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# A parameter-tuned genetic algorithm to optimize two-echelon continuous review inventory systems

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ABSTRACT

This paper deals with a two-echelon inventory system for a non-repairable item where the system consists of one warehouse and $m$ identical retailers and uses continuous-review $(R, Q)$ ordering policy. To find an effective stocking policy for this system, a mathematical model with the objective of minimizing the total annual inventory investment subject to constraints on the average annual order frequency, expected number of backorders, and budget is formulated. The mathematical model of the problem at hand is shown to be nonlinear integer-programming and hence a parameter-tuned genetic algorithm is proposed to solve it efficiently. A numerical example is provided at the end to illustrate the applicability of the proposed methodology.



## 1. Introduction

Successful inventory management is recognized as a crucial activity to increase operational efficiency across competitive business, to improve customer service, and to reduce inventory costs at different locations of a supply network. One of the most important aspects of inventory management that has vital role in supply chain operations is the distribution of goods in multi-echelon inventory systems.

The multi-echelon inventory systems are becoming more prevalent and have begun to draw more attentions from both practitioners and academicians in many industries and communication networks. For instance, the military's usage of multi-echelon knowledge achievements is quite well known and air force used a model for a multi-item, multi-echelon, multi-indenture inventory system as a method to compute recoverable spare stock level for the F-15 weapon system (Muckstadt, 1973).

Multi-echelon spare parts inventory systems have been discussed broadly in the literature. METRIC, one of the earliest models in this topic is a multi-echelon technique for recoverable item presented by Sherbrooke (1968). The objective of this mathematical based-depot supply system model is minimizing expected backorders subject to budget constraints with compound Poisson demand. He also approximated outstanding orders at the retailers. According to this study, the appropriate policy for high-cost, low-demand items is $(s-1, s)$.

Deuermeyer and Schwarz (1981) developed a model based on an exact, single facility $(R, Q)$ model of Hadley and Whitin (1963) to analyze service level in a system consisting of one warehouse and a number of identical retailers. Svoronos and Zipkin (1988) proposed several refinements of this model in a multi-echelon inventory system. They approximated each facility as a single location and calculated the mean and variance of the warehouse and retailer lead-time demand. Graves (1985) presented a multi-echelon inventory model with the failures generated by the compound Poisson process and deterministic shipment time from the repair depot to each site for a repairable item with one-for-one replenishment. He also presented an approximation for the steady-state distribution of net inventory level with ample serves at the repair depot and determined the average and the variance of outstanding orders at the retailers.

Axsäter (1990) presented a simple solution procedure for a two-echelon inventory system with one-for-one replenishment, constant lead-time, and independent Poisson demand at retailers. He used an inventory cost function and focused directly on evaluating the average costs. Furthermore, Axsäter and Zhang (1996) considered a two-echelon inventory system with one warehouse and a number of identical retailers with constant transportation time and compound Poisson demand at retailers. They provided a simple recursive procedure for the evaluation of holding and shortage costs at different control policies. DeBodt and Graves (1985) presented an approximate model to minimize the expected costs including a fixed ordering cost, an echelon inventory holding cost for each level, and a back order cost for end item in the

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multi-echelon inventory system controlled by continuous review policy. Svoronos and Zipkin (1991) described a simple technique to approximate steady state behavior in a multi-echelon with one-for-one replenishment and stochastic transit times of the parts between locations.

Hopp, Spearman, and Zhang (1997) formulated a constrained optimization model in a single location controlled by $(R, Q)$ policy and developed three heuristic to solve it. The objective of this model was minimizing total inventory investment subject to constraints on order frequency and customer service. Axsäter (2000) presented a method for exact evaluation of control policies that provide the complete probability distributions of the retailer inventory levels in a two-echelon inventory system consisting of one central warehouse and $N$ retailers. This system is controlled by different continuous review $(R, Q)$ policies with constant transportation times and independent compound Poisson demand processes at retailers.

Seo, Jung, and Hahm (2001) developed an optimal reorder policy to utilize centralized stock information for a two-echelon inventory system consisting of one warehouse and multiple retailers controlled by continuous review batch ordering policy. Axsäter (2001) evaluated a technique where a high-demand system is approximated by a low-demand system in a two-echelon inventory system with stochastic demand. Marklund (2002) investigated a two level distribution system consisting of one warehouse and a number of non-identical retailers. In order to control the replenishment process at the warehouse, he introduced a new policy by centralized information in which retailers implement continuous review $(R, Q)$ control policies. He also presented a method for exact evaluation of the expected inventory holding and backorder costs for the system. Axsäter (2003) considered a two-echelon distribution inventory system consists of a central warehouse and a number of retailers controlled by continuous review installation stock $(R, Q)$ policies. He presented a simple method that uses normal approximations for the retailer demand and the demand at the warehouse in order to approximate optimization of the reorder points.

