

A Methodology for Design and Management of Product Life Cycle Adapted to Product Usage Modes

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Abstract

For reducing environmental burden due to artifacts and their production processes, it is essentially important to realize a pre-designed closed product life cycle, and to manage it for less products and energy flow without excessive overhead load. For improving this situation with respect to mass-produced consumers' durable goods, we propose a methodology for design and management of a closed product life cycle, based on the idea of product usage modes and product life cycle scenario, where life cycle simulation plays an important role. The basic idea of a method is explained, and some examples are given for showing effectiveness of the method.

Keywords: Sustainable manufacturing, Closed loop manufacturing, Product life cycle

1 INTRODUCTION

For fundamentally reducing environmental burden due to artifacts and their production processes, it is essentially important to realize a pre-designed closed product life cycle, and to manage it for less products and energy flow without excessive overhead load[3]. This concept has been well implemented for large scale industrial products and facilities, but not for mass-produced consumers' durable goods. For improving this situation, we have proposed a methodology for design and management of a closed product life cycle, based on the following idea: promoting the information sharing among manufacturers and users, motivating users to participate in design and management activities, incorporating product take-back processes into product basic functionality, and innovating a concept and structure of products and their life cycle.

A method consists of four steps: (1) design of product life cycle by tight adaptation to product usage modes of mass customers, (2) creation of new life cycle scenario where users can play an active role for closing the life cycle, (3) creation of new product concept and structure which is adapted to the proposed life cycle scenario, (4) designing efficient methods for managing production and maintenance/recycling facilities for new products and production systems. Many technical issues for those steps are still under discussion. Some preliminary explanation and case studies are given in this paper for further elaboration of the method.

2 COORDINATION OF PRODUCT LIFE CYCLE WITH PRODUCT USAGE MODES

For environmentally conscious manufacturing, it is mandatory to close a product life cycle by achieving comprehensive recycling or re-use of used products, and to try not to dispose anything to the environment. However it is not enough to close a life cycle, but it is strongly necessary to really make such closed product cycle as efficient as possible from the standpoint of the reduction of energy and other resource consumption. For achieving this objective, it is effective to reduce the total physical product flow in this cycle, and to minimize

the required management overhead for used product flow. At the same time, it is important to keep the level of services of products for customers. The idea of service engineering has come up from such general consideration, where customers actually want to buy "services" instead of "physical products". Physical products are merely media for conveying required services.

Major sources of inefficiency of closed product life cycle are as follows:

- (1) unexpected early disposal of products,
- (2) non-use or idle products in users' hands,
- (3) long-term use of old and inefficient products,
- (3) life cycle management overhead, particularly maintenance and take-back cycles.

These inefficiencies cannot be diminished by just improving individual product performance. Even if product performance is satisfactory, people dispose products if they find attractive new products. People continue to use old and inefficient products with no particular reason but just due to no product failure. All such inefficiencies can be understood to occur due to the incompatibility of the planned product life cycle and actual product usage style of customers. Here we shall call such product usage style of customers as product usage modes.

Today manufacturers normally do not explicitly explain the pre-planned product life cycle, or feasible/appropriate product usage modes for products. Therefore customers are forced to make arbitrary decision how to select appropriate products for their particular needs. For instance, it is fairly difficult to determine an optimal refrigerator or an air-conditioner for specific family life style.

Traditionally commodity durable goods are mass-produced products sold to customers, and with no maintenance or other life cycle care. Such life cycle care cannot be considered realistic with traditional technology. However, as already well discussed, it is now feasible to connect all such house-hold appliances and cars via communication network, and to efficiently manage their total life cycle. With such possibility in

mind, we shall consider, in this paper, a top-down iterative methodology to design better products by coordination of manufacturers' product life cycle with customers' product usage modes.

3 A METHODOLOGY FOR DESIGN AND MANAGEMENT OF PRODUCT LIFE CYCLE

3.1 Overview

The proposed top-down iterative design method consists of the following four steps:

- (1) Proposal of product usage modes and associated life cycle scenarios based on manufacturers' capability and customers' requirements.
- (2) Design and evaluation of proposed product life cycle by simulation of product flow and services in the life cycle.
- (3) Design of product modular structure and individual components adapted to the proposed life cycle and usage modes.
- (4) More detailed evaluation of product usage support by maintenance during product operation.

Steps (1) to (4) are repeatedly performed to achieve satisfactory design results. Each step is explained below with some examples.

3.2 Product Usage Modes and Life Cycle Scenario

The first important step is to identify characteristics and differences of product usage modes of customers. There seems to be very different usage modes for the same products. Characteristic factors are:

- Long use or short use,
- Heavy use or light use,
- High functionality or common functionality,
- aesthetics or non-functional appeal,
- initial investment or operational cost,
- expensive(high-quality) or cheap, etc.

