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Closed loop supply chain networks: Designs for energy and time value efficiency

Dinesh K. Kadambala [a], Nachiappan Subramanian [b,*], Manoj K. Tiwari [a], Muhammad Abdulrahman [b], Chang Liu [c]

[a] Department of Industrial and System Engineering, Indian Institute of Technology, Kharagpur 721302, West Bengal, India
[b] Nottingham University Business School China, The University of Nottingham Ningbo China, 199 Taikang East Road, Ningbo 315 100, Zhejiang, China
[c] School of Economics, The University of Nottingham Ningbo China, 199 Taikang East Road, Ningbo 315 100, Zhejiang, China

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ABSTRACT

Product recovery has become a viable option for many industries to realize economic gains while protecting the environment. However, insufficient investment and inefficient supply chains have hampered the viability of reuse and/or recycling because of the extended time intervals between the recycling process of recovery and reuse. Manufacturers and distributors face the challenge and necessity to reduce these process delays in order to recover the maximum value of the returned products through an effective, responsive closed loop supply chain (CLSC). This paper quantitatively measures the effective responsiveness of the CLSC model in terms of time and energy efficiency. The proposed multi-objective mixed integer linear programming (MOMILP) model evaluates delay parameters with decision variables that maximize profit, optimize customer surplus and minimize energy use. The model suggests decision makers may achieve an optimal tradeoff among differing objectives in a multiple-objective CLSC scenario. We employed a multi-objective particle swarm optimization (MOPSO) approach to solve the proposed MOMILP model and compared our approach with the Non-Dominated Sorted Genetic Algorithm (NSGA-II) for optimal solution. Results of the comparative evolutionary approaches shows that MOPSO outperforms NSGA-II in almost all cases in achieving the best trade-off solutions. Sensitivity analysis carried out to test the robustness of the model confirms that substantially less cost is feasible through the reduction of return process delays. This paper aims to formulate a multi-objective CLSC problem based on a network-flow model measuring the time value to recover maximum assets lost due to delay at different stages of the recycle process. We also developed a particle swarm approach for a multi-objective CLSC. Our study also offers valuable insights for designers wishing to create a product flow network with an optimal capacity level in case of prioritized objectives scenarios.

1. Introduction

Environmental concerns are increasingly calling for the development of a closed loop supply chain (CLSC) network that will effectively reduce the use of raw materials and energy through reusing, recycling and remanufacturing (Easwaran and Üster, 2010). Product recovery practice in CLSC is well-established in developed economies. In the past, the scope and scale of used product recovery strategies in various sectors increased multifold with the value of the product returns exceeding $100 billion US dollars annually (Stock and Speh, 2002). Our focus in this study is to consider CLSC activities such as the handling of operations of returned products that convert returned products can refurbish used and/or end-of-life products into fully functional products viable for reuse or resale. Product recovery and reuse is meaningful in high value in terms of cost and function from a range of products such as automotive parts and tires, to personal computers and photocopiers (Matsumoto and Umeda, 2011). However, during collection, returned products valuing $1000 will be worth only 55% of that price at reuse or extraction stages, the remaining asset value is lost in the return delivery flow between the points of collection and reuse stages due to long lead times on return as a result of storage necessities and other encumbrances in the return process (Blackburn et al., 2004; Guide et al., 2006). This proportional loss of eroding product value due to delays and other

* Corresponding author. Tel.: +86 574 88180197.
E-mail addresses: dinesh007.iitkgp@gmail.com (D.-K. Kadambala), nachiappan.subramanian@nottingham.edu.cn (N. Subramanian), mkt09@hotmail.com (M.K. Tiwari), Muhammad.abdulrahman@nottingham.edu.cn (M. Abdulrahman), chang.liu@nottingham.edu.cn (C. Liu).

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logistical problems in the reverse chain process leads to the lessening of recovery options (Guide et al., 2006).

Surprisingly, past CLSC studies have ignored this critical time value in product recovery (Souza, 2013). Most of the studies in the past decade paid attention towards the design of cost efficient closed loop supply chain models (Mitra, 2007; Reh, 2006). The impact of bottlenecks and long delays in the high-touch and low-touch refurbishing process of notebook computers was investigated by Guide et al. (2005a) and they estimated the losses incurred by value erosion are due to long lead times in the reverse process. Furthermore, Guide et al. (2005a) illustrated the lack of time sensitive return models as a gap found both in the literature as well as the time-based recovery optimization in the future to improve the recovery process of products. Hence, in this paper, we made an attempt to address the gap by considering time value in the recovery process and modeled high value products as 'perishable items.' Thus, we designed a comprehensive network-flow model with time value consideration aimed to recover maximum asset value. The uniqueness of our model compared with previous models is the quantification of the cost of product value lost due to delays at different stages of the return process. A simple profit-maximization queuing model was developed by Guide et al. (2006) from which we derive the expressions that define the value of lost product due to time delays at each stage that yeild a given mean steady state return rate and a mean sales rate. Hence, with this in mind and but still lacking a generalized mathematical model, we proposed a mixed integer linear programming (MILP) model that determines the optimal number of product flows at each part of the network shown in Fig. 1 in order to maximize profit. To our knowledge, the proposed model is the first to determine the optimal flow of products among the different stages of the network that considers the value of time in a CLSC.

