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Technical Paper

Developing a bi-objective model of the closed-loop supply chain network with green supplier selection and disassembly of products: The impact of parts reliability and product greenness on the recovery network

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ABSTRACT

Closed-loop supply chain network (CLSCN) design aims to incorporate environmental considerations into the traditional supply chain design by including recycling, disassembly and reuse activities. A CLSCN incorporates the use and reuse of environmentally friendly products and materials supported by the design of an appropriate recovery, disassembly, and refurbishing network. In the design process, a trade-off must often be made between the need to maximize profit and maximize greenness. The latter is considered for several reasons including regulatory requirements, corporate responsibility and corporate image. In this paper, a bi-objective mixed integer programming model is developed and solved for a forward/reverse logistic network including three echelons in the forward direction (suppliers, assembly centers and customer zones) and two echelons in the reverse direction (disassembly and recycling center). A set of Pareto optimal solutions is obtained to show the trade-off between the profit and the greenness objectives. Some useful managerial insights are developed through various computational experiments.

1. Introduction

The management of end-of-life products, also called reverse logistics [1], is very relevant in today's environmentally conscious manufacturing sector. The focus on remanufacturing and recycling of end-of-life products has steadily grown in importance over the last decade. According to the Reverse Logistics Executive Council [2], reverse logistics (RL) is "the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal". In other words, RL is the process of moving goods from their typical final destination for the purpose of capturing value or for proper disposal [3]. Authors have used different terms such as reverse flow logistics, reverse distribution, reverse logistics, reverse supply chain, closed loop supply chain systems and supply loops to describe reverse logistics [4].

Legal requirements on environmental protection and related economic benefits have forced an increasing number of companies such as General Motors, Kodak and Xerox to focus on reverse logistics and recovery activities and they have achieved significant successes in this area [5]. Fleischmann et al. [6] stated that in contrast to forward logistics systems, the reversal of flows in the reverse supply chain implies numerous supply sources and few demand points. The design of the network is also severely complicated by a high degree of uncertainty in collection and distribution.

Traditional forward flow supply chain network design (SCND) includes determining the number, locations and capacities of production, manufacturing, and distribution facilities, the buffer inventories in each facility and the amount of flow between them [7]. In reverse logistics or closed-loop networks, other facilities such as collection depots, inspection and recovery centers also need to be integrated in the supply chain. The design of the forward and reverse chains should be integrated because designing these components separately may result in sub-optimal design [8,9].

An important issue in SCND is the establishment of appropriate performance measures to determine the efficiency and effectiveness of a system in comparison to its alternatives. Traditionally, the

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	Green Networks	Traditional Networks
Positive Impact Factors	• Exploit refurbished products market • Sales and service less expensive and naturally in place • Better corporate image	• Cheaper sourcing • Lower fixed costs
Negative Impact Factors	• More expensive sourcing • Higher fixed costs	• Cannot exploit refurbished products market • Sales and service network is more expensive

Fig. 1. Impact of greenness on profit.

focus of SCND problems in the literature has been on a single objective, namely minimizing cost or maximizing profit. Other measures sometimes considered in supply chain design are maximizing customer service level, minimizing financial risk and maximizing quality level. The integration of the RL loop yields new performance measures such the level of recyclability and the flow of recycled materials or remanufactured products. It is therefore very common for companies in CLSCN to deal with two or more performance measures.

In supply chain management (SCM), many organizations have resorted to outsourcing suppliers in recent years as it appeared to be more profitable. There are significant differences between supplier selection in forward flow and backward flow logistical networks. The focus in forward flow is on cost minimization, while in backward flow it is on greenness measures such as the reliability of used components, ease of recovery, and ease of disassembly. Due to the higher importance of these criteria in closed-loop network design, reliability, recyclability, and ease of disassembly should be taken into account in supplier selection.

Based on the above considerations, this paper presents a bi-objective model for closed-loop network design. The objectives included are profit and greenness. When a chain is green (has more opportunity to recover products), it is usually more expensive because green sourcing and recovery often impose additional costs. On the other hand, a network with product recovery may also positively impact profit because the recovery network reduces the cost of after-sales service and creates a new market for refurbished products. Moreover, product recovery reduces environmental costs which are explicitly passed on by governments to companies (see Fig. 1).

Since companies also like to present a green image of their own manufacturing and distribution activities, including both profit and greenness objectives in the network design helps the decision makers make the necessary trade-offs.

The reliability levels of parts have a direct impact on the quality of the components found in returned products. Parts with higher reliability levels will survive consumer usage better and will therefore be in better state when disassembled, thus yielding a higher ratio of parts reusable to parts recovered. Products made of parts with higher reliability will be easier and less expensive to refurbish and reuse (see Fig. 2).

The CLSCN design model developed in this paper has three echelons in the forward direction (suppliers, assembly centers and customer zones) and two echelons in the reverse direction (disassembly and recycling center). It is a single period, multi-part, multi-product and multi-stage model. The rest of this paper is organized as follows: a literature review is presented in Section 2. In Section 3, we define the problem and its scope. The impact of reliability and greenness of parts and products on reverse supply chain network design is presented in Section 4. A bi-objective mixed-integer linear programming model of the logistic network design is developed and its set of Pareto optimal solutions obtained in Section 5. Section 6 presents numerical examples and discusses the main computational results. Finally, we draw the conclusions from this work in Section 7.

2. Literature review

Many models dealing with the design of logistics network are based on inventory planning and facility location theory. These models range from simple single-part, single-product, single-period incapacitated models (see [10,11]) to complex multi-part, multi-product, multi-period capacitated models. Ko and Evans [12] presented a comprehensive literature review on logistics network design to support a variety of future research directions.

A large portion of the literature in logistics network design deals with reverse logistics network design and is aimed at determining the number of collection, recovery and disposal centers, and the optimized reverse flow from customers to recovery and disposal centers (see [13–16]). Jayaraman et al. [15] developed a model to solve the single product two-level hierarchical location problem involving the reverse supply chain operations of hazardous products. Patia et al. [17] proposed a mixed integer goal programming (MIGP) model to assist in the design of a multi-product paper recycling. The objectives considered are reduction in reverse logistics cost; product quality improvement through increased segregation at the source; and environmental benefits through increased wastepaper recovery. The proposed model also assists in determining the facility location, route and flow of different varieties of recyclable wastepaper in the multi-item, multi-echelon and multi-facility decision making framework. A probabilistic mixed integer linear programming model for a multi-product, multi-stage