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Incorporating Quality Function Deployment (QFD) with modularity for the end-of-life of a product family

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ABSTRACT

In the past decades both product family design and eco-product design have been well studied. However, little research work has been done on the development of eco-product families. The aim of this research is to develop a design method for both eco-issues and product family issues. With regard to the eco-issues, only the End-of-life phase is considered, while for product family issues we focus on the product variety issues. Literature shows that Modularity and Quality Function Deployment (QFD) are effective methods for eco-design and product family design. The main idea is to incorporate QFD with modularity. The eco-modular drivers are obtained from the extended-QFD analysis and life cycle modules for eco-product family are identified with a fuzzy clustering method and eco-product family are established with DV (degree of variety) which is calculated by the QFD method. A case study demonstrates and validates our method and the results show that QFD can help designer determine better eco-modular drivers and improve modular method to create more variety considering End-of-life issues.

1. Introduction

Nowadays, customers have an increasing demand for product variety. Offering a variety of products is important for a firm to attract different consumer segments (Kim and Chhajed, 2000). Eco-design also needs to be considered in this mass customization era. Product family design is one of the main design methods to provide product variety. Although both product family design and eco-design are well developed, very few researches have attempted eco-product family design. The aim of this research is to develop a design method considering both eco-issues and product family issues.

With regard to family design issues, this paper focuses more on product variety. In the past decades, Design for variety/mass customization, product family design and modular product platform design were well studied based on the modular architecture research (Jiao et al., 2007). Product life cycle is a new design dimension. Except for creating better functional performances, designers are also required to find new added values of a product along the product life cycle to increase the competitiveness. Since life cycle design considers different objectives along a life cycle, it is usually a multi-objective problem. Along the product life cycle, the end-of-life phase of electronic and electricity product have gained much attention in recent years (Fan et al., 2013; Lee et al., 2001). EU published legislation WEEE (waste electrical and electronic equipment) in 2002. The Law for the Recycling of Specified Kinds of Home Appliances was enacted in June 1998 in Japan and has been in force since April 2001. South Korea introduced WEEE in 2007 (Aizawa et al., 2008), and China introduced WEEE in 2008 and enacted WEEE in 2011 (Chinese WEEE, 2010). The common end-of-life options include reuse, remanufacture, recycle, landfill, and incineration and so on. Our research has a focus on improving the reusability and recyclability of a product family. In this paper reuse is taken to mean that the modules, parts or components of a waste product can be used for other products as a product component or maintenance backup component after simple treatment such as cleaning. Recycling is taken to mean material recycling at the end-of-life of a product. Although this paper considers both product variety and product's end-of-life, it is still within the scope of life cycle design. Some common life cycle design idea and tools are employed to solve our problem.

Modularity is effective for product family design (Jiao et al., 2007), and it is also proved to be effective for life cycle design. Newcomb et al. (1998) introduced modular architecture into the product life cycle design. The concept modularity was extended to lifecycle modularity. They believed that higher life cycle modularity can be beneficial in all aspects. This is a very interesting viewpoint

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of the life cycle design because trade-off among different life cycle phases may be reduced or even unnecessary. There has been much research done on the life cycle design based on Newcomb's idea (Gu and Sosale, 1999). Huang et al. (2012) proposed an approach to product modularity and disassembly with the consideration of 3R (reuse, reduce and recycle). Their modular method is based on DSM and graphic theory. Tseng et al. (2010) developed a modular method for product recycling. It also employs the DSM method. They developed an indicator called liaison intensity to describe the colorations between two DSM elements.

Quality Function Deployment (QFD) is a common tool to map design requirements to functions and engineering attributes. It can be regarded as a bridge connecting two design domains (Akao, 1990). Hsiao and Liu (2004) and Park et al. (2008) employed QFD in their design for a variety method. QFD is also an effective tool for eco-design. In eco-design or design for environment field, QFD was extended to QFDE (Quality function deployment for environment) (Masui et al., 2000). There is a reason to believe that incorporating QFD with modularity for the end-of-life of a product family will also promise useful outcomes.

The aim of our method is to improve the variety, reusability and recyclability of a product family. To incorporate QFD with modularity is a fundamental concept of this research. The eco-modular drivers are obtained from the extended-QFD analysis and eco-modules for a product family are identified by the design structure matrix (DSM) with a fuzzy clustering method. An eco-product family is established with eco-modules and DMV (degree of modular variety), which is calculated by a QFD method. The paper is organized as follows. In Section 2, the research framework is introduced. The eco-product family design method is proposed in Section 3. In Section 4, an example is used to demonstrate and verify the proposed method, which is followed by conclusions in Section 5.

