Computers & Industrial Engineering 76 (2014) 193–203

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

A production base-stock policy for recycling supply chain management in the presence of uncertainty ☆

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ARTICLE INFO

Article history:
Received 2 July 2013
Received in revised form 23 June 2014
Accepted 3 August 2014
Available online 12 August 2014

Keywords:
Recycling process
Uncertainty condition
Stochastic master planning model
Heuristic algorithm
Simulation

ABSTRACT

This study focuses on solving master planning problems for a recycling supply chain with uncertain supply and demand. A recycling supply chain network includes collectors, disassemblers, remanufacturers, and redistributors working from the collection of returned goods to the distribution of recovered products to the market. The objective of this study is to maximize the total profit of the entire recycling supply chain. Considering the stochastic property of the recycling supply chain, this study institutes stocking and processing policies for each member of the recycling supply chain to better respond to unknown future demand. We propose a heuristic algorithm called stochastic recycling process planning algorithm (SRPPA) to address master planning problems in the recycling supply chain and its supply and demand uncertainties. The main SRPPA process consists of three phases. In the leader determination phase, SRPPA identifies the most important node as the leader of the recycling supply chain. In the candidate policy set generation phase, SRPPA defines the search range for the inventory policy and forms the candidate policy sets based on the characteristics of the leader. In the best policy set selection phase, SRPPA constructs the simulation process for each inventory policy candidate to identify the best policy set. A scenario analysis is then presented to show the effectiveness and efficiency of SRPPA.

1. Introduction

In the context of increased environmental awareness and a difficult economic period, an increasing number of manufacturers are forced to recover used products and utilize these in production processes. High resource costs, limited landfill capacity, and customer desire encourage companies in Germany to focus on recycling (Seitz, 2007). Therefore, the recycling supply chain has received increased attention, has been recently studied, and will continue to be studied with increasing intensity by both academicians and industry owners (Sarkis, Zhu, & Lai, 2011). The development of the "green product" concept has enabled manufacturers to develop green production processes for a sustainable future business environment. BMW and DuPont are two examples of well-known green manufacturers. BMW has invested heavily in automobile disassembly and has established a disassembly plant for automobile parts. BMW's strategic goal is to design a completely reclaimable automobile in the 21st century (Brennan, Gupta, & Taleb, 1994). DuPont operates several facilities to recycle nylon from used carpeting materials. The reusable content is separated from waste and is recycled for various applications, including new carpet fibers and automotive parts (Fleischmann, 2001).

The European Union has also taken action by passing legislation for a number of product categories such as packaging materials (packaging and packaging waste), vehicles (end-of-life vehicle solutions), and electronics (WEEE) (EUROPA, 2013). The United States Council for Automotive Research (USCAR) has established Vehicle Recycling Partnership to promote automobile recycling and disassembly (Johnson and Wang, 1998). Private and public sectors are working together to promote environmental consciousness, participate in the green production process movement, improve environmental protection, and reduce production waste.

Reducing costs and adding value by incorporating parts recovery into production are beneficial for manufacturers. Total carpet recycling in the US would provide estimated annual landfill cost savings of USD 65 million and recovered materials valued at approximately USD 750 million (Realff, Ammons, & Newton, 2004). Materials obtained from recycled goods provide a very attractive potential market for all carpet manufacturers. Engaging in recycling practices creates a green image; thus, businesses can improve their reputation by providing recoverable components

☆ This manuscript was processed by Area Editor Qiuhong Zhao.

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http://dx.doi.org/10.1016/j.cie.2014.08.002
0360-8352/

or products made from recovery items (Fleischmann, Krikke, Dekker, & Flapper, 2000). Introducing recovery parts or processes into production has remarkable business advantages.

However, planning for the recycling process is difficult because of high uncertainty in different areas such as returned product quality, quantity, and timing. Guide, Jayaraman, Srivastava, and Benton (2000) identified the seven major characteristics of recoverable manufacturing systems that complicate the management, planning, and control of supply chain functions. The most significant characteristics are uncertain return timing, quantity of returned products, and uncertainty regarding materials recovered from returned products. The major complicating factor in an actual product recovery environment is supply uncertainty (Guide, 1997; Lee, Kang, & Xirouchakis, 2001). The quality, quantity, and timing of returned goods from consumers reflect the uncertain nature of a product's life cycle and lead to uncertain material supply for recovery product chains. These uncertainties make recycling process planning very different from regular production process planning. Consequently, the forward supply chain planning approach cannot be directly applied to the recycling process.

The recycling supply chain involves a series of activities required to retrieve and either dispose or reuse a product utilized by a customer (Guide & Van Wassenhove, 2002). The recycling process generally begins with the collection of used products or returned products. Collectors recover returned products from the market and then inspect and separate usable products from waste. Disassemblers break these products down into recovery materials and parts for reuse. Remanufacturers utilize these recovery materials to produce new products (or called remanufactured products). The remanufactured products are then distributed to the product market. Not all reverse supply chains are identical nor should they be because recovery parts and processes differ depending on the type of recovery items.

