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Admission and inventory control of a single-component make-to-order production system with replenishment setup cost and lead time

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ABSTRACT

We consider the admission control and inventory management problems of a single-component make-to-order production system. Components are purchased from suppliers in batches of fixed size subject to stochastic lead times and setup costs. A control policy specifies when a batch of components is purchased, and whether the demand for each MTO production is accepted upon arrival. We formulate the problem as a Markov decision process (MDP) model, and characterize the structure of optimal admission control and inventory replenishment policies. We show that a state dependent base-stock policy is optimal for the inventory replenishment, although the MDP value function is not necessarily convex. We also show that the optimal admission control can be identified as a lattice dependent policy. A sensitivity analysis is conducted to show how the optimal policy changes as a function of the system parameters. To effectively coordinate admission and inventory control decisions, we propose simple, implementable, and yet effective heuristic policies. Our extensive numerical results suggest that the proposed heuristics can greatly help firms to effectively coordinate their admission and inventory control activities.

1. Introduction

In this paper, we study the admission control and inventory management problem of a make-to-order (MTO) facility with a common component, which is purchased from a supplier under stochastic lead time processes and setup costs. When a customer order arrives at the facility, a component is pulled from inventory, and then the end product is manufactured and delivered to the customer. Each customer order can be accepted or rejected depending on both the current status of the component inventory level and the operating characteristics (e.g., number of backlogged customer orders) of the system. For example, when the component inventory level is low and the size of backlogged customer orders is large, it is reasonable to reject incoming customer orders. An admission control will become more critical if the lead time is too long to replenish the component inventory quickly. Besides the admission control problem, the manufacturing firm has another problem of determining when to place a replenishment order. Even when the component inventory level is not low, if the size of backlogged customer orders is large and the replenishment lead time is long, the firm may need to place a replenishment order due to the risk of an excessive delay of customer order fulfillment due to stockout. Due to component replenishment and demand uncertainties, coordinating the admission control and inventory management becomes new challenging issues in a firm, which has inspired this research. The primary goal of this paper is to develop a Markov decision process model for jointly managing order admission and component inventory controls.

Over the past decade, the consumer market has changed toward more customized products with specific configurations that customers want. The advance in information and manufacturing technologies has allowed firms to manufacture such products that meet customers' requirements. In this market and production environment, it may not be appropriate to practice a make-to-stock manufacturing strategy, where products are stocked ahead of demands. Instead, it has become widely used by firms across many industries in order to initiate manufacturing of products in response to specific customer orders. Furthermore, to better protect themselves against demand variability, lower inventory cost, and reduce time-to-market, firms are increasingly using component-based manufacturing because it is capable of confining the impact of technology innovation to the component level (Xu & Li, 2007). When firms use component-based manufacturing, several issues may emerge at the operational level. If component procurement (production) lead times tend to be longer than the lead time requested by customers,

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components may have to be acquired in advance. Moreover, in the case in which components are acquired from suppliers, the stocking decision for component can be affected by the structure of the relationship between the manufacturer and the suppliers (Zhang, Ou, & Gilbert, 2007). Incorporating an admission control into a make-to-order system is also important due to its applicability to real problems. In many service practices, customers may be refused to enter a service facility due to its capacity restriction. In the case of a manufacturing environment, a finite buffer is a more realistic situation rather than an infinite buffer due to the limited storage buffers for semi-finished goods.

There is a rich literature on joint admission and inventory/ production control for make-to-stock and assemble-to-order systems. Ha (1997a); 2000) considered a single product make-to-stock system with multiple customer classes and lost sales. Single product make-to-stock systems with backordering for two customer classes and N customer classes were studied by Ha (1997b) and de Vericourt, Karaesmen, and Dallery (2002), respectively. Carr and Duenyas (2000) considered a make-to-order/make-to-stock system that produces two classes of products, and studied the problems of joint admission control and production sequencing decision. Benjaafar and ElHafsi (2006) considered a single product assemble-to-order system with multiple customer classes and multiple components under the assumption of instantaneous assembly. ElHafsi (2009) extended the research of Benjaafar and ElHafsi (2006) to the case with a compound Poisson arrival process. Benjaafar, ElHafsi, and Tinglian (2010) considered a single product make-to-stock system with two customer classes, where customer orders can be fulfilled from existing inventory, if there is any, backordered, or rejected. Ioannidis (2011) considered a single product make-to-stock system with two customer classes, and studied production control, inventory rationing, and admission control problems. The references cited above assume that inventory of items is replenished one unit at a time and further, the production is preemptive.

