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Applying queuing approach for a stochastic location-inventory problem with two different mean inventory considerations

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ABSTRACT

This paper studies a three-level supply chain network, which includes a single supplier, multiple potential distribution centers (DCs) and multiple retailers. The problem is to optimize the facility location, allocation retailers' demands, and inventory replenishment decisions simultaneously such that the total expected cost of location, transportation and inventory are minimized. In order to make the problem more realistic, we consider uncertain demand and lead-time, which follow Poisson and Exponential distributions, respectively. Hence, a queueing approach is used to obtain the amount of annual ordering, purchase and shortage as well as the mean inventory in the steady-state condition. Then, according to the results of queuing analysis, we propose a mixed integer nonlinear programming model (MINLP) to address the location-inventory problem. Moreover, the expected mean inventory is calculated using two different methods and the results are also compared through different criteria.

1. Introduction

A supply chain is a network of suppliers, factories, DCs, retailers and customers through which raw materials are acquired, transformed and delivered to customers in order to minimize (maximize) cost (profit) of the total chain. Thus, supply chain management plays an essential role in reducing the total costs of companies and improving competitive conditions.

Supply chain management is considered as a set of strategic, tactical, and operational decision-making functions, which optimizes supply chain performance. The strategic level describes the supply chain network by selecting suppliers, transportation routes, manufacturing facilities, production levels, warehouses, etc. The tactical level plans and schedules the supply chain to meet actual demand while the operational level executes plans. Tactical and operational level decision-making functions are normally distributed across the supply chain [1].

In order to improve the performance of a supply chain, all associated functions must operate in an integrated manner. In this paper, we propose an integrated supply chain that optimizes the location, allocation and inventory replenishment decisions simultaneously.

The problem is to design a three level supply chain that includes a supplier, multiple potential DCs and multiple retailers. In other words, the problem determines three different decisions: (i) the number and location of DC(s) (ii) the best allocation of retailers to opened DC(s) (iii) inventory policy at each opened DC. In order to make the problem more realistic, we consider uncertain demand and lead-time, which follow Poisson and Exponential distributions, respectively. Hence, we apply a

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queuing approach to obtain the amount of annual ordering, purchase and shortage as well as the mean inventory in the steady-state condition. Then, the results are used to formulate the location-inventory problem.

It is assumed that each opened DC has an $(S-1,S)$ inventory policy. According to $(S-1,S)$ inventory policy, if the inventory level is less than S either due to a demand or a failure, we place an order to bring the inventory level to S [2]. This method is often used for controlling the stock levels of expensive, slow moving, with relatively low demand and high inventory holding costs items. In particular, this class of policies is implemented in spare parts inventory systems, in which a failed part is replaced by a new one from inventory [3]. More applications can be observed in military, airlines, and computer manufacturing [4].

The remainder of this paper is organized as follows. In Section 2, we review the relevant literature on location-inventory problems, as well as inventory models based on queuing theory. Next, in Section 3, we describe the problem and then formulate it as an MINLP model in Section 4. We present numerical experiments and compare the two methods with respect to different numbers of DCs and retailers in Section 5. In Section 6, the sensitivity analysis is provided and the two proposed methods are compared through different criteria. Finally, conclusions and avenues for future research are presented in Section 7.

2. Literature review

In some situations, the strategic facility location decisions are extremely affected by the tactical decisions such as the inventory decisions. Traditionally, for modeling purposes, these levels have been managed independently that may lead to sub-optimal decisions, as mentioned by many researchers (see, e.g., [5–7]). In other words, by considering these decisions at the same time, significant cost saving can be obtained. Thereupon, integrated models have attracted much attention in the literature.

The first study that proposed the idea of integrating inventory cost into location models was presented by Baumol and Wolf [8]. They developed the uncapacitated facility location problem and presented a method that can obtain a local optimum. Erlebacher and Meller [9] investigated an analytical integrated location-inventory model and developed some simple constructive heuristics to solve the proposed model. Nozick and Turnquist [10] presented a location-inventory problem to take into account trade-offs between cost and service responsiveness. Daskin et al. [11] developed a DC location problem dealing with safety stock inventory. The problem was formulated as a nonlinear integer-programming problem and a Lagrangian relaxation solution algorithm was suggested. A stochastic transportation-inventory network design problem was provided by Shu et al. [12]. Shen et al. [13] studied this problem as a set-covering integer programming model. Amiri [14] introduced a location problem, which determines the best strategy for distributing products. He considered multiple capacity levels available for warehouses and plants. In addition, a mixed integer-programming model and an efficient heuristic solution method were proposed. Snyder et al. [7] formulated a stochastic location-inventory problem and defined distinct scenarios for parameters. Ozsen et al. [15] and Miranda and Garrido [16] handled inventory capacity constraints at DCs based on previous location- inventory models.

An integrated stochastic supply chain model with uncertain demand and lead-time was formulated by Jabal Ameli et al. [17]. They assumed that in order to reach a certain service level for the customers, each DC has a certain amount of safety stock and presented a nonlinear integer-programming model to address this problem. They solved their model by a hybrid algorithm. Mak and Shen [4] analyzed a location–allocation problem with service constraints and stochastic demand. In their research, manufacturing process was modeled as a queuing system in order to optimize the base stock levels and to determine the location of DCs and allocation of customers to DCs simultaneously. Authors formulated the problem as an MINLP model to minimize the total expected cost of the system. They also developed a Lagrangian heuristic to solve the model. A two-stage supply chain network with uncertain demand was presented by Shu et al. [18]. They formulated the problem as a nonlinear discrete optimization model and solved it using column generation. Liu et al. [19] considered a location problem that assigns online demands to the capacitated regional warehouses serving in-store demands in a multi-channel supply chain. They presented a nonlinear integer-programming model. Additionally, a Lagrangian relaxation was provided for solving the proposed model. A distribution network design problem with random demand was investigated by Ahmadi Javid and Azad [20]. They formulated the problem as a mixed integer convex programming model to solve medium-sized instances, and then a heuristic was presented for solving large-sized instances. Chen et al. [21] investigated a location-inventory problem, where constructed facilities may be interrupted with known probabilities. They presented an integer-programming model for the problem and developed a Lagrangian relaxation solution approach. A location-inventory problem in a three-level supply chain network was studied by Tancrez et al. [22]. They proposed a nonlinear continuous formulation to minimize the transportation, fixed, handling and holding costs. An iterative heuristic was developed to solve the model. Besides, a case study was discussed. An integrated location-inventory problem with multiple DCs and retailers was studied by Tsao et al. [23]. They provided a continuous approximation approach to minimize the total network costs.

More recently, Berman et al. [24] proposed an integrated location-inventory problem with a periodic-review (R,S) inventory policy at each DC. Two types of coordination were introduced: partial coordination, where each DC may choose its own review interval and full coordination, where all DCs have a similar review interval. The problem was formulated as a nonlinear integer-programming model and a Lagrangian relaxation algorithm was presented to solve it. A closed-loop location-inventory problem was suggested by Diabat et al. [25]. Authors formulated the problem as an MINLP model and