Computers & Industrial Engineering 124 (2018) 88–99

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Optimal randomized ordering policies for a capacitated two-echelon distribution inventory system

Taher Ahmadi[a,b], Masoud Mahootchi[c,*], Kumaraswamy Ponnambalam[d]

[a] Amirkabir University of Technology, Iran
[b] Eindhoven University of Technology, The Netherlands
[c] Amirkabir University of Technology, Tehran, Iran
[d] University of Waterloo, Canada

ARTICLE INFO

Keywords:
Multi-echelon inventory system
Periodic review
Randomized ordering policy
Stationary and non-stationary demand patterns
Simulation-based optimization

ABSTRACT

We propose a new formulation for controlling inventory in a two-echelon distribution system consisting of one warehouse and multiple non-identical retailers. In such a system, customer demand occurs based on a normal distribution at the retailers and propagates backward through the system. The warehouse and the retailers have a limited capacity for keeping inventory and if they are not able to fulfill the demand immediately, the demand will be lost. All the locations review their inventory periodically and replenish their inventory spontaneously based on a periodic Randomized Ordering (RO) policy. The RO policy determines order quantity of each location in each period by subtracting corresponding on-hand inventory at the beginning of that period from a deterministic decision variable. We propose a mathematical model to find the optimal RO policies such that an average systemwide cost consisting of ordering, holding, shortage, and surplus costs is minimized. We use the first and second moments of on-hand inventory as auxiliary variables. A remarkable advantage of this model is calculating the immediate fill rate of all locations without adding new variables and facing the curse of dimensionality. Using two numerical examples with stationary and non-stationary demand settings, we validate and evaluate the proposed model. For validation, we simulate the optimal RO policy and demonstrate that the optimal first and second moments of on-hand inventory from our model reasonably follow the corresponding moments obtained through simulation. Furthermore, we evaluate the RO policy by drawing a comparison between the optimal RO policy and the optimal well-known (R, s_n^*, S_n^*) policy. The results confirm that the RO policy could outperform (R, s, S) policy in terms of the average systemwide annual cost.

1. Introduction and brief literature review

A supply chain is a network in which procurement of raw material, transformation of raw material to intermediate and finished products, and distribution of finished products to customers are performed (Lee & Billington, 1993). In different stages of such networks, inventory may be kept in the form of raw material, work-in-process, and finished product to confront the uncertainties. In many industries, inventory is the second largest cost after production costs (Ertogral & Rahim, 2005). Ganeshan (1999) states a fact that between 20% and 60% of the total assets in a company is assigned to inventory. Therefore, one of the main goals of industries might be to find the optimal policies to control inventories such that the respective costs are minimized. In other words, to stay competitive in today's fast changing business environment, companies should have an efficient control policy for managing their inventories.

Inventory management has been studied for more than half a century. After developing the well-known policy of Economic Order Quantity (EOQ) proposed by Haris (1913) for managing inventory in a single echelon inventory system, many researchers and practitioners have investigated this issue using different operating policies under various assumptions for single and multi-echelon inventory systems. The study of multi-echelon inventory management dates back to the 1960s, when Clark and Scarf (1960) investigate a two-echelon serial inventory system and presented the optimality conditions of $(S-1, S)$ policy.

Moreover, the study of multi-echelon distribution systems dates back to the 1960s, when Sherbrooke (1968) investigated the $(S-1, S)$ policy, called METRIC, for a one warehouse multi-retailer (OWMR) distribution system. As an extension to Sherbrook's model, Graves (1985) proposed an exact expression for the expected value and the variance of unsatisfied orders at the retailers under $(S-1, S)$ policy.

* Corresponding author.
E-mail address: mmahootchi@aut.ac.ir (M. Mahootchi).

https://doi.org/10.1016/j.cie.2018.06.032
Received 10 April 2017; Received in revised form 16 January 2018; Accepted 24 June 2018
Available online 03 July 2018
0360-8352/

Table 1
Literature review on the OWMR distribution system.

