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A two-stage queueing network on form postponement supply chain with correlated demands

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ABSTRACT

To ease the conflict between quick response and product variety, more and more business models are developed in supply chains. Among these, the form postponement (FP) strategy is an efficient tool and has been widely adopted. To the supply chain with FP strategy, the design mostly involves two problems: determination of customer order decoupling point (CODP) position and semi-finished product inventory control. In this paper, we develop a two-stage tandem queueing network with MAP arrival to address this issue. Particularly, we introduce a Markov arrival process (MAP) to characterize the correlation of the demand. By using of matrix geometric method, we derive several performance measure of the supply chain, such as inventory level and unfill rate. Our numerical examples show that both the variance and the correlation coefficient of the demand lead to more delayed CODP position and more total cost.

1. Introduction

With the increasing competition in all industrial sectors, product variety and response time have emerged as prominent dimensions in global competition. However, high product variety and quick-response time are often conflicting. The product variety improves service performance on one hand, and increases inventory level on the other ([1]). To capture the cost and benefit of product variety and further find out strategy 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 classes ([2]): One is the form postponement (FP) strategy which delays the differentiation of the product until the detailed requirement is confirmed and the other is the time postponement (TP) strategy which postpones delivery until customer orders arrive.

The FP is one of the most prevailing and successful strategies in mass-customizing supply chains (Lampel and Mintzberg, 1996; [3]). In practice, many companies have implemented the FP strategy and obtained considerable improvement, e.g., Dell computer, Toyota's "Build your Toyota", Amazon's "Built your own ring", and Nike's "Design your shoes", etc. To improve the performance of the FP strategy, an increasing number of companies are considering the customer order decoupling point (CODP) an important input of the strategic design of manufacturing operations and supply chains. CODP is defined as the point in a value-adding chain that separates the forecast-based decision from the customer-dependent decision. In other words, CODP, which is also referred to as "the point of differentiation" ([1]), divides the material flow that is forecast-driven (upstream of the CODP) from the flow that is order-driven (downstream of the CODP).

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Bucklin [4] was probably the first to introduce the term "postponement". Since that, there have been a large number of researches on the postponement strategy. Here, we do not cite and discuss every significant contribution in this area. For a comprehensive review on postponement strategy, the reader can refer to [5–7]. Recently, more related researches are done. Using simulation models, Kumar et al. [8] investigated the impact of product postponement on distribution network supply chains. For a certain product family, an operational procedure to identify and quantify the opportunities for applying the FP strategy was developed by Trentin et al. [9]. And, Wong et al. [10] showed that the postponement strategy can improve the performance in the supply chain of soluble coffee.

In our paper, we develop a two-stage queueing network to model a supply chain with an FP strategy. To characterize the correlation of the demand, we assume that the customers' orders arrive according to a Markovian Arrival Process (MAP). The motivation of the paper is to jointly optimize CODP position and inventory level of the supply chain, and investigate the effect of demand's correlation on the optimal design of the supply chain. In what following, 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 [11,12] investigated the tradeoff between the inventory level and the redesigning cost in a FP supply chain, but they did not consider the congestion and the order delay, which should be the major concern for a supply chain with an FP strategy. Su et al. [13], Gupta and Benjaafar [14] and Jewkes and Alfa [15] used queueing model to capture the impact of congestion on the supply chain. Based on the total operational cost, Su et al. [13] made a comparison between the TP strategy and the FP strategy. In their papers, the FP supply chain is actually modelled as a two-stage MTS queueing network and the CODP position is exogenous. They further assumed that there are n categories of customizing processes in the downstream stage, which are controlled by the base-stock policy. In contrast, both Gupta and Benjaafar [14] and Jewkes and Alfa [15] modeled the customizing process as an MTO queue and involved the CODP position optimization. However, Gupta and Benjaafar [14] considered a multi-stage supply chain in which the potential CODP position is a discrete number, while Jewkes and Alfa [15] constructed a two-stage tandem queueing network where the CODP position is relaxed to continuous number on the interval of $(0,1)$.

Basically, our work is close to Gupta and Benjaafar [14] and Jewkes and Alfa [15]. However, our model differs from these papers in the following ways. First of all, we assume that the cutomers' orders arrive according to a Markovian arrival process, instead of the Poisson process in [14] and [15]. This is because MAPs are excellent models to characterize the correlation of demand. Then, we can investigate the effect of demand's correlation on the supply chain with an FP strategy. Secondly, we also consider the effect of the CODP position on the unit inventory holding cost. It is clear that the further downward the CODP position, the larger the unit inverntory holding cost is. Hence, we assume that the unit inventory holding cost is a increasing function of the CODP position. Finally, for the sake of being closer to reality, we involve the lead-time quotation policy and the penalty cost for tardiness.

The rest of the paper is organized as follows. In Section 2, we present the analytical model. The stationary probability distribution and the stationary probability distribution at arrivals are derived in Sections 3 and 4, respectively. Section 5 gives customer order unfill rate. Several numerical examples are conducted in Section 6. Section 7 concludes the paper.

2. The analytical model

We use a two-stage tandem queueing network to model the FP supply chain. In the first stage, the undifferentiated semi-finished products are produced on a Make-To-Stock (MTS) basis and the inventory is controlled by base-stock policy with base-stock level K. In the second stage, it is the manufacturing process of customization based on the undifferentiated semi-finished products, which starts after the order arrives and the detailed product specification is nailed down. Hence,

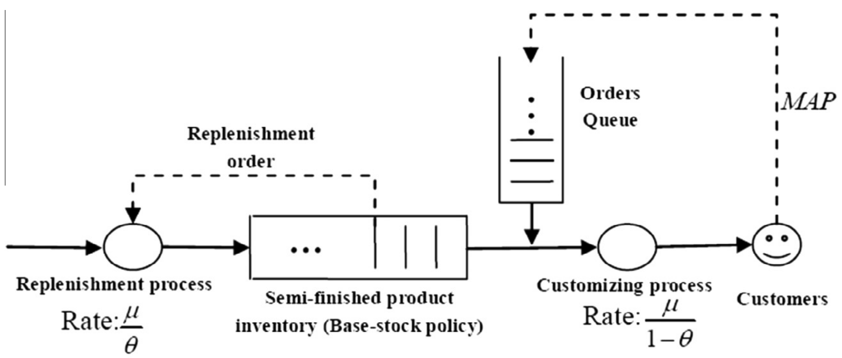

Fig. 1. The structure of the form postponement supply chain.