

The Relationship between Design For Environment (DFE) and Design For Cost (DFC)

Chen XiaoChuan

The Mechanical Engineering College, Donghua University, Shanghai, China, 200051

Abstract. Design for environment (DFE) or Design For Cost (DFC) is one of the branches in DFX. Both of them concern some product life cycle factors in design. The former emphasis is greenness or environmental protection; the later emphasis is life cycle cost (LCC). Using DFE, LCC must be considered. Using DFC, environmental protection must be also considered. By analysis of the relationship between DFE and DFC, the method that integrated them can be found. Namely, LCC estimation methods can be used in DFE; Life Cycle Assessment (LCA) can be used in DFC; the other way is that design is evaluated using Design Compatibility Analysis (DCA) in DFX.

Keywords: Concurrent engineering, Design for environment (DFE), Design for cost (DFC), Life cycle cost (LCC)

1. Introduction

With the development of concurrent engineering, a lot of DFX tools have been appeared. For example, they include design for assembly (DFA), design for manufacturing (DFM), design for quality (DFQ) and so on. Design for environment (DFE) or Design For Cost (DFC) is one of the branches in DFX^[1]. Some papers have been published about DFC^{[2][3][4]}. And DFE have been included in a lot of papers^{[5][6][7][8]}. But the relationship between DFE and DFC is absent.

In this paper, we provide some characters between DFE and DFC. Then we point out how to use DFE in DFC or use DFC in DFE. By analysis of the relationship between DFE and DFC, we can find the method that integrated them. Namely, LCC estimation methods can be used in DFE; Life Cycle Assessment (LCA) can be used in DFC; the other way is that design is evaluated using Design Compatibility Analysis (DCA) fuzzy theory.

2. Design For Cost (DFC) and its Research Areas

Design For Cost (DFC) is a design method which analyzed and evaluated the product's life cycle cost (include manufacturing cost, sale cost, use cost, maintenance cost, recycle cost, etc.), then modified the design to reduce the life cycle cost. Its characters can be concluded as followed:

- 1) In tradition, designers attached importance to the other parameters, but not cost. In product design process of DFC, the LCC must be an equivalent parameter as performance, schedule and reliability.
- 2) Product designers consider reducing product cost in the whole life cycle.
- 3) DFC need confirming parameters of manufacturing, usage, maintenance phases, for example, assembly cost percent unit, usage cost percent unit. Designer should balance performance, schedule, reliability, LCC and so on.
- 4) It makes sure that designers and their related personnel communicate and feedback cost information in time each other. So they can use some effective methods to control product LCC.

The research areas in DFC proposed are the following:

- 1) Cost features are extracted using LCC analysis. Then LCC database and LCC estimation methods base were established.
- 2) In order to provide design information in cost

estimation, we must analyze design stages and models and then extract some design features that are related with LCC in different design models.

3) The research and development of software tools in DFC: DFC is a design method to face designers. To improve design efficiency and design quality, it is important to use DFC software tools in product design process.

4) According to market states, the balance between design and LCC must be found. Under increasingly furious market competition, the lowest product cost did not enough defeat other competitors. Product must be the best performance/price, namely provide the best functions in the suitable price that can be accepted by users. Because the price mostly depends on product cost and designers decide product functions, it is essential to balance between design and cost.

5) DFC must be integrated with the other DFX tools: Because DFC is faced the whole life cycle, it requests that DFC must harmonize the other DFX (DFM, DFA, etc.) tools to work. Therefore, we should establish an evaluation criterion to do it.

In addition, the other key technologies included how to confirm target cost, how to select the methods of manufacturing according to the project investment, etc. Especially we point out that DFC is different from Design to Cost (DTC). DFC is the conscious use of engineering process technology to reduce LCC while DTC obtains a design satisfying the functional requirements for a given cost target^[9]. (Further detailed distinction between the two approaches can be found in the reference)

3. Design For Environment (DFE) and its Benefits

Design For Environment (DFE), also known as eco-design, recognizes that environmental impacts must be considered during the new product design process, along with all of the usual design criteria. It is defined as systemic consideration of design performance with respect to environmental, health, and safety objectives over the full product life cycle. There are three unique characteristics of DFE^[10].

- (1) The entire life cycle of a product is considered.
- (2) Point of application is early in the product realization process.
- (3) Decisions are made using a set of values consistent with industrial ecology, integrative systems thinking or another framework.

DFE considers the potential environmental impacts of a product throughout its life cycle. A product's potential environmental impacts range from the release of toxic chemicals into the environment to consumption of nonrenewable resources and excessive energy use. Life stages of a product include the time from the extraction of resources needed to make the product to its disposal.

In effect, designers design a product life cycle, not just the product. An awareness of a product's life cycle will help the company avoid environmental surprises and liabilities. Ideally, the design team will seek to reduce these environmental impacts to the lowest level possible.

DFE benefits:

DFE offers businesses opportunity to improve environmental performance, while simultaneously improving their profits. Companies that implement DFE find that it:

- λ Reduces environmental impact of products/processes.
- λ Optimizes raw material consumption and energy use.
- λ Improves waste management/pollution prevention systems.
- λ Encourages good design and drives innovation.
- λ Reduces costs.
- λ Meets user needs/wants by exceeding current expectations for price, performance and quality.
- λ Increases product marketability.

DFE can also provide a means for establishing a long-term strategic vision of a company's future products and operations. In general, DFE is an enabling force to shape more sustainable patterns of production and consumption.

4. The Relationship between DFE and DFC

The relationship between DFE and DFC is given in Fig 1. Both of them belong to DFX field together. There are some sameness and differences.

