 17	
Rule 2 to Object 17	Processing Object: 15, 16	
Rule 1 to Object 15, 16		(15, 16)
Rule 2 to Object (8, 11)	Processing Object: 9, 13	
Rule 1 to Object 9, 13	Processing order: (9, 13)	
Rule 2 to Object (9, 13)	Processing Object: 10, 12	
Rule 1 to Object 10, 12		(10, 12)
Rule 2 to Object 2	Processing Object: 1	
Rule 1 to Object 1		1, (9, 13), 17, 2, (8, 11), 14, 3

Following the question template given in Table 4, generic questions can be generated according to the object list in Table 9, shown in Table 11. These questions are sufficient, but not all of them are practically necessary to ask.

Table 11 Questions to detect the real intent for PSS design

Object	Conditions	Questions	Necessity
4	For a concrete noun object N without any constraint	T1: What is a "product"?	
5	For a concrete noun object N without any constraint	T1: What is a "service"?	
6	For a concrete noun object N without any constraint	T1: What is a "supporting network"?	
7	For a concrete noun object N without any constraint	T1: What is an "infrastructure"?	
12	For a concrete noun object N without any constraint	T1: What is a "customer"?	
1	For a concrete noun object N without any constraint	T1: What is a "designer"?	
9 & 10	For a concrete noun N with an adjective constraint A	T2: What is a "competitive company"?	
13	For a concrete noun object N without any constraint	T1: What is a "need"?	
12 & 13	For a noun object A constraining a noun object N	T3: What is "customer needs"?	
15 & 16 & 17	For a concrete noun N with an adjective constraint A	T2: What is "lower environmental impact"?	
3 & 4 & 5 & 6 & 7	For a noun object A constraining a noun object N	T3: What is a "system of products, services, supporting networks and infrastructure"?	
3 & 8 & 9 & 10	For a verb V with its subject N1 and object N2	T4: What do you mean by "make" in the statement "system make company competitive"?	No
		How do "system make company competitive"?	
		When do "system make company competitive"?	No
		Why do "system make company competitive"?	

		Where do "system make company competitive"?	
3 & 11 & 12 & 13	For a verb V with its subject N1 and object N2	T4: What do you mean by "satisfy" in the statement "system satisfy customer needs"?	
		How do "system satisfy customer needs"?	
		When do "system satisfy customer needs"?	No
		Why do "system satisfy customer needs"?	No
		Where do "system satisfy customer needs"?	No
3 & 14 & 15 & 16 & 17	For a verb V with its subject N1 and object N2	T4: What do you mean by "have" in the statement "system have lower environmental impact"?	No
		How do "system have lower environmental impact"?	
		When do "system have lower environmental impact"?	No
		Why do "system have lower environmental impact"?	
		Where do "system have lower environmental impact"?	
1 & 2 & 3	For a verb V with its subject N1 and object N2	T4: What do you mean by "design" in the statement "designers design a system"?	No
		How do "designers design a system"?	
		When do "designers design a system"?	
		Why do "designers design a system"?	Duplicate
		Where do "designers design a system"?	No

After the questions are listed as shown in Table 11, designers are able to answer them based on their knowledge and experience, by consulting the internet or a dictionary, and also communicating with the customer. Since there is no absolute right or wrong answer to a question, different designers can give distinct answers. The guideline given in Table 5 can be used as reference to get as effective and efficient answers as possible, which can lead to a more innovative solution. Following the guideline, questions from Table 11 are answered and shown in Table 12.

Table 12 Q & A Round 2

Q4	What is a “product”?
	A tangible commodity manufactured to be sold. It is capable of ‘falling on your toes’ and of fulfilling a user’s needs. (Tischner et al., 2002)
Q5	What is a “service”?
	In the traditional approach, a service is a set of activities which intends to keep products functionally available. Such services can be maintenance, repair, overhaul, upgrade or other technical services. In a broader perspective, a service is a set of activities which intends to satisfy customer value. Both views are possible depending on the context of the application. If the product is already matured then the traditional perspective is usually more appropriate. If the product is in the early stages of development then the broader approach offers more advantages. (Vasantha et al., 2012)
Q6	What is a “supporting network”?
	A group of people who provide emotional and practical help to someone in serious difficulty.
Q7	What is a “infrastructure”?
	The basic physical and organizational structures and facilities (e.g. buildings, roads, power supplies) needed for the operation of a society or enterprise.
Q8	What is a “customer”?

	A person or an organization that buys goods or services from a shop or business.
Q9	What is a "designer"?
	A person who plans the look or workings of something prior to it being made, by preparing drawings or plans.
Q10	What is a "competitive company"?
	A business organization that produces goods or services with a favorable quality-price ratio that guarantees good profitability while achieving customer preference over other competitors.
Q11	What is a "need"?
	A situation when something is necessary or must be done.
Q12	What is "customer needs"?
	A thing that is wanted or required by the person or organization that buys goods or services.
Q13	What is "lower environmental impact"?
	The effect that the activities of people and businesses have on the environment is below the usual level.
Q14	What is a "system of products, services, supporting networks and infrastructure"?
	A collection of products, services, supporting networks and infrastructure including their relations (Tischner et al., 2002).
Q15	How do "system make company competitive"?
	Understanding PSSs provides the opportunity to see strategic new market opportunities, market trends and developments and potentially to stay competitive as patterns of production and consumption are transformed by

environmental limits. The concept of a PSS facilitates innovation at a more than incremental level and has the potential to bring financial benefits.

For manufacturing companies a service component adds/allows:

To attach additional value to a product, for example, financial schemes or refurbishing or upgrading.

To improve relationships with consumers because of increased contact and flow of information about consumers' preferences.

To improve the total value for the customer because of increased servicing and service components, which include activities and schemes that make the existing product last longer, extend its function (upgrading and refurbishment), and make the product and its materials useful after finishing its life cycle (recycling and reuse of parts or entire product).

To anticipate the implications of future take-back legislation, and might have the potential to turn them into a competitive advantage.

For service companies, product components:

Extend and diversify the service.

Safeguard market share by bringing the service component into the offer that is not so easy to copy.

Facilitate communicating product–service information, because it is easier to convey information about more tangible products than about intangible services.

Safeguard a certain level of quality that is difficult to change (product quality).

	(Mont, 2002)
Q16	Why do “system make company competitive”?
	Customers have short-term memory and an infinite number of options at their fingertips. To stand out from the crowd and achieve customer loyalty, a company has to be competitive through being able to either create and offer quality goods and services at lower costs than competitors, or impose its products or services regardless of their price, thanks to, for example, their quality, innovation, related services or brand image.
Q17	Where do “system make company competitive”?
	Promoting values and reducing costs to bring financial benefits. Improving relationships with customers and establishing customer loyalty. Facilitating innovation to anticipate market trends, see new market opportunities and meet market needs.
Q18	What do you mean by “satisfy” in the statement “system satisfy customer needs”?
	To deliver the products and/or services that the customer requires on time.
Q19	How do “system satisfy customer needs”?
	Consumers benefit from a PSS because they receive greater diversity of choices in the market; maintenance and repair services; various payment schemes; and the prospect of different schemes of product use that suit them best in terms of ownership responsibilities. Consumers get added value through more customized offers of a higher quality (from the product/service per se and the delivery/provision). The service component, being flexible by nature, induces new combinations of products and services, better able to respond to changing needs and conditions. Consumers may be relieved from the responsibility for a product that stays

	under ownership of a producer for its entire life span. (Mont, 2002)
Q20	How do "system have lower environmental impact"?
	A PSS has the potential to decrease the total amount of products by introducing alternative scenarios of product use, for example, sharing/renting/leasing schemes to consumers, however, not affecting design of the products. With PSS, producers become more responsible for their product–services in case material cycles are closed. Producers are encouraged to take back their products, upgrade and refurbish them and use them again. In the end, less waste is incinerated or filled. (Mont, 2002)
Q21	Why do "system have lower environmental impact"?
	The evolution of sustainability awareness and the global crisis of environmental issues led to increase the pressure from sustainability legislation for production and consumption. To survive in this competitive environment the companies must take these trends into consideration.
Q22	Where do "system have lower environmental impact"?
	Raw material consumption, waste and discharges to the environment, and land use area associated with the life of a product or service.
Q23	How do "designers design a system"?
	Analyzing customer requirements, the market, the company itself and then modeling the collection of products, services, supporting networks and infrastructure, including the relations among them.
Q24	When do "designers design a system"?
	After having customer requirements, or when respond to changes is needed.

According to Table 12, answers are merged to the previous ROM diagram in Figure 6 and it is reformulated and updated as in Figure A1 in Appendix. Objects are given the same color if they share a common meaning in the ROM diagram.

Now it is much more detailed than the original problem statement, but to better understand the object "service" and the relations among products, services, supporting networks and infrastructure, one more round of question asking and answering is necessary as shown in Table 13.

Table 13 Q & A Round 3

Q25	What are "the relations among products, services, supporting networks and infrastructure"?
	This thesis mainly analyzes and discusses the relations between products and services, since supporting networks and infrastructure are relatively assistant roles in making PSS work. Thus, it can be simply considered as "people use facilities to help PSS work". Services in PSS can be divided into two categories: core services and support services. Core services are customer-oriented and represent main functions which are required by and sold to customers. The product is the tool or carrier that delivers core services while support services aim to maintain the product to ensure its physical and functional fitness for core service delivery. (Yang et al., 2010) There are three types of PSS, the roles and relations are different in each type. Product-oriented: The manufacturers provide products and related services to the consumers who have the ownership of products. The services include maintenance, repair, distribution, reuse, recycling, and helping customers

optimize the application of a product through training and consulting. In this case, the product is considered as a means to deliver services.

Use-oriented: The manufacturers who have the ownership of products provide customers with the usage and function of products. Typical examples of the use-oriented PSS are product rental, leasing or sharing.

Result-oriented: The manufacturers provide customers with the result or capability instead of a product. The manufacturer offers a customized mix of services to guarantee a certain result and the customers pay only for the result.

(Wang et al., 2011)

According to the first two paragraphs of the answer in Table 13, which is about the relations among the product and two categories of services, PSS elements with relations among them is illustrated in Figure 9.

