B-16.3 Analysis and Evaluation of Product Design Modification for Waste Reduction and Recycling

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Abstract

To reduce the environmental burden such as green house effect gas and waste, caused by industrial products, ecologically conscious design, or design with life cycle analysis will be potential option, and play an important role. Results of design activities may dominate a products' burden in lower stream of processes such as production, use, and disposal. Attention should be paid to a fact that concurrent engineering is promising to optimize total environmental burden by solving trade-off relations among various estimation factors which naturally tend to conflict each other. In this paper, a concept of environmentally conscious design strategy is presented, and a design support system with analysis and evaluation capability for environmental burden is discussed.

A prototype design support system has been developed as software framework. This support system is based on customizing technique for a CAD system and communication technique between different processes. An early-stage design process of material selection for a car body is demonstrated by solving the formulated relation between weight reduction and strength as an example. This design process is guided by an investigated and proposed design strategy which is based on finding and resolving trade-off problem in various criteria. Preliminary structural design process has been also incorporated into the developed system.

Key Words Green House Effect Gas, Waste, Recycle, Life Cycle Analysis, Design

1. Introduction

In recent years, environmental concerns have become wide spread. Human industrial activities seem to be responsible for a variety of environmental problems, such as mass consumption of material and energy resources, wastes, toxic substances, emission of green house effect gases and ozone depletion potentials. In other words, an important contribution to solving such environmental issues, could be made by regarding industrial activities from a more ecological viewpoint.

The importance of reducing and optimizing the environmental burden of a product during its whole life cycle (Material - Production - Use - Recycling - Disposal), is pointed out and emphasized[1]. In European nations like Germany, Holland, and Nordic countries, as well as USA, similar research has been conducted in this Life Cycle Analysis/Assessment[2,3].

As the design phase is the very first of all processes, product design and design modification affect the environmental burden of a product in later life. In other words, they dominate consumption of materials and energy resources, machinability, assemblability in the production phase, serviceability and maintainability in the market, and 'dismantlability' and recyclability in the restoration phase. It becomes clear that the environmentally conscious product depends mainly on how much consideration is given to environmental issues in the design phase. So, for newly developed products, a design strategy which can determine details of products by estimating their environmental burden during their expected life cycles, is required.

The product design process can be roughly described as a series of decisions to meet design specifications. Therefore, design is characterized by continuous trading off between different design options and multidisiplinary constraints. Design strategy may differ in detail in each design stage, however, main concept of such strategy should be consistent.

2. Research Objective

To analyze and evaluate effects of design contents and its modification for reduction of environmental burdens such as green house effect gases, the followings are studied mainly.

1) Investigation and establishment of a design strategy called "environmentally conscious design."

2) Development of EcoDesign support system with CAD system and other application codes, which support a designer as a software framework for evaluating environmental burden.

3. Research results

(1) Trade-off Relations

In product design, it is essential to balance and optimize estimation factors among function-related, economy-related, and environment-related criteria while solving trade-off problems which seem to be incompatible with each other, as shown schematically in Fig.1. Main estimation factors are performance and safety as function criteria, productivity and marketability as economy criteria, and material recyclability and dismantlability of product structure as environment criteria. Taking into consideration the priorities of estimation factors, which may be determined by a process of design and development, each factor should be assessed and be compatible each other. Designed products should balance each factor among these criteria.

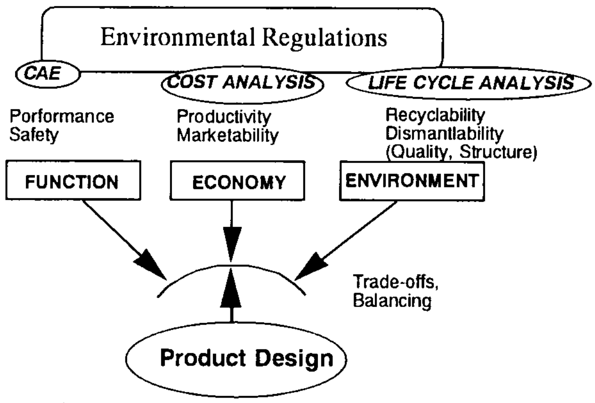

Figure 1. Trade-off Problem in product design.

Estimation tools are desirable. Roughly speaking, there are CAE tools, cost analysis techniques, and life cycle analysis which is still at the research stage. The development of a design support environment which may be integrated with such tools and which is user-friendly, is important and urgently required.

