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Service level enhancement in newsvendor model

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ABSTRACT

Nowadays, competition in global market forced companies to offer high service levels for customers with high expectations. An important type of service levels that businesses usually use in controlling inventory systems is the fill rate. Typically, in such businesses, a vendor orders a batch at the beginning of an inventory cycle such that a certain expected fill rate is met. An obvious shortcoming of this method of ordering is that the expected fill rate may drop to an unacceptable value during consumption period. This disruption in expected fill rate may lead to significant losses to a business. We, thus, propose a newsvendor model which allows the vendor to place an initial order that satisfies a predetermined fill rate. When the expected fill rate drops to a specific value during consumption, another order is placed to increase the expected fill rate. Propositions are developed to reduce the difficulty of the model and we devise a simple solution method which determines the initial optimal lot size, optimal lot size of the second order, and the reorder point.

1. Introduction

Rapidly changing markets due to the introduction of various products with short lifecycles (newsvendor-type products) led to vigorous competition in today's global markets. In order to compete effectively, inventory systems must provide high service level for customers with increasing expectations (Darwish and Aldaihani, 2015). One of the most commonly used service levels is the expected fill rate which is the ratio of expected sales and expected demand (Chen and Li, 2015). Typically, in inventory systems, a vendor places an order at the beginning of an inventory cycle such that a desired expected fill rate is satisfied. A clear disadvantage of this method of ordering is that the expected fill rate may decline to low and unacceptable value during the consumption period. Thus, this method of ordering would not be appropriate for the real world situations and adjustment must be made. We, in this paper, extend the newsvendor model by allowing the vendor to place a first order that achieves a predetermined expected fill rate, however, when the expected fill rate drops to a certain value, the newsvendor places a second order to enhance the expected fill rate in the remaining portion of the selling period.

In recent years, emergency orders in the context of the newsvendor problem has received a lot of attention. For example, Khouja (1996) introduced a newsvendor model where the vendor can place an emergency order. This model is modified by Lodree, Klein, and Jang (2004) by allowing all shortages to be backlogged. However, the waiting cost is assumed to be a linear function of the shortages. Lodree, Kim, and Jang (2008) extended the later model by considering non-linear waiting cost function. Further, Lee and Lodree (2010) studied the same model but investigated different decreasing backorder rate functions. An important paper along this direction is due to Pando, San-José, García-Laguna, and Sicilia (2013) who relaxed the assumptions regarding the rate functions in Lee and Lodree (2010) by investigating a general backorder rate function. Also, Zheng, Shu, and Wu (2014) discussed a two-stage newsvendor problem with regular and emergency orders. The emergency order can be placed at later time based on more accurate demand forecast. However, the unit cost for the emergency order is higher, and the quantity is limited. Moreover, Yan and Wang (2014) developed a newsvendor model with capital constraint and demand forecast update. They considered a newsvendor who has two instants of ordering from a supplier prior to a selling season. In this model, the newsvendor can improve the forecast by utilizing the observed demand between the first and second orders. Another important extension is due to Weng (2004) who studied a newsvendor-type product in a single-vendor single-buyer supply chain with two ordering opportunities. Moreover, Zhou and Li (2007) discussed an issue similar to Weng (2004) by including inventory cost of the buyer but neglecting the buyer's shortage cost. Furthermore, Zhou and Wang (2009) extended the work of Weng (2004) to the case where the excess demand after the first order is partially backordered and both the

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manufacturer and the buyer share the setup cost of the second order. Another related extension is by Khouja and Vergara (2008) who addressed the use of surplus products at the end of the selling season. In specific, they used rebates to sell the excess inventory at a reduced price. Finally, Khouja (2016) developed an interesting model where he studied the effect of assortment (inability to fulfill consumers' secondary features preference) on the inventory decisions of a newsvendor.

Traditionally, the service level approach has not been discussed in the literature in the context of newsvendor problem. In contrast, the approach is addressed extensively in the literature of inventory models with infinite horizon. For example, Senanayake and Subramaniam (2013) developed an interesting approximation that estimates the customer service levels in automated multiple part-type production lines. Another important paper is by Tajbakhsh (2010) who considered a continuous-review (Q, r) inventory model with a fill rate service constraint and adopted a distribution free approach. He derived closed-form solution for the optimal order quantity and reorder point.

