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# A queuing model on supply chain with the form postponement strategy ☆

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ABSTRACT

The form postponement (FP) strategy is an important strategy for manufacturing firms to utilize to achieve a quick response to customer needs while keeping low inventory levels of finished products. It is an important and difficult task to design a supply chain that uses FP strategy to mitigate the conflict between inventory level and service level. To this end, we develop a two-stage tandem queuing network to model the supply chain. The first stage is the manufacturing process of the undifferentiated semi-finished product, which is produced on a Make-To-Stock basis: the inventory is controlled by base-stock policy. The second stage is the customization process based on customers' specified requirements. There are two types of order: ordinary order and special order. The former can be met by customizing from semi-finished product, while the latter must be entirely customized beginning from the first stage. The customer orders arrive according to a Poisson process. We first derive the inventory level and fill rate, and then present a total cost model. It turns out that the model is intractable due to the Poisson distribution in the objective function. To analytically solve the problem, we use normal distribution as an approximation of the Poisson distribution, which works well when the parameter of the Poisson distribution is quite large. Finally, some numerical experiments are conducted and managerial insights are offered based on the numerical results.



## 1. Introduction

Nowadays, more and more companies are enlarging product varieties in order to fulfill demand from increasingly different types of customers. Favorably, information techniques make the diversification of product feasible by providing companies with low cost platforms to interact with their customers and realize mass customization. However, product variety has a significant impact on inventory level and service performance (Lee & Tang, 1997). To offer a large variety of products in highly efficient ways, various supply chain structures have been previously explored. Most of them can be divided into two strategies (Zinn & Bowersox, 1988): One is the time postponement (TP) strategy which delays delivery until customer orders arrive. The other is the form postponement (FP) strategy which delays the differentiation of the product until the detailed specification is confirmed.

Form postponement is one of the most popular and successful strategies in mass-customizing supply chains (Lampel & Mintzberg, 1996;Ahlstrom & Westbrook, 1999). In practice, many companies have successfully implemented the FP strategy, e.g., Dell computer, Toyota's "Build your Toyota", Amazon's "Built your own ring", and Nike's "Design your shoes", etc. For maximizing efficiency of the FP strategy, companies are showing increasing interest in incorporating the customer order decoupling point (CODP) as an important input to the strategic design of manufacturing operations as well as supply chains. CODP is defined as the point in the value-adding chain that separates the decision based on forecast from the decision based on the detailed product specification of the order. In other words, CODP divides the material flow that is forecast-driven (upstream of the CODP) from the flow that is customer order-driven (downstream of the CODP). It is also referred to as "the point of differentiation" (Lee & Tang, 1997).

Since Buclin (1965) first introduced the term "postponement", there have been a large number of researches on the postponement strategy. We do not attempt to cite and discuss every significant contribution in this area. Instead, we refer readers to van Hoek (2001), Swaminathan and Lee (2003), Yang and Burns (2003) for a comprehensive review. More recently, Leung and Ng (2007) use a goal programming model to optimize production planning in a perishable supply chain with postponement. Kumar, Nottestad, and Murphy (2009) investigate the effect of product postponement on distribution network supply chains by using simulation models. Trentin, Salvador, Forza, and Rungtusanatham (2011) develop an operational procedure to identify and quantify the opportunities

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for applying the FP strategy to a given product family. Wong, Potterb, and Naimb (2011) show that the postponement strategy can improve the performance of the soluble coffee supply chain. Sharda and Akiya (2011) investigate the inventory management policy for a specific chemical plant by using a postponement strategy simulation.

Here we focus on a few studies that are the most pertinent to our own work, i.e., the joint optimization of CODP and the inventory level in a mass-customizing supply chain. Aviv and Federgruen (2001a, 2001b) investigate the tradeoff between the inventory level and redesigning cost in a form postponement supply chain, but they do not consider the problems of congestion and order delay. Conversely, Su, Chang, and Feiguson (2005), Gupta and Benjaafar (2004) and Jewkes and Alfa (2009) all capture the impact of congestion on the FP strategy by using queuing models. Su et al. (2005) compare the TP strategy with the FP strategy based on total operational cost. In their paper, the FP supply chain is actually modeled as a two-stage Make-To-Stock (MTS) queuing network with exogenous CODP position. They assume that there are $n$ categories of customizing processes in the downstream stage, which are also controlled by the base-stock policy. Both Gupta and Benjaafar (2004) and Jewkes and Alfa (2009) model the customizing process as an Make-To-Order (MTO) queue that incorporates CODP position optimization. The former assumes that the potential CODP position in a multi-stage supply chain is a discrete number. The latter constructs a two-stage tandem queuing network in which the CODP position is relaxed to be continuous number on the interval of $(0,1)$.

