Int. J. Production Economics 135 (2012) 754–761

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

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

A logistics network design model with vendor managed inventory

Jia Shu [a], Zhengyi Li [a], Houcai Shen [b], Ting Wu [c,*], Weijun Zhong [a]

[a] Department of Management Science and Engineering, School of Economics and Management, Southeast University, China
[b] Department of Management Science and Engineering, Nanjing University, China
[c] School of Business and Department of Mathematics, Nanjing University, China

ARTICLE INFO

Article history:
Received 29 November 2010
Accepted 25 July 2011
Available online 18 October 2011

Keywords:
Vendor managed inventory
Multi-echelon inventory management
Facility location
Set-packing
Branch-and-price

ABSTRACT

In this paper, we study a logistics network design problem with vendor managed inventory in which the company is in charge of managing inventory for its downstream warehouses and retailers, and can choose whether to satisfy each retailer's demand. The problem incorporates the location, transportation, pricing, and warehouse-retailer echelon inventory replenishment decisions. Traditionally, these decisions are made separately. We formulate the problem as a set-packing model and solve it using branch-and-price. The pricing problem that arises from each iteration of the column generation procedure is an interesting nonlinear IP problem. We show the pricing problem can be solved in $O(n^2 \log n)$ time for each warehouse, where n is the number of retailers. The computational results shed insights on the benefits that the integrated approach can achieve significant profit improvement. The computational results also highlight the efficiency of the solution algorithm.

1. Introduction

Vendor managed inventory (VMI) is an effective supply chain planning technique that aims at reducing logistics cost and improving service by coordinating the operations of different logistical entities across the supply chain. Traditionally, each logistical entity involved in the supply chain manages its own inventory independently. By centralizing the inventory control and coordinating the multi-echelon inventory replenishment under VMI, the system-wide logistics cost can be significantly reduced and the service level can be improved. As shown by Simchi-Levi et al. (2003), Ballou (2004), and Yang et al. (2010), a unified systems approach is required to successfully implement VMI, which can help effectively integrate the supplier, its downstream warehouses and retailers so that the product is produced and distributed at the right quantities, to the right locations, and at the right time. Motivated by this recent popular supply chain initiative — vendor managed inventory, in this paper, we study a logistics network design problem integrating multi-echelon inventory management under the VMI framework in which the supplier manages the inventory of a single product for its downstream warehouses and retailers. Under this VMI framework, the system-wide inventory, including the inventory maintained at both warehouses and retailers, is owned by the supplier. The supplier is the sole decision maker who is in charge of the warehouse-retailer echelon inventory replenishment, the transportation of the product from it to the warehouses and from the warehouses to the retailers, and the price of the product. The warehouse-retailer echelon inventory is owned by the supplier until it is sold. The goal of the supplier is to maximize the total profit.

A supply chain distribution network's physical structure can substantially affect its performance and profit margin. Most existing research on supply chain network design pursues a cost-minimization objective and tries to satisfy all the demands. However, the additional revenue generated from serving some retailers could be much lower than the cost associated with serving them. Thus, trying to satisfy all the retailers' demands might not give us the highest profit. As shown by Shen (2006), it could be more profitable for a company to lose some potential demands to competitors. It is difficult to determine whether it is profitable to serve each individual retailer a priori. Thus, we intend to propose a logistics network design model that can help simultaneously determine the location, warehouse-retailer assignment, warehouse-retailer echelon inventory replenishment, sale price, and which set of retailers to serve. The problem can be described as follows. We consider a company that produces a single product in a production site. We are given a set of retailers each of which faces a deterministic demand at a constant rate. We are also given a set of potential warehouse locations and each warehouse is assumed to be uncapacitated. The product will be shipped from the production site to certain retailers via some selected warehouses. The company wants to determine (i) the number and locations of the warehouses to open and the retailers

* Corresponding author. Tel.: +86 13770 785115.
E-mail addresses: jshu@seu.edu.cn (J. Shu), zyli@seu.edu.cn (Z. Li), hcshen@nju.edu.cn (H. Shen), tingwu@nju.edu.cn (T. Wu), zhongweijun@seu.edu.cn (W. Zhong).

0925-5273/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpe.2011.10.008

to serve, (ii) the retailer assignments, (iii) the warehouse-retailer echelon inventory replenishment policy, and (iv) the sale price of the product associated with each warehouse located, so as to maximize the total profit which equals to the total revenue minus the total cost. The cost components include the warehouse establishing and operating cost, the warehouse-retailer echelon inventory related cost, and the shipment cost from the production site to the warehouses open and from each open warehouse to respective retailers served. The cost of establishing and operating a warehouse is fixed, which is assumed to be independent of the number of retailers assigned to that warehouse.

