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Strategic network design for reverse logistics and remanufacturing using new and old product modules

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ABSTRACT

Establishment of reverse logistics (RL) networks for various original equipment manufacturers (OEM's) is gaining significant importance. Various green legislations are forcing OEMs to take back their used, end-of-lease or end-of-life products, or products under warranty to minimize wastes and conserve resources. Therefore OEMs have turned to a better design of their products for maximum reuse and recycling and to retrieve back the used products through a network for reuse, remanufacture, recycle or disposal, so that maximum value can be achieved from their used products. However, designing of network points and assigning capacities to them depend not only on the volume of returned products but also on the demand for remanufactured products and the parts of used products. If OEMs are not able to add value to the used product, there would be no incentive to design a complex network.

In this paper, a mathematical model for the design of a RL network is proposed. It is assumed that the returned products need to be consolidated in the warehouse before they are sent to reprocessing centres for inspection and dismantling. Dismantled parts are sent for remanufacturing or to the secondary market as spare parts. Recycling and disposal of these modules are also considered in the model. The use of the model is shown through its application in a numerical example.

1. Introduction

Implementation of legislation, social responsibility, corporate imaging, environmental concern, economic benefits and customer awareness are forcing OEMs not only to provide more environmentally friendly products but also to take back used products at its end of life. Products can also be returned for reasons such as customer dissatisfaction and warranty (Rogers & Tibben-Lembke, 1999; Tibben-Lembke, 2002). Such products can be sorted for reuse, remanufacture, recycle and disposal. Reuse of used products by some value addition is not a new concept. Also, industries are using remanufacturing for expensive products such as turbines used in airplane and electricity generation systems. In these cases recovery of used products is economically more attractive than disposal (Koh, Hwang, Sohn, & Ko, 2002). OEMs are incorporating 'extended producer responsibility' (EPR) to reduce wastes in a used product (Carter & Ellram, 1998). While on the other hand, they are implementing networks to take back their products through various channels. However, if returned products are not handled efficiently then OEMs would incur larger costs that can increase the cost of the new product. Therefore, network for return of products should be efficient and cost effective.

On the design part, OEMs are increasingly modularizing their products (Fredrikson, 2006) not only to reduce the steps for final assembly but also to facilitate faster dismantling and repair of used products (Ulrich & Tung, 1991). Therefore, modularization helps to avoid disposal of usable modules retrieved from the used products (Dowlatshahi, 2000). Also, OEMs are substituting certain parts and materials by recyclable and environment friendly alternatives (Gupta & Isaacs, 1997).

In this paper, a mathematical model is proposed for the design of a RL network handling product returns. The model considers the supply of returned products through third party collectors. It considers storing, reprocessing, remanufacturing facilities and new module suppliers in the network. If the recovered modules are not sufficient to remanufacture the products to meet the demand, then certain quantities of certain new modules need to be purchased. We also consider demand for used modules in the secondary markets. The design of such a network is strategic as it involves a decision on the number, location and capacities of various facilities and allocation of material flows between them (Dethloff, 2001; Dowlatshahi, 2005; Jayaraman, Guide, & Srivastava, 1999; Lu & Bostel, 2007; Realff, Ammons, & Newton, 2000) and is one of the most challenging elements of managing RL operations (Pochampally & Gupta, 2005). A

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properly designed network can also enhance dealing with remanufacturing activities (Prahinski & Kocabasoglu, 2006) and competitive advantage (Gungor & Gupta, 1999).

2. Research on design of RL network

Several researchers have studied the design of RL network focusing on their cost effectiveness. Studies have concluded that for recycling of the returned products, logistics costs account for a large share of the total costs (Beullens, 2004; Jahre, 1995; Stock, 1992). RL requires high investment and a high portion of logistics costs (Nagel & Meyer, 1999). The RL cost can vary from 4% (Rogers, 2001) to 9.49% (Daugherty, Autry, & Ellinger, 2001) of the total logistics cost. In the retail and manufacturing sectors, it is estimated that RL accounts for about 5–6% of the total logistics cost (Raimer, 1997). Transportation of used products is the most challenging issue in RL (Fleischmann, 2001; Krumwiede & Sheu, 2002) as smaller return quantities and variability in product types increase the transportation costs (Ferrer & Whybark, 2000; Tibben-Lembke & Rogers, 2002). Biehl, Prater, and Realff (2007) emphasize on the need for collection centres in a reverse production system to help in maximizing collection of returned products. Reimer, Sodhi, and Jayaraman (2006) have developed truck sizing models for collection of wastes and transporting them to recovery centres. Murphy (1986) stated that private warehousing was popular for RL because of its convenience and reliability. Min, Ko, and Ko (2006b) have developed a mixed integer non-linear programming model to determine the exact length of holding time for spatial and temporal consolidation at the initial collection points to minimize the total RL costs.

