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Centralized admission and production control in a two-stage supply chain with single component and customized products

Eungab Kim *

College of Business Administration, Ewha Womans University, 52 Ewhayeodae-gil, Seodaemun-gu, Seoul 120-750, Republic of Korea

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ABSTRACT

This paper considers a two-stage supply chain that a make-to-stock facility produces a single component in anticipation of future demand and a make-to-order facility produces customized products using components with the option of to accept or reject each customer order. We address the problem of centralizing the admission and production control that maximizes the supply chain's profit subject to the system costs. Using a Markov decision process model, we characterize the structure of the optimal admission control and production policy and establish the monotonic impact of system parameters on the optimal policy. Two heuristics are presented and their performance is numerically compared to the optimal policy under different operating conditions of the system.

1. Introduction

This paper considers a supply chain that consists of a make-to-stock (MTS) facility and a make-to-order (MTO) facility in successive stages. The MTS facility produces a single component in anticipation of future demand from the MTO facility. With the option of to accept or reject each incoming customer order, the MTO facility produces customized products using components. Revenue is generated if each accepted order is processed and penalty is incurred if each incoming order is rejected. Holding and backlog costs are incurred for components in inventory and outstanding customer orders, respectively. Inter-arrival times of customer orders and production times of components and customized products are stochastic.

This work was motivated by a manufacturer that owns two production facilities: one for semiconductor chips and the other for printed circuit board (PCB) products. The PCB production is driven by customer orders while the semiconductor chip production is scheduled by anticipating demands on chip from the PCB production facility. Inventories of generic chips give the manufacturer a strategic advantage in reducing the component level cost and the lead time for the procurement of generic chips at the customization stage. Our work is intended to serve as a basic study to provide the manufacturer with insights on their strategic decision of selectively accepting or rejecting customer orders and determining when to start or stop production of generic chips. To address such a problem, we define a two-stage production inventory problem which centralizes the admission control at the MTO stage and the production control at the MTS stage.

Compared to the classical inventory control models in multi-stage production systems, our model has a distinct feature that there is a delay between the arrival of a customer order (demand) and the time component is actually needed to process that customer order. Under this circumstance, inventory is not carried at the MTO facility and it is necessary only at the MTS facility. Consequently, production control at the MTS facility will depend on both its component inventory level and the size of outstanding customer orders at the MTO facility, instead of only its component inventory level.

The primary goal of this paper is to study a centralized policy that coordinates the decisions of admission and component production control so as to maximize the supply chain's profit. Coordination of inventory and production control among supply chain members can be beneficial for the whole supply chain (Carr and Duenyas, 2000; Saharidis et al., 2009). However, the question of what level of inventory is optimal for the supply chain is still complicated. Especially, when the supply chain produces both make-to-stock and customized products, the dilemma consists of having to deliver customized products within due dates while reducing inventories of make-to-stock products. Moreover, admission control is an additional challenge for the MTO facility because outstanding customer orders incur expensive backlog costs.

There is a vast literature on production control in multi-stage production systems using queueing network modeling (see Dallery and Gershwin, 1992 for the literature survey). Veatch and Wein (1992, 1994) studied the problem of production planning in a two-stage production system where unmet demands from finished goods inventory are backordered. Assuming Poisson

* Tel.: +82 2 3277 3970; fax: +82 2 3277 2835.
E-mail address: evanston@ewha.ac.kr

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demand and exponential production times, Veatch and Wein (1992) characterized the optimal production decisions as two monotone switching curves. Veatch and Wein (1994) found conditions that certain simple policies are optimal and showed that the base stock policy can never be optimal. Optimal controls were compared with kanban, base stock, and finite buffer control mechanisms. Li and Liu (2006) considered a (s,S) type of production control at component production such that the setup process is switched on when the component inventory reaches s and the production process stops when it reaches S.

There is also a rich literature on admission control in production/inventory systems. Stidham (1985) reviews the literature on customer admission control to single class make-to-order queues. Several papers have considered integrated admission control and production decision in a single-stage production system. Carr and Duenyas (2000) considered a production system that produces MTO and MTS products and studied the problem of joint admission control and production switching. A single-stage, single product, make-to-stock system with multiple customer classes have been covered in Ha (1997a,b, 2000), Benjaafar et al. (2010), de Vericourt and Karaesmen (2002), and Ioannidis (2011). Benjaafar and ElHafsi (2006), ElHafsi (2009), and Benjaafar et al. (2011) studied joint admission control and component production policy in a single product, multi-components, assemble-to-order system with multiple demand classes. Although they considered a two-stage production system (i.e., component production stage and assembly stage), the assembly process is assumed to be instantaneous. Saharidis et al. (2009) studied a joint production and admission control in a two-stage, single component, single product, make-to-stock production system where demands for component during a stockout period should be satisfied immediately from a subcontractor.

