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A methodological framework for end-of-life management of electronic products

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ABSTRACT

A growing number of regulatory interventions such as the European Union's Extended Polluter Responsibility Policy hold manufacturers accountable for the damage inflicted to the natural environment by their products. However, not all components of an industrial product have an equitable role regarding their overall burden to the environment. In this context, it is of great interest to manufacturers to identify and rank those components with the highest potential value at the end of their useful life, employing an array of economical and environmental criteria. In order to assist manufacturers on their decision-making for the optimal end-of-life alternatives for their products, the "Multicriteria Matrix" methodology has been developed. The methodology relies on multicriteria analysis and takes into consideration the residual value, environmental burden, weight, quantity and ease of disassembly of each component. With the developed methodology only those components that do not have any residual value end up in landfills, while the majority of the components are either reused or recycled. The application of the developed methodology is demonstrated employing a real-world case study; that of an ISDN network terminal. Finally, the paper is concluded by presenting interesting managerial insights that were obtained.

1. Introduction

Various regulatory interventions initiatives have been developed imposing certain constraints and environmental obligations on producers of electrical and electronic equipment (EEE). To that effect, the European Union with its Directives 2002/96/EC (European Commission, 2003a) and 2002/95/EC (European Commission, 2003b) regarding the waste electrical and electronic equipment (WEEE) and the restriction of the use of certain hazardous substances (RoHS) in EEE, respectively, has imposed strict limits. Its strategic target is to increase the recycling of EEE products by enforcing producers to decrease the content of hazardous materials and to manage their products at the end of their useful life (Barba-Gutierrez et al., 2008).

Apart from regulatory interventions, there are additional cost related incentives for companies to consider extended producer responsibility (OECD, 2001). In particular, for information technology (IT) hardware products, which represent a considerable part of the total WEEE stream, the materials used have a relatively high residual economic value and therefore, if they can be reintroduced into the manufacturer's supply chain, significant cost savings can be achieved (Truttmann and Rechberger, 2006; Kang and Schoenung, 2005). Moreover, there is a growing trend towards green consumerism, with consumers willing to pay premiums for goods, which are recycled, recyclable and non-damaging to the environment (Gupta, 1995). Consumers are increasingly environmentally conscious, as they realise their potential contribution to environmental protection and are attracted to companies that have invested in green policies and technologies (Chatzipanagioti and Iakovou, 2006; Tsoulfas and Pappis, 2005; Brisson, 1993).

In those situations where the responsibility for the disposal of products at the end of their useful life has been shifted through regulation back to the producer, manufacturing companies have been forced to incorporate take-back requirements into their strategic planning processes and product design strategies (Gutowski et al., 2005; Herold, 2004; Rose and Stevels, 2000; Stevels et al., 1999). Through a take-back system, industrial products are recovered at the end of their useful life, so that waste is diverted away from landfills and incineration into reuse, remanufacture and recycling.

The present study presents a methodological framework that any manufacturer could adopt in order to implement an environment-friendly business strategy, accounting at the same time for the economical benefits from the reuse or the recycling of his/her products' components. The objective of the developed

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methodology is twofold: (i) to assist the manufacturer to rank the components of an industrial product as far as their potential value at the end of their useful life is concerned, and (ii) to identify those components eligible for alternative end-of-life management, such as reuse and recycling. The developed methodology is demonstrated through its application on a real-world case study of an ISDN network terminal.

The rest of the paper is organised as follows. Section 2 presents a brief literature review on the recent research status in the field of the optimal EOL management of the components of the electric and electronic devices. In Section 3 we present the problem under study with the aid of the employed ISDN network terminal. The framework of the methodological approach is presented in Section 4; its detailed implementation is exhibited via its application on a pilot device. In Section 5 we provide managerial insights that are obtained by the application of the developed methodology as these transcend the strategic, tactical and operational decision-making hierarchy. The paper wraps up with conclusions and future research steps.

2. Literature background

The literature body on the optimal identification of the most attractive components to be disassembled for recovery (i.e. reuse, remanufacturing, recycling, etc.) from an EOL product is growing rapidly. In this context, Gungor and Gupta (1997) presented an evaluation methodology to choose the best disassembly process from among several alternative processes based on total time for disassembly. Das et al. (2000) presented an elaborate multicriteria scoring model to compute the disassembly effort index score, which is representative of the total disassembly cost of a product. The factors that considered for the disassembly process are the following: (i) time; (ii) tools; (iii) fixture; (iv) access; (v) instruct; (vi) hazard; and (vii) force requirements. The disassembly effort index score can be compared against the current market value of the disassembled components, so as to derive an economic measure on the potential profitability of their recovery processes. Moreover, Das and Yedlarajiah (2002) proposed a rather simplistic mixed-integer programming model for the optimization of the recovery processes of the recyclable components of an EOL product.