2. Outline of research framework

The research framework is illustrated in Fig. 1. The first step is to expand QFD to QFDE for product family design. Contributions of each component to the family variety (degree of variety, DV) are calculated. The second step is to identify life cycle modules with the information of the variety and eco-attributes of each component based on the DSM method. The third step is to establish an eco-product family. All identified modules are measured by the degree of module variety (DVM). The modules with low DVM value are the candidates of common modules of the product family, while modules with high DVM value are the candidates of variety modules. The details of each sub-step are stated in the next section.

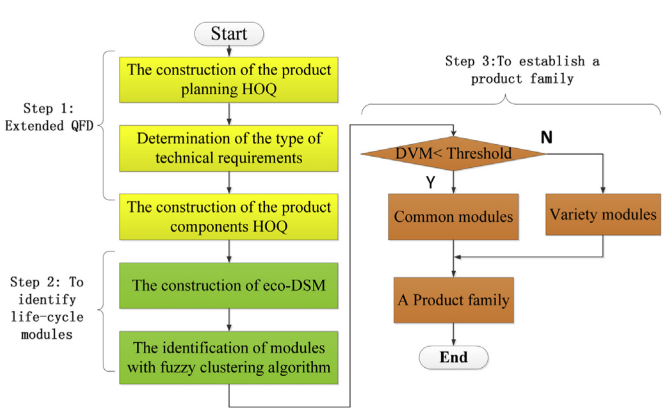

Fig. 1. The eco-product family design method.

3. Methodology: eco-product family design

3.1. Step 1: extended QFD

QFD is a method for ensuring the quality of a new product by translating consumer's demands into design targets throughout each stage of the product design (Akao, 1990). In recent research, the functions of QFD have been extended. There are two related advancements: QFD extended to be QFDE for eco-design and QFD extended to support product family design.

Like QFD, QFDE can map the customer requirements to technologies, so that the components that should be focused on can be identified. Masui et al. (2000) gave a list of customer eco-requirements called Voice of Customer (VOC). Environmental VOC includes less material usage; easy to transport and retain; easy to process and assemble; less energy consumption; high durability; reliable during usage; easy to reuse; easy to disassemble; easy to clean; easy to smash; easy to sort; safe to incinerate; safe to landfill; harmless; safe emission; possible to dispose at ease. Some researchers introduced green technologies into QFDE, such as Life cycle assessment and life cycle cost (Zhang, 1999 , ; Xu et al., 2006) and fuzzy logic (Kuo et al., 2009).

The function of QFD can also be extended from designing a single product to a product family. Martin and Ishii (2002) proposed a two-phase QFD method in which the generation variety index and coupling index are used to develop a modular product platform. Park et al. (2008) also proposed an indicator for product family design called “degree of variety (DV)”. DV calculates the contribution of elements to the product variety. The technologies and components with low DV value are believed to be a common element of the product family. This paper employs DV as the criteria to identify common components and proposed a new DV indicator for modules since modules are the basic elements of a modular product family.

In order to use QFD for an eco-product family, new House of Quality (HOQ) for product planning and part deployment is proposed (Figs. 2 and 3). Compared to a normal HOQ, Customer requirements (CR) and Eco-customer requirements (ECR) are analysed. Calculation of technical importance weights (TRW and

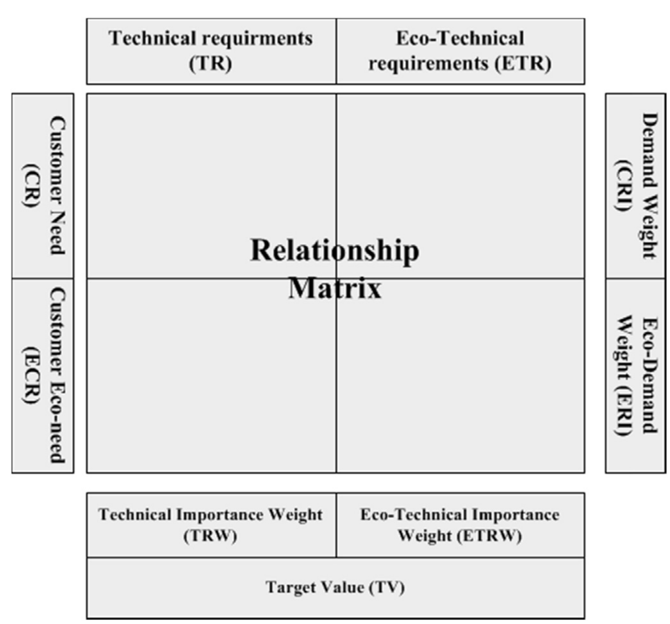

Fig. 2. The product planning HOQ for an eco-product family.