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Optimal design of closed-loop supply chain networks with multifunctional nodes

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ABSTRACT

This paper introduces a general mathematical programming framework that employs an innovative generalized supply chain network (SCN) composition coupled with forward and reverse logistics activities. Generalized echelon will have the ability to produce/distribute all forward materials/products and recover/redistribute simultaneously all the returned which are categorized with respect to their quality zone. The work addresses a multi-product, multi-echelon and multi-period Mixed-Integer Linear Programming (MILP) problem in a closed-loop supply chain network design solved to global optimality using standard branch-and-bound techniques. Further, the model aims to find the optimal structure of the network in order to satisfy market demand with the minimum overall capital and operational cost. Applicability and robustness of the proposed model are illustrated by using a medium real case study from a European consumer goods company whereas its benefits are valued through a comparison with a counterpart model that utilizes the mainstream fixed echelon network structure.

1. Introduction

The high purpose of an organization or goods company is to maximize value creation over the entire life-cycle of a product considering both forward and reverse logistics. The main role in attainment a good performance within a supply chain network is Supply Chain Network Design (SCND) and its critical and strategic decisions. Therefore, by coping with the design and determination of locations, control and operation of the whole network system we manage to maximize value over the entire life cycle of a product and simultaneously meet the customer's requirements. In general, companies can be organized and use advantage technology to process more efficient tasks and activities so as to manage the returns and reduce the costs associated with them. Hence, joint networks make the most sense in inventory intensive industries. More specific a Closed Loop Supply chain network design (CLSCND) includes determining the numbers, locations, and capacities of both forward and reverse facilities (production plants, collection, recovery, disposal centers), buffer inventories in each site, and material flow between each pair of facilities.

It is well known, that researchers coming from the scientific fields of the Supply Chain Management (SCM) were placing much importance on the need for more sufficient, real time and optimized management of the direct forward supply chain processes rather than focusing on the process of recapturing the value of finished goods at the ending point of their final destination. On the contrary, the last fifteen years has been noticed much growing attention about the considerations and appropriate decisions taken for the sustainability and cost profitability of a supply chain network with reverse flows. From this analysis Realff et al. (2000), stressed the need of achieving material efficiency by recycling the products back to raw materials. They defined two strategic reverse production system design problems and tried to address some questions and points around their implementation. The next year, Fleischmann et al. (2001), developed a fundamental generic model for the design of closed-loop logistics networks, which was a first effort to come up against the design of both forward and reverse logistics simultaneously. They observed that an integrated approach, optimizing the forward and return network simultaneously, could provide a significant cost benefit against a sequential approach.

In most studies, forward and reverse logistics designs confront along the supply chain all the facilities separately. A traditional supply chain network assumes a fundamental structure of the network with distinct and consecutive echelons by moving the

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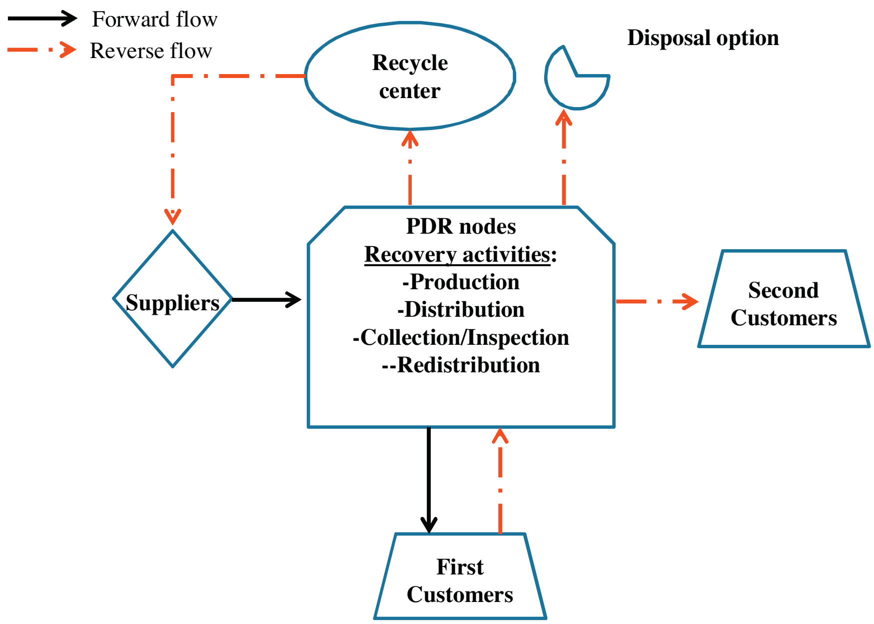

