Computers & Industrial Engineering 70 (2014) 74–89

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Hybrid simulation-analytical modeling approaches for the reverse logistics network design of a third-party logistics provider

Ali Çetin Suyabatmaz [a], F. Tevhide Altekin [b], Güvenç Şahin [c,*]

[a] Desautels Faculty of Management, McGill University, Montreal, Quebec H3A 1G5, Canada
[b] School of Management, Sabanci University, Orhanli-Tuzla, 34956 Istanbul, Turkey
[c] Manufacturing Systems/Industrial Engineering, Faculty of Engineering and Natural Sciences, Sabanci University, Orhanli-Tuzla, 34956 Istanbul, Turkey

ARTICLE INFO

Article history:
Received 15 August 2011
Received in revised form 11 December 2012
Accepted 8 January 2014
Available online 24 January 2014

Keywords:
Reverse logistics
Network design
Supply uncertainty
Hybrid simulation-analytical modeling

ABSTRACT

In this study, we consider a manufacturer that has strategically decided to outsource the company specific reverse logistics (RL) activities to a third-party logistics (3PL) service provider. Given the locations of the collection centers and reprocessing facilities, the RL network design of the 3PL involves finding the number and places of the test centers under supply uncertainty associated with the quantity of the returns. Hybrid simulation-analytical modeling, which iteratively uses mixed integer programming models and simulation, is a suitable framework for handling the uncertainties in the stochastic RL network design problem. We present two hybrid simulation-analytical modeling approaches for the RL network design of the 3PL. The first one is an adaptation of a problem-specific approach proposed in the literature for the design of a distribution network design of a 3PL. The second one involves the development of a generic approach based on a recently proposed novel solution methodology. In the generic approach instead of exchanging problem-specific parameters between the analytical and simulation model, the interaction is governed by reflecting the impact of uncertainty obtained via simulation to the objective function of the analytical model. The results obtained from the two approaches under different scenario and parameter settings are discussed.

1. Introduction

Recently, product and material recovery has received growing attention throughout the world, with its three main motivators that include governmental legislations, economic value to be recovered and environmental concerns. Initially, the activities associated with product and material recovery were mainly driven by profit in the United States and legislations in Europe. In the United States, the early economic motivator enabled product and material recovery as long as it was profitable to do so (Spicer & Johnson, 2004), with examples including automobile recycling and engine remanufacturing. In Europe, the European Union (EU) has put into effect separate product-specific ordinances on waste packaging, batteries, end-of-life vehicles (ELV), and waste of electrical and electronic equipment (WEEE). These governmental legislations demand manufacturers to manage their end-of-life product's recovery and disposal. Similar legislations have been introduced by South Korea, Taiwan, Japan, some states of the United States, and China, and many countries plan to follow (Walther, Steinborn, Spengler, Luger, & Herrmann, 2010).

Attaining a "sustainable" economy requires combining both ecological and economical advantages (Fleischmann et al., 1997). For instance, Xerox Corporation has successfully achieved both economical and environmental gains via advantages introduced by their business model, their high product return rates, their customers' high tolerance for remanufactured products, and their product designs that have high remanufacturing feasibility (Spicer & Johnson, 2004). Unfortunately, many world-wide manufacturers do not simultaneously possess all these advantages and they continue their quest in improving their business processes so as to remain competitive while complying with the environmental legislations. Gerrard and Kandlikar (2007) assess the impact of the ELV legislation and present the achievements in terms of innovation in recycling, increased removal of hazardous materials and improved information dissemination on issues such as environmental performance, disassembly processes, disposal and recovery of vehicle parts. The authors besides pointing out the progress the automotive manufacturers have achieved in improving vehicle disassembly and material recovery, present the barriers hindering reuse and remanufacturing of ELVs in a closed loop context. Similarly,

* Corresponding author. Tel.: +90 216 4839619; fax: +90 216 4839550.
E-mail addresses: ali.suyabatmaz@mail.mcgill.ca (A.Ç.), altekin@sabanciuniv.edu (F.T. Altekin), guvencs@sabanciuniv.edu (G. Şahin).

http://dx.doi.org/10.1016/j.cie.2014.01.004
0360-8352/

the current treatment of products within the scope of WEEE is widely recycling-oriented rather than remanufacturing-oriented (Walther et al., 2010; White, Masanet, Rosen, & Beckman, 2003). Due to obsolete technologies, outdated architectures, advanced age and/or low values associated with these products, reuse potential of the products and/or constituting parts and components is very low. Thus, within the recycling-oriented approach, independent demanufacturing companies manually disassemble different types of electronic products of many manufacturers, sell metal and other tradable material fractions of defined quality grades to recycling companies and then send remaining material fractions to appropriate sites for disposal or incineration (Walther & Spengler, 2005).

