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Lead time minimization of a multi-product, single-processor system: A comparison of cyclic policies

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Abstract

The supply chain under consideration is a two-echelon system consisting of a retailer and a manufacturer. The N different products face stochastic demand at the retailer and are produced using a shared facility at the manufacturer. Production changeover involves setup time that is significantly higher than the processing time. A cyclic polling model with exhaustive limited service policy from the networking literature is applied to the supply chain problem and the service limit values are obtained to minimize the lead time. Mathematically the exhaustive service policy gives least value, but in practice we can set the service limit to values near the stability condition and obtain similar results. Other cyclic policies that take into consideration either the minimum lot size or the production quantity band or the idle time between cycles are also studied. These are tested for different values of plant utilization and a comparison is drawn through simulation. Limitations of the model are discussed and possible extensions identified.

Keywords: Stochastic economic lot scheduling problem; Multi-product; Polling; Lead time; Simulation

1. Introduction

In this paper we consider a two-echelon supply chain system with stochastic demand for N different products at the retailer. All the products are produced by a manufacturer using a single processor with limited capacity. Each product type has its own set of parameters like setup time, processing time and arrival rate. The setup time of a product is usually much larger than its processing time. The manufacturer and the retailer share the point of sale information. For every unit sold at the retailer the corresponding order for the product gets accumulated at the manufacturer in the queue corresponding to that product. These queues are processed by the processor in a cyclic order. The demand at the retailer is stochastic and the transportation time is assumed to be negligible. This type of problem is termed as stochastic economic lot scheduling problem (SELSP). A detailed review on SELSP is provided by Sox et al. (1999). The deterministic version of this problem is NP hard (Hsu, 1985) and is widely studied, but not yet solved in general (Markowitz et al., 2000). We are interested in comparing the various cyclical policies from the standpoint of the manufacturer in reducing the lead time of the overall system.

In today's supply chain, the retailers are willing to share the point of sale information with the higher echelons which can provide significant benefits to all

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the players. We have limited our scope to a retailer–manufacturer supply chain, where the manufacturer has to decide on his production schedule based on the real time information provided by the retailer. We do not get into the problem of determining the optimal quantities to be held by the retailer since, for a given service level, it can be determined using methods available in the literature. As such, the production scheduling of multiple products on a single machine with significant setup time is a classic problem of production planning. The stated problem has a wide range of industrial applications, which include glass manufacturing, injection molding, metal stamping, paper production, semi-continuous chemical processes and production of consumer products like detergents, bar cakes, toothpastes, etc. The practical benefit for the manufacturer is higher plant utilization and the retailer can maintain lower inventory for same level of customer service. In case of multiple retailers having Poisson demand for each of their products, the analysis still holds with the compound Poisson distribution for the demand of products at the manufacturer.

In a supply chain, usually cost and service levels are relevant at the producer end, while lead time is of importance at the retailer end. A short lead time reduces the stockout probability at the retailer and also brings down the holding cost. Karmarkar (1987) explores the impact of lot sizes on manufacturing lead time and uses queueing theory to provide implication of lot sizing and work-in-process inventories on batch manufacturing. A survey by Das and Abdel-Malek (2003) indicates that order quantities and supply lead times are the two most important parameters that determine the flexibility of the supply chain. They extend it to derive the annual procurement cost for the supply chain network. Mohebbi (2004) focuses on incorporating lead time variability into the analysis of continuous-review inventory systems with stochastic demand and random supply interruptions. In an uncertain demand environment, Bourland and Yano (1994) have come up with a production plan that minimizes the expected cost of inventory, setups and overtimes. Their model explicitly considers safety stock, overtime, and the amount and position of planned idle time. The results indicate that capacity slack in the form of planned idle time is not a cost-effective strategy in the context of demand uncertainty. The decisions at the bottleneck not only affect its own performance, but also the performance at other echelons. Federgruen and Katalan (1996) have extensively evaluated the cyclic exhaustive/gated base stock policies and have shown that the long run average cost depends on the total idle time and not on the individual idle time between the different products. The algorithm can be used to compute the steady-state queue size distribution.

A polling model is a system of multiple queues accessed by a single server in a cyclic order. It has been widely used to model time sharing in computer systems. Over the past three decades, there has been extensive research in this field and the focus has been on its application in the networking area. The server has to decide how many packets it should serve from each user before switching over to the next user. The setup time refers to the time to changeover from one queue to another, which is typically very small. Takagi (1988) gives a good survey of the different polling mechanisms and discusses exhaustive, gated, limited and decrementing policies in detail. In the exhaustive limited polling policy, a particular product is processed until the queue becomes empty or a service limit k_i (suffix indicates queue/product) is reached. When k_i equals infinity, the queue is processed till it becomes empty and this is the exhaustive policy. If the processor on arrival at a queue sees m_i units and serves $\min(m_i, k_i)$ units, it is termed as gated limited service policy. k_i equal to infinity in this case will yield gated policy. Decrementing polling policy decreases the queue length by a fixed quantity, which is unity in most of the cases. Chang and Sandhu (1990) provide an exact expression to determine the expected work left in the system when the processor leaves the queue under different service policies. Sarkar and Zangwill (1989) provide an efficient technique to obtain the average waiting time of a product in the queue for the exhaustive and gated policies. They compute the variability by solving a set of equations, having as many equations as the number of queues. Fuhrmann and Wang (1988) have shown that for cyclic service systems the accuracy of the approximations is well within 20% of the simulated results provided the parameters are not extremely asymmetric and the setup times are not large relative to the processing times. These papers estimate the mean waiting times for given values of k_i's. Our interest lies in coming up with an analytical expression for k_i's in the supply chain environment.