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Reliable design of a forward/reverse logistics network under uncertainty: A robust-M/M/c queuing model

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A B S T R A C T

This paper presents a novel model for designing a reliable network of facilities in closed-loop supply chain under uncertainty. For this purpose, a bi-objective mathematical programming formulation is developed which minimizes the total costs and the expected transportation costs after failures of facilities of a logistics network. To solve the model, a new hybrid solution methodology is introduced by combining robust optimization approach, queuing theory and fuzzy multi-objective programming. Computational experiments are provided for a number of test problems using a realistic network instance.

1. Introduction

The issue of product scraps and consumer residuals has always been a critical challenge for manufacturers. This challenge, along with the pressure from governments to produce green products, has prompted companies to restructure their supply chain so that they are able to recycle their products. The issue became a favorite of many manufacturers as they realized that recycling goods and reutilizing products scraps and residues would not only mitigate adverse environmental impacts but could also enhance their competitive status in the market place. Spurred on by these goals, logisticians and strategists significantly restructured their supply chain networks and established global networks of suppliers as this exerted a tremendous influence on maximizing the potential economic benefits of recovering products (Dunning, 1993). In turn, logistics, recycling, and supply chain managers would seek means to evaluate their efforts in order to reduce costs and innovate while trying to keep an appropriate environmental and ecological performance (Pagell et al., 2004).

Attempts at recycling activities and their logistics have caused companies to focus on closing the supply chain loop and devise closed-loop supply chains (CLSCs) (Beamon, 1999; Seuring, 2004). Thus, CLSCs that contain both the forward supply chain and the reverse supply chain have played an extensive role over the last two decades. In basic terms, the forward supply chain considers the movement of materials and products from the upstream suppliers to the downstream customers, while the reverse supply chain considers the upstream movement of used or unsold products from the customer, back to the supply chain, for possible recycling and reuse. The reconfigured forward and reverse supply chain networks highly impact on each other's performance. Hence, to ensure the design optimality of the forward and reverse networks, and also to avoid the sub-optimality caused by a segregated design, the structuring of these two types of networks should be taken into consideration concurrently (Fleischmann et al., 2001; Pishvaee et al., 2010). It has been demonstrated that developing a CLSC can be instrumental in enhancing the economic and ecological performance of companies. One of the biggest challenges in

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the CLSC development phase is to hybridize the forward and reverse supply chains simultaneously. Goods are returned to the manufacturers by distributors and customers for numerous reasons. However, these returns are delayed for the most part, in practice, due to the lack of a pre-defined process for putting returns back into the forward chain. Companies often struggle to reorganize the returned goods flow back into the supply chain. Furthermore, the shortened life cycle of returned goods presents another challenge when developing the CLSC so as to recover the maximum value out of the returns. It is obvious that all activities and occurrences in the CLSCs are subject to noticeable uncertainties. As pointed out, the uncertainties involved in the reverse flow of products due to their natures are higher than those involved in the forward flow of supply chain (Fleischmann et al., 2004).

Uncertainties involved in the CLSCs can be categorized into two main groups: (1) environmental and (2) system (Ho, 1989). Environmental uncertainties are attributed to the performance of each member of supply chain consisting of suppliers, manufacturers, etc. System uncertainties are attributed to routine processes in the supply chain such as production, distribution, etc. Above-mentioned uncertainties adversely contribute to the quality of decisions made in strategic, tactical and operational levels of supply chain. With respect to the alluded points and necessity of considering uncertainties in adopting various decisions in the supply chain networks, researchers, in tune with designing their reverse and CLSC networks, have strived to include foregoing two aspects of uncertainties to better represent the practical features of real-world problems. Thus, for this purpose advanced optimization methodologies are desired. Hence, many researchers have recently made attempts to model the uncertainty in supply chains (e.g., Lee et al., 2010; Zerhouni et al., in press; Kenné et al., in press). According to the literature on CLSC logistics network (see Section 2), all research conducted in the field of facilities location, indicating that only the classical facility location models are utilized. The objective functions of these models are to minimize the sum of fixed opening costs, operating costs and transportation costs between facilities. In these formulations between potential locations, a set of facilities to be opened once, however, one or more of them may sometimes not be available. For example, facilities may become unavailable due to severe weather, workers' strike and changes management and ownership. Thus, it can be stated that these facilities do not have the ability to respond to the customers. In other words, we can say that, these facilities may fail to operate properly. Therefore, customers who previously received services from these facilities are forced to satisfy their requirements, refer to other facilities. It is natural that transportations and operations costs of these new facilities are more than the previous mode (Snyder and Daskin, 2005).

With regard to the matters enumerated, the aim of the paper is to introduce a novel bi-objective model for designing a reliable network of facilities in CLSCs under uncertainties. In order to make the model more realistic, the proposed model encompasses both environmental and system uncertainties. For this purpose, new assumptions including probability of failure of the facility are considered. Moreover, the proposed model makes it possible to develop a robust supply chain management by considering an effective and conceptual reliability approach. Hence, objective functions used in this study are based on minimizing total costs and expected transportation costs after the failures of facilities. Furthermore, we propose a new solution methodology for better accounting for dynamic aspects and multiple uncertainties in order to integrate the robust optimization programming, queuing theory and fuzzy multi-objective programming within a general bi-objective mixed integer linear programming (BOMILP) optimization framework.

The main innovations in this paper (to differentiate our efforts from those already published on the subject) are as follows:

- Designing and modeling a novel reliable network for the facility location to integrate both strategic and tactical decisions in the CLSC.
- Offering a robust-M/M/c queue model which handles different sources of uncertainty influencing closed-loop integrated forward/reverse supply chains by jointly considering unavailability or incompleteness and imprecise nature of data.
- Proposing an efficient hybrid solution methodology by combining a number of efficient solution approaches from the recent literature, namely queuing theory, robust optimization approach and fuzzy multi objective programming, to solve the proposed bi-objective mixed integer linear programming model.
- Proposal of a new comprehensive structure involving simultaneous consideration of all the forward and reverse logistics activities applicable to various industries.
- Consideration of the constraint of capacity of steel scrap processing facilities for each type of product in the model.
- Consideration of the constraints of capacity of iron and steel facilities, metal manufacturing facilities and distribution centers in the model.
- Considering a number of recovery servers in each steel scrap processing facility for performing recovery services.

The rest of the paper is organized as follows. Section 2 presents a brief review of the literature on reverse logistics and CLSCs. Problem definition and formulation are described in Section 3 in detail. The proposed hybrid solution methodology is given in Section 4. Computational experiments are provided in Section 5. Finally, the paper is concluded in Section 6.

2. Literature review

Overall, the focus of current research can be divided into two main categories, namely reverse logistics and CLSCs. Therefore, we address these two categories separately in the following literature survey.