European Journal of Operational Research 262 (2017) 944–953

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

Reduce shortage with self-reservation policy for a manufacturer paying both fixed and variable stockout expenditure

Boray Huang[a], Andy Wu[b,*]

[a] Department of Industrial Engineering & Innovation Sciences, Eindhoven University of Technology, Netherlands
[b] Department of Marketing, National Chung Hsing University, No. 250, Guoguang Rd., South Dist., Taichung 402, Taiwan, ROC

ARTICLE INFO

Article history:
Received 1 September 2015
Accepted 22 March 2017
Available online 31 March 2017

Keywords:
Markov processes
Production management
Reservation policy
Fixed and variable shortage cost

ABSTRACT

This study considers a single item make-to-stock system with continuous-time production and inventory controls to meet bulk demand with an exponential inter-arrival time. A key issue in this system is the non-convex shortage cost consisting of fixed and variable expenditures when the demand is not fully satisfied. We propose a *self-reservation policy* by building a Markov Decision Process to minimize the overall cost. We find that the optimal production control is still a base stock policy, but the structure of the optimal self-reservation policy is very complicated. However, if the effective outstanding variable shortage cost is sufficiently large, the optimal self-reservation policy has an easy form of “Reserve All or Nothing.” Our numerical examples indicate the optimal policy may reduce the total average cost by 47% on average.

1. Introduction

This research studies a continuous-time make-to-stock (MTS) model for a manufacturer who needs to handle bulk demand with shortage expenditure including both fixed and variable costs. The fixed shortage cost can be a part of customers’ goodwill loss (Dahlgaard, Kristensen, & Kanji, 1992) or a monetary penalty enforced by supply agreements in many industries. For instance, vendors of Walmart and Carrefour in China may be fined if stockout happens: in addition to a high cost to expedite the delayed fulfillment of an order, these vendors need to pay a fixed penalty, usually 10% of the order value (see Yan, 2011). In Taiwan, pharmaceutical contractors may be liable for a fixed fee of US$1000 to compensate for their customers’ additional expenditure in urgent shipment from other suppliers if their orders are not satisfied in time.

Some manufacturers also use spot buying to cover their inventory shortage (Wang & Fu, 2014). Such maneuvers incur fixed and variable expenditures in negotiating, monitoring, and expediting the emergency purchasing process (Johnson, Leenders, & Flynn, 2011). For instance, Kamiya Saw, a well-known saw blade manufacturer in East Asia, supplies mower blades to well-known home improvement supplies providers like Bosch and Home Depot. Its demand is usually lumpy because of the volume restriction in container shipment. On the other hand, its customers’ replenishment time is stochastic. Kamiya dedicates a make-to-stock production line to meet the demand from these important buyers. If Kamiya fails to fulfill an order in time, emergency purchase from the spot market is conducted to cover the shortfall. In addition to a higher outsourcing cost per unit of shortfall, there is usually a fixed expenditure in the process of urgent procurement.

Stories like Kamiya motivate this research. It is known that the existence of fixed shortage penalty makes the total cost function non-convex with respect to the shortfall. When the production setup cost is neglectible and the shortage cost is proportional to the shortfall, it is known that the optimal production policy is a base stock policy (Scarf, 1960; Veinott & Wagner, 1965). However, when the demand is lumpy and the shortage cost includes a fixed part, the properties of the optimal production and inventory control is still unclear to our best knowledge.

As stockout incurs additional fixed costs, we propose a *self-reservation policy* along with the production control: in the occurrence of stockout, the manufacturer can place an urgent order whose size is larger than the shortfall, and reserve some inventory for the future demand. Fig. 1 illustrates a scenario to depict the decisions of the self-reservation policy. If an order in size of 10 units is placed to a manufacturer who has 3 units on hand, stockout appears to be inevitable. Apart from urgently acquiring the shortfall (7 units) through spot markets or overtime production, the manufacturer has an option to acquire more and keep the remaining stock after fulfilling the demand. The manufacturer can take this chance to quickly raise its inventory position and reduce

* Corresponding author.
E-mail address: andywu@nchu.edu.tw (A. Wu).

http://dx.doi.org/10.1016/j.ejor.2017.03.063
0377-2217/

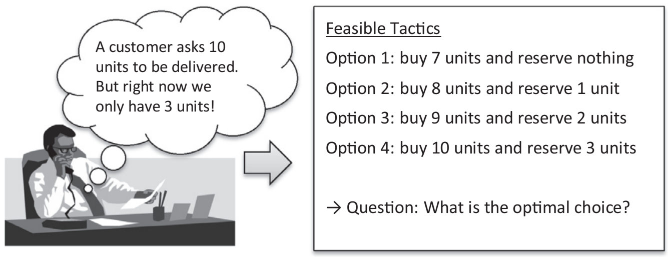

Fig. 1. An example of self reservation policy.

the chance of stockout for future demand. Is it worthy to do so? If yes, how much urgent inventory should the manufacturer acquire in the case of stockout?

The main contribution of this study is investigating the optimal production control and introducing the self-reservation policy to a manufacturer facing lot-size demand with a shortage cost including a fixed penalty. The problem is not rare in practice but existing literature provides little insight. We show that the optimal production control is still a base stock policy, and the self-reservation strategy can be significantly beneficial when a fixed penalty exists. Although the structure of the optimal self-reservation policy is complicated, we find that, if the effective variable shortage cost is sufficiently large, the optimal self-reservation policy has a simple form, i.e., “Reserve All or Nothing,” which is easy to implement in practice.

