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Incorporating location, routing and inventory decisions in supply chain network design

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ABSTRACT

This paper for the first time presents a novel model to simultaneously optimize location, allocation, capacity, inventory, and routing decisions in a stochastic supply chain system. Each customer's demand is uncertain and follows a normal distribution, and each distribution center maintains a certain amount of safety stock. To solve the model, first we present an exact solution method by casting the problem as a mixed integer convex program, and then we establish a heuristic method based on a hybridization of Tabu Search and Simulated Annealing. The results show that the proposed heuristic is considerably efficient and effective for a broad range of problem sizes.

1. Introduction

A key driver of the overall productivity and profitability of a supply chain is its distribution network which can be used to achieve a variety of the supply chain objectives ranging from low cost to high responsiveness. Designing a distribution network consists of three subproblems: location–allocation problem, vehicle routing problem, and inventory control problem. Because of high dependency among these problems, in the literature there are several papers integrating two of the above problems: location–routing problems, inventory–routing problems, and location–inventory problems. Location–routing problems are surveyed and classified by Min et al. (1998) and Nagy and Salhi (2007). Inventory–routing problems are studied in several papers, e.g. Baita et al. (1998), Jaillet et al. (2002), Kleywegt et al. (2002), Adelman (2004), Gaur and Fisher (2004), Zhao et al. (2008), Yu et al. (2008), Oppen and Loketangen (2008) and Day et al. (2009). Also, several papers considered location–inventory problems, e.g. Erlebacher and Meller (2000), Daskin et al. (2002) and Shen (2005).

Recently, Shen and Qi (2007) modified the inventory–location model given in Daskin et al. (2002). The objective function of their model is the sum of the inventory–location cost and an approximate routing cost which depends only on the locations of the opened distribution centers. They showed that significant cost saving can be obtained by their model in comparison with the sequential approach. However, their model optimizes only the inventory and location decisions and does not determine transportation decisions. Furthermore, there is no guarantee that their model can be used for real-world cases since their approximation method is applicable only under some restrictive assumptions.

In this paper, for the first time we present a model which simultaneously optimizes location, allocation, capacity, inventory and routing decisions without any approximation. To solve the problem, first we present an optimal solution method by expressing the problem as a mixed integer convex program. Since location–routing problems have been shown to be

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NP-hard (Perl and Daskin, 1985), our problem belongs to the class of NP-hard problems too. Hence, in the following to solve the large-sized instances, a heuristic method is developed. The heuristic method is decomposed into two stages: constructive stage and improvement stage. In the constructive stage an initial solution is built at random. In the improvement stage we have two phases: location phase and routing phase, and a hybrid algorithm based on Tabu Search and Simulated Annealing is used to improve the initial solution in each phase.

The remainder of the paper is organized as follows. In Section 2, the mathematical formulation of the problem is given. Section 3 presents the solution methods for solving the problem. Section 4 studies the model under extra constraints. The computational results are presented in Section 5. We conclude the paper in Section 6.

2. Problem description and formulation

The goal of our model is to choose, locate and allocate a set of distribution centers, to determine the inventory policy and to schedule vehicles' routes to meet customers' demands such that the total cost is minimized. We assume that each customer has an uncertain demand that follows a normal distribution. In the model, we use different capacity levels for each distribution center, which makes the problem more realistic and increases the capacity utilization of distribution centers to a high level. Our assumptions and decisions determined by the model are explained as follows.

2.1. Assumptions

- Each customer has an uncertain demand that follows a normal distribution, and the customers' demands are independent.
- All the possible capacity levels for the set of distribution centers are known, and the company pays a fixed location cost for opening a distribution center with a capacity level.
- The company pays a fixed cost for placing each order and a cost for holding inventory at each distribution center.
- Each distribution center j is assumed to follow a (Q_j, R_j) inventory policy, i.e., when the inventory level at distribution center j falls to or below a reorder point R_j, a fixed quantity Q_j is ordered to the supplier. Also, each distribution center holds a safety stock to buffer the system against stock out during lead times.
- Vehicles' capacities are the same, and fleet type is homogeneous.

2.2. Decisions

- *Location, capacity level and allocation decisions*: how many distribution centers to locate, where to locate the opened distribution centers, what capacity level to consider for each of them, and how to allocate the customers to them.
- *Routing decisions*: how to build the vehicles' routes starting from an opened distribution center to serve its allocated customers.
- *Inventory decisions*: how often to reorder at a distribution center and what level of safety stock to maintain.

Now we integrate these three decisions in a mathematical programming model under the aforementioned assumptions. Before presenting the model, let us introduce the notation used throughout the paper.

2.3. Index sets

K	set of customers
J	set of potential distribution centers
N_j	set of capacity levels available to distribution center $(j \in J)$
V	set of vehicles
M	merged set of customers and potential distribution centers, i.e. $(K \cup J)$

2.4. Parameters and notations

B	number of customers contained in set K, i.e. $B = \|K\|$
μ_k	mean of yearly demand at customer k $(\forall k \in K)$
σ_k^2	variance of yearly demand at customer k $(\forall k \in K)$
f_j^n	yearly fixed cost for opening and operating distribution center j with capacity level n $(\forall j \in J,\ \forall n \in N_j)$
b_j^n	capacity with level n for distribution center j $(\forall j \in J,\ \forall n \in N_j)$.
d_{kl}	transportation cost between node k and node l $(\forall k, l \in M)$
vc	annual delivery capacity of a vehicle
q	number of visits of each vehicle in a year
h_j	inventory holding cost per unit of product per year at distribution center j $(\forall j \in J)$
p_j	fixed cost per order placed to the supplier by distribution center j $(\forall j \in J)$
lt_j	lead time of distribution center j in years $(\forall j \in J)$