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Disassembly and recycling cost analysis of waste notebook and the efficiency improvement by re-design process

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ABSTRACT

This paper evaluates the recycling rates, costs as well as the disassembly time of a notebook at its end-of-life stage through Prodtect 1.3 calculation using data collected during disassembly processes. The results show that the disassembly and recycle of a notebook at its end-of-life stage may exert positive influence on the environment by introducing the eco-design concept to the product re-design, thus creating more resource-conserving products and enhancing recycle efficiency. Through proper disassembly and disposal processes, a notebook at its end-of-life stage may yield the recycling value of 1.61 EUR. Furthermore, the most revenue of 1.44 EUR is attributed to the recycle of metallic and plastic parts, the major constituents of a notebook. As for the time required for disassembly, the Top Case, Motherboard and LCD (CHI MEI) are the three most time-taking parts in the disassembly process, and their total times required are 133, 67 and 64 s, respectively. Prodtect calculation to assess notebook recycling benefits provides a new set of guidelines for the notebook designer to propose potential modifications of the re-design for reducing the environmental impacts arising from the next-generation products.

1. Introduction

Modern technology has advanced human beings into a society with vast growth and economic prosperity, where the use of electrical and electronic devices becomes inevitable for daily life. According to the study by Cui and Forssberg (2003), more than 6 million tonnes of waste electrical and electronic equipment (WEEE) were generated in 1998 in west Europe, and the amount of WEEE was expected to increase 3–5% per annum. Kang and Schoenung (2005) indicated that more than 54 million personal computers (PCs) were sold in 2003, and nearly 63 million PCs in the U.S. were expected to become obsolete in 2003. In the study by Liu et al. (2009), the amount of electronic waste in urban Beijing area in China was estimated to increase two times in 2010 as compared to that in 2005, and this increase will continue till 2020. Apparently, the significant increase in discarded consumer electronic products will cause enormous environmental problems as no thought has been given to their possible reuse.

Before 1990, the WEEE was treated and disposed as general waste. Since the concept of resource conservation has received considerable attention in late 90s, some European governments have passed laws so that manufacturers and importers are being held responsible for their products when discarded by customers. Therefore, manufacturers have started considering product designs which allow the reuse of components/sub-assemblies and the recycling of raw materials (Bras, 1997; Horvath et al., 1995; Sarkis, 1998; Wapman, 1994).

Incorporating environmental consideration into the product design is deemed an immediate way to enhance the recycling process of the WEEE at its end-of-life stage. The basic concept of eco-design is to reduce environmental impacts by taking the product redesign into account throughout the entire life cycle. The eco-design concept has been applied extensively during the last decade. Donnelly et al. (2006) presented a product-based environmental management system focusing on eco-design to improve the product sustainability throughout the entire product life. Through a five-stage of the applicability framework, Knight and Jenkins (2009) showed how a suite of potential eco-design tools can be identified for application to product development processes. Cerdan et al. (2009) proposed a series of eco-design indicators that can help to reduce the time and resources to choose between alternative eco-design options. The issue that assesses the compliance of a product from eco-design to eco-label was addressed in the study by Houe and Grabot (2009). Yang and Chen (2011) proposed a new approach using case-based reasoning and

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the TRIZ method to accelerate preliminary eco-innovation design. Most of cases studied were focusing on theoretical analyses, conceptual model building, and computation algorithms based on available or collected datasets (Hill, 1993; Ufford and Ward, 1999; Yang et al., 2003; Erol and Thoming, 2005; Moors et al., 2005). In the literature, little has been reported regarding the eco-design application to the notebook recycling process.

In Taiwan, all the generated waste was considered worthless and disposed through incineration or landfill several decades ago. As the concept of resources conservation became more and more popular around 15 years ago, the governing authority started to introduce this concept into waste management. During that time, the waste reduction and recycling of domestic general waste was the major focus. At the same time, many related researches were conducted to evaluate the establishment of recycling system and the impacts of resource conservation policy enforcement, including the recovery and reuse of electronic appliances either by the manufacturers or the professional recovery agents. However, no apparent responsibility of recovering discarded electronic appliances was imposed on the manufacturers by any legitimate regulations. Considering the popularity of using electrical appliances in recent daily life and their abundance in electrical waste generation, the government in Taiwan offered the monetary subsidy for manufacturers in recovering refrigerators, air conditioners, washing machines, television sets, and so many. Recently, the recovery of computers has drawn considerable attentions because of their abundance in use. However, no policy of mandatory recycling and monetary subsidy in recovering computers has been implemented. The current incentive for the manufacturers to implement computer recycling at its end-of-life stage is through the acquirement of Taiwan Green Mark endorsement, which signifies the promise of the manufacturer to produce electronic products through an environmental-friendly way and mandatory recovery of the possible waste at their end-of-life stage. Besides, Taiwan is the largest original equipment manufacturing (OEM) entity, and many notebook manufacturers have to adopt and implement the eco-design concept in compliance with the regulations enforced by European countries and the United States.

