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Analysis of an inventory system under backorder correlated deterministic demand and geometric supply process

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Abstract

In this article we propose a single item, periodic review model that investigates the effects of changes in the demand process that occur after stockout realizations. We investigate a system where the demands in successive periods are deterministic but affected by the backorder realizations. In order to capture the effects of changes in the demand process we use a geometric type supply availability. We analytically derive the necessary components for obtaining profit related performance measures and provide computational analysis. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Backorder correlated demand; Supply uncertainty

1. Introduction and literature review

One of the costs that is frequently used in inventory models is the penalty cost, also known as the shortage or stockout cost, as a hedging against stockouts. The stockout cost has a different interpretation depending on whether excess demand is backordered or lost. In the backorder case, the stockout cost includes book-keeping and/or delay costs. In the lost sales case, it includes the lost profit that would have been made from the sale. In either case, it would also include the 'loss of goodwill' cost, which is a measure of customer satisfaction. Unfortunately, estimating the loss of goodwill component of the stockout cost can be very difficult in practice, since it is not easy to express customer dissatisfaction in monetary terms.

In this article we propose a single item, periodic review model that investigates the effects of changes in the demand patterns that occur after stockout realizations. Obviously, if there is no restriction on the supply or capacity availability in an ordering period, then there will be no successive backorder periods, hence the demand pattern is not expected to change. It is either supply/capacity restrictions or the lead-time effect that would introduce unmet customer demand and therefore shifts in the demand pattern for the product. In order to capture capacity/supply or lead time effects we incorporate a supply process where the number of periods between two supply realizations is random. This would correspond to either uncertainties in the supply/capacity process (imperfect production, machine breakdowns, supplier's capacity constraints) or random lead time where once the order arrives all the outstanding orders during the lead-time period are also met.

We specifically make three contributions. First, we provide a simple model that captures the

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changes in the demand pattern after stockout realizations and the relations between supply availability and system response to post-backorder demand patterns. Then, we derive analytical expressions for the steady-state behavior of the system. These expressions enable us to explicitly characterize the cost/revenue related performance measures for the model. Finally, we perform computational analysis that help us in understanding the essential characteristics of the system.

Several attempts have been made in the literature to model the relation between stockouts and customer satisfaction to eliminate the loss of goodwill component. A common substitute for stockout costs is the use of service levels. Another approach to eliminate the loss of goodwill component of stockout cost is considering the effect of stockouts on the customer behavior, i.e., future demand. The reasoning behind this approach is that stockouts tend to modify demand patterns. Robinson [1] provides a detailed review of studies that support the idea that customers alter their joint behavior according to meeting stockouts, delivery time or service provided. In a highly competitive market, a customer who experiences stockouts will be less likely to buy again from that supplier. In a monopolistic market, on the other hand, stockouts may attract more demand. In this study, both of these cases are investigated.

The majority of all those studies in the literature to model the relation between a system parameter and future demand relate the demand pattern to either the physical on-hand inventory level or the service level provided by the retailer. The idea of inventory level dependent demand was born due to the fact that stock level had motivational effect on the customers. Baker and Urban [2], Datta and Pal [3], Urban [4], and Paul et al. [5] constitute a series of articles that study inventory level dependent demand patterns. In each of these articles, a continuous-time deterministic inventory system is investigated assuming that the demand rate of the item has a polynomial functional form dependent on the inventory level. Our work also assumes a deterministic demand process, however we consider an uncertain supply structure.

The concept of service level dependent demand within a production/inventory system is incorporated by Schwartz [6], Ernst and Cohen [7], and Ernst and Powell [8]. According to these studies, demand rate is proportional to the service level provided by the retailer. This property of service level related demand models requires that the market immediately has full information about the service level, which is not very realistic. On the contrary, information on a retailer's being out of stock is more readily available in the market. Fewer studies have been made on the case that demand changes due to stockouts dynamically throughout the planning horizon. Ref. [1] is an article that contributes to the inventory literature with stockout dependent nonstationary demand. In [1] both the expectation and the variability of demand change over time in response to the actual (not expected) number of satisfied and dissatisfied customers. In the preceding articles, the demand parameters (demand rate or mean demand) are affected from the stockout realizations. Moreover, approaches in these articles do not allow tractable analysis of the system performance. Contrary to theirs, our approach allows us to model situations where the demand distribution, rather than the mean demand, can change after stockout realizations.

Besides the models in which the demand depends on some system parameter, there are also models with external nonstationarity in demand. The first detailed study on nonstationary demand models is due to Karlin [9,10]. Like Karlin [9,10], Zipkin [11] and Morton and Pentico [12] attempt to analyze similar problems in which independent demand varies from period to period. In the literature, there is another approach to incorporate the external nonstationarity in demand. This approach assumes that demand varies with an underlying state-of-the-world variable that can represent economic fluctuations, uncertain market conditions, or stages in the product life cycle. Song and Zipkin [13] and Sethi and Cheng [14] take such an approach to describe the nonstationarity in demand. Certainly, this line of research is similar to ours, as we also consider time-varying demands. However, in our model, nonstationarity of demand is determined by the internal dynamics of the system, the backorders.

Queueing systems with state dependent arrival rates may provide another way to incorporate the