Journal of Manufacturing Systems 41 (2016) 143–156

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

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

Technical Paper

Simultaneous optimization of closed- and open-loop supply chain networks with common components

Eren Özceylan

Department of Industrial Engineering, University of Gaziantep, 27310 Gaziantep, Turkey

ARTICLE INFO

Article history:
Received 3 May 2016
Received in revised form 24 August 2016
Accepted 27 August 2016

Keywords:
Closed-loop supply chain
Common component
Mixed integer programming
Open-loop supply chain
Optimization

ABSTRACT

In this paper, an integrated model that simultaneously optimizes the closed-loop supply chain (CLSC) and open-loop supply chain (OLSC) networks which use common components is described. A novel mixed integer programming (MIP) model is proposed to guarantee the optimal values of transportation amounts of assembled components and disassembled end-products in the CLSC and OLSC – which is also fed by CLSC – simultaneously while determining the location of facilities. Using a realistic network instance, computational results are presented for a number of scenarios to shed light on the effect of reverse rates, uncertainty in demand and capacity and size of the network. Results show that the simultaneous approach results in cost savings of 4.07% and 37.24% over the individual CLSC and OLSC solutions, respectively.

1. Introduction

The increasing need for remanufacturing due to resources shortages, environmental deterioration and new regulations, requires companies to organize their activities in order to explore and take full advantage of the coordination of forward and reverse material flows [1]. Adoption of a product recovery strategy, such as reuse, recycling, refurbishing or disassembling and the design of an associated logistics network for this purpose can take three main forms: reverse supply chain, open-loop supply chain (OLSC) and closed-loop supply chain (CLSC) networks [2], the last two of which is the focus of this study.

In a CLSC network, products or materials are often returned to the original producers, however, in an OLSC network, products are not returned to the original producers but will be recovered by other parties who are willing and able to reuse the products or materials [3]. In practice, HP, Kodak, Xerox, Dell and Apple have created a fully integrated manufacturing–remanufacturing strategy around their reusable product lines. For example, HP, an average of 70% of the disposed cartridges are reused in the production of a new one. Each time a cartridge is returned to HP, the retailers are reimbursed a fixed fee per cartridge and the transportation costs [4]. While Kodak's single use cameras, Xerox Europe's copy machine cartridges and US Naval Aviation Depots' components of naval ships, submarines, aircraft and personnel carriers should be examples for CLSC networks, Intercon Solutions Inc., one of the largest electronics recyclers in the United States, should be shown as an example for OLSC network [3].

The targets for reuse and recycling imply that only products with enough reusable materials/components can be put on the market [5]. This may lead to 'open' systems if the recovered content of the original products leaves the original supply chain(s) and is used by other firms to build products serving a different purpose [6]. Regarding to the definitions of CLSC and OLSC above, it is clear that a reverse facility such as collection or disassembling centers, can serve both its original forward facilities and also another forward facilities which are not belonged to the original network at the same time.

Assume two different supply chain networks which are CLSC and OLSC as shown in Fig. 1. While a flow of single use camera is actualized through the CLSC network, a video camera flow is occurred in OLSC network. Zero and used single use camera components are used to produce a single use camera and then after usage by the customers, used single use cameras are disassembled and flows 'cycle' in the network (Fig. 1). If the components are acquired by recycling, it means they are not zero. So, zero (virgin) components mean unused component which does not comes from recycling. Suppose that some of the components of single use camera are also used to produce video camera. In that case, some of the common components leave the CLSC network and join the OLSC network to produce video camera. To achieve such an agile and competitive supply chain network, open-loop and closed-loop distribution processes have to be able to work simultaneously. The integration of the distribution processes of two different networks will lead

