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Fuzzy multi-objective approach for optimal selection of suppliers and transportation decisions in an eco-efficient closed loop supply chain network

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ABSTRACT

Establishment of a closed loop supply chain (CLSC) network has attracted immense significance due to government policies and societal demand for environmental consciousness. However, to enhance the financial and ecological impact of the network, the forward and reverse supply chain networks must integrate well so that decisions taken in both areas complement each other. In this study, we propose an eco-efficient CLSC design for extending the existing supply chain of an Indian firm that assembles inkjet printers. The network design is configured as a multi-objective model in a multi-period setting and is mathematically formulated into a mixed integer programming problem with fuzzy objectives. Fuzziness provides flexibility to the decision makers because they must accommodate the conflicting nature of the objectives. The fuzzy multi-objective model incorporates the firm's economic and environmental concerns into the decision making process by selecting environmentally responsible suppliers to procure components based on sustainable criteria, choosing appropriate recovery options for end-of-use (EOU) inkjet printers, and planning an efficient transportation network design for reducing the carbon emission of the distribution and collection activities. The uniqueness of the proposed fuzzy CLSC optimization model lies in providing an integrated decision making framework that can aid the manufacturer in making crucial strategic, tactical, and operational decisions of optimal selection of suppliers, component order allocation, recovery flow allocation, and vehicle routing planning. The novelty of the model also lies in simultaneously minimising the overall cost of the activities undertaken, maximizing the performance of the component suppliers and minimising the carbon emissions of the associated transportation activities. A weighted fuzzy mathematical programming approach is utilised for generating a fuzzy, properly efficient solution as the desired compromised solution for the CLSC network problem configuration. The relevance of the model is justified using a real data set derived from a case study of the firm based in the northern capital region (NCR) of India. The findings indicate that the proposed integrated CLSC network model enables the firm in gaining sustainably from the numerous electronic product reuse opportunities in the Indian market. Further, while costly to begin with, choosing suppliers with higher sustainable performance and vehicles with lesser emission rate could substantially enhance firm's sustainable image and result in higher profits in the future.

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1. Introduction

The electronics markets in India are facing many challenges in terms of globalisation, competition, and consumer awareness. Because of these challenges, this market is constantly seeking opportunities for accountability of products discarded by consumers due to lack of desirability or utility. The underlying value in these undesirable products (termed as end-of-use (EOU) in the present study) can be potentially tapped by closing the supply chain so that maximum value in terms of recovery can be retrieved (Fleischmann et al., 2000). The economic viability of closing a supply chain largely depends upon the amount of returns and strategic use of options of repair, refurbish, and remanufacture (Mutha and Pokharel, 2009). Once the customer returns the product, it can be refurbished and sold at the secondary market to generate economic value. Recycling and remanufacturing can also be exercised as profitable recovery

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options (Kannan et al., 2012). These processes can capture the inherent value in the product returns in terms of components and materials (Matsumoto, 2010). In addition to merely focusing on the economic benefits from EOU products, the manufacturers must also strive to reduce the undesirable environmental footprint of the supply chain (Quariguasi et al., 2010). It has become critical for organizations to balance the two objectives due to the tremendous pressures from regulatory authorities, society, and from each other (Shultz and Holbrook, 1999). Developing an efficient recovery system that addresses environmental concerns can enhance the social image of the firm as well (Darbari et al., 2015a). The grave challenge for Indian manufacturers is that product recovery in India is still in an incipient stage due to the lack of significant incentives from the government and low rate of volume returns (Srivastava and Srivastava, 2006). Seen as a mere legal obligation and a financial burden, most Indian manufacturers simply prefer outsourcing reverse logistics (RL) to third party providers (Wath et al., 2011). This lack of interest hampers the process of maximum value recovery.