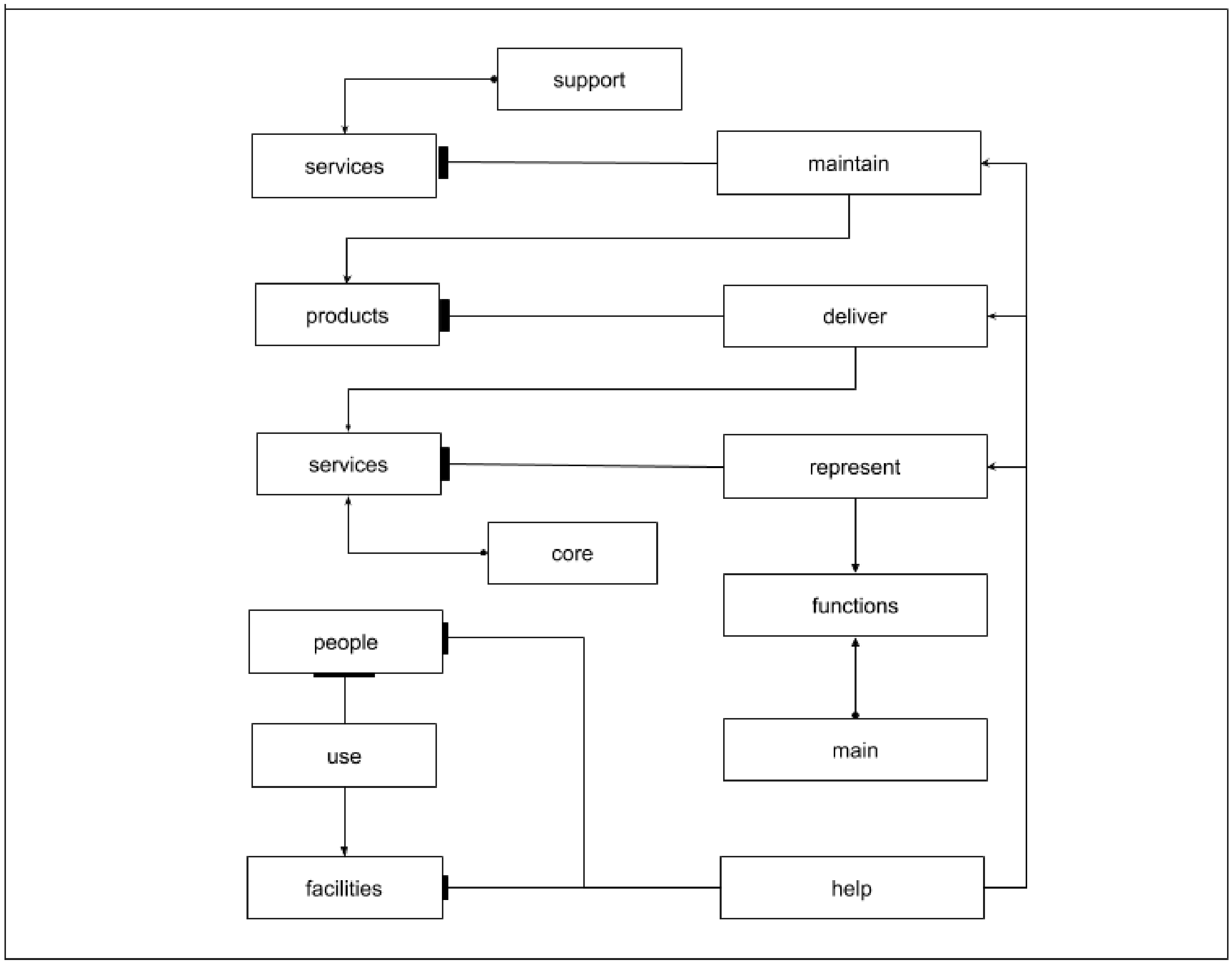
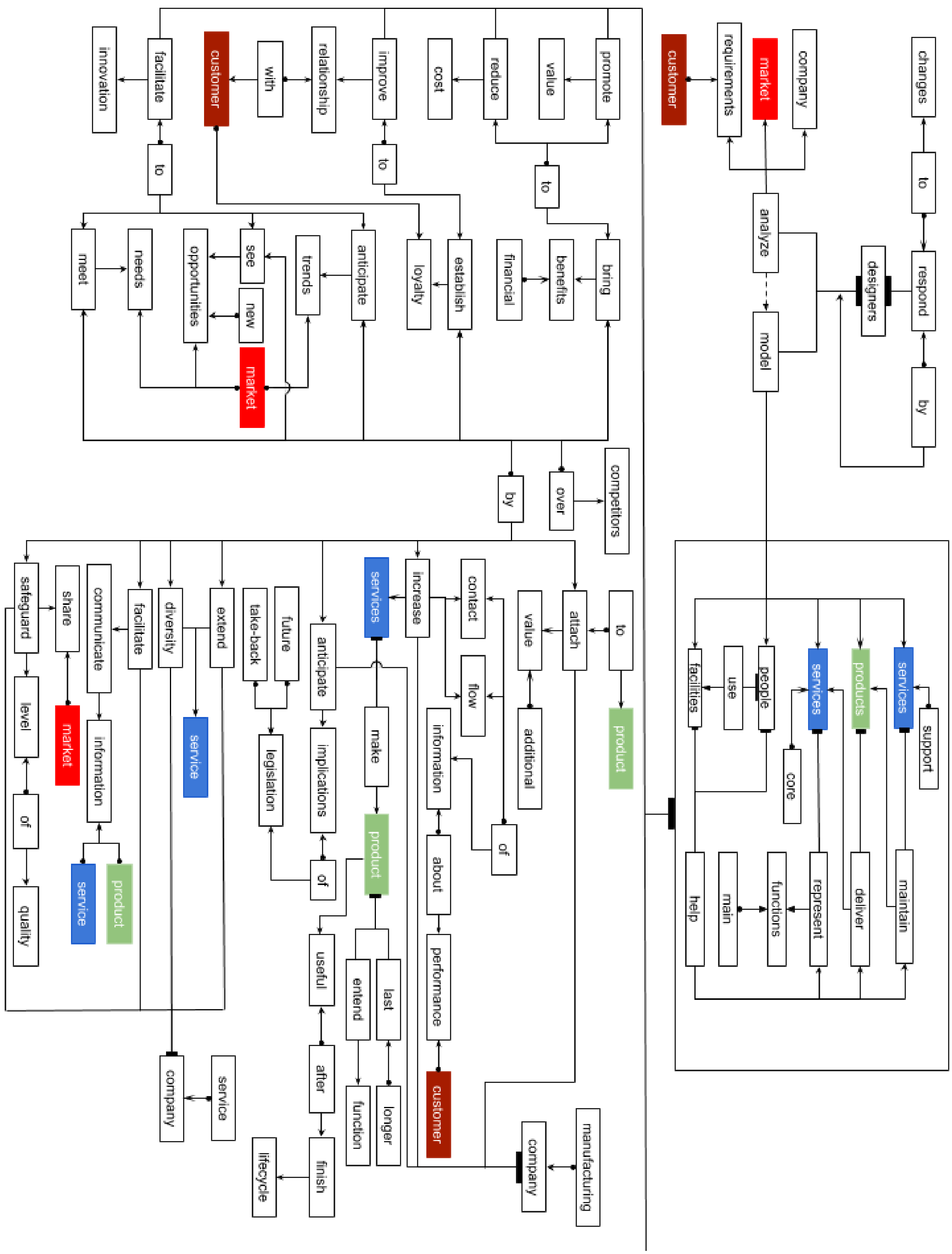


Figure 9 PSS elements with relations among them

Figure 9 can take the place of its corresponding PSS section in the ROM diagram in Figure A1, and the updated ROM diagram is shown in Figure 10.


changes
to
respond
designers
by
company
market
requirements
customer
analyze
model
promote
value
reduce
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improve
relationship
with
customer
facilitate
innovation
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useful
after
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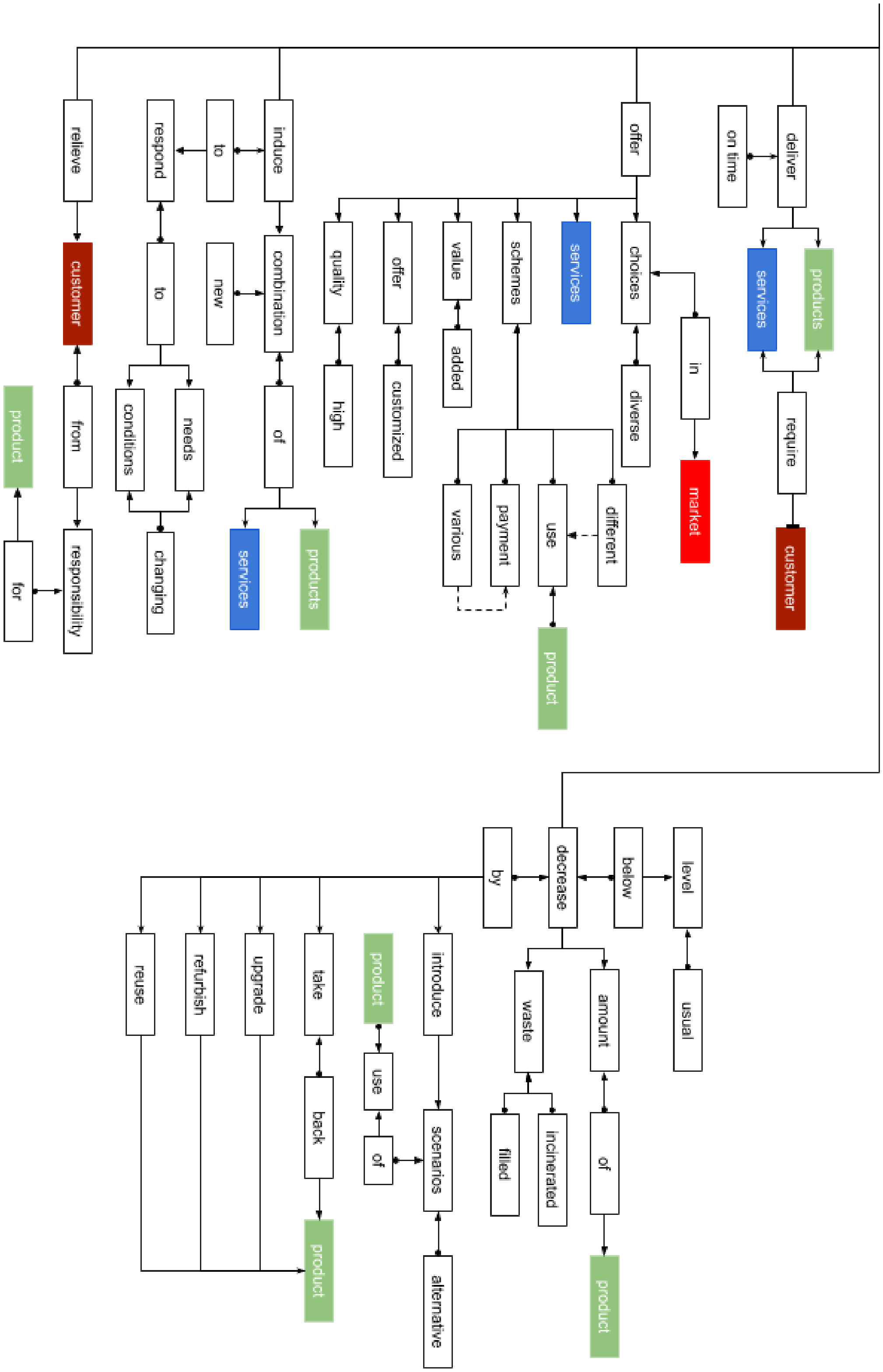


Figure 10 ROM Diagram 3.0

Nevertheless, Figure 10 only represents the general form of PSS without the involvement of manufacturers and customers. Specifically, refer to the rest of the answer in Table 13, three types of PSS with different roles and relations can be illustrated in Figure 11, Figure 12 and Figure 13.

