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Joint location-inventory problem with differentiated service levels using critical level policy

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ABSTRACT

This paper analyzes the design of a distribution network for fast-moving items able to provide differentiated service levels in terms of product availability for two demand classes (high and low priority) using a critical level policy. The model is formulated as a MINLP with chance constraints for which we propose a heuristic to solve it. Although the heuristic does not guarantee an optimal solution, our computational experiments have shown that it provides good-quality solutions that are on average 0.8% and at worst 2.7% from the optimal solution.

1. Introduction

Fast moving-items are products with high demand volume or items with high inventory turnover. Examples include non-perishable food, toiletries, over-the-counter drugs, cleaning supplies, building supplies and office supplies. The distribution channels of these products have been concentrated in large retails chains requiring high service level in terms of product availability at the supplier's expense. Therefore, many wholesalers segment their customers based on service level. The simplest segmentation is to classify customers into two demand classes, (i) high priority class will correspond to large retail chains that require high service levels and (ii) low priority class corresponding to small retailers which can be provided lower service levels.

An efficient way of providing differentiated service levels is through a *critical level policy*. This policy is a inventory control model for rationing the inventory between different classes of customers and its main application is in inventory systems that must provide differentiated service levels to two or more classes of demand. Deshpande et al. (2003) and Escalona and Ordóñez (2015) have provided evidence of the efficiency of the critical level policy compared to other traditional inventory control policies that allow providing differentiated service levels as *round-up* or *separate stock* policies.

Let us now consider the design of a distribution network for fast-moving items able to provide differentiated service levels using a critical level policy. From literature review we observe that (i) models that integrate inventory and location decisions (Daskin et al., 2002; Shen et al., 2003; Miranda and Garrido, 2004; Shen, 2005; Shen and Daskin, 2005; Snyder et al., 2007; Ozsen et al., 2008; You and Grossmann, 2008; Atamtürk et al., 2012) considers that the entire distribution network provides the same service level which is equivalent to considering that all customers require the same service level or

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there is only one class of demand (customer category), (ii) for fast-moving items it is usually more convenient and efficient to model the demand over a time period by a continuous distribution, e.g., normal or gamma distributions (Peterson and Silver, 1979; Axsäter, 2006; Ramaekers and Janssens, 2008), and (iii) the critical level policy when demand volume is large, only it has been analyzed by Escalona and Ordóñez (2015) for a single DC. Therefore, to the best of our knowledge, there does not exist previous works that integrates differentiated service levels in the optimal configuration of a network distribution for fast-moving items using critical level policy.

The objective of this paper is determine the optimal configuration of a distribution network for fast moving items where a rationing inventory policy is used to provided differentiated service levels in terms of product availability to two demand classes (high and low priority). The optimal design of the distribution network should determine the number and location of distribution centers and the allocation of demand to DC, while meeting required service levels, so that fixed installation costs, transportation costs, and storage costs are minimized. We assume at each DC: (i) a continuous review (Q, r) policy, with a critical threshold value C, where Q is the fixed lot size, r is the reorder point and C denote the critical level for rationing the low priority class; (ii) normally distributed demand as a approximation to fast-moving items demand; and (iii) service level type I as service level measure. We formulate the location-inventory model with differentiated service levels, denoted (**P0**), as an MINLP problem with chance constraints and nonlinear objective function. The chance constraints of (**P0**) correspond to the service levels constraints. We observe that the location-inventory model with a single service level is a relaxation of (**P0**). We reformulate the location-inventory model with a single service level as a conic quadratic mixed integer program from which we obtain a lower bound of (**P0**). Using the resulting configuration of the relaxation of (**P0**) in terms of location and allocation variables we obtain the optimal control parameters of the critical level policy at each DC. The result is an upper bound (feasible solution) for the problem (**P0**). Furthermore, we propose a method to improve the solution based in the risk pooling effect. Computational results show that the best feasible solution is a good-quality solution, in which the maximum gap is 2.7%, and that the benefit of using a critical level policy in the configuration of a distribution network is greater when the holding cost per unit and unit time is high, and/or when the difference between the preset service levels for high and low priority class is high. The main contributions in this paper can be summarized as follows: (i) we address for the first time the modeling and solution of a supply chain design problem of fast moving items that considers the ability of the distribution network to provide and fulfill different service levels in term of product availability, (ii) we demonstrate that under no demand for one of the classes, the (Q, r, C) policy is equivalent to the traditional (Q, r) policy and (iii) the service level constraints, under rationing, remain valid under no demand for one of the classes.

The rest of this paper is structured as follows. In Section 2 we discuss relevant results in the literature. In Section 3 we formulate the service level constraints, the cost function and the model that integrates location, inventory and service levels. In Section 4, we describe the solution approach. We present our numerical experiments to evaluate the quality of the proposed solutions in Section 5. Section 6 presents our conclusions and future extensions to this work.

2. Related work

The traditional structure of Facility Location Problem (Erlenkotter, 1978) does not consider the relationship between location and inventory control decisions, nor its impact on the distribution network configuration. This is because the distribution network design is solved sequentially, by first solving the location problem and then the inventory problem. This is related to the natural separation between strategic and tactical decision making. However, when these decisions are addressed separately, it often results in suboptimal solutions. In the last decade there has been a strong move towards integrated models of inventories and location. These models simultaneously determine the location of the DCs that will be opened, the allocation of customers to DCs and the optimal parameters of the inventory policy so as to minimize the total system cost. A comprehensive characterization in location-inventory models can be found in Sadjadi et al. (2015).

Our work focuses on location inventory models that integrate the service level, in terms of product availability, in its formulation. In this sense, Daskin et al. (2002) study a location-inventory model that incorporates fixed facility location cost, ordering, holding and safety-stock inventory cost at the DCs, transportation costs from the supplier to the DCs, and local delivery costs from the DCs to the customers. The main difficulty of this model is that the inventory costs at each DC are not linear respect to customer assignments. The model is formulated as a nonlinear integer program and solved by Lagrangian relaxation for a special case in which the ratio between the variance and expected demand is constant for all customers. Shen et al. (2003) analyze the same problem as Daskin et al. (2002). Their work restructures the model into a set-covering integer programming model and use column generation to solve the LP-relaxation of the set covering model.

The model of Daskin et al. (2002) and Shen et al. (2003) has been generalized in different directions. For example: Shen (2005) generalizes the model to a multi-commodity case with a general cost function and proposes a Lagrangian-relaxation solution algorithm. Shen (2005) also relaxes the assumption that the variance of the demand is proportional to the mean for all customers and proposes a Lagrangian-relaxation approach using an algorithm proposed by Shu et al. (2005). Shen and Daskin (2005) introduce a service level element in the model through the distance coverage and propose a weighting method and a heuristic solution approach based on genetic algorithms. Snyder et al. (2007) present a stochastic version of the model. Ozsen et al. (2008) study a capacitated version of the model. Miranda and Garrido (2004) also study a capacitated version of the model and propose a Lagrangian-relaxation solution algorithm. You and Grossmann (2008) relax the assumption that each customer has identical variance-to-mean ratio, reformulating the INLP model as a MINLP problem and solve it with