Attention should be paid to the fact that estimation criteria may change with social regulations. For instance, marketability of a product may not be reduced, even if it costs a bit more to satisfy the regulation emphasizing recyclability.

(2) Environmentally Conscious Design Support System

To establish a design support environment in which the environmental burden for the entire product life cycle can be estimated, and materials can be selected via an environmentally conscious strategy, the product model, the life cycle model, and the process model are essential, as shown in Fig. 2.

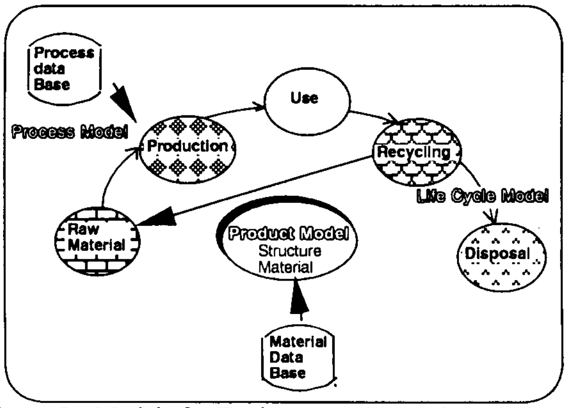

Figure 2. Models for Environmental conscious design

The product model is a model describing structure and properties of product. The life cycle model is a model of the expected whole life cycle of a product, and consisting of a chain and/or network of processes. The process model is a model describing the activity of each process. Material data bases dealing with material properties, and process data bases managing common processes are also necessary, and should be used cooperatively with these models. Establishment of knowledge data base and development of simulation facility are promising subjects to design products by materials selection and structural design cooperatively.

The EcoDesign Support Environment to be developed with a multi-window capability, is shown schematically in Fig.3. An estimation tool of environmental burden should be incorporated into our developing multi-window interactive design support system. Customizing technique for a CAD system and communication technique between different processes have enabled a non-CAD application issue commands for CAD. Specifications for an axial part calculated on a spread sheet are successfully sent to a CAD window, and are displayed graphically.

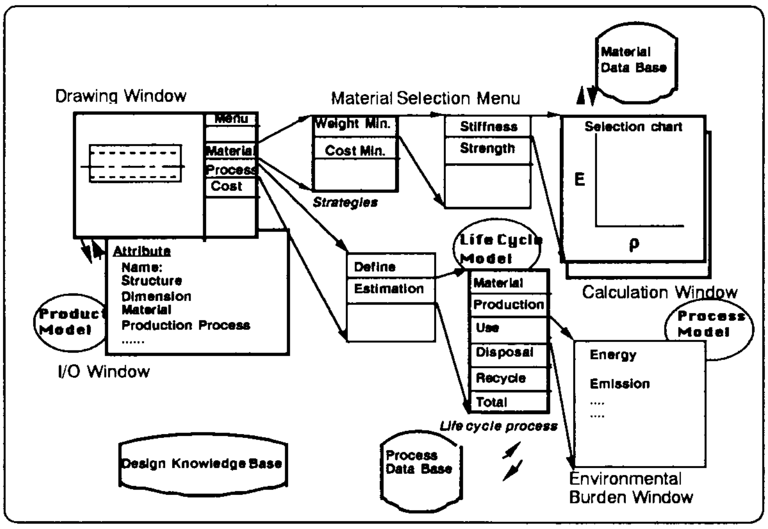

Figure 3. Outline of EcoDesign Support Environment.

A part of materials selection, mainly for the conceptual design, is installed first. For instance, after selecting the menu of materials selection, a basic strategy is chosen. Selecting the required property leads to a material chart helping select material candidates. It is followed by the assignment of a possible life cycle, and an estimation of environmental burden. The product model is referred and modified by I/O-, Drawing-, material-selection- window, and so on.

(3) Design Strategy in Conceptual Design Phase

In this section, a method and strategy for product design with the estimation of environmental burden is discussed. Materials selection for a car is given as an example.