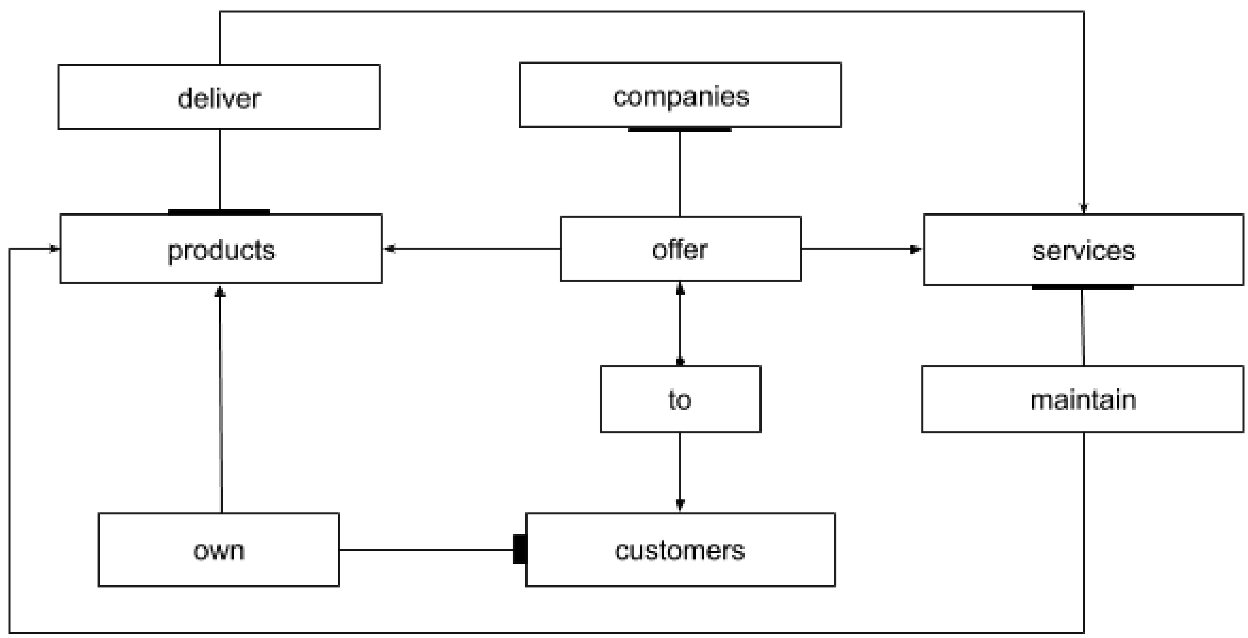


Figure 11 ROM of Product-oriented PSS

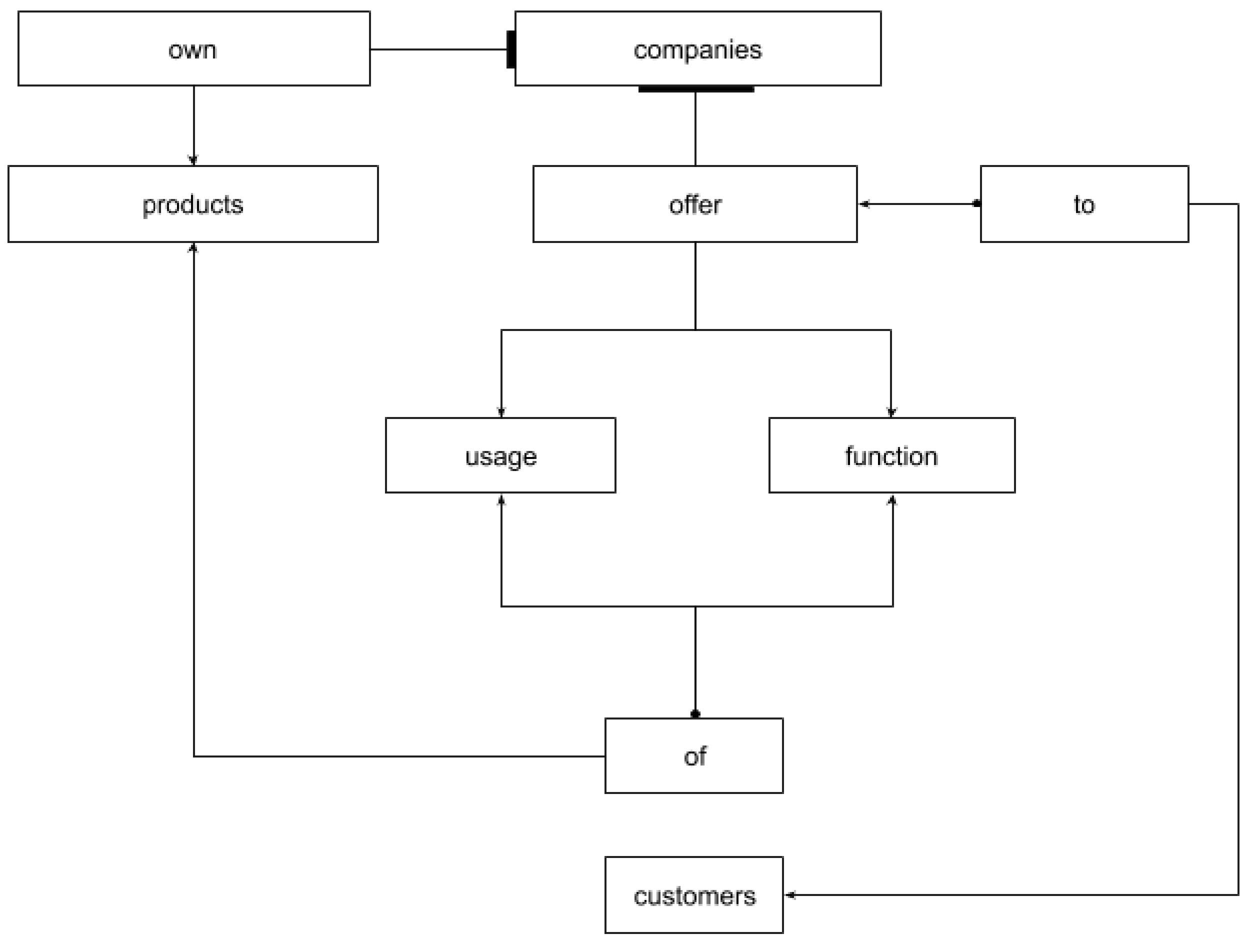


Figure 12 ROM of Use-oriented PSS

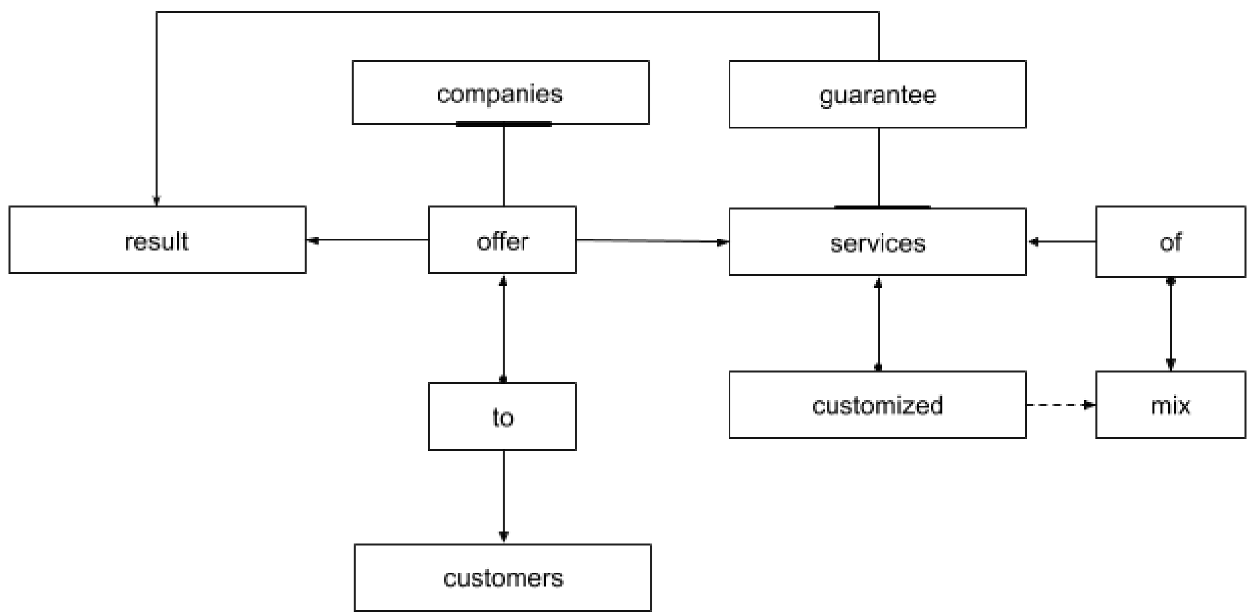


Figure 13 ROM of Result-oriented PSS

The original design statement is quite fuzzy and unclear (Figure 4), while after three rounds of generic question asking, it is expanded and the content becomes much richer and clearer up to this point.

Since there is no more generic question to be asked, domain specific question should be raised now. EBD does not give any rule or template but some procedures as a roadmap for domain specific question asking, because EBD as a generic design methodology is hard to conclude various questions from different fields. Table 14 contains the procedures for domain specific questions.

Table 14 Procedures for domain specific questions (Zeng, 2011)

Step 1	Ask and answer the question: what is the life cycle of the product to be designed?
Step 2	For each event included in the life cycle, ask and answer the question: what are the relevant components for natural, built, and human environments for this event?
Step 3	Generate the ROM diagram for each answer and merge them back to the original ROM diagram.
Step 4	Apply the procedure for generic question asking.

Based on the procedures in Table 14, two domain specific questions are generated and shown in Table 15.

Table 15 Q & A Round 4

Q26	What is the life cycle of a PSS?
	According to Research gaps in Literature Review, there has not been a general PSS life cycle that is recognized and approved by scholars, since authors mostly proposed their own life cycle models based on their research. In Solution generation of this chapter, a conceptual PSS life cycle model based on EBD is proposed, the six stages of which are planning, development, production, delivery, utilization and decomposition. Unlike most existing PSS life cycle models, products and services are considered separately in this thesis.
Q27	What are the relevant components of natural, built, and human environments of each stage of the life cycle of a PSS?
	The answer is shown in Table 16.

Table 16 Environment components

		Natural	Built	Human
Planning	Product	Time	Market, company	Designers, company director, marketing engineers
	Service	Time	Market, company	Designers, company director, marketing engineers
Development	Product	Time	Market, services	Designers, customers, product engineers, marketing engineers
	Service	Time	Market, products	Designers, customers, service engineers, marketing engineers
Production	Product	Time	Manufacturer, company	Workers
	Service	N/A	N/A	N/A
Delivery	Product	Time	Transportation	Deliverers, workers
	Service	Time	Products	Workers, customers
Utilization	Product	Time	Services, company	Customers, customer service manager, workers
	Service	Time	Products, company	Customers, customer service manager, workers
Decomposition	Product	Time, environment	Company	Customers
	Service	N/A	N/A	N/A

3.2.1.4 Interaction dependency network

In EBD theory:

The last step of environment analysis is to form an interaction dependency network as the output, where interactions could be related through dependency constraint relations (Zeng, Unpublished).