The current recycling-orientated approach (rather than a remanufacturing-orientated one within a closed loop context), requires the design of reverse logistics (RL) systems, also referred to as reverse supply chain (RSC) systems. The RL activities first involve collecting end-of-life products and testing/sorting where an assessment is made regarding their quality so as to make a decision on type of recovery for their reprocessing. Then, the sorted products are redistributed for their reprocessing. Within a recycling-oriented approach reprocessing may include reuse of the end-of-life product, refurbishment and recovery of spare parts, recycling and disposal of waste through landfilling and/or incineration. The high level decisions on the design of RL systems require determination of whether the collection should be performed industry-wide (i.e. collect same product type from multiple producers) or company-specific (i.e. manufacturer facilitates collection of its own products), whether the testing/sorting should be centralized (common for commodity-type high-volume returns due to high-cost testing) or distributed (appropriate for reliable, consistent and cheaper testing), and finally whether the reprocessing should be performed at original facilities (preferable for refurbishing and recovery of spare parts) or secondary facilities (good for commodity-type high-volume products usually recovered through recycling) (Barker & Zabinsky, 2008).

The current recycling-oriented focus leads more and more manufacturers to outsource their RL activities to third-party logistics (3PL) service providers (Lee, Bian, & Dong, 2007b). Via outsourcing the RL activities, the manufacturers not only manage to comply with the environmental legislations but also avoid the financial risks associated with end-of-life uncertainties. Moreover, they focus on the forward production flows, which is what they do best and is their core function, and leave RL activities to specialized companies that innovate and increase efficiency due to the fierce competition in the recycling industry (Spicer & Johnson, 2004). As long as the legislations keep favoring the environment and the customer, the need for 3PL service providers performing RL activities is expected to increase (Krumwiede & Sheu, 2002).

In this study, we consider a manufacturer that has strategically decided to perform company-wide collection by outsourcing the company-specific RL activities to a 3PL. The problem setting we describe is plausible for the four configurations classified by Barker and Zabinsky (2008) as company-wide collection where either centralized or distributed sorting/testing is performed and either original or secondary facilities are used for reprocessing. These configurations encompass 23 out of the total 40 case studies categorized in that study.

Nowadays, catastrophic events and uncertainty in business-as-usual factors (such as demand, raw material prices, energy costs, product prices, and exchange rates) inspire more research on supply chain network design to incorporate uncertainty (for a critical review of the relevant literature, we refer the interested reader to Klibi, Martel, & Guitouni (2010)). Still, the supply uncertainty in timing, quantity and quality of the end-of-life products remains to be a major distinction between RL networks and traditional production–distribution networks (Fleischmann, Krikke, Dekker, & Flapper, 2000). When the uncertainties associated with the reprocessing activities are added on the top of the demand and supply uncertainties, efficient and effective design and operation of RL networks (as well as closed loop supply chains (CLSC)) so as to achieve profitability becomes a challenge and requires development of problem-specific methodologies as well as generalized models (Akçalı, Çetinkaya, & Üster, 2009). Although the literature on the design of RL networks as well as CLSC networks recognizes the existence of all these uncertainties, there are very few studies that incorporate them (Akçalı et al., 2009) via mainly analytical models and rarely simulation models.

Analytic and simulation modeling, representing the two end-points of applicable mathematical modeling approaches, bear well known advantages and disadvantages in terms of represented realism and costs associated with developing and using these solution procedures (Shanthikumar & Sargent, 1983). So as to utilize the best of both modeling approaches, combining them within hybrid simulation-analytic modeling has been proposed and used as a viable option as long as it is cost efficient. Hybrid simulation-analytic modeling is defined as "building independent analytic and simulation models of the total system, developing their solution procedures, and using their solution procedures together for problem solving in which hybrid modeling occurs through using the solution procedures together" by either sequential or iterative use of the solution procedures (Shanthikumar & Sargent, 1983). Hybrid simulation-analytical modeling and models are applied in many problem contexts through problem-specific approaches that iteratively use analytical and simulation models through the exchange of problem-specific parameters (some examples include Byrne & Bakir, 1999; Byrne & Hossain, 2005; Ko, Ko, & Kim, 2006). Recently a generic hybrid simulation-analytical modeling approach usable in various combinatorial optimization problems has been proposed (Acar, Kadipasaoglu, & Day, 2009).

In this study, we consider a manufacturer that outsources its company-wide RL activities to a 3PL under supply uncertainty. The 3PL service provider collects the end-of-life products from a set of collection centers provided by the client manufacturer. The collected products are inspected and sorted at test centers that are owned and operated by the 3PL. Finally, recoverable products are consolidated and shipped to reprocessing facilities for further recovery activities and the remaining products are shipped for environmentally-sound disposal reprocessing facilities. The locations of the reprocessing facilities are also assumed to be given by the client manufacturer. Thus, given the locations of the collection centers and the reprocessing facilities, the RL network design problem for the 3PL involves finding the number and places of the test centers under supply uncertainty associated with the quantity of the returns.

As hybrid simulation-analytical modeling is a suitable framework that can incorporate the uncertainties in the stochastic RL network design problem; we propose and compare two hybrid simulation-analytical modeling approaches. The first one is an adaptation of a problem-specific approach proposed for the distribution network design of a 3PL (Ko et al., 2006). The second one involves the deployment of the generic approach based on the novel solution methodology proposed to our problem (Acar et al., 2009). By adapting these two different approaches used in the literature to the stochastic RL network design for a 3PL, we aim to understand their differences as we try to reveal their advantages and disadvantages in a practical decision making context by presenting our findings with an elaborate computational analysis. Our study aims to provide a comprehensive understanding of these two approaches not only for the 3PL companies in reverse logistics business, but also for decision makers facing high level of uncertainty in their problems at the tactical and strategic level planning. The