In this paper, we address the same basic question as Gupta and Benjaafar (2004) and Jewkes and Alfa (2009): How to optimize the CODP position and inventory level to minimize operational cost? Here, we develop a two-stage tandem queuing network to model the supply chain using an FP strategy. The first stage is the manufacturing process of the undifferentiated semi-finished product, which is produced on a Make-To-Stock (MTS) basis and the inventory is controlled by the base-stock policy. The second stage is the customization process based on customers' specific requirements. However, our model differs from Gupta and Benjaafar (2004) and Jewkes and Alfa (2009) in the following ways: First of all, we assume that the processing time (both replenishment process and customizing process) are constant, instead of exponential distributed in Gupta and Benjaafar (2004) and Jewkes and Alfa (2009). This assumption is practicable in some cases, e.g., in automatic production lines. It is shown that the performance evaluation of two stage tandem queuing network with mixed MTS and MTO is very difficult, even in case of the exponential distributed process time. In our work, we derived the closed-form performance measures based on the results of Zipkin (2000) and Sherbrooke (1975), such as inventory level and unfill rate. Secondly, we consider the effect of CODP position on the capability of customization. It is clear that the further downward the CODP position, the more customer orders cannot be met based on semi-finished product. We model this situation with two categories of order: ordinary order and special order. The former can be met by using semi-finished product, while the latter must be entirely customized beginning from the first stage. Furthermore, we assume that the fraction of ordinary customer orders $\gamma$ is a decreasing function of CODP position $\theta$. Third, we involve the lead-time quotation policy and the penalty cost of tardiness for being more practical.

The rest of the paper is organized as follows. In Section 2, we present the model description. Section 3 presents the optimization problem. The approximation of the cost function by normal distribution and the solution of the approximate model are given in Sections 4 and 5, respectively. Section 6 conducts numerical experiments to demonstrate the impact of the parameters on the optimal policy. Section 7 concludes the paper.

## 2. Model description

We consider a mass-customizing supply chain that adopts the FP strategy. The entire manufacturing process is constant (say $L$) and additively separable, where "additively separable" means that the process can be interrupted at any time and continued just like without interruption. For instance, the manufacturing process is interrupted at $\theta L$ $(0 \leqslant \theta \leqslant 1)$, then when the process is continued, it just takes $(1-\theta)L$ to complete the entire process. Here, we refer to $\theta$ as the CODP position. In other words, the manufacturing process of the product is composed of two sub-processes: One is the manufacturing process for the undifferentiated semi-finished product, the time of which is equal to $\theta L$. In this stage, the semi-finished product is produced on a Make-To-Stock (MTS) basis and the inventory is controlled by the base-stock policy, with base-stock level $S$. The other sub-process is the manufacturing process of customization based on the semi-product, which is started after the order arrives and the detailed product specification is confirmed. Hence, the customization process runs based on a Make-To-Order (MTO) basis, and the customization processing time is equal to $(1-\theta)L$. We can easily envision two extreme cases of the policy. In the first case, $\theta = 0$ implies that the company adopts the pure MTO strategy. In the second case, $\theta = 1$, implies that the company adopts the pure MTS strategy. Additionally, the MTS process leads to inventory holding costs: denote $C(\theta)$ as the unit holding cost for the semi-finished product. It is well known that the later the CODP position, the larger the unit inventory holding cost will be, which means that $C(\theta)$ is an increasing function of $\theta$. Denote $C_h$ as the unit holding cost of finished product. It is clear that $C(\theta)$ must satisfy the following condition:

$$\begin{cases} C(1) = C_h, \\ C(0) = 0. \end{cases} \tag{1}$$

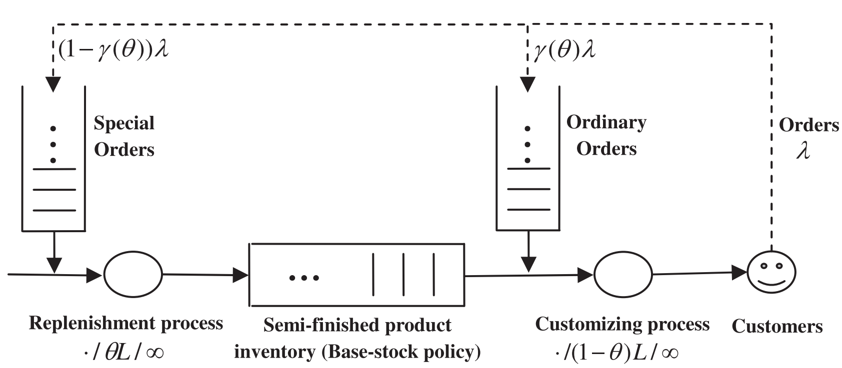


**Fig. 1.** The structure of supply chain with FP strategy.