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A delayed product customization cost model with supplier delivery performance

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ABSTRACT

The concept of delayed product differentiation has received considerable attention in the research literature in recent years. However, few analytical models explain and quantify the benefits of delayed product differentiation strategy with additional consideration of supplier delivery performance. This paper proposes a delayed product differentiation model in which a supply of raw materials is integrated at the beginning of the production process to match uncertain demand in a cost-effective way given the constraint of lead time delivery window. It develops insights regarding a delayed product differentiation strategy and shows that with respect to delivery windows, supplier delivery performance plays an important role in the determination of the optimal point of differentiation. This study also shows that when the "*on-time*" and the "*late*" portions of the delivery window are constant, the proposed cost function coincides with similar models found in the literature. An extension of this work also reveals that when the customer service level varies across various production stages, its choice affects the decision to delay or postpone the customization point. A mini industrial case involving the customization of a personal desktop computer is used to illustrate the applicability of the resulting framework.

1. Introduction

With increasing customization needs, the ability to accurately forecast customer demand for different products, to provide high customer service while maintaining low inventories has emerged as an issue of concern for top management in today's global market (Chase, Aquilano, & Jacobs, 1998). Faced with expanding product variety due to increasing demand for customized products, most companies struggle to offer products of top quality, to manage costs and effectively compete. Product customization calls for an elaborate strategy to face some of these challenges and it can be realized by one of the practical methods, namely delayed product differentiation (also known as form postponement) (da Cunha, Agard, & Kusiak, 2007). According to Lee and Tang (1998), product differentiation is the split of products into separate items when components with different technical specifications are created, multiple end products with diverse functionalities are created, a product is packaged in different ways, or the exact same item is stored in different geographical locations. In this paper, we focus on the application of form postponement in product customization, or "delayed product customization," which relies on delaying as much as possible the point where a work-in-process inventory is committed to a particular end-product.

Form postponement has grown in popularity among supply chain practitioners and presents a number of benefits during product customization. For example: it attempts to reduce the risks associated with product variety by exploiting the commonality between items and by designing the production and distribution processes to delay the point of differentiation (Anand & Girota, 2007; Granot & Yin, 2008; Lee, 1996; Ma, Wang, & Liming, 2002; Ngniatedema, 2010, 2012). It also provides the flexibility for holding the right inventory at the right place and in the right form, therefore enabling a company to minimize supply chain risks and to respond more quickly to market demand while lowering inventory costs (Aviv & Federgruen, 2001; Christopher, Christopher, & Hanna, 2007; Garg & Tang, 1997; Lee & Tang, 1997; Nair, 2005; Ngniatedema & Chakravarthy, 2013; Sánchez & Pérez, 2005; Shao & Ji, 2008; Yang, Burns, & Backhouse, 2004).

Lee and Tang (1997) proposed a delayed differentiation model for a production process in which two products can be manufactured in a series of N discrete stages and inventories can be stored in a buffer following each operation. The processes from the first to the kth stage are defined as the common production processes, whereas

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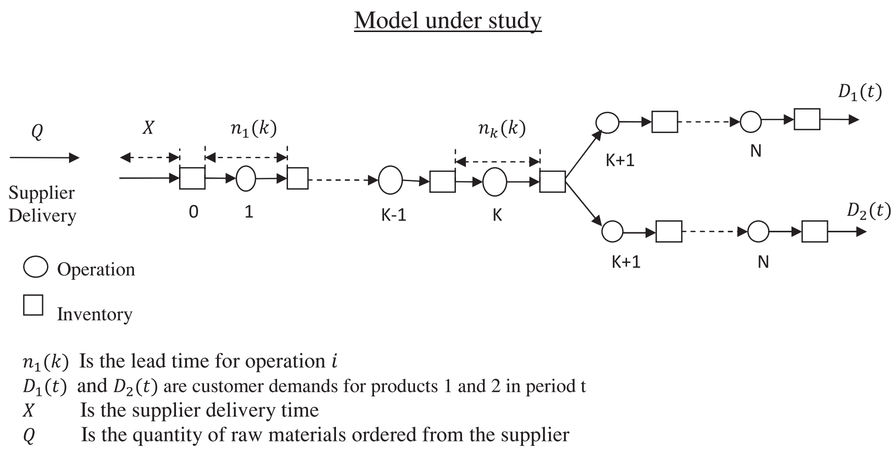

Fig. 1. Production network under delayed product differentiation scenario.

those from the $(k+1)$th to end stages are called differentiated production processes for each individual product. The point k, also known as differentiation point, is assumed to be the point of last common operation after which the products are differentiated. An increase in the value of k implies that the postponement timing is deferred in the entire production process.