2. Literature review

Three lines of literature are relevant to this research: (1) inventory replenishment problems considering linear or quasi-convex shortage/purchasing costs, (2) multiple sourcing and emergency purchasing, and (3) lumpy demand and inventory rationing. We briefly compare our research with these strands of literature.

In traditional inventory replenishment problems, a linear shortage cost is commonly assumed where the total shortage cost increases proportionally to the shortfall. Some studies consider the shortage cost as a penalty for each stockout unit (with the dimension of $/unit,) which is independent of the shortage period. Others consider the shortage cost which accumulates over shortage period (with the dimension of $/period,) see Chen and Zhang (1993), Hadley and Whitin (1963), and Chao and Zhou (2009). Zheng and Federgruen (1991), indicate that it is better for the shortage cost function to be quasi-convex or else the optimal policies may not have simple forms. Rosling (2002, 2007) further specifies the requirement on the demand distribution for the cost function to be quasi-convex. In our study, the shortage cost includes a fixed term which is independent of shortfalls. After considering the fixed term, the cost function is neither continuous nor quasi-convex with respect to the inventory position, making the analysis more complicated than the traditional models.

This research is also related to the classical lot-sizing problems with fixed ordering/setup costs. For instance, see EOQ/EPQ models in deterministic demand processes and the (s, S) optimality in stochastic ones by Scarf (1959), Veinott and Wagner (1965), Wager (1972). When the production capacity is limited, Chen and Lambrecht (1996) investigate the X–Y band structure of the optimal production policies. Chen (1996) further introduces (C,K)-convexity to tighten the X–Y band boundaries. Compared with these works, we assume that the fixed cost occurs when emergency purchase happens, not at the time the manufacturer starts its in-house production.

The second line of related research is multiple sourcing. The literature dates back to Barankin (1961), who considers a single-period model with emergency orders of a fixed size. The research is later extended to a multi-period model by Fukuda (1964) who shows that dual-base-stock policies are optimal under mild conditions. Veeraraghavan and Scheller-Wolf (2008) introduce a dual-index policy[1] for capacitated systems and use simulation-based optimization to solve the problem. They show the optimal dual-index policy is nearly optimal under stationary demand. Sheopuri et al. (2010) consider two classes of policies that have an order-up-to structure for the emergency and regular supplier respectively. Their policies further improve the performance of dual-index policies. Chen et al. (2012) study a system consisting of two suppliers with fixed order costs. The regular source is unreliable and the reliable one is taken as a backup. They characterize a band structure for the optimal ordering policy and provide bounds on the band to ease the computational burden.

The aforementioned multiple-sourcing literature assumes periodical review systems. For continuous review models, Moinzadeh and Nahmias (1988) consider a dual sourcing problem with deterministic lead times and fixed ordering costs. Their work is based on a standard (r,Q) policy with different order sizes and reorder levels for the two suppliers, and optimizes the four control parameters. Moinzadeh and Schmidt (1991) later assume negligible fixed order costs and consider a (S-1,S) policy for a slow moving but expensive item. Song and Zipkin (2009) investigate a policy similar to Veeraraghavan and Scheller-Wolf (2008), but in a continuous-time framework with multiple suppliers as well as stochastic lead times and demand. They develop closed-form performance measures for a family of policies that utilize real-time supply information and under which the supply system becomes a network of queues.

Due to globalization of supply chains, multiple sourcing problems bring a surge of interest in recent years. We refer to Minner (2003) for further overview of relevant literature. Most of the existing multiple sourcing papers do not assume lumpy demand, while our assumption of demand is not unitary.

The third line of literature addresses the issue of inventory rationing. Under the limited production capacity, inventory rationing policies or admission controls have been extensively studied in revenue management literature. See Frank, Zhang, and Duenyas (2003), Ha (1997a, 1997b) and de Véricourt et al. (2002) for example. Most researches in this line consider unitary demand, which is suitable in business-to-customer (B2C) scenarios. Recent works extend the analysis to business-to-business (B2B) scenarios and take lot-size orders into consideration, e.g., Barankin (1961), Barut and Sridharan (2004, 2005), Huang and Iravani (2006, 2008), Chiang and Wu (2011), Wu, Chiang, and Chang (2010) and Zhou, Lee, and Wu (2011). As with Ha (1997a) and Huang and Iravani (2006), we model the production and reservation controls as a continuous-time Markov Decision Process (CTMDP).

The key of inventory rationing is to discriminate customers and provide different service levels according to their respective contributions. It does not apply to the case where the customers' contributions are homogeneous. In our research, even with equal importance of all customers, the reservation policy can still benefit the manufacturer as it reduces future occurrences of stockout.

In the remaining part of the paper, we construct the CTMDP model in Section 3, and investigate the properties of the optimal production and self-reservation policies in Section 4. In Section 5, a numerical study is performed to demonstrate the benefit of the self-reservation policy. A brief conclusion is made in Section 6.

[1] A dual-index policy uses two state variables (i.e., inventory position of the emergency supplier and the total inventory position), while a single-index policy tracks only one state variable (i.e., the total inventory position).