It is true that a vendor may order a quantity such that a desired service level is met at the beginning of a selling period. However, if the inventory system is subjected to high demand at some point(s) in time, the inventory level may decrease such that the desired service level is significantly violated. With current competitive global market, this may threaten the very survival of a company. As such, the service level should be revised during a selling period and if necessary another order (during the selling period) should be considered to raise the service level to an acceptable value. In this paper, and in contrast to many literature studies, we propose a decision rule that allows a newsvendor to order a quantity that satisfies a predetermined initial expected service level. At the time when the expected service level declines to a certain value (or equivalently, when the inventory level reaches a specific reorder point), the vendor places another order to raise the expected service level. The service level method used in this paper is the fill rate as it is the most commonly used approach in businesses. We establish propositions to reduce the difficulty of the model and devise a simple solution method which determines the first optimal lot size, optimal lot size of the second order, and the reorder point.

The remainder of the paper is organized as follows: We define the problem and state notation used in developing the model in the next section. We then develop the model in Section 3. In Section 4, we devise the solution method and in Section 5, numerical results are presented. Finally, we conclude the paper in Section 6.

2. Problem statement and notation

We consider a newsvendor who is subjected to a random demand X with a probability density function $f_X(x)$, mean μ_X, and variance σ_X^2. It is assumed that the pattern of demand does not change during the selling period. At the beginning of a selling period, the newsvendor places a first order of size Q_1 to satisfy the demand in the whole selling period. Moreover, the newsvendor requires that the order size Q_1 is large enough such that the expected fill rate $SLV(Q_1, X)$ is greater than or equal to a predetermined threshold value SLV_1. During consumption period, the realized demand in the first period can be high leading to significant drop in inventory and consequently reducing the service level to unacceptable low value. As depicted in Fig. 1, when the inventory level reaches R, where the expected fill rate is equal to SLV_2, an order of size Q_2 is placed to raise the inventory level from R to $R + Q_2$ and expected fill rate from SLV_2 to SLV_3 where $SLV_3 > SLV_2$. The random variable that represents the remaining demand when inventory level reaches R for the first time is denoted by Y.

Since the demand is assumed to be generated by a Poisson process then the probability distribution of the time (L) until the inventory level drops to R is known to be Gamma distribution with a shape parameter $Q_1 - R$ and rate parameter μ_X (Hadley & Whitin, 1963, p. 126). Hence, the expected value and variance of L, denoted by μ_L and σ_L^2 respectively, are given by:

$$\mu_L = \frac{Q_1 - R}{\mu_X} \tag{1}$$

$$\sigma_L^2 = \frac{Q_1 - R}{\mu_X^2} \tag{2}$$

Without loss of generality, we consider the selling period length to be one unit of time. Moreover, assume that the remaining demand, Y, in the period $[L, 1]$ has probability density function $f_Y(y)$, mean μ_Y and variance σ_Y^2. Since the newsvendor observes the demand in $[0, L]$, he updates the demand information in $[L, 1]$ accordingly. Thus, the relationship among the random variables X, L, and the updated demand Y is as follows:

$$Y = \begin{cases} (1 - L)X & L \leqslant 1 \\ 0 & L > 1 \end{cases} \tag{3}$$

The expectation and variance of Y is given by:

$$\mu_Y = \mu_X(1 - \mu_L) \tag{4}$$

$$\sigma_Y^2 = \sigma_X^2 + \mu_L\sigma_X^2 + \mu_X^2\sigma_L^2 \tag{5}$$

Furthermore, at a cost of v_1, the newsvendor buys the item from a supplier at the beginning of a selling period and he or she sells it to customers at a price p per item. Since the demand on the newsvendor is random, there are two possibilities; the first of which is when the demand is less than the ordered quantity, in this case, he or she returns the item to the supplier at a salvage value g per returned item. In contrast, if the demand is higher than the ordered lot, a shortage is experienced and a cost b per unit short is incurred. Thus, the profit generated from ordering a lot of size Q_1 at the beginning of a selling period and a second lot of size Q_2 ordered when the inventory level reaches R is given by:

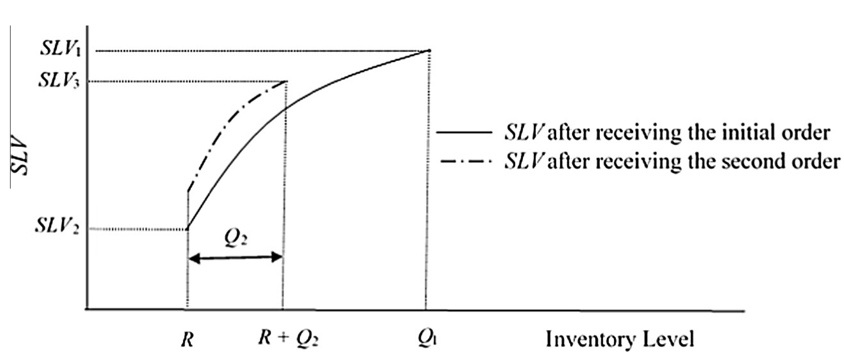

Fig. 1. A possible relation between expected fill rate and inventory level.