Disassembly is necessary in a recycling process so that returned products can be broken down into usable items or materials. Disassembly and assembly have two major differences. First, disassembly and assembly processes are asymmetric, meaning that disassembly routing and yield rates are not simply the reverse of assembly routing and yield rates. Second, the common parts of returned products determine the strategy for selecting which returned product should be disassembled first.

Several studies mention disassembly as the key product recycling process because it separates materials, components, and toxic substances (Torres, Gil, Puente, Pomares, & Aracil, 2004). Disassembly activities are of two types: destructive and non-destructive and the disassembly process of a product can be total or partial (Lee et al., 2001). Disassembly of returned products requires disassemblers to know the degree and method of disassembly in advance. Matthieu, François, and Tchangani (2011) proposed an integrated approach based on Bayesian networks to model and optimize disassembly activities. Kuo (2013) determined disassembly process with considering operational cost and environmental impact by using Petri Net approach. Different product recovery options (repair, refurbish, remanufacture, cannibalize, and recycle) require different degrees of disassembly (Guide et al., 2000). Aydemir-Karadag and Turkbey (2013) applied Genetic Algorithm to solve a disassembly line balancing problem with two objectives: balancing workload and minimizing the number of machines.

Other studies focused on production problem solutions, including inventory control systems, production controls, and reverse logistics, for the recycling supply chain (Cohen, Pierskalla, & Nahmias, 1980; Fleisc, 2001; Fleischmann et al., 1997; Jayaraman, Guide, & Srivastava, 1999; Spengler, Ploog, & Schroter, 2003). Several studies considered only a part of the recycling process, such as disassembly scheduling (Lee et al., 2001; Taleb & Gupta, 1997; Taleb, Gupta, & Brennan, 1997). Most researchers assumed a deterministic environment (Adenso-Diaz, Garcia-Carbajal, & Lozano, 2007; Ferrao & Amaral, 2006; Fröhling, Schwaderer, Bartuch, & Rentz, 2010; Jayaraman et al., 1999; Lambert, 1999; Spengler et al., 2003; Taleb et al., 1997; Wongthatsanekorn, 2009), and a few studies coped with the issues of uncertainty (Cohen et al., 1980; Pishvaee, Rabbani, & Torabi, 2011; Realff et al., 2004; Reveliotis, 2007; Shi, Zhang, & Sha, 2011). Realff et al. (2004) captured uncertainty by assuming the presence of "experts" who establish scenarios representing the different possible outcomes of infrastructure alternatives, and analyzed the scenarios to develop a robust mixed-integer linear programming model. Reveliotis (2007) addressed uncertainty by designing an effective and computationally efficient learning-based algorithm for optimal disassembly planning. Shi et al. (2011) utilized the expected values of cost and profit to address uncertain return quantities and uncertain demand and proposed a nonlinear programming model. Cardoso, Barbosa-Póvoa, and Relvas (2013) adopted scenario tree analysis to consider demand uncertainty in planning the activities for a supply chain with reverse flows. Although the abovementioned studies include the concept of uncertainty, the studies did not consider complete and general situations. Therefore, a specific recycling planning solution that reflects the actual recycling environment should be developed.

A master planning approach that considers returned products must be developed for a recycling supply chain to be competitive and eco-efficient. Considering that the integration of recovery items and processes into regular production processes is the current trend. Kim, Saghafian, and Van Oyen (2013) developed optimal control policies for coordinating a hybrid system of production and remanufacturing while demand can be satisfied by either new items or recovery items. Similarly, Feng and Viswanathan (2014) also studied production policies for inventory model with both new products and remanufactured products. Baki, Chaouch, and Abdul-Kader (2014) considered a production planning problem with lot sizing of product returns and remanufacturing by developing an mixed-integer model and constructing a dynamic programming. In this study, a stochastic model and a planning algorithm are proposed to solve the recycling process planning problem; in turn, recycling supply chains can be improved and environment protection can be enhanced.

The rest of the paper is organized as follows: The problem is described in Section 2. Section 3 presents our three-level interval search heuristic algorithm called SRPPA. The results obtained with our heuristic algorithm are compared with those obtained with other heuristic methods in Section 4 to evaluate the efficiency and optimality of SRPPA. Section 5 provides the conclusions of this study and suggestions for future research.

2. Problem description

This study focuses on solving master planning problems encountered in the recycling supply chain. It seeks to support recycling activity decision making by providing solutions that coordinate recycling supply chain members to maximize total profit given the recycling supply chain network, bills of material (BOM), and cost structure. It is assumed that all players of the supply chain are coordinated for pursuing the overall profit of the entire supply chain, and players have full information of others. The recycling supply chain is considered as well as certain properties such as multiple periods and stochastic supply and demand. We institute inventory policies for each supply chain member to control the stochastic process of supply and demand. Time bucket is employed as the basic time unit for the master planning mechanism. In other words, the operational decisions of each member in each time bucket are determined.