Traditionally those factors are considered trivially seen from products. But, for today's products, those factors are not so easy to identify for normal customers.

Associated with those product usage modes, appropriate product life cycles should be proposed by manufacturers. Particular pattern of product life cycle is called as life cycle scenario. Life cycle scenario is characterized by the following factors:

- closed loop shape: simple or complicated take-back loop,
- speed and volume of product flow,
- re-use, recycle or disposal,
- maintenance-free or heavy maintenance,
- purchase or rental/lease,
- with or without upgrade, etc.

It is often considered that long life products are generally good for reducing environmental burden. It is true, if those products are on proper operational condition, and coincide with product usage modes. If products are not fitted with customers' usage modes, they are simply left idle, and eventually inappropriately disposed. In this sense, it is not simple to determine appropriate life cycle scenario according to the required usage modes.

3.3 Design of Product Life Cycle

For optimal product life cycle design, certain evaluation of environmental performance is necessary. LCA is not suited for this purpose, because it is too detailed and static. Here life cycle simulation method is proposed for computing various factors of product usage modes for accessing the life cycle performance[2].

Typical procedures are shown in Fig.1, and simply explained below.

- (1) appropriate life cycle scenarios are assumed for simulation, for example:
 - very rapid take-back of whole products(ex. Single use camera),
 - rapid take-back of partial products with reuse/upgrade (ex. Audio/visual devices)
 - long life with maintenance (ex. Car)
- (2) simulation is done for individual product life cycle with assumed production volume, scheduling, product failure rate, recycling rate, etc. (Those may be affected by usage mode characteristics.)
- (3) statistical computation is performed to estimate various factors concerning with product usage and environmental effect, such as total resource/energy consumption, disposal volume, total cost, average functionality or quality, etc.

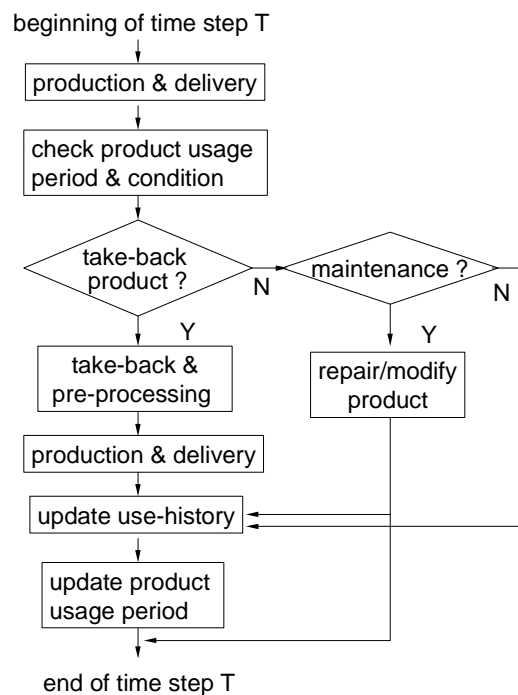


Fig.1 Procedure for Life Cycle Simulation.

At the first stage, the simulation result may be a very rough indication of feasibility of proposed life cycle. By repeating the procedure described in 3.1, accuracy of simulation will be enhanced.

Simulation example of home-use air-conditioner is shown in Fig.2 and Fig.3. Outer unit of this air-conditioner is shown in Fig.2. For each component, appropriate assumptions for life cycle treatment is given, such as simple material recycling or parts-reuse. Fig.3 shows an example result of simulation. In this case, Three different life cycle scenarios are compared with respect to the total life cycle electrical energy consumption. "Normal" scenario is to buy a new air-

conditioner every 10 years. "Lease" scenario is to lease an air-conditioner every 5 years. In this case taken-back machine will be re-used, while in "Normal" scenario, all old products are disposed or recycled. "Long-Life" scenario is to prolong the life to 15 years. Based on this result with other results indicating cooling performance, cost, material consumption, etc., appropriate scenario according to the required usage mode can be selected.

