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Study of Life Cycle Design Focusing on Resource Balance throughout Product Life Cycles

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Abstract

Life cycle design is a promising approach for introducing efficient resource circulation. In such design, there are difficulties in balancing demand and supply for resources throughout product life cycles. For the resource balance, it is important to design a product life cycle focusing on individual products and their parts, since they change their states diversely and flow along different circulation paths through their life cycles. This paper proposes a modelling method for the individual products and parts in addition to its design information. The design information is the nominal information of the product specified by designers. To achieve this, this paper defines three models; hierarchical structure model, life cycle flow model, and entity information model. Hierarchical structure model represents design information of a product. Life cycle flow model represents a network of processes included in product life cycles. Entity information model represents information of individual products and parts. The information indicates when each product and part flows along which circulation paths in which state. With this information, this method represents resource balance throughout product life cycles. Moreover, this study employs life cycle simulation technique to derive the entity information model from the hierarchical structure model and life cycle flow model. We demonstrate the proposed modelling method via its application to a smart phone in a case study.

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1. Introduction

The question of how to minimize environmental loads and resource consumption throughout a product life cycle (LC) is a major issue in the manufacturing industry [1]. LC design [2] is a promising approach toward provision of answers to this question. The term *LC design* refers to an integrated design of a product and its LC flow [3].

One of key issues in LC design involves the problem of how to introduce efficient resource circulation (*e.g.*, recycling, reuse, and remanufacturing) in product LCs [4]. There are difficulties in balancing demand and supply for resources in product LCs, which are controllable in the conventional production system that has no resource circulation. The difficulties come from the fact that these resources are contained in products and parts that have individual different and changing states throughout the product LCs. This study refers to these individual products and parts as 'entities.'

Even if entities are produced from the same nominal information (*i.e.,* the designed and intended dimension, tolerance, material, etc), each entity changes its state variously due to its different life history such as different operation in diverse user environments. A quantity of entities also varies with time, depending on their individual circulation paths. This study refers to the information of the individual entities, which forms the diverse changes in their states and the changes in their quantities, as 'entity information' against the nominal information. The entity information affects the balance in the resource circulation.

While CAD systems for product modelling are indispensable for designers, few have been equipped with function of supporting LC design. We have proposed a

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computational framework called Life Cycle-CAD (LC-CAD) [5] for modelling a product and its LC flow in an integrated manner. The design object model in LC-CAD, however, does not represent entity information but the nominal information of a product LC. For managing the entire product LC, numerous researchers have addressed product LC management (PLM) (*e.g.*, [6][7]). PLM manages product data throughout product LCs from design stage through manufacturing and service to disposal stage [8]. This approach, however, deals with the nominal information of a product at the management stage after its design stage.

As a CAD system for LC design, LC-CAD should support designers for representing the entity information so as to design a product and its LC flow for keeping the resource balance throughout product LCs. For this purpose, this paper proposes a modelling method of the entity information in addition to the nominal information of a product LC.

2. Life cycle design focusing on the resource balance

This section analyzes two key aspects of the entity information; changes in states of individual entities and changes in their quantities.

2.1. Changes in states of individual entities

States of entities change through their LCs. For example, a product may be damaged during its transportation and may deteriorate during use. These entities may have different states by diverse treatments such as use in different operational environments. The difference in states of entities may arise and be accumulated through their LCs. For example, geometrical deviation of parts generated in manufacturing stage causes differences in performance and quality of individual assembled products [9]. The geometrical deviation may be caused by material defects and manufacturing process errors [10].

The current CAD/CAM systems deal with the differences in geometry, which would be generated in manufacturing and assembly process, as tolerance. However, they give no support for modelling individual states of entities such as deterioration in their middle-of-life processes (*e.g.,* use and maintenance) and in their end-of-life processes (*e.g.,* disassembly, inspection, and repair).

2.2. Changes in quantity of entities

In each LC process, a quantity of entities varies along time due to two factors. First, according to the individual states, entities follow different circulation paths even from the same LC process. For example, according to the degree of deterioration, each entity is treated differently at its end-of-life stage; less deteriorated parts may be reused, while parts severely deteriorated may be recycled or landfilled.

Second, circulation timing of each entity may differ. For example, some users dispose of products after using them for a long term, while others dispose of them in a short term.

Takata *et al.* [11] proposed a model for estimating the number of products that will be collected, using actual data of photocopiers. This model includes sale modes such as selling and lease, which affect the timing and quantity of collected products. However, the timing and quantity differs depending on various parameters in the nominal information of a product LC such as whether the LC flow includes maintenance and what kinds of parts the product has. Studies for estimating product returns have been widely discussed (*e.g.,* [12][13]). Few provide methods for modelling the changes in quantity by using entity information derived from the nominal information of a product through its LC flow.

2.3. Requirements for supporting life cycle design focusing on the resource balance

A CAD system for LC design requires a model for product LCs representing not only the nominal information of a product but also the entity information. Section 2.1 pointed out that the model should represent the changes and differences in states of entities. Section 2.2 pointed out that the model should represent the changes in quantity throughout a designing product LC.

As mentioned in Section 1, we have proposed a design object model for LC design [5]. This model consists of two sub-models; Hierarchical Structure Model (HS Model) and LC Flow Model (LCF Model). HS Model represents structure and attributes of a product. LCF Model represents a network of LC processes. We also have defined an integration scheme for these two models. However, the design object model in LC-CAD simply represents the nominal information of a product LC.

3. The framework of the modelling method

This section outlines a method for modelling product LCs based on the analysis in Section 2.

For achieving the requirements discussed in Section 2.3, we take two approaches. First, this study defines a design

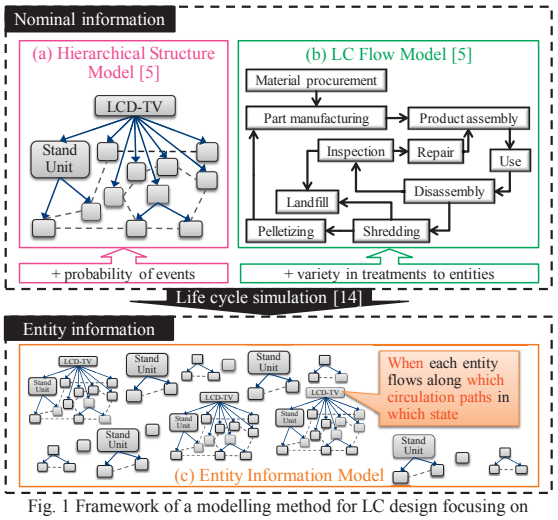

Fig. 1 Framework of a modelling method for LC design focusing on entities throughout product life cycles