Computers in Industry 63 (2012) 298–308

Contents lists available at SciVerse ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

# Module partition process model and method of integrated service product

Hao Li [a,b], Yangjian Ji [a,*], Xinjian Gu [a], Guoning Qi [a], Renzhong Tang [a]

[a] Department of Mechanical Engineering, Zhejiang University, Hangzhou, 310027, PR China
[b] School of Mechanical and Electric Engineering, Zhengzhou University of Light Industry, Zhengzhou 450002, PR China

ARTICLE INFO

*Article history:*
Received 20 July 2011
Received in revised form 15 February 2012
Accepted 16 February 2012
Available online 6 April 2012

*Keywords:*
Integrated service product
Physical product
Product service
Product-service system
Module partition
Quality function deployment

ABSTRACT

Due to customers' constantly increasing demand for personalized products and services, manufacturing enterprises must provide more diverse physical products and services in the product sale stage. However, the massive diversity of personalized products and services offered leads to the internal diversification of products and services, which greatly increases production costs. The application of the modular method can effectively improve the reusability of a product or service, and reduce internal diversification of the product and service. In this paper, the interactive modular design process is established by the analysis of the relationship between a product or service of integrated service product (ISP) and the analysis of the physical module and service module. This paper deals with the module partition principle of ISP, puts forward the three-stages module partition processes and methods, mainly including service module partition processes based on the "Top-Down" and "Bottom-Up" methods, the physical module partition process based on the "Top-Down", and the module partition methods based on Quality Function Deployment and mapping matrix. Finally, a case study is done on an electric power transformer using proposed principle and methods, and the processes and methods can achieve the interactive module partition of ISP.



## 1. Introduction

As environmental pollution and unsustainable development intensify, so do people's needs for environmental protection and sustainable products. From this demand comes the emergence of a new strategy:product-service system (PSS), which changes traditional product and consumer offering patterns. This strategy aims to integrate tangible physical products and intangible services to achieve a minimum environmental load and sustainability [1,2]. At the same time, the enterprise provides the user with value-added services, achieves more sustainable profit, and enhances the competitiveness of the enterprise [3]. With the development of research on PSS, the popular understandings for PSS are: satisfy customers' needs, create more value and make low environmental impact. Various phrases in the literature: "functional sales/economy", "integrated product-service offerings", "product-to-service" and "product-service systems" all refer to this concept [4]. Goedkoop et al. [1], Mont [2], Manzini and Vezzoli [5], Brandstotter et al. [6] and Wong [7] analyzed the concept of PSS, Baines et al. put forward three types of PSS systems: product-oriented PSS, use-oriented PSS and result-oriented PSS, which has become the popular classification of PSS [8].

In recent years, the users show more and more requirements for the personalized product and service [9,10]. Individualized and changeable products and services inevitably cause cost increases in enterprise management, design and manufacture and the supply chain [11]. The modularization of physical products and services can solve the conflicts between personalization and low cost. By establishing a series of standard physical modules and service modules, it can simplify product internal structure and reduce production cost and environmental impact; through the combinations of modulars, it can achieve a variety of physical products and services, and satisfy the customers' personalized needs [12]. However, the modularization offering of physical product and service needs to be realized through the modular design platform [9], and the Baines classification of PSS cannot meet the needs of establishing the modular design platform [8]. For example, product-oriented PSS may have pure physical products or "physical product plus service", but due to complex relationships between physical products and services, larger differences may exist between pure physical product modularization principle and "physical product plus service" modularization principle, which makes it impossible to establish a uniform product-oriented PSS modular design platform. Therefore, the reclassification of the PSS is needed to establish an adaptable modular product platform.

* Corresponding author. Tel.: +86 057187953242.
*E-mail addresses:* lh9666@hotmail.com (H. Li), mejyj@zju.edu.cn (Y. Ji), xjgu@zju.edu.cn (X. Gu), gnqi@zju.edu.cn (G. Qi), tangrz@zju.edu.cn (R. Tang).

0166-3615/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.compind.2012.02.015

In order to establish the customer personalized modular product platform, the author puts forward the concept of "integrated service product (ISP)" in Refs. [3,13], pointing out that: in product sales stage, to meet the clients' multi-level needs, the manufacturer provides customers with "physical product plus service" service packs; whereas, physical product is the carrier of product service, and product services are function added and the value added for the physical product. However, since the ISP combines characteristics of both physical products and services, it becomes the most complex product type. In module partition process, how to effectively and reasonably divide the modules of ISP has become the most pressing problem to be solved in the product design.