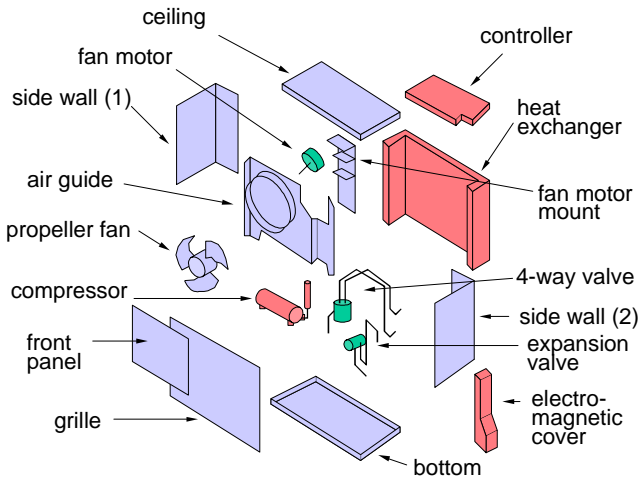


Fig.2 Outer Unit of an Air-Conditioner.

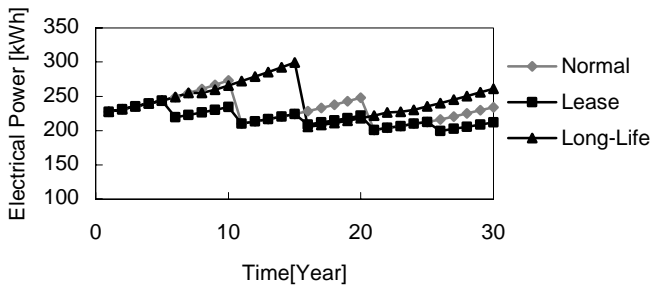


Fig.3 Example Result of Life Cycle Simulation.

3.4 Product Design Adapted to Product Usage Modes

Individual product should be designed to be adapted to the required product usage mode or selected life cycle scenario. This process is the same as the product design in the conventional sense. However new design criteria are important in this case, such as:

- functional up-grade,
- parts re-use,
- ease of maintenance,
- quality assurance of used products/parts, etc.

Modularization of product structure is one of the fundamental approaches for coping with those requirements. It has been considered that it should be intuitively clear how to modularize a product. But, in new situations as explained in product life cycle simulation, modularization is a very complicated matter which has a strong influence on each parts functionality, and product performance/cost.

Here we propose a new method for modularization. The basic idea is as follows. Based on the functional description of products, primitive functional components, whether they are abstract or physical, are first identified,

and those components are step-by-step merged into the so-called "modules". This merging process is controlled by the evaluation of such factors as functional up-gradability, serviceability, product/disposal cost, re-usability, etc. Evaluation can be done by static calculation similar to conventional LCA or by dynamic simulation similar to life cycle simulation in the previous section. With this exhaustive modularization, rather new modular structure can be derived from the new environmental requirements for product usage modes.

Simple example is shown in Fig.4 and Fig.5. In this "Telephone with Fax" example, primitive physical components are assumed, because this is a mature product. Compared with Fig.4, higher disposal cost and lower maintenance operation cost are assumed for Fig.5. In this case, result is intuitively clear, but in practical situations, it may be more complicated.

For achieving good modularization, reliability is another important factor. For supporting computer aided reliability design, we have developed a prototype system for computer aided FMEA(Failure Mode and Effect Analysis)[1]. As a basis for computerizing FMEA, a machine function model and part failure models are necessary. Based on those models, failure identification can be done automatically as shown in Fig.6.

Simple example is shown in Fig.7 and Fig.8 for the case of a computer "mouse". In this case, with the aid of a conventional CAD system, a product model of a mouse has been constructed as shown in Fig.7. Functional model has been defined, which can relate components property with product functionality, in this case, pointing to a position, as shown in Fig.8. By giving general failure model, such as wear, friction and miss-alignment, effects of components error on product functionality have been automatically derived. Such computer support system is very useful for efficient product design in long-term life cycle context.

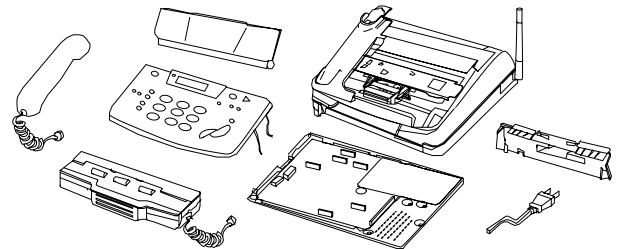


Fig.4 Example for Modularization (1)

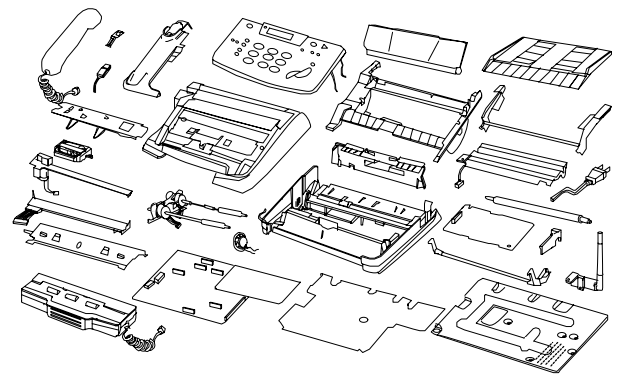


Fig.5 Example for Modularization (2)