E-mail address: erenozceylan@gmail.com

http://dx.doi.org/10.1016/j.jmsy.2016.08.008

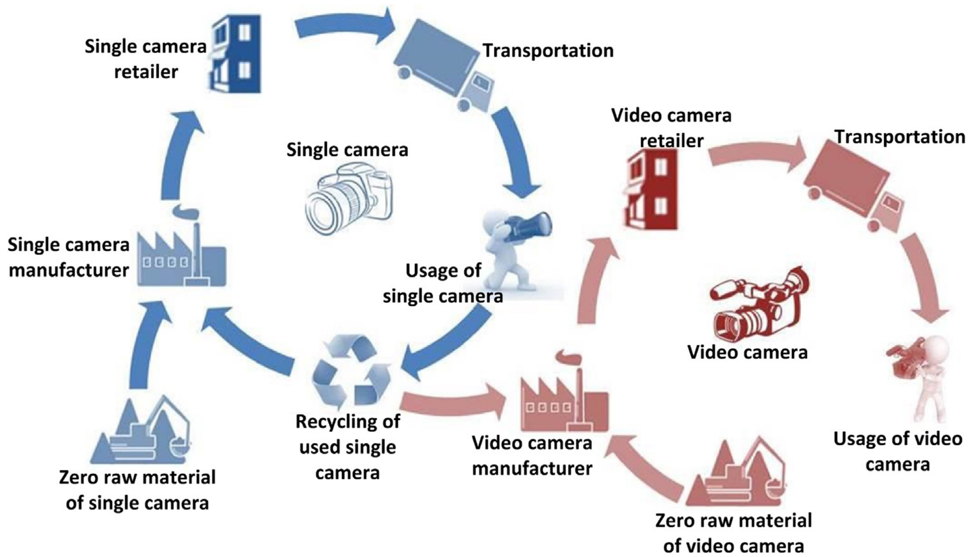

Fig. 1. Closed- and open-loop supply chains.

to a more accurate, reliable and controllable plan. However, in this case, there would be two or more objectives which must be handled simultaneously. One of them is minimization the total cost (including transportation, purchasing, disassembling, collection and fixed costs) of CLSC and the other is the minimization of total cost (purchasing costs zero and used components, transportation and fixed costs) of OLSC.

Most of the papers in literature assume that there is only either CLSC network or OLSC network. However, in many cases, a reverse facility such as collection or disassembly center can serve both original network and another network if there are common components between both networks. To fill this gap in literature, we try to optimize a structure that involves both an OLSC and a CLSC network simultaneously. To do so, a mixed integer programming model is proposed. In contrast to existing studies, this paper breaks away from the literature with following contributions: (i) introducing simultaneous optimization of CLSC and OLSC networks; (ii) modeling a novel MIP model with multi-period, multi-component, multi-product and multi-objective; (iii) capturing the trade-offs between various performance measures for managerial insights.

2. Literature review

In spite of a considerable amount of research having already been carried out on forward and reverse supply chain network design problems, in recent years there has been a growing awareness on CLSC and OLSC network design problems. We provide several pointers to the relevant literature below. One of the first papers on CLSC network design problems has been studied by Jayaraman et al. [7] in which decisions relevant to shipment and remanufacturing of a set of products, as well as establishment of facilities to store the remanufactured products, are taken into consideration. The model is in the form of a 0–1 integer programming formulation and minimizes a total cost function of shipment, remanufacturing and inventory. Then, as a case study, Krikke et al. [8] developed a single period, multi-objective mixed integer linear programming (MILP) model, taking to a weighted goal programming approach. This model is applied to a CLSC design problem for refrigerators using real-life data for a Japanese consumer electronics company. To investigate reverse activities in CLSC network, Jayaraman [9] presented an analytical approach toward production planning and control for CLSCs with product recovery and reuse. Key decisions of the model include the number of units of core type with a nominal quality level that is disassembled, disposed, remanufactured and acquired in a given time period. One of the first heuristic applications on CLSC problems was considered by Min et al. [10] who proposed a mixed-integer, nonlinear programming model and a genetic algorithm approach to a CLSC network design problem that includes consolidating returned products. To provide an exact solution for large CLSC design problems, Üster et al. [11] presented a multi-product CLSC network design model solved by the Bender decomposition method. They considered the production and reproduction separately and assumed a single sourcing for the customers. In the frame of environmental factors, Wang and Hsu [12] looked into the operations of 3R (Reduce, Recovery and Reuse) in green supply chain management and optimizing location of various facilities. They describe a CLSC network model in the form of an integer linear programming formulation and a genetic algorithm based on spanning trees to solve the problem. Dobos et al. [13] study an extended joint economic lot size problem which incorporates the return flow of remanufacturable used products in a CLSC network. Qiang et al. [14] study a CLSC network with decentralized decision makers, where the chain consists of raw material suppliers, retailers and the manufacturers that collect the recycled product directly from the demand market.

Different to the above references, a bi-objective integrated forward/reverse supply chain design model was suggested by Pishvaee et al. [15], in which the cost minimization and the responsiveness maximization of a logistic network was considered as objectives of the model. They developed an efficient multi-objective memetic algorithm for a CLSC network in order to find the set of non-dominated solutions. Paksoy et al. [16] propose a mixed integer programming model to optimize a CLSC problem which captures the trade-offs between various costs, including those of emissions and of transporting commodities within the chain. Özceylan and Paksoy [17] propose a mixed integer model for a CLSC network with multiple periods and multiple subassemblies, with an objective to minimize transportation, purchasing and refurbishing costs as well as the fixed costs of the potential plants and retailers. Giovanni and Zaccour [18] consider a two-period CLSC game where a remanufacturer appropriates of the returns' residual value and decides whether to exclusively manage the end-of-use product collection or to outsource it to either a retailer or a third-service provider. Ramezani et al. [19] address the application of fuzzy sets to design a multi-product, multi-period, CLSC network. The presented supply chain includes three objective