Journal of Manufacturing Systems 34 (2015) 23–33

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

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

Continuous review inventory model with controllable lead time, lost sales rate and order processing cost when the received quantity is uncertain

S. Priyan*, R. Uthayakumar

Department of Mathematics, The Gandhigram Rural Institute – Deemed University, Gandhigram 624 302, Dindigul, Tamil Nadu, India.

ARTICLE INFO

Article history:
Received 18 January 2013
Received in revised form 10 June 2014
Accepted 3 September 2014
Available online 30 October 2014

Keywords:
Continuous review
Shortage
Crashing cost
Order processing cost
Investment

ABSTRACT

In practice the quantity received may not match the quantity ordered due to worker's strike, rejection during inspection, damage during transportation, human errors in counting, etc. Accordingly, the managers often must make decisions under uncertain quantity received circumstances. In this study, we investigate the continuous review inventory model with shortages include the case where the quantity received is uncertain, in which the lead time, lost sales rate and order processing cost are decision variables. Here, we consider the lead time crashing cost is an exponential function of lead time, and the order processing cost and lost sales rate are logarithmic functions of capital investment. The objective of this study is to minimize the total relevant cost by simultaneously optimizing the order quantity, lost sales rate and order processing cost. In addition, an efficient algorithm is developed to determine the optimal policy, and our approach is illustrated through a numerical example. From the results of numerical example, it can be shown that, the significant savings can be achieved through the reductions of order processing cost and lost sales rate.

1. Introduction

Traditional inventory models assumed that lead time is a constant or random variable which is not a controllable factor. However, in practice, lead time could be shortened by paying an additional crashing cost; in other words, it is controllable. Hsu and Lee [1] stated that this crashing cost could be expenditures on equipment improvement, information technology, order expedite, or special shipping and handling. By shortening lead time, buyers can lower the safety stock, reduce the out-of-stock loss, and improve the customer service level. Thus, in present supply chain and inventory management system, controllable lead time is a key to business achievement and has attracted considerable research attention. Liao and Shyu [2] first devised a probabilistic inventory model in which lead time was the unique decision variable. Later many researchers (see [3–8]) developed lead time reduction inventory models under various crashing cost function and practical situations. The underlying assumption in the above studies was that lead time could be decomposed into n mutually independent components, each with a different but fixed crash cost independent of the lead time. Recently, Hsu and Lee [1] investigated the decisions of replenishment and lead-time reduction for a single manufacturer multiple-retailer integrated inventory system with the assumption of lead time crashing cost is a non-increasing stairstep function of lead time. Later, Yang [9] developed supply chain integrated inventory model with present value and the crashing cost is determined by the length of lead time, which is polynomial form. In contrast to existing inventory models, this paper considers that the crashing cost is an exponential function of lead time.

Order processing cost reduction inventory research has received increasing attentions and hot topic in recent years. However, most of the existing inventory model assumed that order processing cost is fixed. In practice, order processing cost can be controlled and reduced through various efforts such as worker training, procedural changes and specialized equipment acquisition. Initially, Porteus [10] investigated the impact of capital investment in reducing ordering cost on the classical economic order quantity (EOQ) model for the first time. Ouyang et al. [11] discussed lead time and ordering cost reductions in continuous review inventory systems with partial backorders. Later, Chang et al. [12] presented lead time and ordering cost reduction problem in the single-vendor single-buyer integrated inventory model. They considered that buyer lead time can be shortened at an extra crashing cost which depends on

* Corresponding author. Tel.: +91 451 2452371; fax: +91 451 2453071.
E-mail addresses: jaisilpriyan@gmail.com (S. Priyan), uthayagri@gmail.com (R. Uthayakumar).

http://dx.doi.org/10.1016/j.jmsy.2014.09.002
0278-6125/

the lead time length to be reduced and the ordering lot size, as well buyer ordering cost can be reduced through further investment. Recently, Annadurai and Uthayakumar [13] presented and analyzed a probabilistic inventory model under continuous review for the system with controllable lead time and optimal ordering cost caused by investment strategy subject to a service level constraint.

