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Interlinking multiple decision variables over different life cycle stages to realize effective reuse and recycling from a strategic viewpoint

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Abstract

Effective reuse and recycling of End-Of-Life (EOL) products is essential for improving resource efficiency. Many studies have been conducted for enabling effective reuse and recycling of EOL products. However, their individual application is not sufficient for the purposes because the main concerns dealt with in each method are strongly interrelated. The objective of the study is proposing a method for interlinking multiple factors over different life cycle stages so that multiple stakeholders involved in different life cycle stages can collaboratively find out more effective solutions than those individually achieved by each stakeholder from a strategic viewpoint.

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Keywords: "Reuse; recycling; product design; capacity planning"

1. Introduction

Effective reuse and recycling of End-Of-Life (EOL) products is essential for improving resource efficiency. Many studies have been conducted for enabling effective reuse and recycling of End-of-Life (EOL) products [1-10]. Some focused on the product design methods that ease disassembly and recycling of EOL products [2, 3]. Others focused on the planning and sequencing of disassembly operations [4, 5], capacity planning of remanufacturing facilities [6], material separation technologies [7], the design of reverse network for EOL products [8], and functional sales and service offering design [9,10]. Although these methods and tools are quite effective for widening the opportunities for product reuse and recycling, their individual application is not sufficient for the purposes because the main concerns dealt with in each method are strongly interrelated. Thus, the simultaneous consideration of these factors is essential for solving the problem.

The objective of the study is proposing a method for interlinking multiple factors, some of which are to be designated as decision variables, over different life cycle stages. Based on such interlinking, multiple stakeholders involved in different life cycle stages can collaboratively find out more effective solutions than those individually achieved by each stakeholder.

This paper especially focuses on interlinking product design variables to those affecting profitability in reuse and recycling processes so that the original equipment manufacturers (OEMs), second hand product retailers, and recyclers can collaboratively decide more optimal product structure with adequate capacity in reuse and recycling facilities. As a first step of this attempt, a linear programing model is introduced to quantitatively correlate such multiple factors. Through a simplified case study of a mobile phone recycling, the possibility of the model for interlinking these factors is demonstrated.

The rest of the paper is organized as follows. Section 2 introduces a linear programing model that are used in the study. Section 3 explains the method that computes the optimal reuse and recycling plan for EOL products with its optimal assignment to corresponding firms. Section 4 provides a simplified calculation example of a mobile phone. Section 5 discusses the advantages and drawbacks of the proposed model. Section 6 concludes the paper.

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2. The model interlinking product design to reuse and recycling planning

2.1. Interdependency between product design and reuse/recycling of EOL products

Among multiple criteria for evaluating the desirability of reuse/recycling of EOL products, the paper especially focuses on the economic benefit as a first step. Fig.1 shows the possible interdependency among decisions in product design and reuse/recycling process planning from the economic viewpoint. According to the interview result with engineers in recycling firms, reuse/recycling process parameters such as capacity and location of disassembly/separation facilities and maturity of disassembly/separation technology, which directly affect disassembly, separation, and transportation cost of EOL products as well as the quality of the retrieved items, are regarded as key decision variables for the reuse/recycling planning. However, the decisions made in product design (e.g., material composition, fastening method, and geometrical structure etc.) have also significant potential for improving the profitability of the reuse and recycling. To highlight such potential, quantitative evaluation of the effect of product design is indispensable. Thus, a linear programing model which correlate product design with profitability of reuse/recycling of EOL product is proposed in the paper.

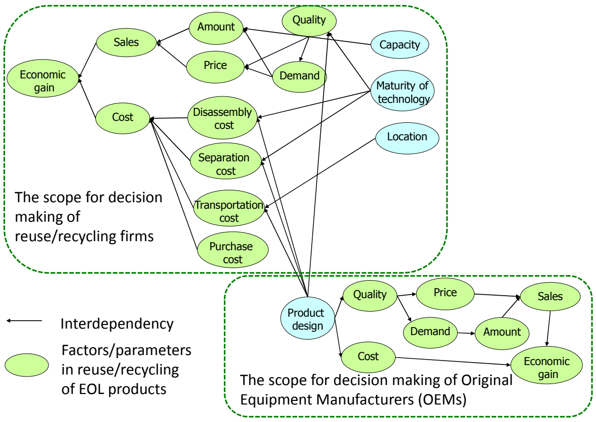

Fig. 1. Interdependency between product design and reuse/recycling process

2.2. The Reuse/Recycling Tree (RRT) model

As the product design include a lot of information, it is not feasible to directly correlate every decision variables with those used in reuse/recycling planning. Thus, we encapsulate product design information as Reuse and Recycling Tree (RRT) model and correlate it with Provider and Receptor Network (PRN), which represents possible assignment of reuse/recycling tasks to firms.

The RRT represents a possible sequence of component reuse and material recycling for a given EOL product in addition with the average market price for each item recovered from the product. Each node of the tree corresponds to the item (i.e., EOL product, sub-assembly, component, or mixed material fraction) that can be sold to reuse or recycling firms. The root item represents the product itself and a leaf item represents any item that is to be reused or discarded without any further disassembly operations. A set of edges between the parent item and its child items corresponds to the disassembly or dismantling process that is required to obtain the child items from the parent item. Fig. 2 shows a simplified RRT of a mobile phone. A mobile phone can be disassembled into two parts: liquid crystal display (LCD) and printed-circuit board (PCB). LCD can be further dismantled to mixed material factions, each of which contains steel, aluminum, and other materials. Rare metal fraction (e.g., tantalum-rich fraction) can also be dismantled from PCB. In addition, the average market price for each item is given as a number beside each node in the RRT. Negative price for “Others” implies that the fraction cannot be sold but should be landfilled or incinerated by its producer’s cost.

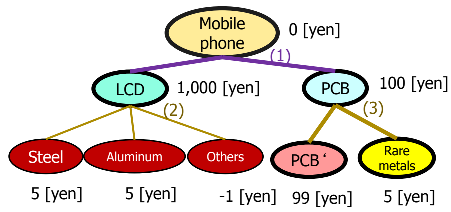

Fig. 2. Simplified RRT of a mobile phone.

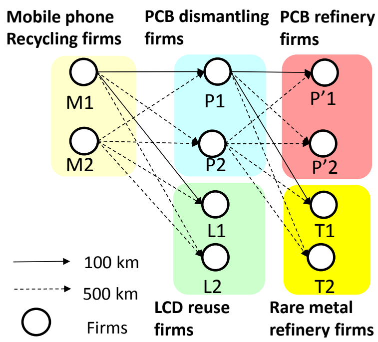

Fig. 3. Partial PRN of a mobile phone.

2.3. The Provider Receptor Network (PRN) model

The PRN represents assignment of the recycling (or reuse) processes to firms, which are sparsely located in Japan. Each node of the PRN corresponds to the reuse or recycling firm that can execute one of the processes represented in the RRT. The processing capacity, cost, and storage capacity of each firm are also tagged to each node. Each edge of the PRN corresponds to the transportation (and transaction) among two firms. The origin node and the destination node of the edge are referred as the provider and the receptor, respectively. The traveling distance among two firms, based on which the transportation