Kiesmüller, de Kok, Smits, and van Laarhoven (2004) developed analytical approximations based on asymptotic result from renewal theory for performance characteristics of a divergent multi-echelon network controlled by continuous review $(s, nQ)$ installation stock policies under compound renewal demand. Caglar, Chung-Lun, and Simchi-Levi (2004) investigated a two-echelon, multi-item spare parts inventory system and presented a mathematical model with the objective of minimizing the system-wide inventory cost subject to constraint on response time at each field depot. They also used a heuristic algorithm to solve it efficiently.

Axsäter (2005) determined warehouse backorder cost and provided a newly decentralized way with optimizing sum of expected holding and backorder costs to warehouse and retailers regarding their reorder point in a two-echelon distribution system with installation stock $(R, Q)$ inventory control policy. Seifbarghi and Jokar (2006) developed an approximate cost function to find optimal reorder points of given batch sizes in a two-echelon inventory system consisting of a warehouse and many identical retailers with lost sales and independent Poisson demands controlled by continuous-review policy. Jokar and Zangeneh (2006) developed a model in a two-echelon inventory system consisting of one warehouse, several retailers, and two items with lost sale and demand substitution. They also presented a heuristic algorithm to find cost effective based stock policies. Al-Rifai and Rossetti (2007) investigated a two-echelon inventory system consisting of a central warehouse and a number of identical retailers controlled by $(R, Q)$ inventory policy for non-repairable items. The objective function of their model is minimizing the total annual inventory investment subject to constraint on average annual order frequency and expected number of backorder. They solved the model by decomposing the system by echelon and location. They also derived expressions for the inventory policy parameters and developed an iterative heuristic optimization algorithm. Haji, Neghab, and Baboli (2008) considered a two-echelon inventory system consisting of one warehouse and a number of non-identical retailers with Poisson demand in which warehouse is facing a uniform and deterministic demand ordered by each retailer and introduced a new ordering policy for inventory control.

In this paper, an inventory system is considered in which there is a network of inventory holding facilities organized into two levels. More specifically, the problem that is considered consists of a two-echelon non-repairable item inventory system of one warehouse and $m$ identical retailers. We consider the reorder policy for a continuous-review distribution system, utilizing the total inventory investment in both echelons subject to constraints on the average annual order frequency and expected number of backorder. The dominant model of this system in practical applications is based on the assumptions of unlimited warehouse and retailers' budget. These assumptions can lead to a serious underestimating of the spare parts requirements. To deal with this dilemma, warehouse and retailers' budget constraints are also considered. Considering a new objective function and several constraints makes the model more applicable to real-world inventory control systems. In addition, the solution method that is based on a parameter-tuned meta-heuristic algorithm seems more compact and simpler than the ones provided in earlier studies.

The remainder of the paper is organized as follows. In Section 2, the problem is defined precisely. Section 3 is dedicated to the mathematical formulation of the problem. Comprehensive explanation of the methodology proposed to solve the model is discussed in Section 4. In Section 5, parameter adjustment and numerical example are given. Finally, conclusions are provided and future research directions are proposed in Section 6.

## 2. Problem definition

Consider a two-echelon inventory system of non-repairable items consisting of a warehouse and $m$ identical retailers in which all installations use continuous review $(R, Q)$ policy to replenish their inventories. The system is assumed to work in the following manner:

At the beginning of a period, an outside supplier with unlimited capacity delivers the bulk of inventory directly to the warehouse. The warehouse allocates the stock to the retailers. The demand at a retailer level is either satisfied or backordered. Backorders, both at the warehouse and retailer levels, are filled according to the first in first out (FIFO) policy. At both echelon, $(R, Q)$ ordering policy continuously monitors the inventory position (minus backorders plus on hand and on order inventory) for each item. It means that as soon as the stock level declines to the reorder point $R$, an order of batch size $Q$ is placed. Note that the real lead-time at the retailer level consists of two components: retard and delay times. Retard time is the time between placement of an order by a retailer and the release of a batch by the warehouse (Svoronos & Zipkin, 1988). Delay time is due to the ordering and transportation times. As a result, the effective lead-time at the retailer level is the sum of the waiting time due to a lack of stock in the warehouse (retard) and the transportation and ordering times (delay). In this paper, we assume that the retard time at the retailer level is zero. In other words, the real lead-time at the retailer level is equal to retailer's delay. Fig. 1 provides a pictorial representation of the system under study.

In order to define the problem precisely, a set of critical assumptions are required as follows: