Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 53 (2016) 21 – 28

www.elsevier.com/locate/procedia

The 10th International Conference on Axiomatic Design, ICAD 2016

A systematic approach to coupling disposal of product family design (part 1): methodology

Renbin Xiao[a,]*, Xianfu Cheng[b]

[a]*School of Automation, Huazhong University of Science and Technology, Wuhan 430074, China*
[b]*School of Mechanical and Electronical Engineering, East China Jiaotong University, Nanchang 330013, China*

* Corresponding author. *E-mail address:* rbxiao@163.com

Abstract

In this paper, on the basis of comparison and analysis on the similarities and differences of design coupling between product family and single product, a systematic approach to coupling disposal of product family design is proposed, and coupling disposal flow of two level including strategy level and operation level is given. From strategy level of platform plan, axiomatic design theory is utilized as framework to analyze and classify functional requirements, design parameters are mapped with "zigzagging" mode, and platform parameters are identified. In the view of platform operation level, design structure matrix (DSM) converted by design matrix DSM are clustered and grouped into modules, and coupling correlation matrix of product family design is established, which can realize high cohesion degree in a single module and low coupling degree among all the modules. Then, from the coupling inside platform modules, inside customization modules, and among design parameters with different modules, the corresponding decoupling methods of product family design are presented, and the methods architecture of to coupling disposal of product family design is established.

Peer-review under responsibility of the scientific committee of The 10th International Conference on Axiomatic Design

Keywords: product family, coupled design, coupling disposal, decoupling

1. Introduction

With the users' increasing demands for product customization and the rapid development of information technology, Mass Customization has recently received a significant amount of attentions within the business community [1]. Product family development has been widely recognized as an effective way to implement mass customization [2]. A product family is a group of related products based on the same product platform by providing a variety of products for achieving the economy of scale and accommodating the proliferation of customized product variants across different market segments. Platform-based product family design is an effective means not only to capture total cost savings and speed time to market but also to maintain differentiation and competitiveness. However, the design of a product family is typically more challenging than designing single product.

In regard to the design of product families, many literatures have been published during the last decades. A variety of methods and tools have been extensively developed to support product family design. Simpson [3] as well as Jose and Tollenaere [4] provided comprehensive state-of-the-art reviews of modular design, product family design and platform-based product development. Kumar et al. [5] proposed a methodology to design product families integrating market considerations to examine the impact of increasing the product variety. Barajas and Agard [6] proposed a comprehensive methodology to form product families by taking advantage of the fuzzy logic to tackle uncertainties. Eichstetter et al. [7] presented an approach to identify components in order to optimize commonality for a product family of arbitrary high-dimensional nonlinear systems.

Peer-review under responsibility of the scientific committee of The 10th International Conference on Axiomatic Design
doi:10.1016/j.procir.2016.07.064

There exist generally relationships between product variants in product family that cause physical coupling between product platforms and it will increase the difficulty of product design. Thus the coupling should be avoided to the greatest extent. But in the actual product design, due to technical or other limitations, it is very difficult to get uncoupled design or decoupled design. Therefore, coupling problem in product design has become one of the key problems to be solved urgently in engineering and industry fields. Chen and Teng [8] introduced the concept and description methods of product design coupling, elaborated the coupling analysis method which was commonly used at present and its application in product design, and discussed the comparison of the studies on direct coupling and coupling propagation and the existing problems.

Independence axiom in Axiomatic Design (AD) theory provided the fundamental criterion to judge whether the design is success or not and its improvement directions [9]. For example, Johannesson [10] defined coupling function as mutual negative effect between two subsystems while implementing a functional requirement. Kang [11] proposed using TRIZ conflict matrix into axiomatic design, choosing appropriate invention principle to decouple the coupling in axiomatic design. Choi and Hwang [12] proposed to represent the system structure using the flow chart, taking axiomatic design matrix as nonlinear, and then analysis the coupling relationship between the various modules. Su et al [13] used the split algorithm to rearrange the design matrix, measured the function coupling through analytic hierarchy process, and searched the optimum and initial iteration sequence of coupling function through optimization algorithm. Lee [14] comprehensive considered the costs and benefits of removing nondiagonal elements in the design matrix and achieved decoupling by determining the minimum sequence nondiagonal elements. Based on the design association, redesign division and mode selection, Chen et al. [15] analyzed the product internal coupling relationship and put forward the decomposition coupling design methods so as to realize the rapid redesign to support the product agile manufacturing. Cao et al. [16] proposed the structured coupling design method based on the independence axiom, using decomposition operation to identify the independent function and the coupling function sets, applying the pairwise comparison method and triangular fuzzy number to measure coupling function. Yu et al. [17] based on the network analysis method to study the interactions between functional requirements in axiomatic design, and put forward the evaluation algorithm in interaction and discriminated method to determine whether the interaction could be ignored. Cai et al. [18] used the axiomatic design theory to identify the coupling function while planning the design matrix, adopted systematic innovative thinking mode to describe the coupling problems, selected and applied innovative thinking motivation techniques to completely decouple the associated functional requirements. They also defined the concept of “fuzzy independent range”, put forward a decoupling method based on satisfaction, decoupling design those coupling design that violation the independence axiom according to the satisfaction degree and the fuzzy independent range [19].

The above researches mainly focus on the coupling design problems of single product and used the explicit way of product design decoupling. This paper aims at the problem that the product family design is unable to complete decoupling, and discusses how to deal with physical coupling design problem. This paper mainly studies the coupling disposal strategy and decoupling methods in product family design.

2. Coupling analysis and processing in product family design

For single product design, from the perspective of product functionality - parameter, the coupling problem can be divided into two categories: functional coupling and physical coupling. For functional coupling, we can use the independence axiom, guided by the “zigzagging” mapping process in the adjacent domain of AD framework, to decompose FRs and adjust the design matrix, and reveal the interaction between FRs and DPs to identify independent design tasks and coupling design tasks. The functional coupling is disposed by this way. For physical coupling that is also called parameter association, we can use the Directed Graph, CMP (Critical Path Method), PERT (Program Evaluation and Review Technique), IDEF (Integrated Definition Methods), Petri nets, DSM (Design Structure Matrix) or other methods for coupling analysis and decoupling. Especially DSM method is widely used, and it may make the design task achieve the sequence optimization of design tasks [20]. In product design, there are two ways to deal with coupling problems: one is the split method, and the other is internal iteration method [21]. Therefore, design coupling problem of single product mainly determine the parameters or the properties of the task or iterative sequence from micro level, and can be used in customize design as well as innovation design, to improve the design efficiency and reduce the design complexity.

Product family refers to a group or a series of products. It is suitable to adaptability design of the product, and mainly consists of modular design and parametric design. The purpose is to improve and modify the existing products. Product family design is based on common platform and derives series of products. Common platform parameters reflect the universalities of product platform, and individual parameters reflect the differences of product platform. Generality and difference of product platform is a pair of contradictions. The more common platform parameters, the better platform generality, the lower design cost, but the customization ability will become poorer and can’t fully meet customers’ diverse demands. The less common platform parameters, the lager platform diversity, the easier to satisfy the customized needs, but the generality will become less and design costs will increase.

In both modular and parametric product family, the design coupling not only has the characteristics of single product design, but also takes the relationship between product variants in product family into consideration. Overall, there may be coupling relationship between parameters in product family design, and there exist association relationship and