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Development of Eco-Innovative Framework and Methodology for Product Design

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Abstract

"Design for X" has been an important design philosophy for product engineers. In recent years, many eco-design methods have been proposed. At the same time, many TRIZ tools have been adopted to assist the process. However, issues concerning how to utilize an integrated method to analyze the product design problem and how to evaluate the improved design are seldom investigated. In this paper, we propose an eco-innovative framework and methodology for product design. The framework includes three design modules— problem analysis, problem solving and solution evaluation, along with two auxiliary modules to assist the design process with collaborative coordination and information recording. The related design methodology adopts some popular tools, such as the TRIZ tools, system analysis tools, as well as criteria-evaluation tools. An example was used to illustrate the feasibility of this framework and methodology.

Keywords: TRIZ, Eco-Design, Eco-Innovation, Function Attribute Analysis Diagram.

1. Introduction

In the past, products were designed without considering environmental impacts. Often, traditional factors considered in the product design stage are function, quality, cost, ergonomics and safety. Now, it is imperative to consider the environmental influences of a product throughout its entire life cycle. Traditional end-of-pipe directives or regulations only focused on the emissions from the manufacturing processes of a product. However, adverse impacts on the environment may occur in any one of the life cycle stages such as use, recycle, distribution, and material acquisition. Therefore, enterprises need to analyze and evaluate the environmental impacts of the entire life cycle of a product, and thus target the core of the problem and effectively resolve the problem.

In the early design stage, decisions made during the preliminary design stage greatly affect the eco-effectiveness of a product. Therefore, it is very important to consider the environmental impact during the design stage. "Design for X" has been an important design philosophy for product engineers (Kuo et al., 2001; Huang and Mak, 1999). The "X" may be reliability, safety, quality, manufacturability, assembly, logistics, ergonomics, serviceability, maintainability, environment, etc. In recent years, many eco-design methods have been proposed (Tukker and Eder, 1999; Gottberg et al., 2006). Furthermore, many innovative ideas and tools are integrated into eco-design tasks, which then evolve into many eco-innovative methods (Pujari, 2006; Smith, 1999). However, issues concerning how to analyze the design problem and how to evaluate the design result were seldom investigated in previous researches. Therefore, it is worthwhile to discuss how one can develop an integrated method that can be used to solve design problems, as opposed to solving problems with piecewise tools. In this paper, some popular tools such as the TRIZ tools, system analysis tools, as well as criteria-evaluation tools are adopted to form an integrated eco-innovative design methodology for the analysis and evaluation of a product design and development. A practical example with Function Attribute Analysis (FAA) diagram (Mann, 2007), IDEF0 (Integration Definition for Function Modeling) system analysis (Colguhoun and Baines, 1989), TRIZ-Eco-innovation matrix (Chen and Liu, 2002) and 40 Inventive Principles as well as Eco-Compass diagram (Fussler and James, 1996) was demonstrated to illustrate the feasibility of this method.

2. Literature Review

2.1 TRIZ

The TRIZ method was developed by Altshuller, who had analyzed over 400,000 patents to build the contradiction matrix and 40 inventive principles. TRIZ shows the feasibility of the problem solving by extracting generic principles from patents (Terninko et al., 1998). Mann (2007) proposed a hierarchical view of TRIZ that is shown in Fig. 1. In this figure, TRIZ is an integrative system that includes a set of tools, a method, a way of thinking and a philosophy. At its highest level, TRIZ may be seen as the systematic study of excellence. At the philosophy level, there are five key elements in TRIZ— Ideality, Resources, Space/Time/Interface, Functionality, and Contradiction. The method level, located between the philosophy level and the tool level, is the main research interest of many scholars. In this paper, the research also focuses on this level. At the bottom of the TRIZ hierarchy, there are many tools in the tool level; these tools include: Inventive Principles, Contradiction Matrix, Ideal Final Result (IFR), S-Fields, Function Analysis, Separation Principles, Subversion Analysis, Trimming, etc. Among these tools, the contradiction matrix and the 40 inventive principles are the most famous tools. When adopting the contradiction matrix method to solve a specific problem, the designer needs to find the contradiction that contains a pair of improving and worsening parameters. Consequently, the designer can find around 3~4 recommended inventive principles in the contradiction matrix. With consideration to the specific situations and scenario in different disciplines, many scholars have recently proposed some new contradiction matrices in their researches.