Comparing with other logistics network design models in the literature, the novelties of our model lie in the following three aspects. First, it brings the VMI concept into logistics distribution network design with a profit-maximizing objective. Second, it allows the supplier to decide whether to serve each retailer, i.e., the supplier can choose the set of retailers to serve within the multi-echelon inventory management context. This gives rise to a set-packing profit-maximizing model. It is unlike other traditional multi-echelon logistics network design models which pursue a cost-minimizing objective and try to satisfy all the demands. Third, we use extensive computational experiments to demonstrate the potential practical impact of integrated decision-making by comparing the solutions obtained from our model with the traditional sequential decision-making process. The average benefit ranges from 10.4% to 21.7% in terms of the total profit. The computational results also shed insights on the benefits of our model with the supplier having retailer-serving flexibility over the traditional model that requires all the demands should be served.

The rest of this paper is organized as follows. In Section 2, we review the related literature. In Section 3, we present a set-packing model with a profit-maximizing objective for our network design problem. In Section 4, we study the solution procedure which includes the solution to the pricing problem and a speed up heuristic for column generation. In Section 5, we present a traditional sequential decision-making approach for the problem. In Section 6, we report and discuss the computational results. Finally, we outline a few generalizations of our model and conclude the paper in Sections 7 and 8, respectively.

2. Literature review

The integrated logistics network design optimization received increasing attentions in the literature recently. One important stream of this research focuses on the single-echelon risk-pooling network design problems with a single supplier and with warehouses serving as the intermediate facilities between the supplier and the retailers, and holding two types of inventory: the working inventory and the safety stock. Shen et al. (2003) formulate the uncapacitated risk-pooling network design problem as a set-covering model and solve it using a column generation approach when the mean-to-variance ratio of the demand at each retailer is identical for all retailers. Daskin et al. (2002) solve the same problem using a Lagrangian relaxation based approach. Shu et al. (2005) propose an efficient algorithm for the subproblem by relaxing the assumption on the mean-to-variance ratio being identical for all retailers and solve the problem using column generation. Qi et al. (2010) study a similar problem with supply disruptions. Miranda and Garrido (2006, 2009) and Ozsen et al. (2008, 2009) study various capacitated risk-pooling network design models. Sourirajan et al. (2007, 2009) study a more general risk-pooling network design problem in which the replenishment lead time is explicitly modeled. They develop a Lagrangian relaxation based heuristic and a genetic algorithm, respectively, to solve the problem. Park et al. (2010) study a risk-pooling network design problem with the consideration of selecting suppliers and lead times being DC-to-supplier dependent. Shen (2005), Snyder et al. (2007), and Vidyarthi et al. (2007) study multi-commodity risk-pooling network design problems. While the last one considers the selection of suppliers and ignores the working inventory in the system. Manzini and Bindi (2009) and Gebennini et al. (2009) continue this line of research by further considering the production decisions. Shen and Qi (2007) and Javid and Azad (2010) study the single-echelon risk-pooling network design problems integrating routing costs. Some other important single-echelon logistics network design models are contributed by Candas and Kutanoglu (2007) and Jeet et al. (2009) for the service parts industry and Lee et al. (2010) for the sustainable logistics network design.

In another stream of this research, the multi-echelon inventory replenishment related cost is considered. Teo and Shu (2004) propose a two-echelon location-inventory distribution network design problem in which both warehouses and retailers carry inventory and each retailer faces a deterministic demand at a constant rate. They solve the problem using column generation. Üster et al. (2008) study a similar problem in which they assume a single warehouse is located and the location decision is continuous, and propose several heuristic algorithms that are both effective and efficient to tackle it. Keskin et al. (2010) study a stochastic two-echelon location-inventory distribution network design problem.

The literature on retailer demand selection and profit maximization in logistics is also related to our problem, for example, Bakal et al. (2008), Chahar and Taaffe (2009), Geunes et al. (2004, 2005, 2006, 2011), and Taaffe et al. (2008a,b).

Nevertheless, all the models proposed and studied by the aforementioned papers either do cost minimization for network design or ignore the location decision. The literature on profit-maximizing supply chain network design is rather limited. Zhang (2001) studies a profit-maximizing location model in which a single warehouse is located and the price for its product is the same. It assumes that if the price charged by the supplier is higher than a customer's reserve price, the supplier will lose this customer. The model does not consider any cost terms. In a recent paper, Shen (2006) presents a profit-maximizing supply chain design model in which the location, transportation, and inventory replenishment related costs at the warehouse level are considered.

3. Model development

In this section, we first define the notations, assumptions, and then develop a set-packing model for the logistics network design problem with vendor managed inventory.

3.1. Notations and assumptions

To model the logistics network design problem with vendor managed inventory we first define the following notations: **Sets**

I	set of the retailers, $\lvert I\rvert = n$;
W	set of the potential warehouse locations, $\lvert W\rvert = m$.

Inputs and parameters

λ_i	annual demand rate faced by retailer i for each $i \in I$;
$K_{w,0}$	fixed ordering cost incurred by warehouse w every time it places an order to the supplier for each $w \in W$. It is independent of the ordering quantity;