From the engineering perspective, disassembly is defined as the organized process of taking apart a systematic assembly of components. By doing this, product disassembly can enable maintenance through modularity in design, enhance serviceability and affect end-of-life objectives, such as product/component reuse, remanufacture, and recycling. Therefore, the notebook disassembly is a critical part for the notebook recycling at the end-of-life stage. Having evaluated the economic incentive from the domestic recycling activities in Taiwan, the notebook industry should benefit much from design for reuse and recycling. A typical notebook consists of relatively large pieces of recoverable materials as well as smaller specialized components. In this regard, this paper evaluates an exemplary study of the eco-design practice for notebook recycling. The recycling rates and costs as well as the disassembly time of a notebook at its end-of-life stage will be thoroughly investigated using Prodtect 1.3 calculation with data collected during its disassembly processes. The evaluation results can serve as a useful reference for future notebook design modification.

2. Research setting

This study aims to analyze the notebook disassembly procedure at its end-of-life stage. The notebook is selected because of its increasing market share compared to the traditional desktop computer. Meanwhile, the commercial notebooks usually have similar components such as the processor, system memory, display panel, video/audio output, hard drive, DVD drive and battery. All these components are connected with various joining techniques. The disassembly of the notebooks with different computation capabilities leads to similar recycle parts. Besides, from the perspective of eco-design, IEEE 1680.1 encourages the notebook manufactures to employ general joining techniques rather than newly-invented techniques so that further notebook disassembly at its end-of-life stage may not require unusual tools or techniques in the disassembly process.

2.1. Notebook and analytical software selection

In this study, a major name-brand commercial notebook is selected as the research example because (i) the computer is necessary equipment in daily life, and (ii) the notebook becomes more popular in place of desktop computer recently. Besides, Taiwan is the largest notebook assembly country in the world, and a comprehensive database on notebook manufacturing is available. The investigated notebook belongs to one of the most popular series manufactured by a multinational computer hardware and electronics company headquartered in Taiwan. Its products include motherboards, desktops, notebooks, monitors, tablet PCs, servers, video cards and mobile phones. It primarily sells its products under its own brand but also produces components for other manufacturers. According to 2011 unit sales, it is ranked the fifth-largest PC vendor in the world. The specification of the investigated notebook is with Intel Pentium 4 processor, 256 megabyte SDRAM, 15-inch active matrix colour display, 30 gigabyte hard drive, 8-cell Li-ion battery pack, 5.25-inch DVD-ROM drive.

Prodtech 1.3 is an environmental design and analysis software developed by the German company of Kerp-Engineering GmbH. This software evaluates the life cycle analysis of a product through a series of operation stages of model parameter input, calculation, assessment, and result comparison. In particular, this software uses methods-time measurement (MTM) algorithm to estimate the time required for equipment disassembly and recycling cost. The applications of Prodtect may be referred to the studies by Kernbaum et al. (2009) and Santini et al. (2010).

2.2. Cost analysis for notebook recycling

In the Prodtect analysis, the input parameters are categorized as (i) parts information, (ii) connection information, and (iii) disassembly priority information. The parts information contains their names, sizes, configuration, and weights. The connection information describes the connecting methods between parts or modules. The disassembly priority information characterizes the order of the parts/modules disassembled from the investigated device in the recycling process. All the information of the three categories is the input into the Prodtect 1.3 software that evaluates the end-of-life destination, end-of-life value, disassembly time and cost, and disassembly sequence of the investigated notebook. Hence, the corresponding results may provide a useful benchmark for future product re-design. To disassemble a notebook, the principle to reduce, to reuse and to recycle (3Rs) is followed, through which a notebook is separated into parts, components subassemblies and groupings (Huang et al., 2012; Lautsen, 2007). In the 3Rs principle, the durability, applicability, and environmental impacts of the raw materials are the important factors that should be taken into account. The materials containing toxic constituents should be excluded during manufacturing process. As for the parts/components configuration, the recyclability, re-selling profits, and treatability of recycled parts are the top priority for consideration.

The end-of-life destination is the optimization of disassembly level in the recycling process. The disassembly is not a reverse action of parts/modules assembly. In fact, all the parts do not have to be separated individually, if some connected parts can be