Currently, growing concerns of the depletion of natural resources and high energy consumption have demanded the devising of Green Supply Chain factors, which are becoming a primary concern for both global and local economies irrespective of development (Geng et al., 2013; Zhang et al., 2011). Energy consumption in the forward supply chain during production of products is therefore measured in our model. Our focus in this paper will be on the design and planning of effective CLSC networks with consideration of time value to maximize profit and customer surplus using the minimum consumption of energy. This paper aims to formulate the multi-objective CLSC problem and to propose a well-structured CLSC network via dispositional decisions to create the optimal product flow quantity between the entities of the network, which will lower costs and enhance efficiency. Once the return product arrives, dispositional decisions have to be made based on unit margins and quality of the returned product. Calculation of optimal solutions guide production managers to finalize plans that maximize the firm profits using purchase of materials to produce virgin products as well as to remanufacture used products. Simple performance measures like the ratio of number of new products manufactured to the number of remanufactured refurbished products provide a useful indicator of the level of recycling of used products.

A large set of variables makes our model difficult to formulate optimal flow by exact optimization methods. Furthermore, it has been observed that most of the closed loop supply chain problems are characterized as NP-hard problems (Pishvaee et al., 2009; Wang and Hsu, 2010). For this reason the application of different combinations of decision variables is necessary to obtain a near optimal solution.The computational time to solve these problems is extremely long due to the large problem set. The network complexity further increases with the number of participating facilities leading to an increase in the size of the problem solution set. To deal with complexity, evolutionary algorithims have been widely used as they are found to be efficient in obtaining the near optimal solutions in less computational time (Soleimani et al., 2013, Bachlaus et al., 2006). Accordingly, in this paper, we employed a multi-objective particle swarm optimization (MOPSO) algorithm to efficiently solve the proposed NP-hard problem. Development of a particle swarm approach for multi-objective CLSC is another contribution presented in terms of methodology.

The rest of the paper is structured as follows: In Section 2, we review studies related to CLSC and energy consideration. Section 3 explains our proposed model, formulation and characteristics. In Section 4, a brief explanation of the solution methodology is demonstrated. Section 5 illustrates the model with a numerical example as well as summarizing the major findings. Finally, Section 6 concludes with a brief summary of our contributions and indicates possible future research directions.

2. Literature review

A literature overview is presented, based on relevant studies in CLSC network design in regards to concepts and characteristics, energy consumption in supply chains, and multi-objective modeling and particle swarm evolutionary algorithm applications. The review is followed by the research gaps and contributions to the research.

2.1. Close loop supply chain (CLSC)

To achieve environmental and economic sustainability dimensions, a CLSC needs to integrate business opportunities with environmental concerns (Guide and Van Wassenhove, 2009). The first extensive work on a CLSC network was studied by Fleischmann et al. (2000), where they discussed logistics network characteristics, distribution and production planning, and inventory

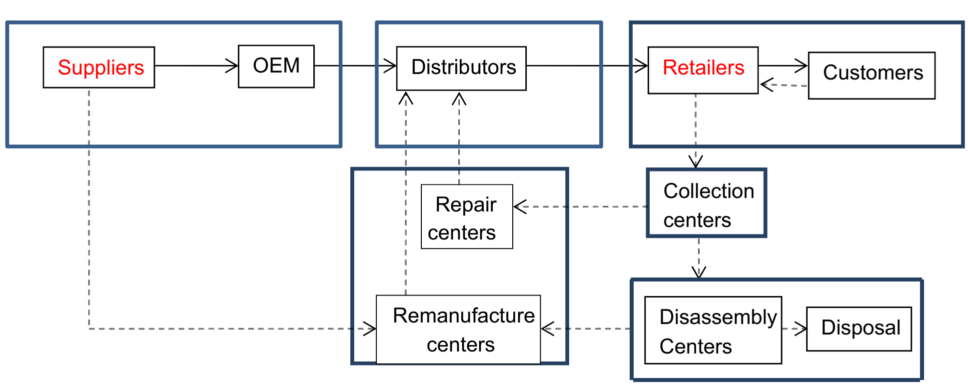

Fig. 1. Closed loop supply chain network (Srivastava, 2008).