Authors	Demand type	Ordering policy	Shortage	Review	Retailers
Sherbrooke (1968)	Poisson	$(S-1, S)$	B	C	I
Graves (1985)	C. Poisson	$(S-1, S)$	B	C	I
Schwarz, Deuermeyer, and Badinelli (1985)	Poisson	(r, Q)	B	C	I
Park and Kim (1989)	Normal	$(R, T)/(r, Q)$	B	C/P	I
Axsäter (1990)	Poisson	$(S-1, S)$	B	C	I
Schneider and Rinks (1991)	Stochastic	(s, S)	B	P	I
Axsäter (1993)	Poisson	(r, Q)	B	C	I
McGavin, Schwarz, and Ward (1993)	Poisson/Gamma	Two-interval	L	P	I
Schneider et al. (1995)	Stochastic	(s, S)	B	P	I
Graves (1996)	Poisson	$(S-1, S)$	B	C	I
Axsäter (1998)	Poisson	(r, Q)	B	C	N
Ganeshan (1999)	Poisson	(r, Q)	B	C	I
Cachon and Fisher (2000)	Stochastic	(r, nQ)	B	C	I
Andersson and Melchiors (2001)	Poisson	$(S-1, S)$	B/L	C	I
Cachon (2001a)	Poisson	(r, Q)	B	C	N
Cachon (2001b)	Stochastic	(r, nQ)	B	C	I
Axsäter (2003)	C Poisson	(r, Q)	B	C	I
Jokar and Seifbarghy (2006)	Normal	(r, Q)	B/L	C	I
Seifbarghy and Jokar (2006)	Poisson	(r, Q)	B/L	C	I
van Houtum (2006)	Stochastic	$(S-1, S)$	B	P	I
Al-Rifai and Rossetti (2007)	Poisson	(r, Q)	B	C	I
Axsäter, Olsson, and Tydesjö (2007)	C. Poisson	(r, Q)	B	C	I
Gallego, Özer, and Zipkin (2007)	Poisson/C. Poisson	$(S-1, S)$	B	C	I/N
Hill, Seifbarghy, and Smith (2007)	Poisson	$(nr, (n-1)Q)$	L	C	I/N
Monthatipkul and Yenradee (2008)	Stochastic	IDP	L	P	I
Haji, Neghab, and Baboli (2009)	Poisson	$(S-1, S)$	L	C	N
Chu and Shen (2010)	Stochastic	Power-of-two	B	P	N
Geng, Qiu, and Zhao (2010)	Stochastic	Up-to-level	L	P	I/N
Duc, Luong, and Kim (2010)	Stochastic	Up-to-level	B	P	I
Lee and Jeong (2010)	Deterministic	Power-of-two	None	P	I
Atan and Snyder (2012)	Deterministic	$(S-1, S)$	B	P	I/N
Yang, Chan, and Kumar (2012)	Deterministic	Batch size	B	P	I
Basten and van Houtum (2013)	Poisson	$(S-1, S)$	B	C	I
Wang (2013)	Poisson	Up-to-level	B	P	I
Berling and Marklund (2014)	Normal/C. Poisson	(r, nQ)	B	C	I
Howard, Marklund, Tan, and Reijnen (2015)	Poisson	$(S-1, S)$	B/L	C	I/N
Mateen, Chatterjee, and Mitra (2015)	Normal	Up-to-level	B	P	I
Gayon, Massonnet, Rapine, and Stauffer (2016)	Deterministic	JRP	B/L	P	I
Stenius, Karaarslan, Marklund, and De Kok (2016)	C. Poisson	(r, nQ)	B	C	I
Feng, Fung, and Wu (2017)	Stochastic	Up-to-level	L	P	I
Turan, Minner, and Hartl (2017)	Stochastic	Batch size	L	–	I
Verma and Chatterjee (2017)	Deterministic	Batch size	None	P	N

C. Poisson: compound Poisson; L: lost sale; B: backorder; C: continuous; P: periodic; I: identical; N: non-identical.

Afterwards, researchers have studied the OWMR distribution system under different settings. We summarize all the relevant work in the literature of the OWMR distribution system in Table 1. Although the literature on the OWMR distribution systems is rich, there are still some restrictions to be relaxed.

As illustrated in Table 1, the majority of researchers have considered unsatisfied demand as backordered demand, while in reality approximately 85% of unsatisfied demand is lost (Bijvank & Vis, 2011). Modeling complexity of the lost demand situations is one of the reasons that the majority of researchers have considered backordered demand situations which are less realistic compared to similar situations with lost demand. Moreover, in a real distribution system, retailers may have different characteristics such as demand size, capacity limitation, ordering policy, etc. In this case, dealing with all the retailers in an OWMR system identically is a simplifying assumption that makes the problem less realistic. Table 1 shows that this simplification has been a common assumption in the literature. Furthermore, considering capacity limitation for all the locations (i.e., warehouse and retailers) is not a straightforward task.

In this study, we consider an OWMR distribution system consisting of one-warehouse and N non-identical retailers as illustrated in Fig. 1. In such a system, all locations, i.e., the warehouse and all the retailers, monitor their inventory periodically. Customer demand happens just at

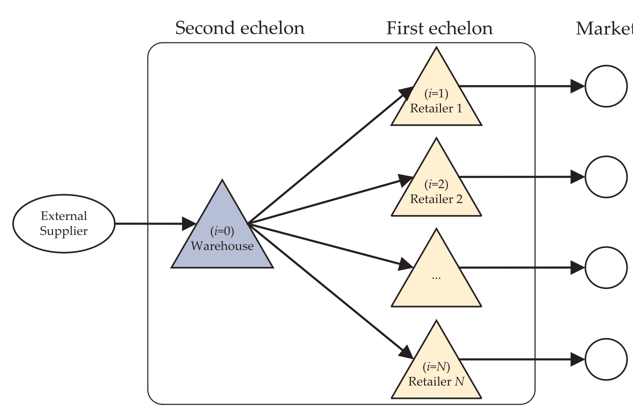

Fig. 1. An OWMR distribution system.

the lowest echelon where the retailers are located. We would like to contribute to the literature of the OWMR distribution systems by providing a new mathematical model under the following assumptions:

(1) Lost sale situation at all the locations,
(2) Non-identical retailers,