2.2 Eco-design

Product design concerning environmental impact has many forms of expressions such as ecological design, environmental design, environmentally conscious design, environmentally responsible design, sustainable design, green design, etc. In this paper, we adopt eco-design as a term of choice. There are many definitions and interpretations for "eco-design." In this paper, we adopt the statement of Lee and Park (2005)— eco-design is an activity that integrates environmental aspects into product design and development.

The aim of eco-design is to reduce the environmental impact during the product life cycle through the following: raw materials, preliminary design, detailed design, manufacturing, assembly, packaging and transportation, use, and disposal (Jones and Harrison, 2000). Fleischer and Schmidt (1997) proposed a top-down 3-layered eco-design tool for the selection of materials. Michelini and Razzoli (2004) developed a knowledge-based infrastructure for product-service eco-design. They proposed a framework that included three types of innovations—product-innovation, function-innovation and method-innovation. Horváth (2004) suggested that the eco-design research should investigate the concepts of corrective products, reduce the environmental degradation, and ameliorative products and cope with the environmental effects. Dewulf and Duflou (2005) discussed how one could integrate different levels into business operations, and they proposed a concept of the 3-layered framework for eco-design. Ritchie (2005) considered that virtual technologies and applications might provide product design with many feasible tools and result in an eco-friendly approach. He also suggested the use of virtual prototypes and virtual concurrent engineering practices would reduce the need for physical prototypes and allow for evaluation and checking of product life cycle costs. Trappey et al. (2008) proposed an integrated green product design methodology and system. Though there have been many researches done on eco-design, it is necessary to develop a systematic method in order to design products that comply with ecological and economic requirements.

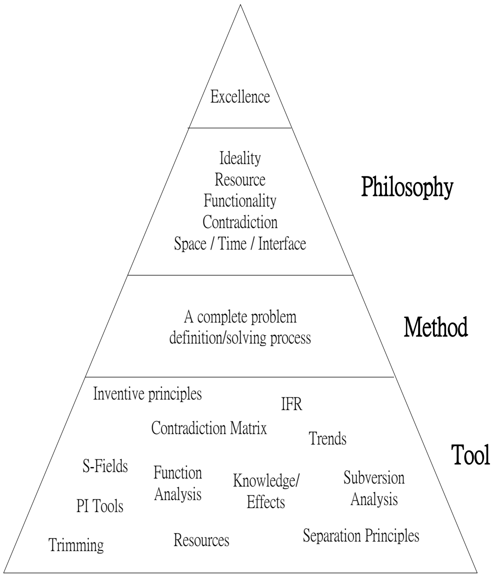


Fig. 1. Hierarchical view of TRIZ (Mann, 2007)

2.3 Eco-innovation

Facing the growing societal concerns with the global environment, enterprises are responsible for many directives and regulations such as Restriction of Hazardous Substances Directive (RoHS), Waste Electrical and Electronic Equipment Directive (WEEE), the Registration, Evaluation and Authorization of Chemicals (REACH) Regulation, and the Eco-Design for Energy Using Products (EuP). In order to comply with these directives and regulations, the cost of products involving entire life cycle stages inevitably increases. Although these costs are considerable, the costs of non-compliance are even more significant. Enterprises might face the risk of exclusion from key markets, stopped shipments, product recalls, etc. Non-compliance would result in not only loss of revenue, but also damage done to brand image and corporate reputation**.**

Although enterprises inevitably must cope with the cost pressure, this trend has also brought new opportunities for enterprises. For example, the trend has brought in financial institutions or individual shareholders looking to invest in and to support "greener" and "environmentally sustainable" companies (Butler and McGovern, 2009). Moreover, economic principles offer useful insights here. These principles suggest that the incentive to avoid costs associated with extended producer responsibility gives firms an economic inducement to undertake innovatory activities that may be conceptualized as eco-design (Gottberg et al., 2006).

Eco-innovation is a process that develops new products, processes or services that provide customer and business value but significantly decrease environmental impact (James, 1997). The simplest way to integrate TRIZ into eco-innovation is to use the TRIZ classical method to identify the contradiction parameters and to find suitable principles from the contradiction matrix. Chen and Liu (2002) linked seven major eco-efficiency elements from World Business Council for Sustainable Development (WBCSD) with classical TRIZ engineering parameters and developed an inventive design method to solve eco-design problems. Proposed by WBCSD, the seven major elements used to consider the eco-efficiency of developing environmental friendly products or processes are:

A. Reduce the material intensity of its goods and services

B. Reduce the energy intensity of its goods and services

C. Reduce the dispersion of any toxic materials

D. Enhance the recyclability of its materials

E. Maximize the sustainable use of renewable resources

F. Extend the durability of its products

G. Increase the service intensity of its goods and service

The eco-TRIZ matrix (Chen and Liu, 2003) was adopted as a tool in the problem solving stage and it is shown in Appendix.

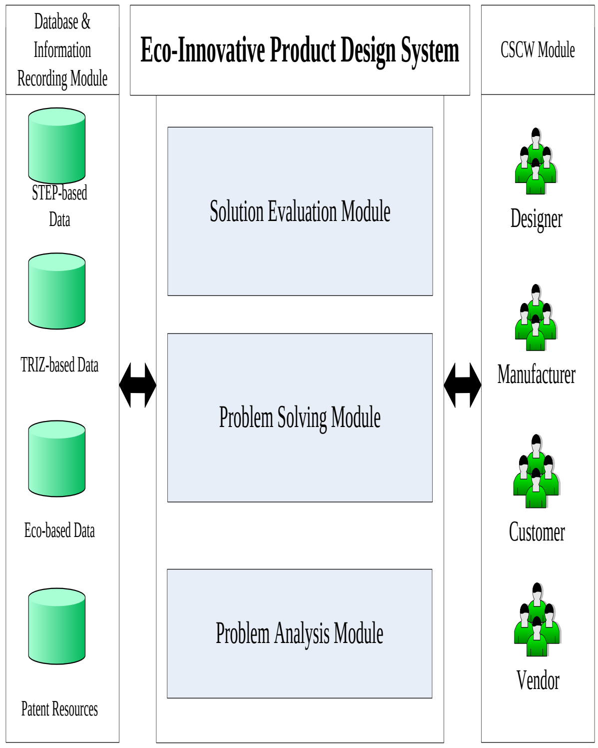
3. Framework and methodology

In this paper, a framework and its related methodology for eco-innovative product design are proposed and shown in Fig. 2 and Fig. 3.

In Fig. 2, the framework includes three design modules— problem analysis module, problem solving module and solution evaluation module, along with two auxiliary modules, database & information recording module and computer-supported cooperative work (CSCW) (Santos, 1995) module. The two auxiliary modules are used to assist the design process with collaborative coordination and information recording. The problem analysis module is the most important stage in product design and development, since the wrong direction of a problem will result in incorrect solutions and will waste resources (time, money, etc.). The essence of problem analysis is problem definition, in which one should simultaneously note the requirements of members in the supply chain and green directives and regulation. The database & information recording module includes STEP (STandard for Exchange of Product model data) based data (Lee et al., 2003), TRIZ-based data, eco-based data and patent resources. The CSCW module can support the collaborative tools and method for members located in different places.

The corresponding methodology for the framework is shown on the left side of Fig. 3, which is a 3-stage design process. In the first stage, the problem analysis, there are two analytical tools adopted to analyze the scenario and the focus of the problem. The second stage focuses on problem solving, and it may adopt many TRIZ-based tools such as Technical Contradictions/Inventive Principles, Physical Contradictions, S-Field Analysis/Inventive Standards, Trends of Technical Evolution, and ARIZ. For the last stage, the solution evaluation, Multiple Criteria Decision Making (MCDM) method (Tsai et al, 2010) and other design assessment methods can be adopted.

Fig. 2. The proposed framework of eco-innovative product design system



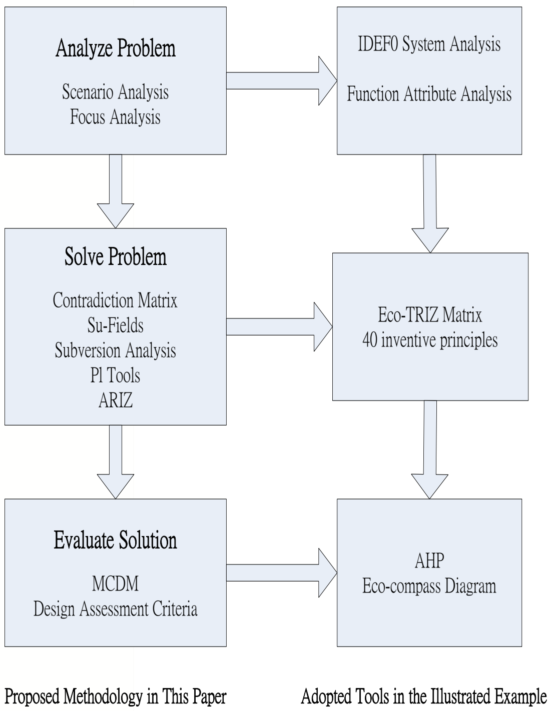


Fig. 3. Proposed design methodology and adopted tools

4. Case Study

In this section, an improved design of a fire-extinguishing system is used as an example to illustrate how one can implement the method. The tools chosen in this example are shown in the right side of Fig. 3. In the first stage, we use IDEF0 system analysis (Shen et al., 2004) and Function Attribute Analysis (Mann, 2007) to find the focus and the key point of the problem. In the middle stage, Eco-TRIZ matrix (Chen and Liu, 2003), along with 40 inventive principles, are adopted as the tools of problem solving. In the last stage, analytic hierarchy process (AHP) method (Tsai et al., 2010) and Eco-Compass diagram (Fussler and James, 1996) are used to evaluate the improved effect of the new design. In this paper, a traditional dry-powder fire extinguishing device is chosen to be the original design that needs to be improved. This fire extinguisher has exhibited flaws when used in a household kitchen. Fig. 4 shows the IDEF0 analysis diagram used as a tool to analyze the entire product life cycle of a product so that we can know what constraints and resources can be utilized. From this figure, we find the focus of the problem located in the stages of product use and product recycling.

To explore the product problem in depth, we adopt the FAA diagram (Mann, 2007) to find the problematic components and the interactive functions in the traditional, dry-powder extinguisher. The analysis result of the FAA diagram is shown in Fig. 5, and these results identify the causes of the problem that occur in three harmful relations: between nozzle and chemical powder, between chemical powder and kitchen equipment, and between kitchen equipment and fire. And thus, the key functions and the related components are discovered. From the FAA diagram, the dry powder may block the nozzle. Thus, the problem is solved by the Eco-TRIZ matrix as shown in the Appendix along with inventive principles. Fig. 6 shows a photograph of the improved design of the fire-extinguishing system for household kitchens. The Eco-compass for comparison of the improved design with original product is shown in Fig. 7.

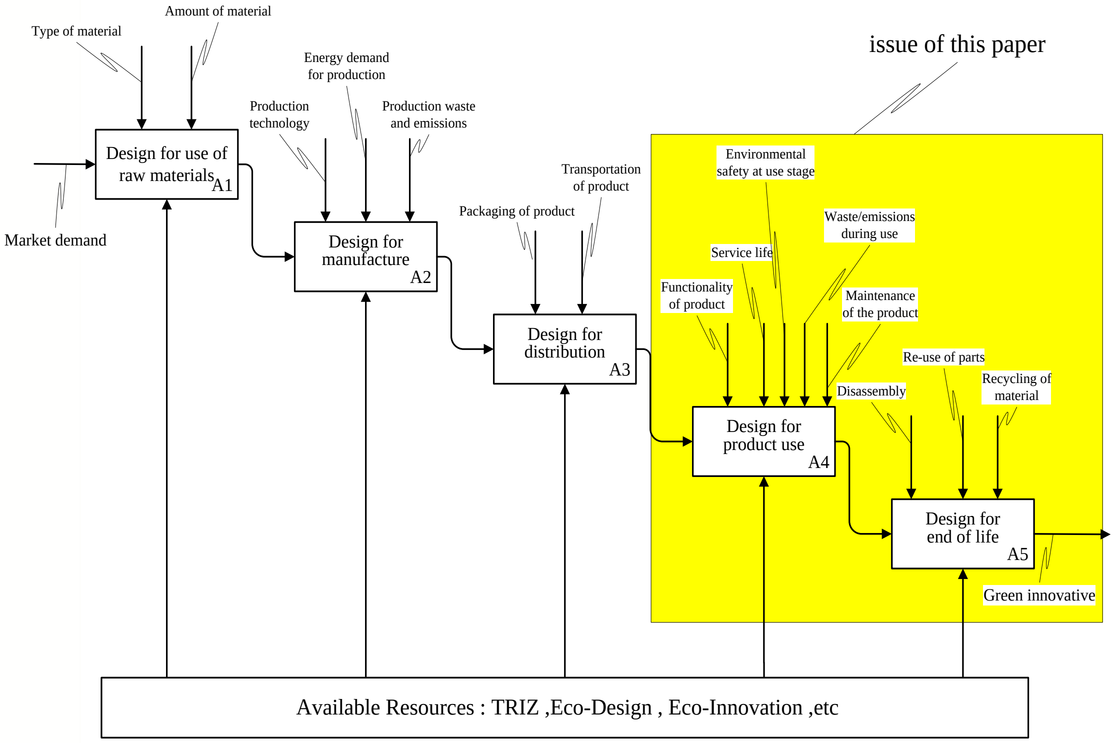


Fig. 4. IDEF0 system analysis diagram of green innovative product design

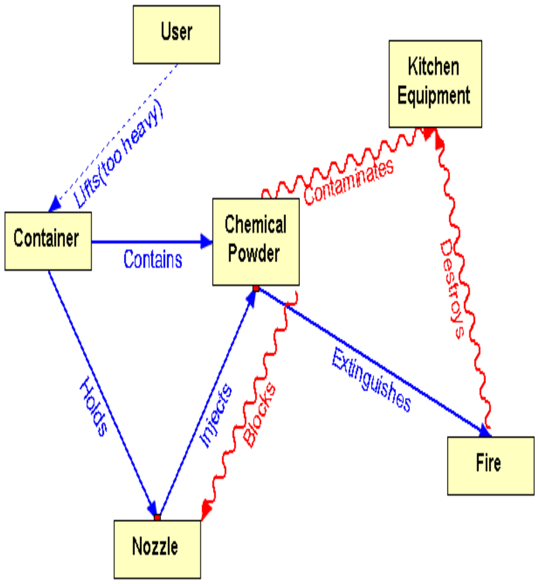


Fig. 5. Function attribute analysis diagram of dry-powder fire extinguisher

Fig. 6. Photograph of the improved design of fire-extinguishing system for household kitchen

5. Conclusions

As consumer demand and environmental consciousness increases, TRIZ and eco-design have attracted more attention from the academy and industries in recent years. The main contribution of this paper is to propose an integrated eco-innovative framework and its related methodology as a reference for product design that complies with both economical and ecological needs. Moreover, an example was used to illustrate the design process in order to prove the feasibility of this framework and methodology.

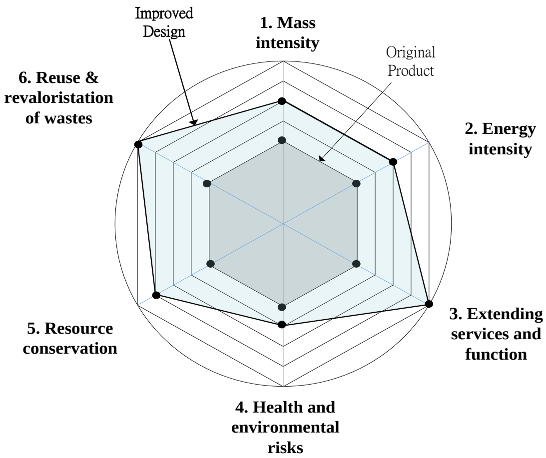


Fig. 7. Eco-compass for comparison of improved design with original product

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Appendix:

Table A. The relationship of engineering parameters and eco-efficiency elements [Chen & Liu, 2003]

TRIZ parameters engineering parameters		Eco-efficiency elements						
		A	**B**	**C**	**D**	**E**	**F**	**G**
1	Weight of moving object	◎	◎					
2	Weight of non-moving object	◎						
3	Length of moving object	◎	◎					
4	Length of non-moving object	◎						
5	Area of moving object	◎	◎					
6	Area of non-moving object	◎						
7	Volume of moving object	◎	◎					
8	Volume of non-moving object	◎						
9	Speed				◎			◎
10	Force				◎			
11	Tension/pressure				◎			
12	Shape	◎						
13	Stability of object			◎			◎	
14	Strength	◎				◎	◎	
15	Durability of moving object						◎	
16	Durability of non-moving object						◎	
17	Temperature		◎					
18	Brightness		◎					
19	Energy spent by moving object		◎					
20	Energy spent by non-moving		◎					
21	Power		◎					
22	Waste of energy		◎					
23	Waste of substance	◎		◎				
24	Loss of information							◎
25	Waste of time							◎
26	Amount of substance	◎		◎				
27	Reliability							◎
28	Accuracy of measurement			◎	◎			
29	Accuracy of manufacture				◎			
30	Harmful factors acting on object					◎	◎	
31	Harmful side effects			◎				
32	Manufacturability	◎	◎		◎			
33	Convenience of use							◎
34	Repair ability					◎	◎	
35	Adaptability							◎
36	Complexity of device				◎			
37	Complexity of control							◎
38	Level of automation							◎
39	Productivity	◎	◎					◎

Note: A, reduce the material intensity of its goods and services; B, reduce the energy intensity of its goods and services; C, reduce the dispersion of any toxic materials; D, enhance the recyclability of its materials; E, maximize the sustainable use of renewable resources; F, increase the service intensity of its goods and services; G, extend the durability of its products.