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An improved Lagrangian relaxation-based heuristic for a joint location-inventory problem

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ABSTRACT

We consider a multi-echelon joint inventory-location (MJIL) problem that makes location, order assignment, and inventory decisions simultaneously. The model deals with the distribution of a single commodity from a single manufacturer to a set of retailers through a set of sites where distribution centers can be located. The retailers face deterministic demand and hold working inventory. The distribution centers order a single commodity from the manufacturer at regular intervals and distribute the product to the retailers. The distribution centers also hold working inventory representing product that has been ordered from the manufacturer but has not been yet requested by any of the retailers. Lateral supply among the distribution centers is not allowed. The problem is formulated as a nonlinear mixed-integer program, which is shown to be NP-hard. This problem has recently attracted attention, and a number of different solution approaches have been proposed to solve it. In this paper, we present a Lagrangian relaxation-based heuristic that is capable of efficiently solving large-size instances of the problem. A computational study demonstrates that our heuristic solution procedure is efficient and yields optimal or near-optimal solutions.

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1. Introduction

Supply chain management (SCM) involves a group of organizations that perform the various processes that are required to manage the flow of products at the lowest possible cost and highest degree of customer satisfaction. The chain typically begins with raw materials and ends with the finished product that is delivered to the customer. The supply chain includes the manufacturer, transporters, warehouses, retailers, and customers themselves. Within each organization, the supply chain includes all functions involved in satisfying customer demand. Supply chain decision phases are classified into the following three categories based on the frequency with which they are made and the time frame over which a decision phase has an impact: (1) strategic decisions, which impact the firm over several years, for example the locations of distribution centers; (2) tactical decisions, which are usually made one to four times a year, for example determining transportation and inventory policies; and (3) operational decisions, which are usually made on a daily basis, for example scheduling and routing decisions; see Chopra and Meindl [6] and Simchi-Levi et al. [31]. In today's competitive environment, only efficient supply chains that integrate decisions in the various phases can survive.

Inventory management and facility location are two major issues in the efficient design of a supply chain network; see Gunasekaran et al. [16,17] and Stevens [34]. However, literature on supply chain optimization has traditionally considered these issues independently not only because of different planning horizons but principally because of the computational complexity of the joint optimization problem. Indeed, facility location problems are typically NP-hard combinatorial optimization problems, and the majority of inventory management problems are formulated as nonlinear programming problems. Combining such two problems leads to more difficult NP-hard problems that are usually nonconvex, and therefore cannot be easily solved to optimality using exact optimization methods. However, such an integration offers a possibility to considerably improve the supply chain management and reduce the costs.

It is worth mentioning a real-world example, in the interest of demonstrating how the strategic level decision of facility location (which does not necessarily refer to an actual location of a new facility) can be successfully integrated with the tactical level inventory decisions, to provide better solutions and lead to improved performance. The motivation behind initial work on joint inventory location problems arose from the problem of

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producing and distributing blood platelets for a blood bank in Chicago and it was addressed by Daskin et al. [8], Shen et al. [23] and Ozsen et al. [27,28]. This particular bank distributes blood to more than thirty hospitals in the region and the inventory cost of the platelets is high, due to specific conditions that should be maintained at all times, such as the frequent agitation of the platelets or the temperature that must be kept between 20 and 24 °C. Furthermore, the expiration of the blood platelets a few days after they are collected is another important factor to be considered. Each hospital stored its own platelet inventory and this independent inventory and location policy led to platelets going to waste after expiration in certain hospitals, while others ran out very soon. After re-addressing this problem as a joint location-inventory model, by enforcing some hospitals to serve as distribution centers and others as retailers, the efficiency and usage of the platelets greatly improved. The same example motivated Le et al. [22] to jointly study inventory decisions and routing decisions for perishable goods. Therefore, many real-world problems can be formulated as location-inventory problems without including any "real" location decisions for opening new warehouses. The existence of the location-type decision variables, in addition to the inventory decision variables, is the only reason for calling such problems location-inventory problems.

The objective of the present paper is to develop an efficient Lagrangian-based heuristic for such an integrated problem, which we call a large-scale multi-echelon joint inventory-location problem and which we refer to as the MJIL problem.

The paper is organized as follows: Section 2 reviews existing joint inventory-location models; Section 3 introduces the MJIL problem; Section 4 introduces the new Lagrangian relaxation algorithm for solving the MJIL problem; Section 5 presents computational studies; and Section 6 discusses future research directions.

2. Literature review

Integrated supply chain network design involves several core components, among which are facility location and inventory management. Most literature on supply chain optimization has traditionally considered facility location decisions and inventory management decisions independently: Amiri [1], Daskin et al. [9], Hindi and Pienkosz [18], Pirkul and Jayaraman [29], and Tsiakis et al. [40] focused on location decisions, while Axsäter [2], Jones and Riley [20], Muckstadt and Roundy [25], Svoronos and Zipkin [35], and Wee and Yang [41] focused on inventory management decisions. Only recently, integrated models have attracted the attention of researchers.

Barahona and Jensen [3] introduced a large-scale integer programming formulation for a location-inventory model, and used Dantzig–Wolfe decomposition to solve the linear programming relaxation of this problem. Because the standard implementation of the Dantzig-Wolfe decomposition algorithm was too slow, the authors used subgradient optimization to improve the rate of convergence of their solution procedure. Although they included ordering and inventory costs in their model, they considered these costs only for one echelon. Thus, their model represents the integration of a location model with an economic order quantity (EOQ) model; see Nahmias [26].

Erlebacher and Meller [11] developed an analytical joint location-inventory model. The general version of their problem is NP-hard, and is therefore difficult to solve, so they developed a heuristic algorithm which performs well on their test problems. They consider ordering and inventory costs at the distribution centers but these costs are omitted at the retailer level. Teo et al. [37] used an analytical modeling approach to study the impact on facility investments and inventory costs when several distribution

Table 1
Comparison of relevant published papers.

Paper	Model features	Decision variables	Solution methodology
This paper	• Ordering, inventory and transportation costs • Multi-echelon • Single sourcing	• Average inventory level at retailer • Average inventory level at DC • Order-quantity at retailer • Cycle time of retailer • Cycle-time of DC	Lagrangian relaxation-based heuristic
[3]	• Ordering and inventory costs • Single echelon	• Whether or not a plant is opened • Customer-plant assignment • Whether or not a customer that is assigned to a plant requires a certain part	Dantzig–Wolfe decomposition and subgradient optimization
[11]	• Ordering and inventory costs • Two-level distribution system	• Number of DCs • Location of DCs • If DC is open • If DC serves certain customer grid • Average distance from DC to customer • Demand shipped • Distance from plant to DC	Stylized analytical model, heuristics
[37]	• Stochastic demands at customer locations • Warehouse consolidation	• Location of DC • Assignment of demand location to DC	Consolidation strategy
[36]	• Possibility for direct flow between customer and factory • Multiple sourcing	• Flows between customers, factories, DCs • Size of shipments sent • Total flow passing from every DC	Iterative heuristic
[4]	• Two stage distribution system • Explicit modeling of inventory replenishment, holding and transportation costs	• Set of open DCs • Assignment of open DCs	Analytical solution
[39]	• Multiple sourcing	• Location of DCs • Assignment of retailers to DCs	Continuous approximation

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