Montgomery et al. [14] is among the first who considered that a fraction of demand is back ordered and the remaining fraction is lost. Ouyang et al. [15] considered an inventory model with a mixture of backorders and lost sales to generalize Ben-Daya and Raouf's [16] model, where the backorder rate is fixed. However, Ouyang and Chuang [17] investigated, a mixture inventory model involving variable lead time and controllable backorder rate. They observe that many products of famous brands or fashionable goods such as certain brand gum shoes (or leather shoes), hi-fi equipment, cosmetics and clothes may lead to a situation in which customers prefer their demands to be backordered when shortages occur. Certainly, if the quantity of shortages is accumulated to a degree that exceeds the waiting patience of customers, some customers may refuse the backorder case. This phenomenon reveals that, as shortages occur, the longer the length of lead time is, the larger the amount of shortages is, the smaller the proportion of customers can wait and hence the smaller the backorder rate would be. Under the situation, for a vendor, how to control an appropriate length of lead time to determine a target value of backorder rate so as to minimize the relevant inventory cost and to increase the competitive edge in business is worth discussing. As a result, Lee [18] assumed that the backorder rate is dependent on the length of lead time through the amount of shortages and let the backorder rate be a control variable. Then, Ouyang and Chuang [19] investigated a continuous review inventory model and presented that the lost sales rate can be reduced by an effective capital investment. In addition, Annadurai and Uthayakumar [20] developed ordering policy for periodic review inventory model with controllable lead time by reducing lost sales rate. Recently, Uthayakumar and Parvathi [21] investigated a two-stage supply chain system with order cost reduction and credit period incentives for deteriorating items.

The above inventory models assumed that the quantity received is the same as the quantity ordered. But in real life circumstances, the quantity received may not match the quantity ordered due to various reasons such as rejection during inspection, damage or breakage during transportation, human errors in counting, transcribing, etc., an example would be one individual recording a 7 on an order form, with a second person interpreting it as a 9 (for more see Silver [22]). Supply chain risk uncertainty can create severe repercussions, thus it is not surprising that research interest in supply chain uncertainty has been growing. Whereas extant inquiry is instructive, there is a lack of investigations that core on supply chain investment decisions when facing high levels of risk uncertainty. Given the prospective dollar value involved in these decisions, an understanding of how these supply chain decisions are made is of significant hypothetical and practical importance. Supply chain and inventory management, with its focus on decision making under conditions of uncertainty, is an appealing hypothetical lens for this enterprise. In essence, supply chain and inventory management declares that managerial decisions core on creating and then exercising or not exercising certain opportunities. Having the flexibility provided by options or decisions is advantageous when facing uncertainty. To the extent that uncertainty surrounds a decision, managers prefer to postpone major investments while maintaining the potential to exercise the option by moving more boldly at some future point. In recent years, researchers have used real options to analyze firms' investments in areas such as research and development, knowledge, and technology.

Noori and Keller [23] developed one-period order quantity strategy with uncertain match between the amount received and quantity requisitioned. They investigated the case where the demand was stochastic, and considered two possible demand distributions: uniform and exponential. For both these demand distributions, they considered the distributions of the amount received to be either normal or gamma. Karlo and Gohil [24] extended silver's model by allowing shortages when the amount received is uncertain. Warrier and Shah [25] offered a lot-size model with partial backordering and partial lost sales when the quantity received is uncertain and units in the inventory are subject to deterioration at a constant rate. Leung [26] developed EOQ formula using the complete squares method, taking into account the scenario where the quantity backordered and the quantity received are both uncertain. Recently, Shah and Gor [27] analyzed the optimal ordering policy in the integrated vendor–buyer inventory system when the input is random. Apart from the aforementioned models, Wu [28] developed a continuous review inventory model with variable lead time when the amount received is uncertain, in which the order quantity, reorder point and lead time are decision variables. From the authors' literature, none of the authors developed inventory model under the assumptions of uncertain received quantity and demand, controllable lead time, order processing cost and lost sales rate. Therefore, this paper intends to fill this remarkable gap in the literature.

In this paper, we attempt to model a continuous review inventory system with controllable lead time and order processing cost, backorder price discount, and we further consider the received quantity is uncertain. We examine a continuous review inventory model in which the buyer offers backorder price discount to his customers with outstanding orders during the shortage period to secure customer orders, and analyze the effects of investment to reduce the order processing cost. We minimize the expected annual total cost per unit time by simultaneously optimizing the order quantity, order processing cost, backorder price discount, and lead time. Additionally, an iterative procedure is developed to find the optimal solution. Finally, the numerical example is given to clarify the solution algorithm and to demonstrate the advantage of implementing the capital investment strategies. Numerical results also indicated that considerable cost savings could be realized through the order processing cost reduction and offering backorder price discount.

The remainder of this study is organized as follows: In Section 2, we provide the fundamental notations and assumptions of this study. Section 3 describes model development. Section 4 describes the solution procedure and algorithm of this study. Numerical example is illustrated in Section 5. Section 6 discuss the numerical results and concludes the study.

2. Notations and assumptions

In order to develop the mathematical model of the problem, let us first introduce the notations and assumptions.

2.1. Notations

D	Average demand per year
Q	Order quantity, a decision variable
Y	Received quantity, a random variable
α	Bias factor which is the expected amount received ÷ amount ordered, $0 < \alpha < 1$
A	Ordering cost per order, a decision variable
A_0	Original ordering cost (before any investment is made)
h	Inventory holding cost per unit per year