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A Method for Green Modular Design Considering Product Platform Planning Strategy

Qi Wang[a], Dunbing Tang[a]*, Leilei Yin[a], JunYang[a]

[a]*College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China*

* Corresponding author. Tel.: +86 25 84892051; fax: +86 25 84891501. *E-mail address:* d.tang@nuaa.edu.cn

Abstract

Green modular product design plays one of the most important roles to create products with less environmental impact targeting the sustainable society. Nevertheless, traditional green modular design has the risk of losing the use of strategy of product platform planning. And this strategy is widely employed by company in order to shorten time to market and reduce costs. Aiming at the problem, a modular design method is proposed in this paper considering not only the environmental impact of product but also product platform planning strategy. The instability index of component is first presented to evaluate the change likelihood of component in future generations. Based on the instability index, the calculation method for the probability of product platform planning between product generations is illustrated. Next, a mathematical formulation for green modular design with consideration of product platform planning strategy is given. Moreover, for obtaining an optimal design scheme, a genetic algorithm is employed to conduct modular optimization. Finally, the effectiveness of the proposed method is demonstrated through a case study.

Keywords: Green design; Modularity; Product platform planning strategy; Design optimization

1. Introduction

Manufacturing industry is faced with a challenge to create products with less environmental impact targeting the sustainable society. Green design or eco-design plays one of the most important roles to cope with this challenge. Green product design is defined as a practical tries to reduce environmental impact of a product at the design stage. Some methods are appeared for green product design such as design for recycling (DFR) and design for disassembly (DFD). Since green modular structures can improve the environmental performance of product cycle life, green modular design is considered to be an important method of green design. In recently years, many researches have been carried out in the green modular product design field.

Ishii [1] introduced the concept of 'Technology modules' based on 'clump' analysis to link 'Design for Product Retirement' and 'Modularity'. The aim of 'Technology modules' is that components with the same retirement methods (e.g. recycling, and disposal) should be grouped in the same module. Gu [2] studied the modular design method considering the requirement of the entire product life cycle. A weighted method is used in determination of the interaction of components in a product. Krikke [3] developed a model to support decision-making concerning both the design structure of a product, i.e. modularity, reparability and recyclability, and the design structure of the logistics network. Sensitivity analysis is then provided to analyze their impact to the environmental and the life cycle costs. Five basic rules is employed by Huang [4] for recycling in modular design. Five rules include life-cycle analysis, materials compatibility, recycling profit, environmental impact of recycling, and structural and physical interaction analysis. Then a fuzzy clustering algorithm was adopted to form the component clusters based on a fuzzy correlation matrix. Umeda [5] presented a modular design methodology that derives modular structures based on both life-cycle properties and geometric information. It aggregates attributes related to a product life

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cycle using a technique called self-organizing maps. A grouping genetic algorithm was employed by Tseng [6] to cluster components into modules supporting life-cycle engineering, and subsequently the modules are adjusted according to green design issues. With green considerations incorporated into new modules, Smith [7] putted forward a green modularization method based on the atomic theory, whereby the green modules are created by merging or separating structural modules with respect to environmental impacts. Based on re-design risk control, Yang [8] explored a modular eco-design method for life-cycle engineering, in which functional and physical risk assessments are introduced as two constraints during the re-design optimization process. Yu [9] proposed a product redesign method for modular design with consideration of both product life issues and the original physical connection relations.

Although many researches can be found in green modular design, traditional green modular design has the risk of losing the use of strategy of product platform planning. In today's highly competitive global business environment, the speed of the product replacement is becoming faster and faster. The platform-based strategy is widely used in company due to the fact that it is benefit for enterprises to decrease frequent redesign cost and time to market. In this paper, a methodology for green modular design with consideration of platform planning strategy is proposed. The proposed approach can provide an optimal solution for modular design of product in simultaneously considering the environmental impact of product and product platform planning strategy.

2. Green modular design with consideration of platform planning strategy

2.1. The instability index of component

A product contains platform components and non-platform components. The platform component can be used in multiple generations of products, and the non-platform component is only used in a generation. If a module involves non-platform component, the module cannot be used as a modular product platform in future generations. Therefore, in product modular design, the platform component and non-platform component should be avoided to cluster into one modular from the aspect of product platform planning. Due to the uncertain in future market, it is impossible to determine that a component is platform component or non-platform component. This paper proposes the instability index to evaluate the probability that a component is non-platform component. When the instability index of component is given, the platform planning probability of different modular design schemes can be evaluated.

As shown in Fig.1, the calculation method for instability index of component is divided into four steps. Each step is introduced as follows:

Step 1: Prediction the change in future market needs

Here, the product specification with the risk of change is called variability specification. In first step, the variability specifications are judged by market experts, while their change likelihoods need to be estimated. The change of market demand does not mean that a company will change its products, and whether to make the change is determined by the decision-makers of company. Therefore, the change probability of a variability specification is estimated based on two aspects: market and company strategy. It is assumed that the change probability of the specification i (*Spec.i*) in future market demand is represented by $P_{sp}^{m(i)}$, and the probability which the decision-makers determine to change the specification i (*Spec.i*) is indicated by $P_{sp}^{c(i)}$. Then, the change probability ($P_{sp}^{(i)}$) of specification i (*Spec.i*) is calculated as follows.

$$P_{sp}^{(i)} = P_{sp}^{m(i)} \times P_{sp}^{c(i)} \tag{1}$$

The $P_{sp}^{m(i)}$ and $P_{sp}^{c(i)}$ is given by experts according to Table 1.

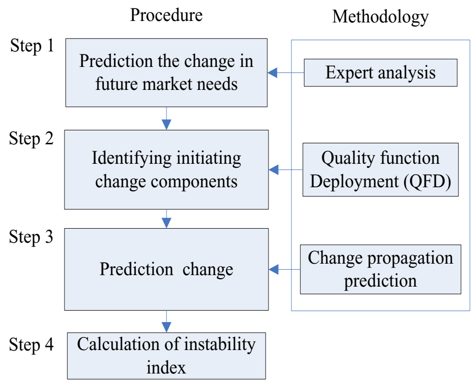

Fig. 1. Calculation of instability index for component

Table 1. Grades of change.

Description of change	Change probability
No change	0
Very small	0.2
Small	0.4
Big	0.6
Very big	0.8
change	1

Step 2: Identifying initiating change components

In this paper, the component directly related with the variability specification is called initiating change component (IC component). In the second step, IC components are identified by using Quality Function Deployment (QFD). To mark the relationships between specifications and components, the rows (what) of a QFD matrix are filled with specifications and the column (how) are filled with components. As seen in Fig. 2, the value in each cell represents the change probability of component if relevant variability specifications are changed. The value of change probability is derived from a history of previous design changes and from the view of experienced product designers, and it is estimated based on the description of Table. 1. Assuming that the change probability of IC component 'k' is $P_k^{(i)}$ if the *spec.* i is changed. Then, the initiating change probability of IC component 'k', which is triggered by the variability *spec.* i , is calculated as follows.

$$P_{k,(In)}^{(i)} = P_{sp}^{(i)} \times P_k^{(i)} \tag{2}$$

where $P_{k,(In)}^{(i)}$ is the initiating change probability of IC