Computers & Operations Research 54 (2015) 245–256

Contents lists available at ScienceDirect

Computers & Operations Research

journal homepage: www.elsevier.com/locate/caor

A closed-loop location-inventory problem with spare parts consideration

Ali Diabat [a,*], Tarek Abdallah [b], Andreas Henschel [a]

[a] Masdar Institute of Science and Technology, Abu Dhabi, United Arab Emirates
[b] University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

ARTICLE INFO

Available online 3 September 2013

Keywords:
Closed-loop supply chain
Reverse logistics
Remanufacturing
Economic order quantity
Lagrangian relaxation

ABSTRACT

A closed-loop location-inventory problem is considered. Forward supply chain consists of a single echelon where the distribution centers (DCs) have to distribute a single product to different retailers with random demands. Reverse supply chain also contains only one echelon where the remanufacturing centers (RCs) collect the returns from the retailers, remanufacture them as spare parts and then push them back to the retailers assigned to the DCs through the forward supply chain. The problem is to choose which DCs and RCs are to be opened and to associate the retailers with them. The problem is formulated using a mixed integer nonlinear location allocation model. An exact two-phase Lagrangian relaxation algorithm is developed to solve it. The computational results and sensitivity analysis are presented.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

Supply chain management has been traditionally defined as the management of operations through which raw materials are converted into final products and then are delivered to end-use customers. However, research into sustainable supply chains extends this focus to the management of used and obsolete products [5]. The operations related to the return of damaged, unsold, end-of-life products along with handling, consolidation, remanufacturing and disposal are becoming of increasing interest and are referred to in literature as reverse logistics research. On the other hand, closed-loop supply chain management is the integration of both traditional forward supply chain management and reverse logistics simultaneously, in which the company's distribution system forms a closed-loop where the recovered products are remanufactured to as good as new products or sold as spare parts or new products to a secondary market.

The after-sales service and the spare parts markets represent a huge profit potential for companies. A report by McKinsey [11] estimates the spare parts market to be worth more than $400 billion in 2006. Another report by Deloitte [14] which studies more than 80 multi-national companies across different industries states that the spare parts and after-sales service business accounts for more than 50% of the total revenue of many high-tech companies such as Rolls-Royce and Xerox. However, the increasing complexities and intricacies of product development and distribution activities can highly impact the revenues of after-sales service and spare parts market. According to [22] design and development decisions made earlier in the supply chain impact up to 85% of the total product life cycle costs including after-sales costs and services. As a result, integrating the strategic decision of the forward supply chain and the reverse supply chain with inventory costs can help to overcome short-sighted sub-optimal network designs.

In this paper, we present the uncapacitated closed-loop location-inventory (UCLLI) model which integrates the inventory decision into the location allocation decisions in a closed-loop supply chain. We consider a central manufacturer delivering its products to local distribution centers (DCs) which keep safety stocks to meet the uncertain demands of the assigned retailers. The central manufacturer location is known and the shipping cost to the warehouses is assumed independent of the distance. We assume single sourcing for the retailers, so that a retailer has to be served by a single DC. In order to manage the reverse flow of products, the retailers collect the returned products and send them to a remanufacturing center (RC). The RCs are responsible for remanufacturing the returned products which are pushed to the retailers as spare parts. The RCs maintain a certain safety stock of subassemblies used in the remanufacturing of the returned product. We also assume single sourcing for the retailers in the reverse supply chain, so that a retailer sends its returns to a single RC. Furthermore, we assume that the subassemblies are ordered from the central manufacturer and the RCs can only be opened near DCs to minimize unnecessary transportation. This is a common assumption in the closed-loop supply chains as presented in [12].

* Corresponding author. Tel.: +9 7128109101.
E-mail address: adiabat@masdar.ac.ae (A. Diabat).

0305-0548/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cor.2013.08.023

This paper is organized as follows. Section 2 reviews the literature on location-inventory models and reverse logistics. Section 3 formulates the UCLLI problem as a mixed integer non-linear program (MINLP). Section 4 investigates the different mathematical properties of the model. Section 5 outlines a two phase Lagrangian relaxation algorithm. Section 6 summarizes the computational and sensitivity analysis of the algorithm. Finally, Section 7 outlines our conclusions and future research plans.