Interaction is defined as a relation from one object to another that will generate a new object. The action from environment to an object and the reaction from an object to its environment are both regarded as an interaction. From the ROM diagram of a design problem statement, interactions included can be extracted. Accordingly, there are four types of basic interactions that can be identified in a ROM diagram, as shown in Figure 14. Each action verb defines one interaction.

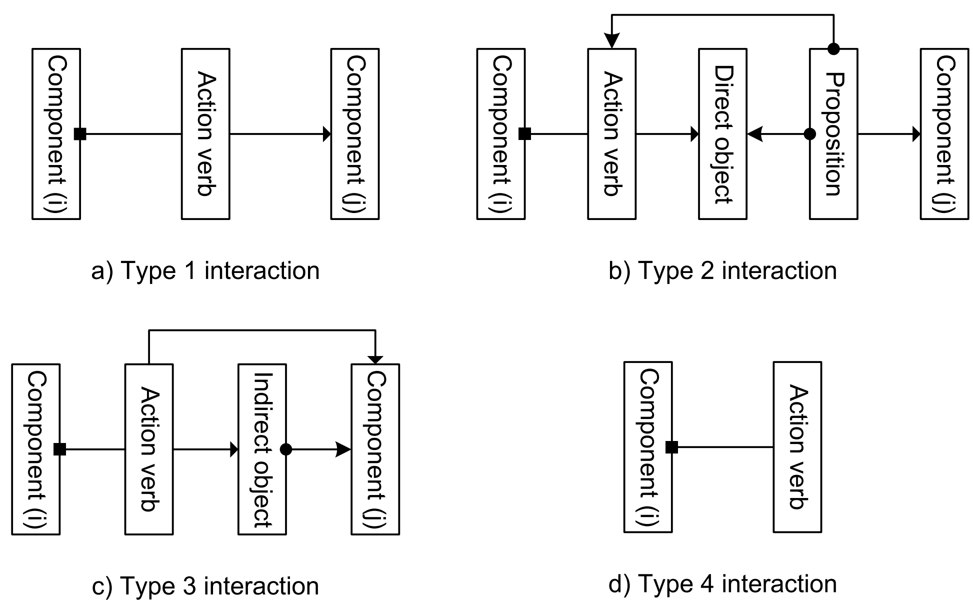


Figure 14 Four types of basic interactions (Zeng, Unpublished)

A dependency relation from an interaction I_m to another I_n refers to a situation where the presence of I_n depends on the presence of I_m, or a situation where I_n will not occur without the presence of I_m (Zeng, Unpublished). Figure 15 represents this dependency relation.

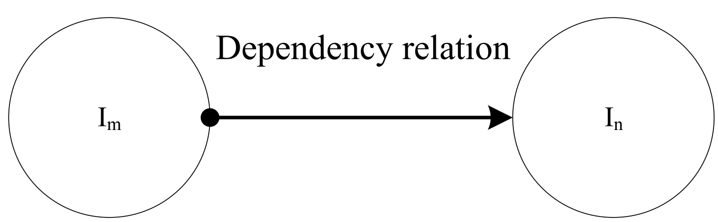


Figure 15 Dependency relation (Zeng, Unpublished)

For PSS design:

Based on the four basic forms of interactions in Figure 14, interactions included in the ROM diagram in Figure 10 are identified and listed in Table 17.

Table 17 Interactions included in Figure 10

Interaction#	Descriptions
I_1	PSS promotes values for the company.
I_2	PSS reduces costs for the company.
I_3	PSS brings financial benefits for the company.
I_4	PSS improves relationships with customers.
I_5	PSS establishes customer loyalty.
I_6	PSS facilitates innovation.
I_7	PSS anticipates market trends.
I_8	PSS sees new market opportunities.
I_9	PSS meets market needs.
I_{10}	Services attach additional value to a product.
I_{11}	Services increase contact and flow of information about customers' preferences.
I_{12}	Services make the existing product last longer.
I_{13}	Services extend product's function.
I_{14}	Services make the product and its materials useful after finishing its life cycle.
I_{15}	Services anticipate the implications of future take-back

	legislation.
I_{16}	Products extend the service.
I_{17}	Products diversify the service.
I_{18}	Products safeguard market share.
I_{19}	Products facilitate communicating product–service information.
I_{20}	Products safeguard a certain level of quality that is difficult to change .
I_{21}	PSS delivers the products and/or services that the customer requires on time.
I_{22}	PSS offers greater diversity of choices in the market.
I_{23}	PSS offers various payment schemes.
I_{24}	PSS offers the prospect of different schemes of product use that suit customers best in terms of ownership responsibilities.
I_{25}	PSS offers customization of a higher quality.
I_{26}	PSS induces new combinations of products and services, better able to respond to changing needs and conditions.
I_{27}	PSS relieves customers from the responsibility for a product that stays under ownership of the company for its entire life span.
I_{28}	PSS decreases the total amount of products.
I_{29}	PSS introduces alternative scenarios of product use to customers, however, not affecting design of the products.
I_{30}	PSS encourages companies to take back their products.
I_{31}	PSS encourages companies to upgrade their products.

I_{32}	PSS encourages companies to refurbish their products.
I_{33}	PSS encourages companies to reuse their products.
I_{34}	PSS decreases incinerated and filled waste.
I_{35}	Core services represent main functions which are required by and sold to customers.
I_{36}	Products are the tools or carriers that deliver core services.
I_{37}	Support services aim to maintain the product to ensure its physical and functional fitness for core service delivery.
I_{38}	People use facilities to help PSS work.
I_{39}	Designers analyze the company.
I_{40}	Designers analyze the market.
I_{41}	Designers analyze customer requirements.
I_{42}	Designers design the PSS.
I_{43}	Designers respond to changes.

Interactions I_{39} ~ I_{43} are ignored in the following content since they are not related to the design problem itself. The dependency relations between interactions listed in Table 17 are shown in Table 18.

Table 18 Dependency relations between interactions

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17	I18	I19	I20	I21	I22	I23	I24	I25	I26	I27	I28	I29	I30	I31	I32	I33	I34	I35	I36	I37	I38
I1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I4	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

l6	0	0	0	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l10	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l11	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0
l12	0	3	3	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	3	3	3	3	0	0	0	0
l13	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l14	0	3	3	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	3	3	3	3	0	0	0	0
l15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l18	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l19	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0
l20	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l21	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l22	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l24	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
l25	3	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
l27	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l28	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
l29	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
l30	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0
l31	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0
l32	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0
l33	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0
l34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

I35	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I37	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	3	3	3	3	0	0	0	0
I38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

As such, the interaction dependency network of PSS can be graphically represented. However, since too many relations are shown in the figure, the interaction dependency network is left to Figure A2 in Appendix.

3.2.2 Conflicts identification

Conflict identification is the second activity in EBD. Since the focus of this thesis is on environment analysis, theoretical knowledge of conflict identification will not be introduced much.

3.2.2.1 Definitions

Resource: refers to any object that can be used to produce an action on its environment or to accommodate an object's action on its environment.

Conflict: refers to an insufficiency of resources for an object to produce a desired action on its environment or to accommodate the object's action on its environment.

Active conflict: refers to an insufficiency of resources to an object in order to produce a response from the object.

Reactive conflict: refers to an insufficiency of resources to accommodate an object or the responses from the object.

(Zeng, Unpublished)

3.2.2.2 Critical conflict

In EBD theory:

Among all the conflicts, the one that has the most influence on other conflicts is called the critical conflict.

According to the definition of active conflict given above, it is easy to understand that most of interactions could be associated with an active conflict. However, when it comes to the resolution of an active conflict, the entire interaction dependency network may be redefined. Hence, it is necessary to identify and start with the critical active conflict.

With the process presented in Table 19, critical active conflicts can be identified from an interaction dependency network (Zeng, Unpublished).

Table 19 Process to identify critical active conflict (Zeng, Unpublished)

```
IdentifyCriticalActiveConflict(input: Interaction Dependency Network IDN,
output: Critical Active Conflict C-IDN)
{
   If IDN ≠ NULL
   {
      {I^a} ← interactions that least constrain other interactions;
      {I^c} ← interactions in {I^a} that are most constrained;
      for every interaction I_i in {I^c}
      {
         {I_c^i} ← interactions that constrain I_i
         Ask the question: "Is I_c^i sufficient to trigger and define I_i?
         A←Answer;
         if A=="Yes"
         {
            IDN ← IDN − I_i;
            IdentifyCriticalActiveConflict (IDN, C-IDN);
         }
         else
         {
            An active conflict γ_i will be added as a constraint for I_i;
            C-IDN ← the part of IDN including I_i, I_c^i, and γ_i;
         }
      }
   }
}
```

With regard to reactive conflicts which refer to an insufficiency of resources to accommodate an object or the responses from the object, they will not be covering in this design problem, since time and space are not considered as main concerns for a company.

For PSS design:

The process of identifying the critical conflict from the interaction dependency network in Figure A2 is shown in Table 20, referring to the process in Table 19.

Table 20 Process for identifying critical active conflicts for the IDN in Figure A2

Process	Result
Line 6: $\{I^a\}$	I3, I5, I8, I15, I23, I34, I38
Line 7: $\{I^c\}$	I3
Line 10: $\{I_c^i\}$	I1, I2, I10, I12, I14, I18, I20, I22, I25, I28, I30, I31, I32, I33
Line 12: A	No
Line 20	γ3 will be added as a constraint for I3
Line 21	C-IDN←IDN in Figure 16

The critical active conflict of PSS design problem is found to be γ_3, as illustrated in Figure 16.