This paper deals with a module partition methodology of ISP. The second section briefly reviews the existing design method for ISP. The third section analyzes the product modularization design of ISP, as well as the relations between the product and service, and related concepts. The fourth section analyzes the module dividing principle of ISP. The fifth section puts forward a three-stage process for module partition, and provides the realization method at each stage. Finally, a transformer case is used to show the feasibility of the related methods. The discussion and summary show the significance of the described process and methods, as well as limitations and future prospects.

## 2. An overview of related research

### 2.1. Research progress of PSS design

In recent years, the environment and sustainable development have become of increasing concern to both producers and consumers. Thus, PSS has attracted great interest from industry and academia as an important means for sustainable product development [1]. PSS design is the most important stage in the realization of PSS, and has become a hot research spot in the field of PSS.

Scholars have proposed a set of methods to support PSS System design, such as Kathalys PSS method [14], sustainable product and service development method [15], Methodology for PSS development [16], and the product-service blueprint method [17]. These methods provide specific design frames, PSS development processes, implement tools, and play important roles in service design process and PSS implementation.

However, research on product and service integration design theory and on the overall scheme description is still lacking [18]. For this issue, Aurich put forward the design methodology for integrated products and services system development, the result reflects the interactive design of product and service [19]. Ge et al. put forward product/service integration design methodology based on the axiomatic design theory and the fault tree analysis [18]. Zhang et al. put forward the product/service overall design of full product, and proposed variational configuration model of full product based on general bill of material [20]. These studies make up for the research deficiency on the design methodology of integrated products and services, and provide PSS design with technical support.

### 2.2. Research progress of PSS modular design

For the research on physical product modulization, many scholars such as Aoki [21], Pahl and Beitz [22], Suh [23], Tong [12], Li [24], Hou et al. [25], Qi et al [9], Erixon et al. [26], Tseng and Jiao [27], Dahmus et al. [28], Gu and Sosale [29], and Fan et al. [30], have already built a mature system of modularization theory and methodology. The main methods used in the physical product modulization are: the design structure matrix, genetic algorithms, the quality house matrix, the function flow model, simulated annealing algorithms, the axiomatic design theory, clustering algorithms, and complex networks [9,12,21–30]. These methods aim at the particular stage of the product life cycle, and make physical product module division more quantitative.

For the intangibility and changeability of the service product, Li divided the service modularization into content modularization and process modularization, interfaces between modulars are more loose than interfaces between industry product modules [31]. Guan put forward a module partition method based on service blueprints and function flow [32]. Deng put forward the basic characteristics and processes based on the module combination of financial service innovation [33]. The above findings refine the service module partition and make it more concrete.

With the emergence of PSS strategy, the traditional module partition methodology needs to be expanded [34]. With the customer's increasing personalized needs for products and services, the product offering and system implementation of PSS become more and more complex. Therefore, the modular strategy for products and services has been applied to reduce the complexity of product engineering. In order to improve the product and service potential, Aurich gave a modular principle to realize the technical PSS, and put forward a process library used to design and manufacture module technical PSS [35]. Wang deeply investigated PSS parallel modular development and the relationship between the physical products and services, and used QFD method and portfolio technique to complete PSS module development [36].

According to the above studies, many scholars have made great advances in physical product modularization, service modularization, integrated design of ISP, but mainly from the perspective of strategy, management, and process. Up to now, the research on the modular design methodology of ISP is still minimal, and the influence relation analysis between physical product and service has not been revealed. Therefore, the key question remaining in the field is how to solve ISP module partitioning.

## 3. The modular design of ISP

### 3.1. Understanding the relationship between the product and service

ISP includes physical products and services, and the relationship between physical products and services can be analyzed from the product structure (Fig. 1). According to the correlation degree of physical products and service, service can be divided into functional service and non-functional service.

A functional service is a type of service which needs to be completed with specific physical components for support, including maintenance service, remote monitoring, etc., and these services will directly affect the function and structure of physical product. Non-functional service is independent of the function physical module, including consulting service, installation service, transportation service, training service and so on. As shown in Fig. 1, functional services can be carried out when the special optional physical component assembled in the physical product; but the non-functional service can be carried out without the physical component. Therefore, ISP design not only considers the service-oriented physical product design, but should also take into account service design based on the physical product, so ISP design is the integrated design process of physical product and service.

### 3.2. Physical module V.S. Service module

#### 3.2.1. Physical module

For the traditional physical product, many scholars have given definitions of the "physical module" [21–26], but there is still no unified standard definition and the popular view is the definition from Masahiko. He described the module as a kind of semi-self-disciplined subsystem with independent function that could