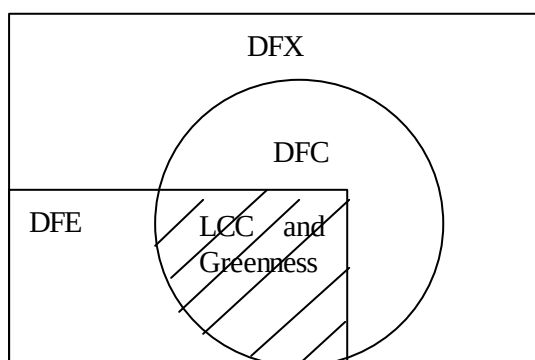


Fig1 Relationship between DFC and DFE

The differences: DFC is a design methodology that uses all kind of ways to cut down production's LCC; DFE facilitates systematic evaluation of a product and continuous improvement goals for the entire product life cycle. LCC is one of the design factors in DFE, it also

includes reducing environmental impact, energy supply, raw materials and so on. Namely DFC evaluates a design from LCC, but DFE evaluates a design from greenness. DFC use LCC analysis methods, but DFE use life cycle assessment (LCA) methodology.

The sameness: both of them consider the production life cycle cost in design. And they evaluate a design from life cycle. In DFC greenness is also considered.

4.1 The Application of LCC in DFE

The life cycle cost of a product is made of the cost to the manufacturer, user, and society^[11]. The total cost of any product from its earliest concept through its retirement will eventually be borne by the user and will have a direct bearing on the marketability of that product.

The LCC concept was initially applied by the US Department of Defense (DoD). Its importance in defense was stimulated by findings that operation and support costs for typical weapon systems accounted for as much as 75% of the total cost^[12]. However, most of the methodologies developed by the DoD were not intended for use for design but for procurement purposes.

While the life cycle cost is the aggregate of all the costs incurred in the product's life, it must be point out that there are differences between the cost issue that will be of interest to the person designing the product and the firm developing the product in a life cycle cost analysis. While the firm must know the total cost of the product, the designer is only interested in the costs that he/she can control. Some of the costs incurred in the life of the product are not as a result of the design. These costs are related to the way we do things. Life cycle cost can thus be classified into management related costs and design related costs. It is latter component that the designer is interested in. In this paper, we mainly discussed it in DFC. One cost category that may not be of interest to the designer is the research and development cost. This cost is not related to the actual design of the product but rather to the kind of product we are developing, the resources we commit to the process and the manner in which we use these resources to arrive at a design solution.

TABLE I MAINLY COST ESTIMATION MTHODS [15]

Cost estimation methods	Properties		
	Uncertainty	Phase of design process	Precision
Parametric Cost Method	Low	Early	Middle
Analogy Cost Method	High	Late	Middle
ANN Cost Method	Middle	Early	High
ABC Method	High	Late	High
Engineering Cost Method	Low	Late	High

We must estimate LCC in DFE because customers can't purchase a product that is greenness but that they can't afford. There are a lot of cost estimation methods in DFC. We can use them to estimate LCC in DFE. Table I shows five familiar methods. In our opinion, the different estimation methods are selected at the different design

stages. Generally, ANN cost method can be used at the conceptual design stage; ANN and parameter cost method can be selected at the earlier overall (general) design stage; Then parameter cost method can be used at the general design stage; Finally, engineering cost method can be selected at the detail design stage. For more detail see Chen Ke-zhang, Feng Xin-an and Chen Xiao-chuan[13] in English or Chen Xiao-Chuan, Liu Xiao-Bing and Feng Xin-An [14] in Chinese.

4.2 The Application of LCA in DFC

LCA is a technique for assessing the environmental impacts associated with a product or service [16]. It was developed as an environmental policy support measure in the past decade. LCA's goal is to compare the environmental impacts of different products and services that satisfy comparable needs. To do so, all stages of the life cycles of goods and services have to be considered, i.e. resource extraction, production, utilization, and disposal. So we can use LCA in DFC in order to improve production's greenness. For example, from life cycle phases, the factors that can be considered as followed:

- λ Manufacturing: In this phase, we consider materials, process and product packing from greenness. We select a design that must reduce the influence of environment. For example, we select recycling material
- λ Transportation: In transportation phase, conveyance and handling tool can be selected from environmental protection point. And optimization sale channel is needed. That can decrease transportation cost and energy supply.
- λ Store: Mechanical manufacturing production will not influence the environment normally in store.
- λ Maintenance: In maintenance, we need notice whether produce the trash and waste gas etc. that pollute environment.
- λ Product use: In this phase, the production does not produce waste gas and trash that pollute environment.
- λ Disposal: In this phase, material recycle and function reuse are the key technologies.

In DFX, we can use Design Compatibility Analysis (DCA) in order to evaluate a design [17]. DCA method does not only include LCC but also include greenness. And it includes manufacturing, assembly, disassembly, serviceability and so on. How use DCA does not repeat again in this paper. For more details please see the reference [18].

5. Conclusions

DFE is the most effective method of improving product environmental properties. From theories and facts, DFE's development is very quickly. In order to realize DFE's goals, there are not a unified technology and method. But the substances of DFE already reach extensive common recognitions. Now there are a lot of applications in the world.

In this paper, the relationship between DFE and DFC is given. Then the methods of using LCC in DFE and using LCA in DFC are proposed. Namely, LCC estimation methods can be used in DFE; Life Cycle Assessment (LCA) can be used in DFC; the other way is that design is evaluated using Design Compatibility Analysis (DCA) in DFX.

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