Fig. 1. The generalized supply chain network structure.

material/product from an echelon's node to subsequent echelon's node in a downstream fashion. Jayaraman et al. (1999), were the first to arouse the prospect of gaining advantage by installing a hybrid facility that might include cost savings as a result of sharing material handling equipment, infrastructure and so on. Ko and Evans (2007), applied this idea, by considering in their supply integrated network a type of a hybrid warehouse-repair facility instead of dealing these facilities solely. Lee and Dong (2008), also marked this issue, by applying a hybrid facility in a logistics network design for end-of-lease computer products recovery. They concluded that advantages in building such facilities in electronic industry include cost savings and pollution reduction as results of sharing the material handling equipment and infrastructure. Furthermore, Min and Ko (2008), mentioned that some warehouses can function as partial repair facilities and initial collection points for returned products where returned products should be inspected for quality failure, sorted for repair or refurbishment, stored long enough to create volume for freight consolidation, and then shipped to the original manufacturers.

Our work, aims at enriching the literature on SCND in this specific field by introducing a general mathematical programming framework that employs an innovative composition coupled with forward and reverse logistics. The main feature that discriminates this paper is the innovative generalized node with fourfold role in place of a hybrid facility. The generalized Production/Distribution/Recovery/Re-distribution (PDR) nodes will substitute the traditional plants and distribution centers at the forward flow and the traditional collection and re-distribution centers at the reverse flow of the materials (Fig. 1.). A generalized node can be a manufacturing plant, a distribution, a recovery, a redistribution center, can combine all capabilities together or among them. The model will manage different types of products, these could include types of products like, products unwanted, damaged, or defective; but can be repaired or remanufactured and resold; products unsold from retailers, or products that can be recycled such as pallets, containers.

The rest of the paper is structured as follows. Section 2 reviews the most relevant and recent works in SCND literature. Section 3 introduces the generalized SCND problem and presents its mathematical formulation. The applicability of the proposed model is demonstrated, through a real case study, in Section 4 followed by concluding remarks, managerial implications and further research directions in Section 5.

2. Literature overview

The literature on SC Network Design (SCND) the last decade revealed an increasing number of models confronting with forward and reverse logistics. Aravendan and Panneerselvam (2014) presented a detailed review on of the design of reverse logistics network as well as the reverse logistics network in conjunction with forward logistics network in 9 categories among them 40 models while Govindan et al. (2015) analyzed and categorized a total of 382 papers published in the area of reverse logistics and closed-loop supply chain. As aforementioned, the configuration of both forward and reverse supply chain networks has a strong influence on the performance of each other. Therefore, to avoid the sub-optimalities resulting from the separated design, the design of the forward and reverse networks should be integrated (Fleischmann et al., 2001; Lee and Dong, 2008; Verstrepen et al., 2007). In terms of this issue, Pishvaee et al. (2010) developed a mixed integer programming formulation so as to minimize the total costs and maximize the responsiveness of logistics network while Amin and Zhang (2012) proposed an integrated two-phase model considering supply chain configuration and suppliers' selection.

Papageorgiou (2009) discussed the presence of uncertainty within supply chains being important issue for efficient capacity utilization and robust infrastructure decisions. Many important models applied uncertainty as a crucial aspect in the CLSC management (Biehl et al., 2007; Salema et al., 2007; Pishvaee and Torabi, 2010; Pishvaee et al., 2011; Kaya et al., 2013; Rodriguez et al., 2014). In terms of this issue, Ramezani et al. (2013) presented a robust optimization approach to cope with the uncertainty of demand and the return rate in a multi-product supply chain closed-loop network. Cardoso et al. (2013) developed a mixed integer linear programming for the design and planning model for CLSC where capacity expansion and dynamic transportation links were explored considering simultaneously all processes and