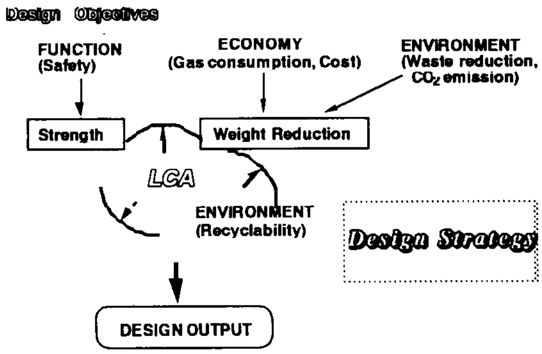

Figure 4. Conceptual design for a car

As shown in Fig. 4, safety as a function factor, fuel consumption in the market and material cost as economic factors, and ultimate waste, and CO_2 emission as environmental factors, are listed. These have to be satisfied to meet design objectives. When attacking the trade-off problems among the three criteria -function, economy, environment- , design objectives which lead in the same direction should be checked first, to reduce estimation factors. 'Weight reduction' can be the design objective of both the economy and environment criteria. This leads to a trade-off problem between weight reduction and function factors like strength of materials. Material candidates which satisfy weight reduction and posses the required strength, could be determined by solving the formulated relation between them.

Materials selection in the conceptual design phase, should be aimed at meeting required properties for a product, especially strength-related properties. Required properties may differ depending on the location of parts and components in the product. Fig. 5 shows strength-related properties for a car component example. Twisting stiffness and bending stiffness as so-called body stiffness, and impact strength are important estimation factors for a car body.

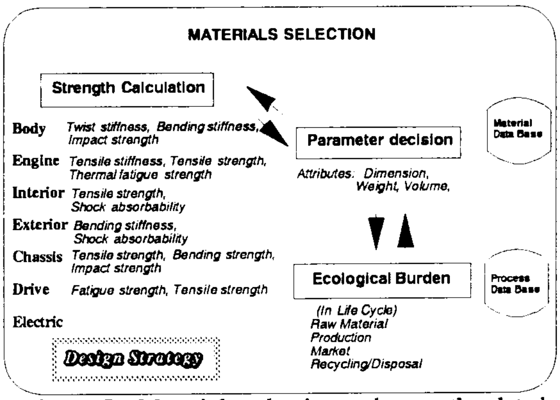

Figure 5. Materials selection and strength-related properties.

Material candidates and parameters like rough dimensions have to be determined whilst solving such trade-off relations as strength, weight reduction, and cost.

A simple example for materials selection can be given if it is assumed that a car body is a rectangular tube with a square section as shown in Fig. 6. Twisting stiffness around the section and bending stiffness in the longitudinal direction are required factors. Weight reduction is also required. The trade-off relation between weight reduction and maintaining stiffness, should be formulated and solved.

In this structure, both stiffnesses are approximately proportional to the thickness 't' in Fig.6. So, materials with the same specific modulus of elasticity (modulus / density) means that the same weight of materials are necessary to keep the same stiffness[15]. The material chart which shows the modulus of elasticity and density of many materials in Y- and X- axes respectively, helps a great deal in this case. Equivalent materials are on the same line in this chart. Other charts can be chosen for other trade-off relations.

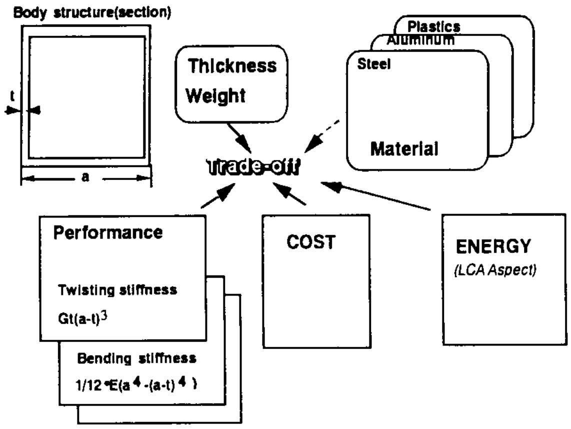

Figure 6. Design example of a car body

Fig. 7 shows the output window of the prototype system. Steel and aluminum have almost the same specific modulus of elasticity. So, selecting aluminum does not mean 'weight reduction'. Energy consumption in aluminum production is estimated 10 times larger than in steel production. Only recovered aluminum may be comparable. No weight reduction by selecting aluminum also means no reduction of environmental burden -fuel consumption- in the market, although environmental burden in other processes have not been estimated. Plastics have very low specific moduli of elasticity. This means that plastics have little possibility to be selected, in this case.

If bending strength is the only required factor, Aluminum is a good selection because its specific strength is almost twice as much as steel's.

