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On the effect of inventory policies on distribution network design with several demand classes

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ABSTRACT

This paper studies the effect of several inventory policies on the design of a distribution network for fast-moving items able to provide differentiated service levels in terms of product availability for several demand classes. We consider the distribution network design problem when the *global round-up*, *single class allocation*, *local separate stock*, *local round-up*, and *critical level* inventory policies are used. We show how to formulate these problems as conic quadratic mixed-integer problems and prove that the critical level policy provides the lowest cost distribution network design. Further results and a computational study show how these different models compare in practice.

1. Introduction

Several types of inventory policies can be implemented in a distribution network of fast-moving consumer goods (FMCG) to deal with different service requirements in terms of product availability. Escalona et al. (2015) classified these policies into two types when a distribution network observes demand from several classes of customers, where each class demand is a group of customers with the same preset service level. The first group imposes general service conditions over the entire network and the second group imposes conditions on the operation of the inventory system at each distribution center (DC). The first policy group includes the *global round-up policy* (GRU policy), which sets the service level of the entire distribution network based on the highest priority class, and the *single class allocation* (SCA policy), where each DC serves a single demand class. The second policy group includes: the *local separate stock policy* (LSS policy), according to which each DC serves the demand assigned to it from a common stockpile and uses separate safety stocks for each demand class; the *local round-up policy* (LRU policy), in which each DC serves all demand assigned to it from a common stockpile and sets the safety stock as the maximum among the sets of classes assigned to it; and the *local critical level policy* (LCL policy), in which each DC serves the demand assigned to it from a common stockpile and uses rationing to provide differentiated service levels.

To the best of our knowledge, only the critical level policy has been used to design a distribution network able to provide differentiated service levels to different demand classes. This policy is an efficient way of providing differentiated service levels that outperforms the round-up and separate stock policies in a FMCG single-echelon system Escalona et al. (2017b,a). However, we have no evidence that the critical level policy has the best performance when designing a distribution network that observes demand from several classes of customers with different service level requirements. In addition, it seems surprising that only the inventory policy that minimizes total cost in a single-echelon is used in designing a distribution network that can deal with different service level

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requirements. Therefore, the SCA, LSS, or LRU policies should also be considered owing to customer configurations, security, the existence of contracts, image, or simplicity.

The objective of this paper is to expand the design alternatives of distribution networks that provide differentiated service levels to different demand classes. We do so by modeling and solving the SCA, LSS, and LRU policies. Furthermore, we compare these models, including GRU and LCL policies, to establish the demand configuration and spatial distribution of customer classes that make each design alternative attractive. For each policy, we formulate an integer non-linear model (INLP) proving various relations between them, e.g., the location-inventory model using GRU, LSS, or LRU policies are lower bounds of the SCA policy. We show how to formulate GRU, SCA, LSS, and LRU models as conic quadratic mixed-integer models (CQMIPs) that can be solved using standard optimization solvers. Finally, using different configurations of demand and spatial distribution of customer classes, we establish the most likely order relationship of these policies in terms of total cost.

The research questions we answer in this paper are: (i) Are there alternative ways to design a supply chain that provides different service levels in terms of product availability, which have not been previously analyzed? (ii) If so, is it possible to prove total cost order relations between them?; and (iii) what are these order relations, or the most likely ones, under different configurations of demand and spatial distribution of customer classes?

The rest of this paper is structured as follows. In Section 2, we discuss relevant results in the literature. In Section 3, we present the mathematical programming models for each policy. In Section 4, we show how to formulate the models as CQMIPs. In Section 5, we explore total cost order relations among the policies. In Section 6, we report computational results. Finally, in Section 7, we conclude with managerial insights and future extensions to this work.

2. Literature review

In the last decade, there has been a trend towards integration of inventory and location decisions, because when these decisions are addressed separately it often results in sub-optimal solutions (see Farahani et al., 2015). These integrated models determine at the same time which DCs will be opened, their location, and customer allocations to them, how much inventory to keep and the optimal parameters of the inventory policy in each DC, while minimizing the total cost of the system. A comprehensive review in location-inventory models can be found in Farahani et al. (2015) and a characterization can be found in Sadjadi et al. (2015).

There is a rich body of literature on location-inventory problems that consider the ability of the distribution network to guarantee a desired service level in terms of product availability. Daskin et al. (2002) incorporated safety stocks into their location-inventory model such that the probability of a stockout at each DC is equal to some preset service level. They considered the same preset service level for all the DCs. The model is formulated as a INLP and solved by Lagrangian relaxation. The model of Daskin et al. (2002) has been reformulated and extended in a number of ways by relaxing one or more of their underlying assumptions. The immediate generalizations are the capacitated versions studied by Miranda and Garrido (2004) and later by Ozsen et al. (2008), the multi-commodity version studied by Shen (2005), and the stochastic version studied by Snyder et al. (2007). Other extensions were given by Sourirajan et al. (2007) in which the assumption of identical replenishment lead time was relaxed, Shen and Qi (2007) who considered the shipment from a DC to its customers using a vehicle routing model instead the linear direct shipping of Daskin et al. (2002),Shahabi et al. (2014) who relaxed the assumption of customer demand independence. Some reformulations of the Daskin et al. (2002) model include the set-covering integer programming model of Shen et al. (2003) solved using column generation, the mixed integer non-linear problem (MINLP) of You and Grossmann (2008) solved using heuristic method and a Lagrangian relaxation algorithm, and the CQMIP of Atamtürk et al. (2012). Using a different approach, Miranda and Garrido (2009) proposed a two-stage heuristic approach to determine the distribution network optimal preset service level using a known unit penalty cost for unfulfilled demand. The first step optimizes the preset service level and the second step optimizes the location and inventory decisions. All the above authors considered the same preset service level for the distribution network, i.e., they considered only one demand class because all customers require the same service level.

Our work focuses on a location-inventory model able to provide differentiated service levels in terms of product availability for several demand classes. In this context, Escalona et al. (2015) analyzed a location-inventory model with differentiated service levels, in which the DCs observe demand from two classes of customers, high and low priority. To provide differentiated service levels, they assumed, at each DC, a continuous review (Q,r,C) inventory policy and that the service level provided by a DC is measured by the probability of satisfying the entire demand of each class assigned to the DC during a replenishment cycle from on-hand inventory. The location-inventory model with differentiated service levels is formulated as a MINLP with chance constraints and the authors propose a decomposition heuristic to solve it. Using a different approach, Berman et al. (2012) considered a location-inventory model where the DCs operate under a periodic review (R,S) policy, i.e., where a replenishment order is placed every R periods (review range) such that the inventory position reaches S. Berman et al. (2012) included differentiated shortage costs for each DC in their model. This allows the service level provided by different DCs to be different. The model is formulated as an INLP and solved with Lagrangian relaxation using the procedure proposed by Daskin et al. (2002). Liu et al. (2010) studied a capacitated location-inventory model that assigns online demands to regional warehouses currently serving in-store demands in a multi-channel supply chain. Each regional warehouse provided differentiated service levels using an order-up-to inventory policy with differentiated shortage costs. The model is formulated as an INLP and a Lagrangian relaxation-based procedure is proposed to solve it. Tsao et al. (2012) studied a location-inventory problem for designing a distribution network with several local DCs and retailers. Each local DC operate under a continuous review (Q,r) policy with type I service level where the preset service level is different for each local DC. They develop a continuous approximation approach, with the motivation of solving larger-scale problems.

In summary, only Escalona et al. (2015) considered a location-inventory model when a distribution network observes demand

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