A review on various quantitative models for RL networks is given by Fleischmann et al. (1997). The location of collection points in a RL system has been examined by Bloemhof-Ruwaard, Fleischmann, and van Nunen (1999). Fleischmann, Beullens, Bloemhof-Ruwaard, and van Wassenhove (2001) have presented a generic MILP model considering a single product flow between incapacitated facilities and reprocessing as a product-recovery option. Jayaraman, Patterson, and Rolland (2003) have proposed a MILP model by considering the reverse flow of goods. Pochampally, Gupta, and Kamarthi (2004) have proposed a physical programming approach to identify potential recovery facilities in a region where reverse supply chain is to be established. Savaskan, Bhattacharya, and van Wassenhove (2004) have proposed a product-recovery strategy depending on who collects the used products namely the manufacturer; the retailer; or a designated third party. The findings suggest that optimal results are achieved when the retailer collects the returned products. However, the authors consider the flow of goods in only a two echelon system i.e. retailer and manufacturer. De Koster, de Brito, and van de Vendel (2002) have investigated the factors contributing to RL network decisions by considering inbound and outbound flows, the transport routes, the return volume, choice of receiving warehouse and the market location for returned products. The authors recommend that retailers that supply to stores should collect the returned material to the distribution centre using the same truck which delivered the products. Also, retailers that handle a high volume of returns should unload and sort returns in a separate area in the distribution centre. Beamon and Fernandes (2004) have developed an integer programming model for a four echelon reverse supply chain by assuming infinite storage capacities and same holding costs for recovered and new products. The authors assume that the remanufactured products are of the same quality as that of the new products. Therefore remanufactured products can be sold in the same condition as new ones to meet the market demand. Kusumastuti, Piplani, and Lim (2004) have presented a multi-objective and multi-period MILP model for RL network design for modularized products. The model determines the number of existing forward flow facilities to be used and the number of dedicated facilities to be setup for handling return flows. The authors have not considered the use of new modules in remanufactured products. Salema, Povoa, and Novais (2007) have proposed a MILP model to analyze the problem of closed loop supply chains. They consider multi-product returns with uncertain behaviour but limit their consideration of demand for returned products to factories and not to secondary markets or spare markets. Thus a supplier network which may be required to remanufacture a new product to meet the market demand is not considered. Also, this model is not suitable for modular products. Lu and Bostel (2007) have also developed an incapacitated model for RL.

Pohlen and Farris (1992) have investigated the reverse distribution channel structure in plastics recycling and analyzed the compaction and routing issues related to transportation in the RL process. Spengler, Puchert, Penkuhn, and Rentz (1997) have developed a model based on linear activity analysis to determine locations and capacities of recycling facilities for reprocessing by-products of steel industries. Barros, Dekker, and Scholten (1998) have proposed a logistics network for recycling of polluted sand by using MILP to determine the optimum number, capacities, and locations of the depots and cleaning facilities in the network. Louwers, Kip, Peters, Souren, and Flapper (1999) have proposed a RL network model to determine appropriate locations and capacities for collection, preprocessing and redistribution facilities of carpet wastes. Realff, Ammons, and Newton (2004) have proposed a multi-period MILP model for carpet recycling. Their model analyzes a set of alternative scenarios identified by the decision maker and provides a near optimal solution for network design. Schultmann, Zumkeller, and Rentz (2006) have developed a recycling network for the German automotive industry by minimizing the travel routes between dismantling centres and reprocessing facilities. The authors solve their network model by using linear programming and meta-heuristics methods. Wojanowski, Verter, and Boyaci (2007) have developed a stochastic model to analyze the network structure for product returns under a refundable-deposit scheme. They show that the success of the profitability of the network depends on the accessibility of the customers to the collection centres. Zhou, Naim, and Wang (2007) analyzed the battery recycling practices in China and identified its obstacles and weaknesses. They recommend legislative actions, technical guidance and administrative resources, and cost-effective recycling and RL infrastructure to improve the system.

Kroon and Vrijens (1995) have considered the design of a logistics system for used plastic containers. They propose a MILP model to determine the number of containers required to run a five echelon system under consideration, the appropriate service, and distribution and collection fee per shipment for empty containers and location of depots for empty containers. Berger and Debaillie (1997) have proposed a model for extending a production/distribution network with disassembly centres to allow the recovery of used products. The authors consider each plant and distribution centres with fixed locations and capacities, but determine the location and capacity of the disassembly centres based on a multi-level capacitated MILP model. Jayaraman et al. (1999) have also proposed a model for location of remanufacturing and distribution facilities by optimizing the quantities for remanufacturing, transshipment and stocking. Pati, Vrat, and Kumar (2006) have formulated a mixed integer goal programming model for analyzing paper recycling network. The model assumes five echelons and studies the inter-relationship between cost reduction, product quality improvement through increased segregation at the source, and environmental benefits through waste paper recovery. The