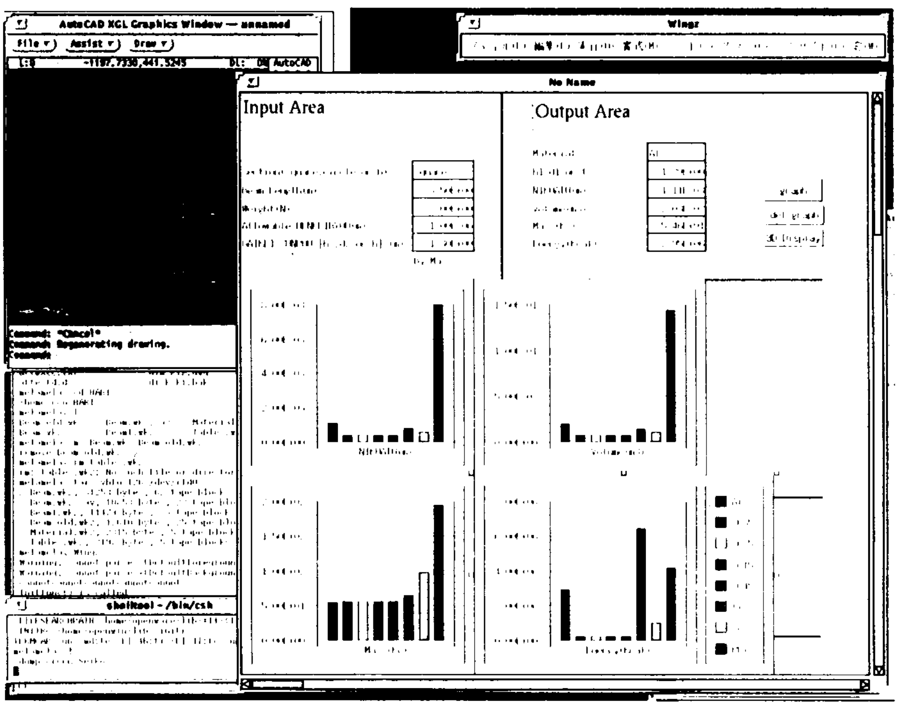

Figure 7. Calculation results for material candidates

(4) Disassemblability

In the previous discussion, material selection has been focused. Structural design is another important issue for environmentally conscious design strategy. Recyclability of a product depends on 'Disassemblability.' In order to support to design easy to recycle products, incorporating evaluation function of disassembling potential of these products into the developed design support system, is investigated. Motion analysis in the field of Industrial Engineering has been concluded as one of the options. Part geometry, location, alignment, fastening points, and disassembling sequence are given, and operation time is estimated with collision check capability. Disassembling operations are divided into basic motion modes by motion analysis method. Motion analysis support has been installed into the developed system. In this support program, part geometry of target components is handled in the CAD system, and Operator's motions are processed in the Control system as shown in Fig. 8. As information of operator's motion distance is processed in the CAD system, Motion analysis could be done effectively. In this system, short operation time is estimated as high disassemblability for the first step.

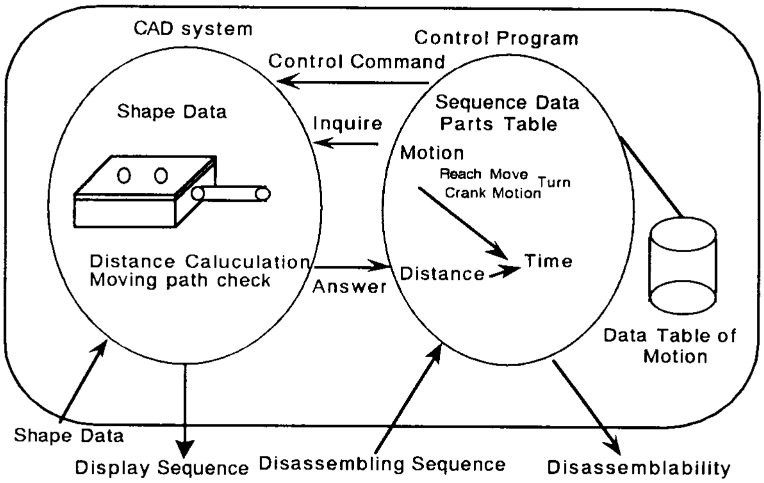

Figure 8. Evaluation of Disassemblability

4. Concluding Remarks

(1) The process of design plays a decisive role to realize environmentally conscious products. New criteria regarding the environmental burden for the entire life cycle of a product should be added to conventional criteria concerning function/performance and economy.
(2) Design strategy should be focused on solving trade-off problems among various estimation factors.
(3) A design strategy of materials selection for car bodies is demonstrated by solving the formulated relation between weight reduction and strength.
(4) The models necessary for environmentally conscious design, and developing a design support environment are outlined.

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