2. Literature review

The design of efficient supply chains has been long investigated in literature and can be divided into three main categories: inventory theory, traditional forward location theory, and reverse logistics theory. Recently, [4,21] opened an interesting line of research by integrating inventory decisions into strategic facility location decisions. They both incorporated a (Q, r) inventory control policy, which specifies a safety stock level at each site, into the widely studied uncapacitated fixed-charge location problem. In the inventory control policy considered, a fixed quantity Q is ordered from the supplier once the inventory level falls below a reorder point r. The total number of shipments per year was considered as a decision variable. To solve the problem, [4] used Lagrangian relaxation, while [21] reformulated the model as a set-covering problem and solved it by using a column generation method. Miranda and Garrido [17] also studied the (Q, r) inventory control policy, but considered the order quantity for each DC as a decision variable. The problem was transformed into a series of capacitated facility location problems and solved using Lagrangian relaxation. Ozsen et al. [19] formulated the capacitated location model using risk pooling. They considered DCs with limited capacities and solved the problem using Lagrangian relaxation. Qi and Shen [20] proposed an integrated stochastic supply chain design model that takes into consideration location, inventory, and routing costs. They modeled the shipment from a DC to its customers using a vehicle routing model instead of the linear direct shipping model. Finally, [24] reformulated the location-inventory problem and proposed a heuristic method to quickly obtain good-quality solutions; they also developed a decomposition algorithm based on Lagrangian relaxation for obtaining globally optimal or near-globally optimal solutions. Diabat et al. [7] considered a two-echelon location-inventory model where inventory was accounted for at the level of the warehouse and the retailers at the same time. They assumed that retailers follow a power-of-two ordering policy. They propose a Lagrangian-based heuristic to solve the problem due to the high non-linearity of the subproblem.

As for reverse logistics literature, [10] studied reverse logistics opportunities for IBM spare parts. Their inventory control model and simulation showed that reverse logistics present significant savings over procurement costs. Fleischmann and Minner [9] reviewed the different inventory control models in the reverse logistics supply chains and concluded that there is a need for integration of inventory control decisions with the other business functions in closed-loop supply chains. Minner and Lindner [16] also proposed several variants of economic-order-quantity (EOQ) models for lot-sizing decisions in product recovery operations. Mitra [18] developed two inventory models, a deterministic and a stochastic one, in order to address the inventory management problem of uncertain product returns. The model considered a two-echelon inventory system with returns under generalized conditions. Lieckens and Vandaele [15] designed a mixed-integer non-linear model to address the problem of queueing relationships as well as to deal with the higher degree of uncertainty and congestion in reverse supply chains. The model was solved using a genetic algorithm based on the technique of differential evolution. Finally, [12] considered the integration problem of the remanufacturing problem for location and inventory. However, a simplistic inventory cost was added to the objective function without considering the demand uncertainty or the risk pooling impact. The model also assumed that the remanufacturing centers are built next to the distribution centers as this is a common trend in reverse logistics. Furthermore, there has been an emerging line of research which studies forward and reverse logistics problems and their impact on carbon emissions, for further references see [2,13,6].

The above review shows that while the design of efficient reverse logistics networks has received much attention, not much work has been done on combining strategic with operational level decisions in reverse logistics. In this regards, [1] have first proposed the integration of the location and inventory decisions in a closed-loop supply chain. The authors formulate the problem as a non-linear mixed-integer problem; however they did not propose a solution methodology. In the following sections, we will briefly discuss the problem and then propose a two-phase Lagrangian relaxation algorithm to solve the problem.

3. Model formulation

We consider a supply chain network in which a single plant ships one type of product through distribution centers to a set of retailers, each with uncertain demand. Conversely, retailers are given the responsibility of collecting and sorting the returned products. The recovered products are then returned to remanufacturing centers. The re-entrance of the products is modeled as spare parts, thus not influencing the demand of the original product. The uncapacitated closed-loop location-inventory model was first introduced by [1] which is an extension of the uncapacitated forward loop location-inventory problem (UFLP) described in [4]. The UFLP integrates location, transport and inventory stock decisions. It accounts for the risk pooling effect, which yields inventory-cost savings achieved by grouping retailers. The closed-loop location-inventory problem is formulated as a combination of two UFLP problems with the additional constraint that RCs can only be opened where DCs exist.

We denote the demand at retailer i on a particular day ℓ by $R_{i\ell}$, where the daily demands at the retailers are assumed to be independent and normally distributed, i.e. $R_{i\ell} \sim N(\mu_i, \sigma_i^2)$. Similarly, we denote the returns of the customers of the forward supply chain at retailer i on a particular day ℓ by $r_{i\ell}$, where these returns are assumed to be independent and normally distributed, i.e. $r_{i\ell} \sim N(\lambda_i, \rho_i^2)$. However, we assume that the expected number of daily returns is a fixed ratio of the daily demands such that $\mu = \delta\lambda_i$ (where $\delta \in [0, 1]$).

In order to integrate the inventory cost into the location model, we consider an EOQ approximation for the end products available at the DCs and the subassemblies awaiting remanufacturing at the RCs. The safety stock cost is calculated based on a Type 1 service level with fixed lead time. As for the working inventory at the RCs, we consider a product that has $M+1$ subassemblies, where one main subassembly is salvaged and M subassemblies are shipped from the plant which is decided a priori. To simplify the model we consider an aggregate subassembly based on the dollar value of the M subassemblies. As a result we consider the holding cost of the aggregate subassembly, q, to be related to h, the holding cost of the main product such that $q = \nu h$ (where $\nu \in (0, 1)$ and the value of ν depends on the overall dollar value of the aggregate subassembly with respect to the overall dollar value of the main product).

In order to simultaneously determine the location of the DCs and RCs, the assignment of retailers' orders to the DCs, the

Download English Version:

https://daneshyari.com/en/article/475108

Download Persian Version:

https://daneshyari.com/article/475108

Daneshyari.com