Manufacturers are actively looking for innovative and real life solutions for sustainably managing their returns at minimum economic and ecological expense. To begin with, substantial amounts of returns are needed to reap maximum benefits from the reverse part of the supply chain (Guide and Van Wassenhove, 2009). Economic viability of the closed loop supply chain (CLSC) can be achieved, therefore, with an increase in the rate of returns. Since the reverse flow is consumer driven, manufacturers must enhance the flow of returns by providing buy back incentives to the consumers and by educating them about the harmful effects of the unsafe disposal of unused products (Hammond and Beullens, 2007). Reusing recovered products and feeding the recovered parts and materials back into different stages of the forward supply process can enable economic productivity (Subramoniam et al., 2010). For this, it is also essential to collaborate with suppliers who are receptive to the idea of reusing parts and materials (Hsu and Hu, 2009). Further, since the activities related to forward and reverse movement of the products account for a major percentage of the overall carbon emissions of the SC (Paksoy et al., 2011), the incorporation of environmentally effective transportation strategies can provide a tactical solution to the increased carbon footprint problem of the SC (Govindan et al., 2014b). Integration of forward and reverse flows can profoundly reduce the overall cost and carbon emissions of the network (Darbari et al., 2016). However, Indian manufacturers face many obstacles in the practical implementation of such a desirable CLSC model. First, although the electronic product reuse business in India has potentially a huge market because of the affordability factor for the economically weaker section of the society (Dwivedy and Mittal, 2012), still most recovery activities are undertaken by an informal sector of collectors and waste pickers (Verma and Agrawal, 2014). Second, since domestic component manufacturing in India is at nascent stage of development, many Indian manufacturers rely on importing electronic parts. Hence, the challenge lies in associating with those suppliers who can comply with the sustainable needs of the manufacturer. Third, the ever-increasing demand for electronics from urban and rural areas in India results in large transportation volumes, shipped at high frequency and covering large distances, which results in higher carbon emission levels, a major issue that manufacturers have to address. As a result, it is a long process for any electronic manufacturer in India to commit to an integrated forward-reverse program, because its financial and environmental viability depends largely upon support from the stakeholders, including the government, consumers, logistics providers, suppliers, and social organizations (Borthakur and Sinha, 2013). Therefore, many important decisions need to be reviewed in order to successfully and sustainably close a supply chain. Incorporating recovery decisions within an already existing forward supply chain affects many important supply chain (SC) decisions such as the amount of materials and components to be procured for production, the hiring and training of staff to manage sales, and the collection of products. Some decisions easily influence the strategic planning of the network, such as which recovery activities can be integrated with forward activities and which can be outsourced for maximum economic utility. The tactical design of the network must consider the integrated logistics network for forward and reverse flows so that the environmental impact of recovery activities is minimised. Accordingly, it is considered top managerial priority that the CLSC model is able to cope with these strategic, tactical, and operational issues. This goal has raised the interest of academicians and practitioners to develop eco-efficient CLSC optimization models, which can be suitably adopted by manufacturers for long-term sustainable productivity (Schenkel et al., 2015; Govindan et al., 2014a).

The above discussion leads to the motivation behind the present research. Existing literature resources focus on CLSC network design problems. Some of these issues include decisions pertaining to the selection of sustainable suppliers, to order allocation, and to determining the optimal flow of products and parts. Other works examine transportation decisions, including the selection of vehicles and the construction of optimal flow routes. However, no study has yet addressed all of these concerns simultaneously in CLSC network configuration. To bridge this important gap, this paper reflects upon how an Indian electronic manufacturing firm based in the Northern Capital Region (NCR) can gain sustainably from the numerous electronic product reuse opportunities in the Indian market under uncertainty of the business environment. The study aims to present a CLSC network configuration model developed to address the following research questions:

- How to create a seamless link between the forward and reverse flows while striving for sustainability in a CLSC network aimed at product recovery?
- How to strategically select environmentally responsible suppliers who are mutually aligned towards the common goal of value creation in CLSC?
- How to redesign the logistics network of the supply chain so that the transportation efforts in the vastly spread region of NCR are controlled and the overall carbon footprint is minimised?
- How to configure the CLSC network so that strategic, tactical, and operational decisions are integrated and environmental sustainability can be achieved at minimum economic loss?
- Is the CLSC network configuration viable to function under uncertain environments and is it relevant in the Indian scenario?

Recognising the importance of the above aspects, the core objective of the present research is to assimilate all of these issues into the CLSC network model and simultaneously to reflect on its financial and environmental implications for the firm. The key goals are:

(i) to develop an integrated optimization model for CLSC network configuration;
(ii) to present an Indian case study with appropriate parametric inputs to validate the model application;
(iii) to identify an applicable solution methodology for solving the CLSC model and to analyse the solution results;
(iv) to understand the various aspects involved in successfully managing the model through an extensive result analysis; and

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