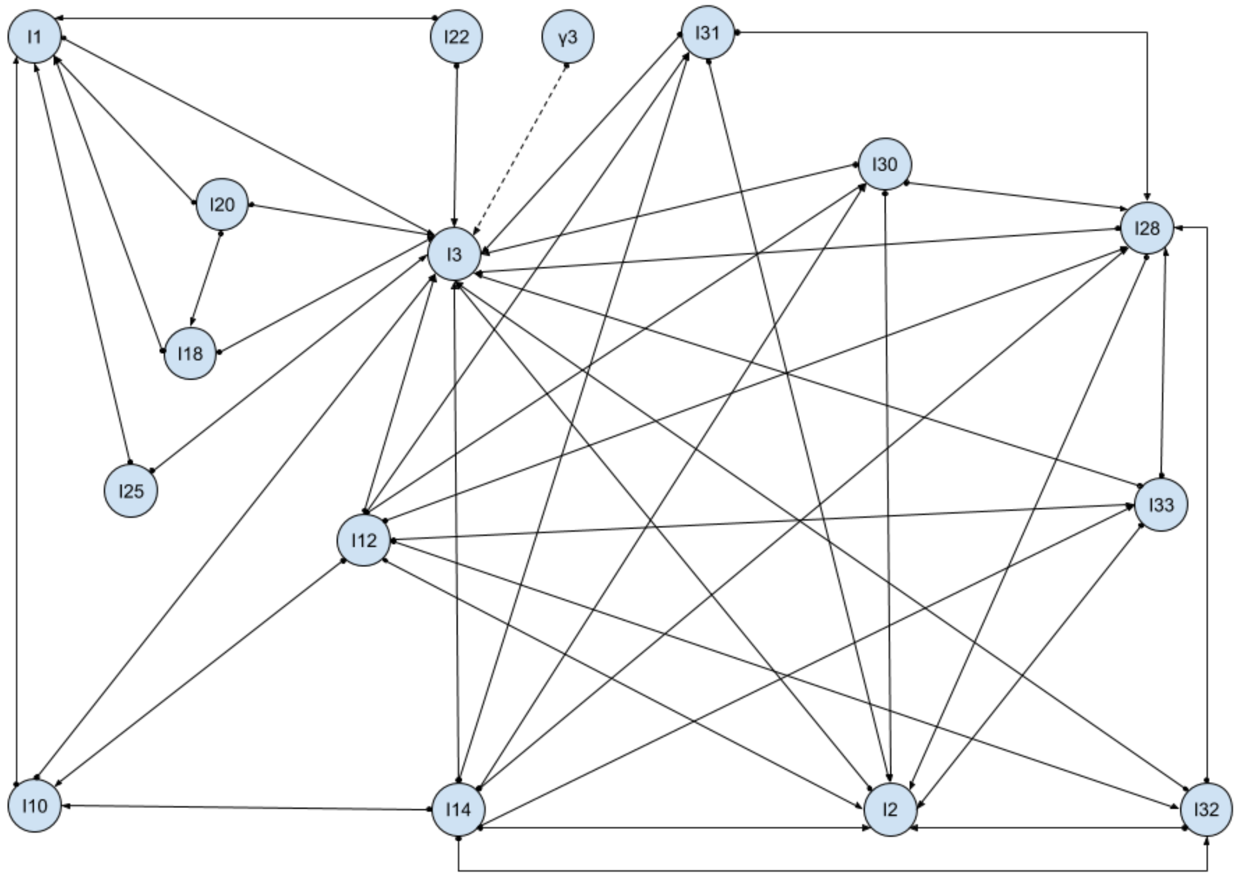


Figure 16 C-IDN for the PSS design problem

The interaction associated with the critical active conflict γ_3 is called a critical interaction, which is I_3: PSS brings financial benefits for the company. The critical conflict should be the first issue that designers focus on during the solution generation stage.

3.2.3 Solution generation

Since the identified critical conflict is associated with the interaction "PSS brings financial benefits for the company", the company should look for all the necessary conditions to ensure PSS to bring financial benefits for the company. Then move to the next conflict until there is no more needs to be resolved. To actually resolve these conflicts and generate a final solution for

PSS design problem need more domain knowledge and tools, so that it is difficult to conduct in this thesis.

However, as mentioned in the generic question asking stage, it is necessary to have a life cycle model to guide the PSS design process, since there has not been a general one recognized and approved by scholars, but mostly research-based.

3.3 EBD based PSS life cycle model

In this chapter, a conceptual life cycle model is proposed based on the previous work of using EBD methodologies to formalize PSS design process, as shown in Figure 17.

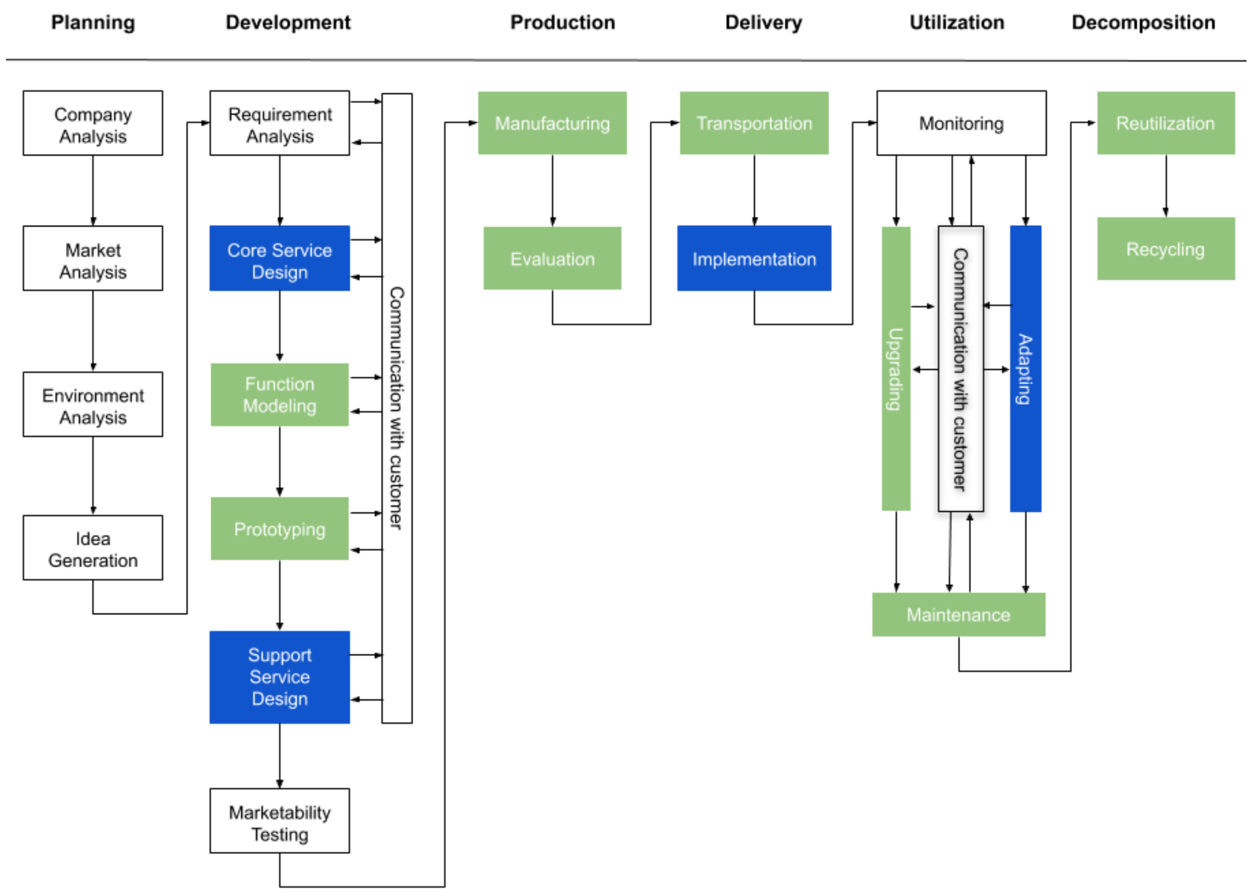


Figure 17 EBD based PSS life cycle model

There are six life cycle stages in the proposed model: planning, development, production, delivery, utilization and decomposition. Modules in green represent the activities of products; modules in blue represent the activities of services; modules in black are the activities of both products and services. The arrows among the modules indicate the sequence of conducting the activities.

Based on the EBD analysis on PSS design problem, which include question asking and answering process (Table 12), the ROM diagram (Figure 10) and also the environment components identified (Table 16), explanations of how this life cycle model is conducted are given in Table 21.

Table 21 Module details of PSS life cycle model

Planning	
Company Analysis	First thing in Planning phase for designers is to do the company analysis, as it is always important to know the internal situation of the company, such as value proposition, enterprise architecture, resources and core competitiveness, in order to choose the right market.
Market Analysis	With the right market chosen, external situation such as competitors should be analyzed. What are the market trends and needs should be detected so that opportunities can be discovered.
Environment Analysis	Environment analysis here is to cover all the rest analysis, besides the company itself and the market, for exploring the potentials of applying PSS concepts.
Idea Generation	After all kinds of analysis are done, ideas of what type of PSS is more suitable and what is the basic structure of the PSS can be generated.
Development	
Requirement Analysis	When the company receives customer requirements, it can move to Development stage and start with requirement analysis.
Core Service Design	With the understanding of the customer needs, core services should be considered first as core services represent main functions that customers require.
Function Modeling	As the tool or carrier that delivers core services to customers, products are designed by two activities. First is modeling functions according to the core services designed in advance
Prototyping	The second activity to design the products is prototyping for the complete products.
Support Service Design	With the prototype of the products, support services can be designed to maintain and ensure the physical and functional fitness of the products.
Communication With Customers	The above five activities are all conducted along with the communication with customers to ensure the satisfaction of customers while improving relationship with them.
Marketability Testing	Marketability testing is the last step of Development stage, after design processes of both products and services are completed, in order to make sure this PSS designed can move to next stage.

Production	
Manufacturing	At Production stage, products are manufactured and assembled in factories by manufacturers.
Evaluation	The company needs to evaluate them before they are delivered to customers.
Delivery	
Transportation	At Delivery stage, products are delivered to customers via transportation.
Implementation	Services are implemented after products are delivered to customers.
Utilization	
Monitoring	At Utilization stage, the company should keep in touch with customers to monitor the use of both products and services.
Updating	The company and customers communicate to determine when to upgrade the products.
Adapting	The company and customers communicate to determine when to adapt the services for them.
Maintenance	Support services such as maintenance are necessary if something goes wrong with products.
Communication With Customers	The above four activities are all conducted along with the communication with customers to ensure the satisfaction of customers while improving relationship with them.
Decomposition	
Reutilization	As the final stage, Decomposition stage deals with the reutilization of the products since services make products last longer and useful after finishing life cycle.
Recycling	Products that can not be reused anymore are recycled to decrease the products produced and reduce the cost.

When there are changes occur, whether of customers or market or anything else, designers can quickly respond by locating the corresponding modules and making adjustment.

This proposed EBD based PSS life cycle model separates products and services from each other, and is applicable for different fields that apply PSS concepts since it is generic.

3.4 Comparison with former PSS methodologies

In PSS design process, three indicators are often evaluated when assessing the success of a PSS design. The three indicators are knowledge requirements of the PSS designer, cost of design process and the quality of the product-service system.

3.4.1 The knowledge requirements of the PSS designer

Undoubtedly, the designer is playing a key role in any product-service system design process. In the conventional PSS methodologies, the level of knowledge and expertise of the designer often results in the level of the success of PSS design. The more domain knowledge the designer has, the higher chance of success of the PSS. Therefore, the conventional PSS methodologies are heavily domain-dependent.

Unlike the conventional PSS design methodologies, EBD based PSS design process is based on the systematic and recursive requirement-solution mode, therefore can offer formalized PSS design process. The success of EBD based PSS design does not rely on the domain knowledge of the designer, although the domain knowledge is certainly an add-on to the design. EBD based PSS design process is domain-independent.

3.4.2 The cost of design process

The cost resulting from the time spent on the design is another key factor for the success or failure of PSS design. The conventional PSS design process are based on trial-and-error mode, therefore are passive. The uncertain number of repeated trials could end up with large consumption of resources and postpone of PSS delivery time.

Unlike the conventional PSS design process, EBD is based on recursive requirement-solution mode, therefore is proactive. The analysis of the requirement does not necessarily require the product trial and therefore the cost could be cut down dramatically and under control.

