Managing Uncertainties in Design Alternatives of EOL Products With Fractional Disassembly Yields

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ABSTRACT

This paper proposes a model of an advanced remanufacturing to order and disassembly to order (ARTODTO) system which evaluates various design alternatives of products to satisfy the demands of retrieved products, components, and materials by disassembling these products at the end of their lives. The quality, quantity, and variety of end-of-life (EOL) products are uncertain which leads to fractional disassembly yields. Goal programming is used to determine the quantities of EOL products to be acquired in order to meet all the demands of retrieved products, components, and materials. A case example of EOL dryers is presented to demonstrate the steps and implementation of the proposed model.

KEYWORDS

Advanced Remanufacturing-to-Order and Disassembly-to-Order System (ARTODTO), Design Alternatives, Design for X, Disassembly, Dryer, End-of-Life Products, Goal Programming, Remanufacturing, Uncertainty

INTRODUCTION

Technological advances in every type of consumer product have improved people's lives. Products with advanced technologies improve consumers' lives and thus they are always hungry for them. Because of this, new and advanced products are continuously introduced in the market, and in response, consumers continuously buy and upgrade products. This results in products reaching their End-Of-Lives (EOL) sooner. Therefore, even though a product may be in good condition, its disposal is unavoidable. According to the Environmental Protection Agency (EPA), United States generates over 8 billion tons of industrial waste each year, more than one third of which is hazardous. Because of the rate of increasing waste, available landfills are filling up rapidly, and the number of landfills is decreasing at an alarming rate (Gungor & Gupta, 1999). Depletion of natural resources and reduction in the available landfills for disposal has led legislators to require Original Equipment Manufacturers (OEMs) to take responsibility of their own EOL products. To comply with the regulations and to make profits, OEMs have started to invest in the product recovery facilities. Product recovery facilities are used to collect returned EOL products and reduce waste by managing EOL products by various recovery processes such as recycling, reuse, and remanufacturing. Product designs with high potential for recycling, reuse, and remanufacturing are ways OEMs can contribute to the conservation of natural resources and manage the EOL products.

The design of a product plays an important role in the EOL product management (Sabaghi et al., 2016). The efficiency of the product recovery processes can have a profound impact on the management of EOL products. Therefore, OEMs would like to consider EOL strategies at the product

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design stage. Traditionally, product development aims at designing products for cost, functionality, and manufacturability. However, increasing awareness about the environmental issues has forced the product designers to consider environmental factors during the product design phase. Various methodologies to ease the work of designers have been developed, such as Design for X (DfX), Life Cycle Assessment, and material selection. DfX involves different design specialties such as Design for Environment (DfE), Design for Disassembly (DfD), Design for Recycling (DfR), and Design for Remanufacturing (DfRem). Veerakamolmal and Gupta (2000) defined Design for Disassembly (DfD) as the ease of disassembly in the design process. Disassembly is a systematic separation of an assembly into its components, subassemblies, or other groupings (Ondemir & Gupta, 2014). It is an important process as it allows selective separation of desired parts and materials. The aim of DfD is to design products that can be readily disassembled at the end of their lives, to optimize recycling, reuse, and remanufacturing of materials, products, and components. DfD minimizes the complexity of the product structure by minimizing the number of different parts, increasing the use of common materials, optimizing the spatial alignment between various components without affecting the assemblability, functionality, and structural soundness (Veerakamolmal & Gupta, 1999).

Design for Remanufacturing (DfRem) is another method that is of interest here. Remanufacturing is key to sustainable production as it brings back the EOL products to 'as good as new' working conditions through a series of processes including disassembly, sorting, cleaning, reconditioning, and assembly. However, there are a few hurdles in carrying out remanufacturing such as heavily damaged components, unavailability of sufficient equipment and labor (Yang et al., 2016). Many of these barriers can be addressed by designing the product for remanufacturing. Charter and Gray (2008) defined DfRem as "a combination of design processes whereby an item is designed to facilitate remanufacture." It includes a combination of processes such as design for disassembly, design for multiple life-cycles, modular design, and product support for take back decisions. The products/modules/components need to be evaluated to know if they are suitable for remanufacturing. The evaluation includes the following considerations: value and cost of component, reusability, disassemblability (can the component be extracted without damage), economic feasibility of remanufacturing, recoverable value at EOL, remanufacturing cost, disposal options and environmental impact or legislations (Nasr & Thurston, 2006). Therefore, evaluation of product designs for disassembly and remanufacturing is a vital step in EOL product recovery.

This paper proposes a multi-criteria Advanced-Remanufacturing-To-Order-Disassembly-To-Order (ARTODTO) system, which purchases EOL products available in various design alternatives of to meet products, components, and materials demands, to satisfy various criteria. The returned EOL products are sent to a collection facility for inspection, sorting, cleaning, and preparation for disassembly. Once the EOL products are prepared for disassembly, they are sent to the disassembly facility. Depending on the final use and condition of the component, the type of disassembly process is determined (Germani et al., 2014). Disassembly can be partial (only selected items are disassembled) or complete (all items are disassembled), and destructive (items can be damaged) or non-destructive (items are not allowed to be damaged). Non-destructive disassembly is normally performed only when components are reused or stored for future use as it can be expensive and labor intensive. Destructive disassembly is performed when the product is recycled for material, or is disposed of. The purpose of this paper is to determine the exact number of EOL products needed for disassembly, to fulfill all the demands. This is challenging due to the numerous uncertainties in the disassembly process such as the conditions of the received EOL products, and the quantity and variety of EOL products from different suppliers (Imtanavanich & Gupta, 2006). Although fulfilling the demands is the top priority, manufacturers also must strategize a plan, which not only fulfills the demands but also satisfies physical, financial, and environmental goals. Therefore, this problem is considered as a multi-criteria decision-making problem (Ilgin and Gupta, 2015; Gupta and Ilgin, 2018). Since the main input to the system is EOL products, the number of EOL products to be acquired is important, and should be optimally determined such that it satisfies all the demands.