Kongar and Gupta (2000) presented a goal-programming methodology for the optimization of the recovery processes in a remanufacturing environment. The objective of their paper is to optimise economically the demand fulfilment in recovered EOL components by considering inventory management issues, while minimizing waste generation. Later on, the authors presented a variation of this work (Kongar and Gupta, 2006) in the form of a multicriteria fuzzy goal-programming model of a disassembly-to-order system under uncertainty, aiming to identify the number of EOL products to be collected, recovered and disposed of.

Kim et al. (2004) employed life cycle analysis (LCA) methodology and a simple deterministic economic model, in order to assess the recycling potential of the materials contained into the waste home appliances. In parallel, Herrmann et al. (2004) presented specific qualitative guidelines for the calculation of economic and ecological indicators to evaluate EOL products regarding material recycling. Furthermore, Kiritsis et al. (2005) presented a multicriteria-based methodology to evaluate EOL product treatment options with regard to environmental, economic and social criteria. Gonzalez and Adenso-Diaz (2005) examined the following problem: "given a product structure and the joining and geometrical relationships among its components, which should be the disassembly depth and the EOL recovery strategy for each disassembled part?" Towards this effect, a scatter search metaheuristic algorithm is proposed. Zhou and Schoenung (2006) provided a theoretical framework for the environmentally conscious design and EOL management of cellular phones. Moreover, Kuo (2006) presented a graph-based heuristic method for the disassembly analysis of EOL products. LCA was used for the evaluation of the disassemblability and recyclability of the components contained to EOL products. Finally, Lambert (2002), Lambert and Gupta (2002), Huisman (2003) and Zhou and Schoenung (2007) proposed also interesting methodological approaches for tackling the EOL products' disassembly and recovery problem.

The research efforts dealing with the optimal determination of the fate of the individual components of the EOL electric and electronic devices have reached a critical mass. However, only few of them provide integrated approaches for the optimal selection of the components of the EOL products for recovery purposes, while in most cases these approaches are rather complicated. In this paper, following the new concept of extended producer responsibility (EPR), a new research, industry-oriented multicriteria scoring model is proposed for determining the best EOL strategy for EEE products. Towards this effect, economic, environmental and technological issues are taken explicitly into account. Moreover, the provided methodology is presented on a real-world case-study basis, in order to demonstrate its applicability and user-friendliness, as well as to address a need clearly identified by industry.

3. The problem under study

Manufacturers often recognise that not all components of a product are of equal significance regarding their economic and environmental burden. According to Pareto's Law (also the "80/20 rule"), a small percentage of parts or components of a product seem to be responsible for the vast majority of its production costs, as well as its overall environmental burden (Moussiopoulos et al., 2006; Koroneos et al., 2005b). Since the alternative management of products or their components (such as reuse and recycling) often demands resources and capital from the manufacturer, discarding certain components of a product to a landfill or an incinerator might appear at least myopically, as the most convenient end-of-life management option. As this option is not necessarily the optimal one, the problem that a manufacturer is facing is the identification of the components that need to be reused, those that need to be recycled, and/or the ones that could simply end up in a landfill or an incinerator.

We motivate the study by demonstrating its contextual framework employing the real-world case study of the netMod ISDN network terminal, an IT product developed by Intracom S.A., one of the leading Greek companies with a significant exporting record (Intracom S.A., 2008). Our involvement with this product emanates from a research project funded by the Greek Ministry of National Education and Religious Affairs (MIPEL Project, 2004, 2005a, 2005b, 2005c, 2006a, 2006b, 2006c). We used this product throughout the course of the project as a pilot device.

The ISDN network terminal is depicted in Fig. 1 and represents the full package of netMod, as this is promoted to the Greek IT market. It is comprised of plastic parts which constitute the product's base and cover, electrical and electronic components inside netMod (capacitors, resistors, diodes, switches, etc.), installation materials (screws, wall plugs, etc.), cables, as well as packaging materials (plastic bags and cartons). The proposed decision-making methodology is presented in the rest of the paper on a case-study basis, so as to better demonstrate its structure and ease of application on a real-word electronic device (i.e. netMod). Clearly, this does not limit the application of the overall methodology, as it has been developed to assist manufacturers on their decision-making for the identification, ranking and end-of-life treatment of the components of any industrial product.