3.4.3 The quality of the PSS design

One important aspect of the quality of a product design is that none of the needed features of the product is missing. In the conventional PSS design process, the requirement analysis relies on the results of product trial and the domain expertise of the designer. Neither of the above two factors could ensure the completeness of requirement analysis.

Whereas in EBD based PSS design process, the formalization of the design process could ensure all the needed features are figured out systematically, without considering the domain expertise of the designer. The quality of the PSS design is guaranteed by the formalization of the design process.

3.5 Benefits of applying EBD to PSS for different stakeholders

By comparing EBD based PSS design process with conventional PSS design process, the benefits of using EBD in PSS design process achieved by the designer /service provider /customer are outstanding. The benefits identified are:

a. It is designer-friendly. Because PSS design process becomes formalized (rather than experience based), the completeness of product features can be guaranteed and easily achieved. Also because EBD makes PSS design process programmable (rather than trial-error cycle of the product), EBD based PSS design process could save the design time of PSS significantly;
b. It is service-provider-friendly. Because EBD makes it easier to include the service provider in PSS design phase, the features and usability of the product could be more friendly to the service provider, therefore it could greatly save service time and increase customer satisfaction;
c. It is customer-friendly. Because EBD makes it easier to include the customer in the requirement analysis in product design phase, as a result, the features of the product are more intuitive and the learning curve of utilizing the product could be greatly reduced.

Chapter 4

Case Study

4.1 Introduction

To demonstrate how EBD approach can formalize PSS design, A real PSS design following EBD approach is conducted in this chapter.. The elevator manufacturing Company M is performing well in the market by providing different types of elevators including passenger elevator, freight elevator, hospital elevator, escalator, and elevator monitoring system, etc. The company also provides elevator services including installation, maintenance, repair, remote monitoring, elevator upgrading and spare parts supply, etc. Some critical service requirements in the elevator life cycle of Company M were often overlooked, because they had not been expressed by customers. Company M wants to enhance its competitiveness in the elevator service market by applying PSS concepts (Song and Sakao, 2017).

4.2 Case study procedures

4.2.1 Problem statement for Company M

From the introduction of Company M, it can be noticed that although Company M is doing great in the elevator market, it lacks communication with customers about service requirements and it hopes to enhance its competitiveness by applying PSS concepts. Therefore, the problem statement of this design problem could be as following:

Design a PSS for Company M to enhance its competitiveness in the elevator market and increase communication with customers about service requirements.

4.2.2 ROM diagrams for Company M

Following EBD process, the corresponding ROM diagram should be generated after the problem statement is in place. Thanks to the formalization of EBD approach, the ROM diagram created in Chapter 3 (Figure 10) is so generic that there is no need to create a ROM diagram specifically for the case of Company M from scratch. In this case study, the ROM diagram for Company M is generated by getting rid of the undesired information while keeping the useful ones in the generic ROM diagram in Figure 10. The ROM diagram for Company M is presented in Figure 18.

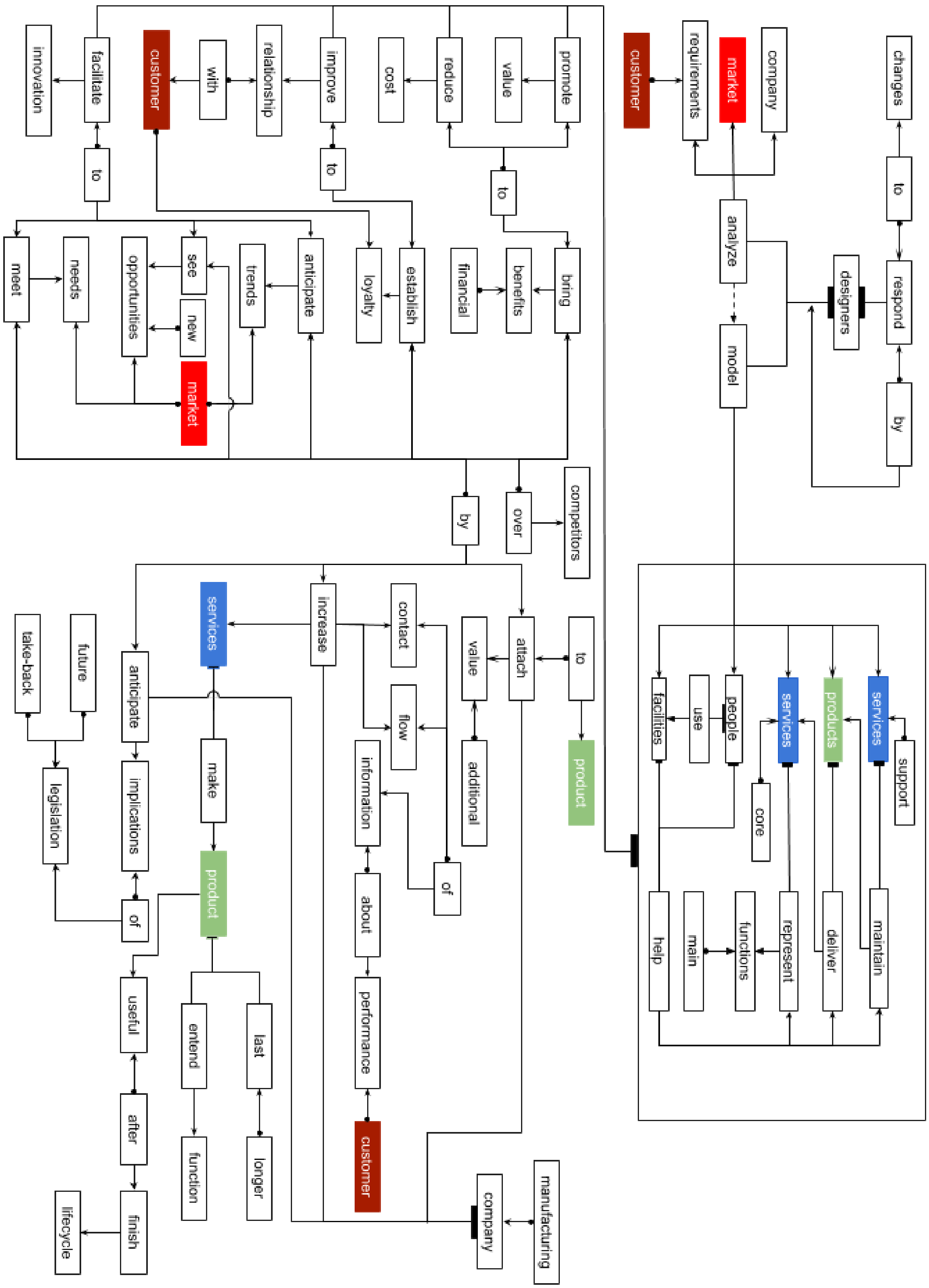


Figure 18 ROM diagram for Company M

4.2.3 Question asking and answering for Company M

In Chapter 3, the generic question asking and answering process ends at round 3, since it is clear enough for designers to understand the fuzzy problem statement "design a PSS". It could not go deeper either without extra information. For the same reason mentioned above in Rom diagram for the case study, the questions and answers stated in Chapter 3 (Table 6, Table 12, Table 13) are again generic enough that there is no need to raise the questions all over again. Only a few additional questions are asked based on the specific situation of Company M. These questions are simple enough for designers without EBD or PSS knowledge to answer.

Additional generic questions and answers based on the ROM diagram for Company M in Figure 10 are presented in Table 22, which are listed in random order. Question 4, 9, 10 need to be answered by designers in Company M, because they are related to the actual situation of Company M.

Table 22 Generic questions for Company M

Q1	What is the type of PSS for Company M?
	It is product-oriented, as shown in Figure 9, since the services are all related to elevators.
Q2	What is the market for Company M?
	It is the elevator market.
Q3	Who are the competitors of Company M?
	Elevator manufacturers, elevator service companies and other companies in the elevator market.
Q4	Who are the customers of Company M?
Q5	What are the current products of Company M?

	Different types of elevators including passenger elevator, freight elevator, hospital elevator, escalator, and elevator monitoring system, etc.
Q6	What are the current functions of the elevators?
	To transfer passengers or goods up and down by controls.
Q7	What are the current support services of Company M?
	Including installation, maintenance, repair, remote monitoring, elevator upgrading and spare parts supply, etc.
Q8	What are the current core services of Company M?
	To transfer passengers or goods effectively and efficiently.
Q9	What is the additional value that services attach to the elevators?
Q10	What are the current contact and flow of information about customer preferences?

After generic questions are answered, domain specific questions for Company M are asked and answered. The two domain specific questions are listed in Table 23.

Table 23 Domain specific questions for Company M

Q11	What is the life cycle of the PSS of Company M?
Q12	What are the relevant components of natural, built, and human environments of each stage of the life cycle of the PSS of Company M?

4.2.4 EBD based PSS life cycle model for Company M

Answers referring to EBD based PSS life cycle model and environment components are integrated and shown in Figure 19. As a natural environment component for all activities in a PSS life cycle, "time" is omitted in Figure 19.

