Chapter 2
Analysis of Design Alternatives of End-of-Life Products Under Fractional Yields

Aditi D. Joshi
Northeastern University, USA

Surendra M. Gupta
Northeastern University, USA

ABSTRACT

In this chapter, an advanced remanufacturing-to-order and disassembly-to-order (ARTODTO) system is considered to evaluate various design alternatives of end-of-life (EOL) products to meet products, components, and materials demands. There are uncertainties about the quantity, quality, and variety of returned EOL products, and these uncertainties lead to fractional disassembly yields. Since the main input to the system is EOL products, their quantities to be acquired is important, and should be determined such that they satisfy all the demands. The designs are evaluated based on four criteria: total profit, procurement cost, purchase cost, and disposal cost using goal programming (GP). A numerical example using EOL dryers is considered to illustrate the implementation of the proposed model.

INTRODUCTION

Technological advances in every type of consumer products have improved people's lives. Products with superior technologies are continuously introduced in the market, and to keep up with the latest technology, consumers are constantly buying upgraded products. This has forced the products to reach their End-Of-Lives (EOL) sooner. Therefore, even though a product may be in good condition, its disposal is inevitable. According to the Environmental Protection Agency (EPA), United States generates 7.6 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 quickly, and the number of landfills is decreasing at an alarming rate (Gungor & Gupta, 1999).

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Depletion of natural resources and reduction in the available landfills for disposal has led legislators to compel Original Equipment Manufacturers (OEMs) to take the responsibility of their own EOL products. To comply with the regulations and to make profits, OEMs have started investing in the product recovery facilities. Product recovery facilities collect EOL products and use various recovery processes such as recycling, reuse, and remanufacturing to reduce disposal to landfills and manage EOL product waste. Product development with high potential for reuse, remanufacturing, and recycling are ways OEMs can contribute to the conservation of natural resources and manage the EOL products.

Product design 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 and one of the major factors affecting the product recovery processes' efficiency is the products' design. Therefore, OEMs would like to consider EOL strategies at the product 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 reuse, remanufacturing, or recycling of products, materials, and components. DfD leads to minimizing 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 is another technique that is of interest here. Remanufacturing is key to sustainable production as it brings back the EOL products to good 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 Design for Remanufacturing (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.

In this chapter, a multi-criteria Advanced-Remanufacturing-To-Order-Disassembly-To-Order (ARTODTO) system, which purchases design alternatives of EOL products to meet products, components, and materials demands, and satisfies various criteria, is proposed. The ARTODTO system takes back a wide variety of EOL products from suppliers to fulfill the products, components, and materials de-

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