However, their model, useful for analyzing the costs and benefits of delayed product differentiation, has a common major weakness in that it fails to address the possible risks associated with the supply of raw materials at the beginning of the production process. Ignoring such factors during postponement implementation can lead to considerable sunk costs and hence should be treated cautiously.

In this article, we complement Lee and Tang's (1997) deficiency by incorporating the delivery of components from an external supplier at the beginning of the production network. This additional consideration is depicted in Fig. 1 with the point "0" designed to hold inventory of incoming components. We then introduce the following two random variables: (1) the quantity of raw materials received from the supplier prior to the start of the production process and, (2) the lead time delivery window, respectively. Our study also goes beyond Lee and Tang's (1997) decoupling assumption of using constant customer service levels at different production stages to examine the effect of non-constant service levels on postponement decisions.

Building from previous modeling approaches, (e.g. Guiffrida & Nagi, 2006), we use the following notations at the point "0" of the production network: c_1 represents the earliest acceptable delivery date, c_2 represents the latest acceptable delivery date of components ordered from an external supplier, and the difference $c_2 - c_1$ representing the difference between the earliest acceptable delivery date and the latest acceptable delivery date is known as "*delivery window*." This delivery window, specified by a contractual agreement between the manufacturer and the supplier, reflects the case in which a manufacturer is given a fixed due date at the moment where an order is placed. It also defines the benchmark provided by the manufacturer and it is used as criterion to classify deliveries as being early, on-time, or late. The former specifies a delivery range through c_1 and c_2, whereas the later also maintains or promises a delivery range through an early delivery date "a" and a late delivery date "b", respectively. Fig. 2 depicts a simplified example of a normally distributed delivery window with the parameters a; b; c_1 and c_2 (Guiffrida & Nagi, 2006). Ideally, the manager would like a scenario where $c_2 - c_1 = 0$ for economic reasons. However, when $c_2 - c_1 > 0$, this difference can be measured in hours, days, or weeks depending on each industry case. According to these authors, a delivery lead time consists of the internal manufacturing lead time(s) of the supplier plus the external lead time associated with transporting the delivery of raw materials from the supplier to manufacturer.

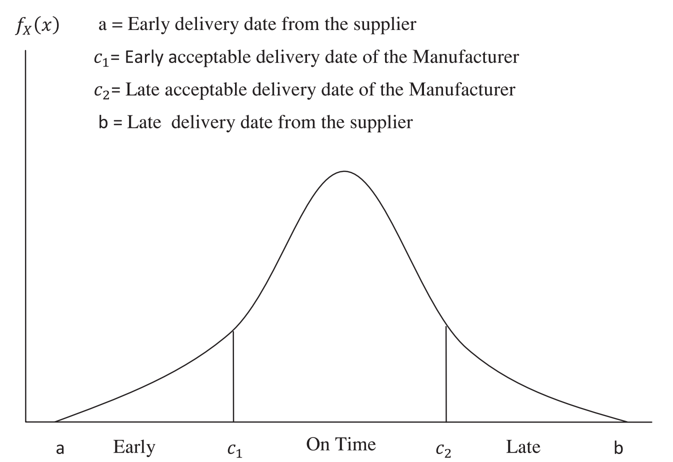

Fig. 2. Delivery window with normal distribution.

Under these considerations, we contribute to the literature by introducing two additional costs components which are likely to impact the total customization cost. The first cost results from the buffer inventory coming from the supplier side, whereas the second one results from the impact of supplier reliability with respect to the firm's specification of delivery timeliness. Technically speaking, we introduce two important random variables to the delayed differentiation framework during a postponement scenario: (i) the quantity of raw materials coming from the supply side to match customer demand and (ii) the supplier lead time that follows a general distribution, thus complementing the literature on supplier lead time delivery performance with respect to the on-time delivery window (Guiffrida & Nagi, 2006). We also examine a special case where the supplier lead time is normally distributed and important conclusions are derived. According to (Guiffrida & Nagi, 2006), "*delivery performance*" refers to delivery timeliness to the final customer in a serial supply chain that is operating under a centralized management structure. In the remainder of this paper, delivery performance refers to the delivery timeliness of raw materials to the point "0" of Fig. 1 introduced in Kadje (2012).

The paper is organized as follows. In Section 2, we present Lee and Tang's (1997) model in the context of product customization and we recall Guiffrida and Nagi's (2006) model on lead time delivery performance with respect to the delivery window. We then highlight some shortcomings in these two streams of research followed by our new modeling assumptions and the new average total cost function for delayed product differentiation. Section 3 contains the analytical study of the proposed cost function in product customization scenar-