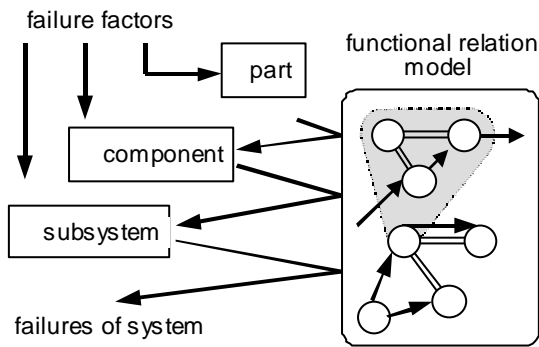


Fig.6 Failure Identification.

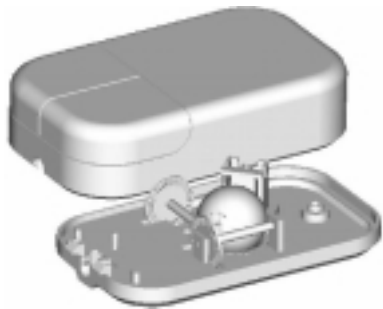


Fig.7 A Computer "Mouse".

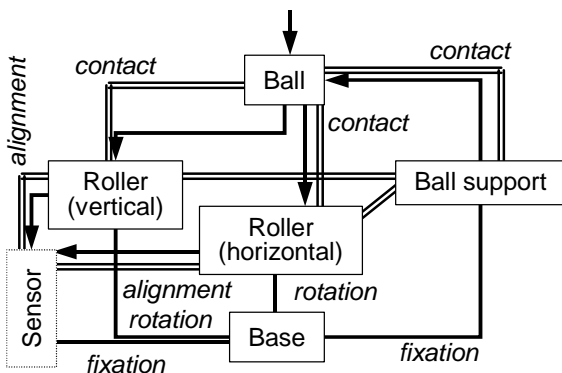


Fig.8 Functional Relation Model of a Mouse.

3.5 Management of Product Usage

According to usage modes and life cycle scenario, maintenance support can be different. Appropriate maintenance support is a very important factor for evaluating life cycle performance. Simulation is a very effective tool for making a maintenance planning before actual product operation.

Here we show a simple example to give an idea for performance evaluation of operational support. In Fig.9, a horizontal axis shows an interval between maintenance operation. A vertical axis of a graph shows waiting (or idle) time of a machine before maintenance. Three different curves are derived from a simulation of maintenance operation, according to the difference of the capacity of maintenance facility (y). Fig.9 shows an intuitively very natural result, that is, less idle time can be achieved with large capacity of maintenance facility and short maintenance interval.

Of course large capacity and short interval are normally expensive. For feasibility evaluation of maintenance, control factors, such as maintenance interval, facility capacity and monitoring capability, should be determined according to the evaluation of maintenance cost, product availability, etc.

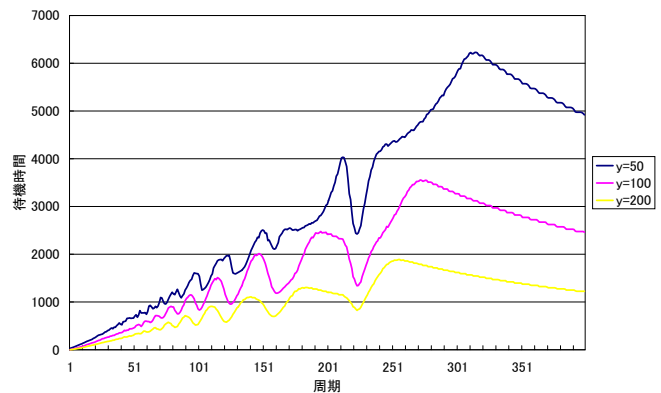


Fig.9 Simulation Example:
Maintenance Interval vs. Machine Idle Time.

4 DISCUSSION AND CONCLUSION

A basic idea and selected simple examples for a method for designing products and their life cycles according to the required usage modes are explained. Simulation of product life cycle under assumed usage mode and scenario is a generic and powerful tool for design decision making.

It is clear that the proposed procedure in section 3.1 should be an iterative one, and gradually the design results are being elaborated. Currently integrated life cycle modelling is not yet realized, to support all involved steps in section 3.1. Formalization and elaboration of such integrated product modelling is a major research theme for the future.

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