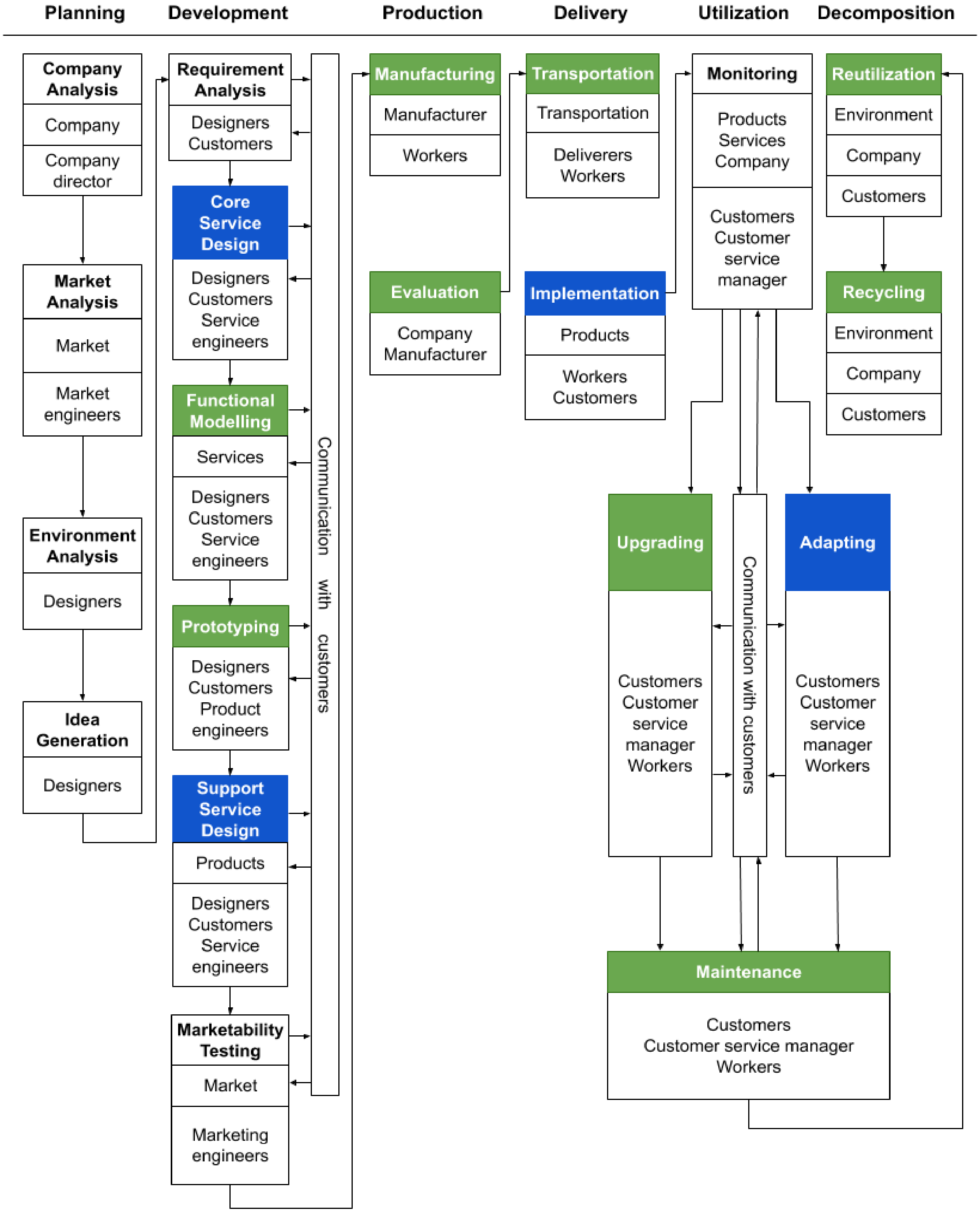


Figure 19 PSS life cycle model with environment components for Company M

Each module in Figure 19 is explained in detail in Table 24.

Table 24 Module details of PSS life cycle model for Company M

Planning	
Company Analysis	The PSS designers are to conduct the analysis of Company M. In the analysis, the value proposition, enterprise architecture, resources and core competitiveness of Company M are figured out in order to be aware of the internal environment.
Market Analysis	The external situation is analyzed. The situation of the competitors, the market trends and needs are detected, by which the opportunities are discovered.
Environment Analysis	Cover all the remaining analysis, in addition to Company M itself and the market.
Idea Generation	The ideas of what type of PSS is more suitable and what is the basic structure of the PSS are generated.
Development	
Requirement Analysis	When Company M receives customer requirements, it moves to the development stage and starts with the requirement analysis. The major requirements of the customer are the faster response to service request and cost effectiveness.
Core Service Design	With the understanding of the customer needs, the core services are considered in the first place. The service model is therefore designed to have less layers of decision making in Company M in order to reduce the time responding to customer's request.
Function Modeling	Functions of elevators are modeled according to the core services
Prototyping	With the modeled functions, the elevators are prototyped.
Support Service Design	With the prototypes of the elevators, support services are designed to maintain and ensure the physical and functional fitness of the elevators.
Communication With Customers	The above five activities are all conducted along with the communication with customers to ensure the satisfaction of customers and relationship improvement.

Marketability Testing	In the last, Marketability testing of elevator PSS is conducted, after design processes of both products and services are completed. This is to make sure this PSS design can move to the next stage.
Production	
Manufacturing	Elevators are manufactured and assembled in factories of manufacturers.
Evaluation	Company M evaluates the elevators before they are delivered to the customers.
Delivery	
Transportation	After the elevators are produced, they are delivered to customers via transportation.
Implementation	The elevators are assembled and installed onsite for customers.
Utilization	
Monitoring	Company M keeps in touch with the customers to monitor the use of both elevators and their main functions. The advanced IT technology is adopted to achieve the real-time effect of system and service monitoring.
Updating	Thanks to the real-time monitoring system, the determination of updating the elevator is easy to be made.
Adapting	With the real-time status of the elevator in production, the services to the elevator can be conveyed adaptively.
Maintenance	Thanks to the monitoring system, when to maintain and what to maintain can be easily determined.
Communication With Customers	All above activities are conducted with communication with the customers in real-time fashion.
Decomposition	
Reutilization	Reutilization of the elevators would save the expense on the parts.
Recycling	Recycling the disposed elevators would decrease the elevator produced, save cost and further contribute to the sustainable world.

With this clearly defined life cycle for Company M, designers can quickly respond to the customer's request by locating the corresponding modules and making adjustment. This EBD based PSS life cycle model separates elevators and their related services from each other, and proves that the proposed model is applicable for different fields due to its generic nature.

4.2.5 Comparison with former PSS methodologies

Following the points detailed in Chapter 3.4, EBD based PSS design process applied in Company M is compared with former PSS methodologies from the following three aspects.

a. Knowledge requirements of the PSS designer;
b. Cost of design process;
c. Quality of the product-service system.

The knowledge requirements of the PSS designer

Utilizing the former PSS design methodologies, the elevator designers in Company M have to be equipped with adequate elevator-specific domain knowledge and experiences, in order to complete the design process. They have to be well knowledgeable in the mechanical and electrical engineering fields, in order to conduct the requirement analysis. Without those professional knowledge, it is impossible to raise appropriate questions and give correct answers. The requirement of cross-field professional knowledge results in the lack of qualified designers in Company M.

By adopting EBS based PSS design methodologies, the designers in Company M can easily finish the requirement analysis as it illustrates in chapter 4.2.1 to 4.2.4. This swipes off the obstacle of cross-field knowledge requirement for many designers. As a result, the number of elevator design is reduced significantly. This is a big progress to Company M, thanks to the formalization of EBD based systematic approaches.

The cost of design process

Because of former PSS design methodologies that are based on trail-and-error pattern, the time and resources spent on the design process in Company M was significant and out of expectation in many cases. For example, the operation patterns for the elevators in different types of buildings could be dramatically different. The software in the elevator control system had to be tuned many times even after the elevator was deployed. As a result, the cost of manpower of the designers is considerably high.

By utilizing EBD based PSS methodologies, the system requirements are all figured out in the design stage. Many requirements that were not obvious are exposed in the design stage. Therefore, the number of times of trail-and-error is greatly reduced. Again take the software in the elevator control system for example. By utilizing EBD's systematic approaches, the requirements of elevator operation patterns are worked out for the elevators in different types of buildings in the design stage, the software in the control system is able to be customized to match the elevator operation pattern in different types of buildings. This saves a lot of time and cost by cutting the number of trips to the field of the elevator. The time of elevator deployment is also shortened.

The quality of the PSS design

One important benchmark of the quality of an elevator system design is that all needed features are considered in the design stage. This requires the completeness of requirement analysis. In the former PSS design methodologies, the designer of Company M could hardly figure out the complete requirements in the design stage. For example, there are a cluster of elevator installed in an office building. Whether or not an elevator should skip certain floors while another elevator should stop on every floor could not be determined in the design stage, if such requirement was not figured out in advance. Again, it is the formalization of EBD based PSS design methodologies that could dig out the appropriate questions against such very customized requirements and give the correct answers. In the current market, such subtle advantages of an elevator system could be the winning point of the customers.

4.2.6 Benefits of applying EBD in elevator PSS

By following the systematic method of EBD, the requirement analysis of an elevator PSS is completely figured out by the designers themselves. Meanwhile, the design is conducted by multiple designers in parallel, therefore creating the opportunity of reaching a better design result by either consolidating the multiple design results or customer choosing a favorable result. The requirements from all groups of people (designer, service provider and customer) could be met and therefore the quality of the elevator design is noticeably leveraged.

Since the six stages of the life cycle for the elevator PSS design is in place, all the people in the life cycle of the PSS, such as engineers of the design, technician of installation and after-sale service, the operator of elevator and parts vendor, can quickly locate and address the request with the same protocol described in the life cycle of the elevator PSS. As a result, the service time is greatly reduced and customer’s satisfaction is leveraged.

In the elevator PSS design stage, all people involved in the life cycle are invited to participate. The customer's requirements are well-known to the designer of the elevator PSS, and are converted to the system requirements by following the formalized EBD approach. As a result, the requirements of the people in every stage of the life cycle of the elevator PSS are met early in the design stage. This will greatly facilitate the customers in all stages of the life cycle of the elevator PSS.

Chapter 5

Conclusion and Future work

5.1 Conclusion

In the recent years, the Product-Service System (PSS) design process has been illustrating its advantages in separating the product-related services with the product itself in the product design stage. There are a number of prevailing PSS design methodologies on the market. However, these PSS design methodologies are proven to have a noticeable problem of lacking formalization. The lack of formalization results in higher requirements of domain knowledge for the product designer, higher cost for the design process and the discrepancy of the quality of a product design. Thanks to the advantages of EBD approach, adopting EBD approach to recreate the PSS design process just eliminates the said problem of the prevailing PSS design process and leverages the PSS design process into a systematic level.

EBD based PSS design process starts from a fuzzy problem statement, from which the generic ROM diagram is generated, and the iteratively asking and answering questions follows up for several rounds. After the environment analysis is done, the product designer gets much clearer to the after the environment than that in the very beginning. Conflicts are then identified from the interaction dependency network, and the critical conflicts are found to be solved in the solution generation phase.

Since the outstanding systematic nature of EBD methodologies, the EBD based PSS design process proposed in this thesis is redesigned to such a level of formalization. The design works that used to be done by means of various approaches are done in much identical ways. The quantity of the jobs left for the specific product design is greatly reduced, and the quality of the product design is guaranteed.

The proposed lifecycle in this thesis separates the products from the services by defining six stages of the lifecycle of a product. Such lifecycle definition makes the product design and service implementation much more effective.

In the case study, an elevator company M is carried out to prove the effectiveness and efficiency of EBD approach as a design methodology. It also proves the practicability of the PSS life cycle model.

5.2 Discussion

The environment analysis process of EBD approach is generic and systematic, which is quite useful when the design problem is from a relatively new field for designers. When it goes to a common field, is EBD still a priority or how to improve its effectiveness and efficiency should be a research direction.

When it moves to conflict identification and solution generation stages, it looks like not as powerful as environment analysis, since more and more domain knowledge are demanded. How to use these two activities properly and use EBD not only in planning stage are two questions that should be considered.