In this paper, using a Markov decision process (MDP) model, we characterize the structure of the optimal admission and production control that states when to accept incoming customer orders and when to produce components under the discounted profit criterion. We identify the properties of the optimal policy under special cases and the monotonic impact of system parameters on the optimal policy. We show that there exist certain limits on the size of outstanding customer orders and component inventory level beyond which accepting an incoming order and producing a component can be never optimal for the average profit problem. We then present two heuristics: one uses two switching functions and the other uses two fixed thresholds for the control. Finally, we present numerical results which show the performance comparison between the optimal policy and two heuristics under different operating conditions of the system.

The rest of the paper is organized as follows. In Section 2 we present modeling assumptions and problem formulation. Section 3 characterizes the structure of optimal production and admission control under the discounted profit criterion. In Section 4, we study the properties of the optimal policy under special cases. Section 5 presents a sensitivity analysis on the optimal policy. In Section 6, we extend the results to the average profit criterion. Section 7 reports the results of numerical experiment and the last section states conclusions.

2. System description and formulation

Customer orders arrive at the MTO facility according to a Poisson process with rate λ. The facility can accept or reject each incoming customer order. A penalty cost of c_r is incurred whenever it is rejected. This cost is associated with loss of goodwill (Iravani et al.). Each MTO operation requires one unit of component and takes an exponentially distributed amount of time with mean μ_1^{-1}. If it is completed, a revenue of R_o is generated. The MTS facility produces components one unit at a time according to an exponential distribution with mean μ_2^{-1}. R_o is assumed to contain unit component purchasing price the MTO facility pays the MTS facility. Backlog and holding costs are incurred at the rate of h_1 per unit time for each outstanding customer order and at the rate of h_2 per unit time for each unit of component in inventory.

The set of decision epochs in our model corresponds to the epochs of customer order arrival, MTO operation completion, and component production event. At each decision epoch, the MTS facility should determine whether to produce a component or not. Furthermore, at each epoch of customer order arrival, the MTO facility must decide whether to accept or reject it. Fig. 1 graphically illustrates a schematic model of the problem described above. The goal of this paper is to find a production and admission control which maximizes the expected total discounted profit over an infinite horizon.

The state of the system is described by the vector $n=(n_1,n_2)$ where n_1 is the number of outstanding customer orders and n_2 is the inventory level of components. We can formulate the optimal control problem as a discrete-time MDP problem by using uniformization (see Lippman, 1975). This uniformized version has a transition rate $\gamma=\mu_1+\lambda+\mu_2$ and a discounted factor $\gamma/(\beta+\gamma)$ where β is a continuous interest rate. We denote the state space by Γ.

Let $v(n)$ be the optimal expected discounted profit over an infinite horizon when the initial state is given by $n=(n_1,n_2)$. Then, we can write the optimality equation of the discounted profit MDP as

$$v(n)=\frac{1}{\beta+\gamma}[H(n)+\mu_1\{v(O(n))+R_o 1(n_1>0,n_2>0)\} + \lambda\max\{v(n+e_1),v(n)-c_r\}+\mu_2\max\{v(n+e_2),v(n)\},] \quad (1)$$

where $H(n)=-h_1n_1-h_2n_2$, $1(a)=1$ if a is true; 0 otherwise, $O(n)=n-e_1-e_2$ if $n_1n_2>0$; n otherwise, and e_i $(i=1,2)$ is the unit vector along the ith axis. In (1), the term multiplied by μ_1

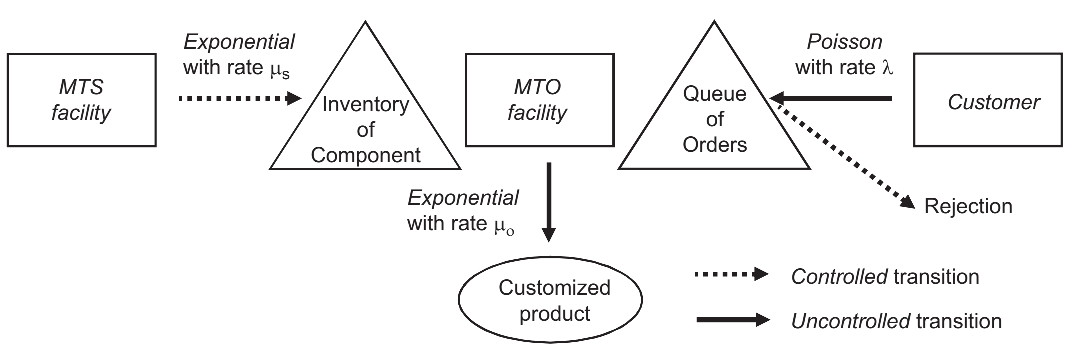

Fig. 1. A two-stage supply chain model with joint production and admission control.