The inventory control for a make-to-order system is studied in Kim (2005), where inventory is replenished in batch under a non-preemptive lead time process. We extend (Kim, 2005) by considering the admission control of customer orders.

Since we consider the admission and inventory control under a continuous inventory review, our model has some features similar to the classical continuous review inventory models with lost sales. The references in this area have the constraint that at most one replenishment order may be outstanding at any time. Archibald (1981) presented both optimal and approximate solution procedures for the model with a compound Poisson demand process and a fixed lead time. Buchanan and Love (1985) derived a solution procedure for the model with a Poisson demand process and an Erlang-distributed lead time. Beckmann and Srinivasan (1987) studied the model with Poisson demand and exponential lead time processes. Mohebbi and Posner (1998) analyzed the (r, Q) policies for the system with compound Poisson demand and Erlang or hyper-exponential lead time distributions. Hill and Johansen (2006) explored the behavior of optimal inventory control policies under both continuous and periodic reviews. In the classical periodic review inventory models with lost sales, some references analyzed the case with multiple outstanding orders. Morton (1971), Nahmias (1979), and Van Donselaar, de Kok, and Rutten (1996) developed myopic heuristic solution procedures under a fixed lead time which is an integral number of review periods and a negligible set-up cost. When demand is discrete, Johansen (2001) explored the optimal and near optimal base stock policies with negligible set-up costs and constant lead times.

Our model contributes to the current literature in the following two essential aspects. First, we study the joint admission and inventory control for a make-to-order system with a non-preemptive lead time process and explicitly incorporate the replenishment setup cost into the model. Second, introducing submodularity and convexity with step size q, where q is an order quantity, we characterize the structure of the optimal admission and inventory control policy.

The optimal policy identified in this paper has structural features similar to those studied in Nadar, Akan, and Scheller-Wolf (2014). They consider an assemble-to-order system where multiple products are produced using multiple components, and study a control policy which specifies when to produce a batch of each component type and whether or not to fulfill a demand for each product type from inventory upon arrival. By showing that the optimal cost function satisfies the submodularity, supermodularity, and convexity with respect to certain lattices of the state space, they characterize optimal inventory replenishment and allocation policies under a certain condition on component batch sizes as lattice-dependent base stock and lattice-dependent rationing policies, respectively. However, it should be noted that they assume preemption and no setup cost in the component production, whereas we assume non-preemption and setup cost in the component replenishment.

The rest of the paper is organized as follows. We provide a Markov decision process model under the discounted cost criterion in the next section. Section 3 characterizes the optimal admission and inventory control. In Section 4, we implement a sensitivity analysis on the optimal policy. Section 5 extends the results to the average cost criterion. In Section 6, we develop the heuristic policies and present a numerical study. The last section states the conclusions.

2. Problem formulation

Customer orders arrive according to a Poisson process with rate λ and can be accepted or rejected. Whenever each customer order is rejected, a penalty cost of c_R is incurred. The MTO facility produces a product for each accepted customer order using a common component. Production times for each customer order are the exponential random variables with mean μ_1^{-1}. Replenishment lead times of a common component are the exponential random variables with mean μ_2^{-1}. A backlog cost is assessed at rate c_1 for each backlogged customer order, whereas a holding cost is incurred at rate c_2 for each component in the inventory. At each instant a replenishment order with size q units is placed, a setup cost of c_K is incurred. The replenishment process is assumed to be non-preemptive, that is, a replenishment order is never interrupted until it is completed.

For tractability of the analysis, at most one outstanding replenishment order is assumed. In the inventory management literature, particularly in the literature of continuous review inventory with lost sales, it is a quite common assumption, and is often justified in practice when order cycles are usually large compared to lead times (Teunter & Haneveld, 2008). According to Tempelmeier (2006), in a typical practical case with high setup times or setup costs, the replenishment lead time is three weeks and the order cycle is about 25 weeks. Consequently the probability that several orders are outstanding simultaneously is very low.

Let $X(t) = (X_1(t), X_2(t))$, where $X_1(t)$ and $X_2(t)$ denote the number of backlogged customer orders and the component inventory level at time t, respectively. Then, the state of the system at time t is described by the vector ($X(t)$, $n(t)$), where $n(t)$ represents the number of replenishment order in process at time t. The state space is denoted by Γ. The set of decision epochs in our model corresponds to the epochs of customer order arrival, MTO production completion, and replenishment order arrival. At each decision epoch, the facility determines whether or not to place a replenishment order. Furthermore, in the epochs corresponding