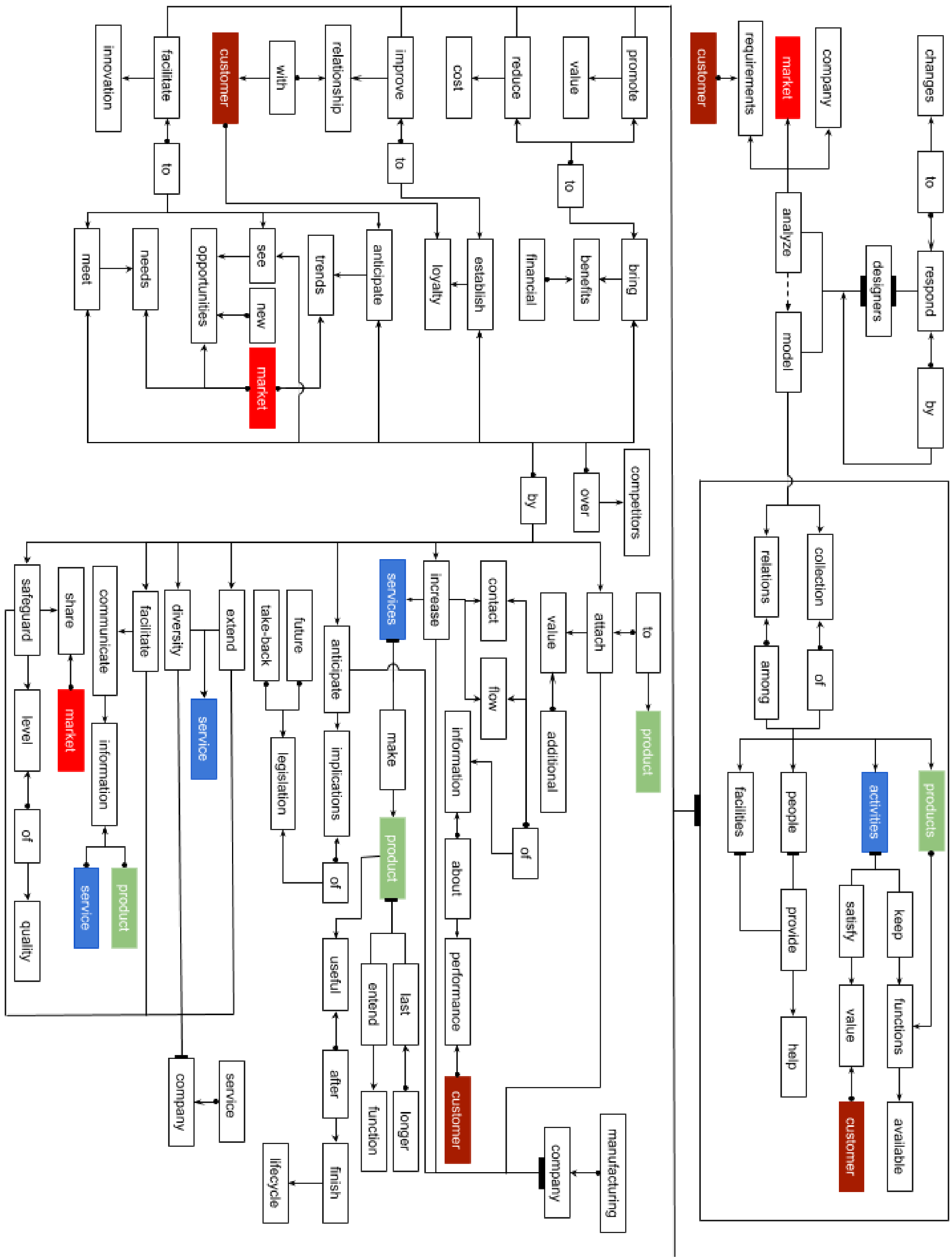
For PSS, as it is still developing rapidly, three types of PSS are clearly not enough to learn about. Since only formalizing and guiding its design process in this thesis, how PSS really works and benefits companies, customers and the environment should also be explored.

5.3 Future work

To prove the effectiveness and efficiency of EBD approach as a generic design methodology, it should be applied in more and more new fields. But when applied to a common familiar field, the performance should be improved as well. As for conflict identification, the rules and concepts are quite difficult to capture, so perhaps the process can be simplified.

For the case study, questions may be asked continually for some more detailed requirements and more conflicts and relations can be found. But it requires to participate in the design process of PSS in Company M and get access to actual information.

Appendix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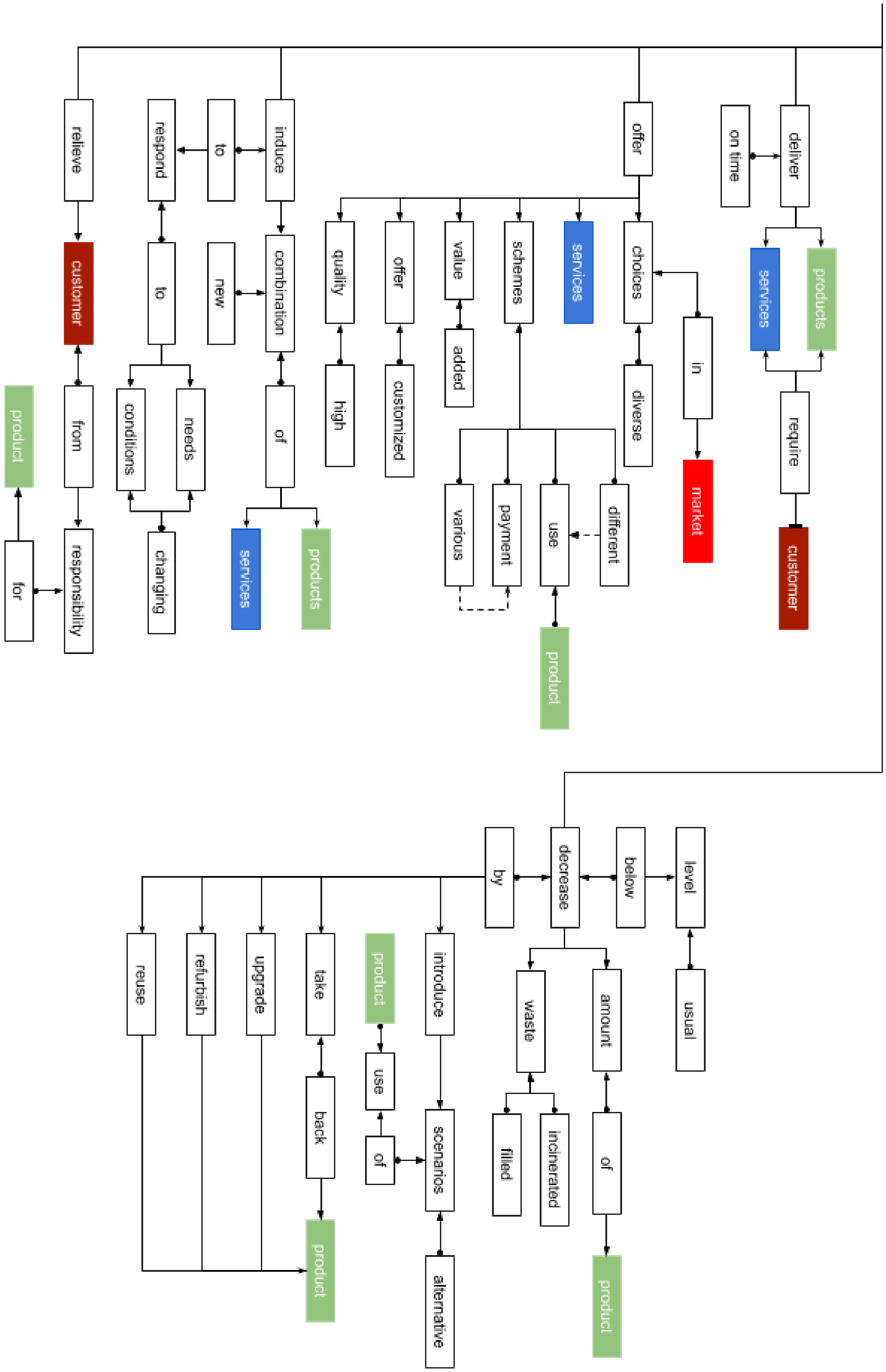

Figure A1 ROM diagram 2.5

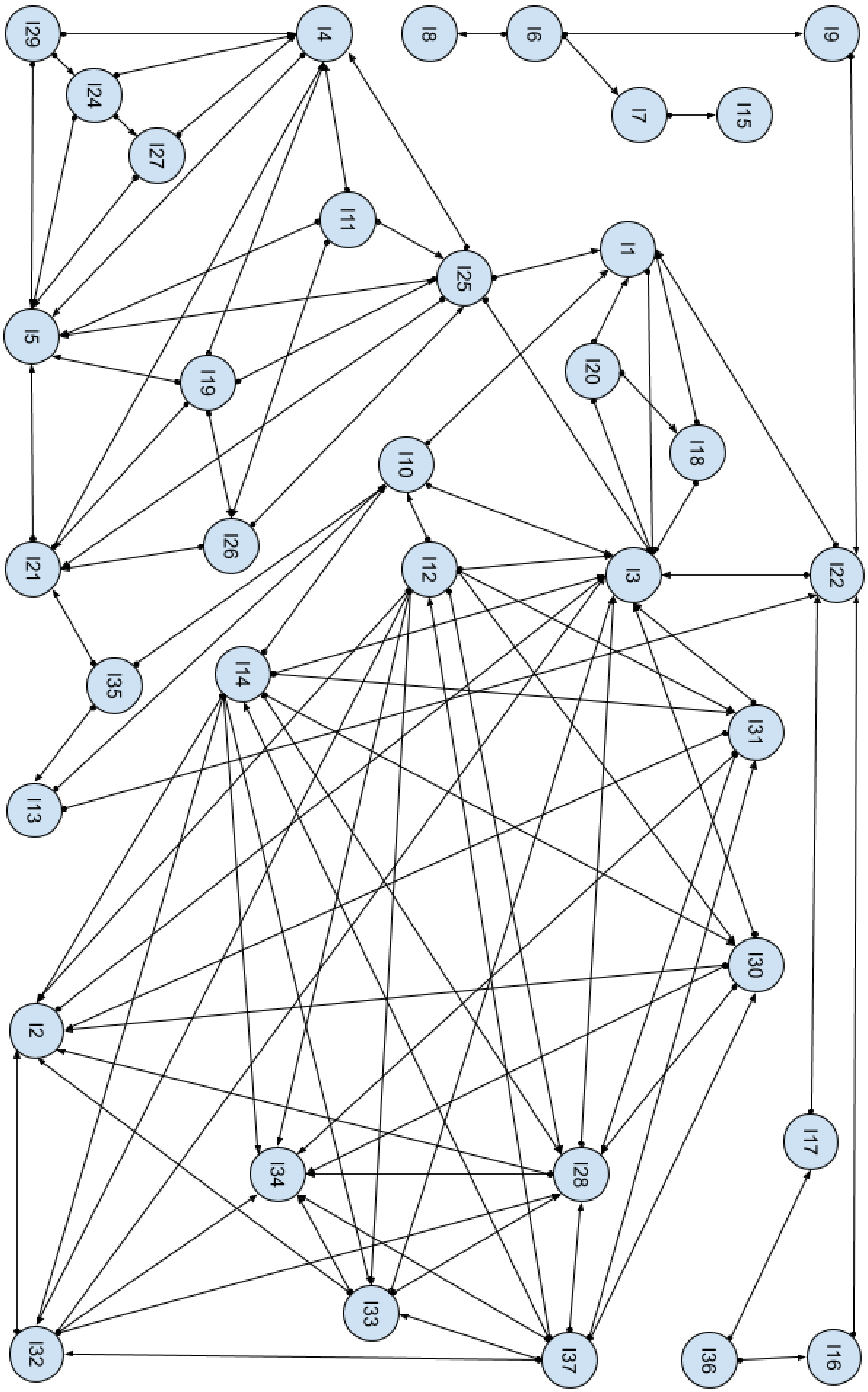

Figure A2 Interaction dependency network

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