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Decision Support

Capacity and lead-time management when demand for service is seasonal and lead-time sensitive

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ABSTRACT

In today's competitive business environment, quick service with minimal waiting time is an important factor for customers when choosing a service. Many service organizations guarantee a uniform lead-time to all customers in order to gain competitive advantages in the market. In selecting a lead-time to quote, the firm has to take into consideration not only how customers will react to the delivery time guarantee, but also whether it has adequate capacity to fulfill the commitment. A short lead-time can bring both benefits and costs. It can increase customer demand, but might require a higher capacity level. We present a mathematical model and a solution method for determining the optimal quoted lead-time and capacity level for a profit-maximizing firm with time-varying and lead-time sensitive demand. The firm incurs convex capacity costs and pays lateness penalties whenever the actual lead-time exceeds the quoted lead-time. A few studies have been conducted on the relationship between uniform lead-time, capacity, demand, and overall profitability. However, none of them takes the time variation of demand into account. Our work differs from previous research in that we explicitly model such a demand pattern.

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1. Introduction

The increasing importance of the service sector and the intense competition in a global economy have led to a worldwide expansion in research on services. In the past decade, a large amount of literature has recognized the power of using time to gain competitive advantage in the service market; see for example (Blackburn, Elrod, Lindsley, & Zahorik, 1992; Hum & Sim, 1994; Stalk & Hout, 1990). Besides price, service time has become one of the most important instruments for companies to compete in today's business environment.

Considering speed as the basis of competitive advantage, following (So & Song, 1998) there are three main strategies companies can use to attract customers:

1. to serve customers as quickly as possible;
2. to encourage potential customers to call ahead to get a quoted lead-time prior to ordering;
3. to guarantee a uniform lead-time for all potential customers.

Today, many service companies are applying the third strategy of uniform lead-time. For instance, banks and supermarkets have introduced a "maximum waiting-time guarantee" where customers receive a money voucher or credit if they wait for more than 5 minutes in line. Next-day delivery is often offered by freight or postal services. Other examples are restaurants that offer free lunches if customers are not served within 10 minutes (see So & Song, 1998; So, 2000; Rao, Swaminathan, & Zhang, 2005). In order to make the right decision about delivery lead-time setting, it is important for firms to understand the interrelationships between delivery time, pricing, demand and the overall profitability of service offering.

A vast number of papers have noted that customer demand increases with shorter lead-times as well as with lower prices (see e.g Blackburn et al., 1992; So & Song, 1998; So, 2000). Short lead-time can also allow a price premium, as customers may be willing to pay a higher price to reduce their wait time (Blackburn et al., 1992; Weng, 1996; So & Song, 1998; Ray & Jewkes, 2004). The potential increase in demand and/or a price premium is clearly an incentive for companies to improve lead-time performance. However, the risk that demand may exceed the firm's available capacity still exists. Hence, in selecting a lead-time to quote, the firm has to take into consideration not only how customers will react to the delivery time guarantee, but also whether it has adequate capacity to fulfill the commitment.

Due to the special character of service, there are several difficulties that managers face to match capacity with customer demand.

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The perishable nature of services do not allow mass production and inventory for future consumption (see e.g. Zeithaml, Bittner, & Gremler, 2004; Fitzsimmons & Fitzsimmons, 2006). Instead services are simultaneously or near-simultaneously consumed at the time they are produced. On the other hand, the inherent variability in demand creates a challenge for managers trying to make the best use of capacity. The demand variability is quite natural. For example, peak times in restaurants are caused by people's behavior of eating at the same hours; the demands for flights and hotels are high in summer, because vacations are usually taken in this season. When demand for a service falls short of the capacity to serve, the results are idle servers and facilities. On the contrary, when demand exceeds the available capacity, resulting in long wait-time for customers, service companies have to cope with customer dissatisfaction and costs for compensating delayed or failed service deliveries. Different strategies for managing service capacity have been proposed in (Armistead & Clark, 1994; Johnston & Clark, 2001; Sasser, 1976). For instance, in order to be able to reliably promise a short lead-time, firms can invest to increase capacity by hiring extra workers or acquiring improved equipment etc. However, the trade-off between the cost of capacity and the potential increase in demand and / or price must then be taken into consideration.

The key contributions of this paper are the following:

1. Developing a model that captures the profit impact of variation in demand as well as the service process when customers are lead-time sensitive and the firm incurs capacity costs and lateness penalties. This model should help to understand the interrelationships among quoted lead-time, capacity, demand and the overall profitability of offering services.
2. Proposing a solution procedure from which analytical results are derived to characterize the optimal lead-time and capacity decisions.

The remainder of the paper is organized as follows: the next section provides an overview of relevant literature. In Section 3, we present a deterministic model formulation and in Section 4 propose a solution method for the problem of interest. A concrete numerical example is provided in Section 5 to illustrate our approach. Using a simulation we show in Section 6 that the proposed approach can be used as an approximation in case of stochastic demand. Section 7 provides a summary and discusses avenues for future research.

2. Related literature

This paper primarily addresses a problem frequently arising in service enterprises. However, the results of our work are equally applicable to make-to-order (MTO) manufacturing environments. In the latter case, lead-time is understood as the interval between the time an order is placed and the time the requested product is delivered to the customer.

Several works are related to our study, but with different emphases (see e.g. (Keskinocak & Tayur, 2004) for an overview). Since the 1990s extensive research has been conducted on the effects of customer responsiveness as a key weapon in time-based competition. Much of this literature is qualitative in nature; only a number of papers present quantitative models to support managerial decisions. In some of those quantitative studies, customer delay costs are considered, which, either implicitly or explicitly, drive demand to be sensitive to the quoted lead-time. Dewan and Mendelson (1990), for example, study the optimal capacity and pricing decisions while taking users' delay cost into account, expressed as a function of the actual delivery time. In (Loch, 1991) demand is assumed to be a function of full-price, which equals price charged plus cost of waiting. Li and Lee (1994) and Lederer and Li (1997) propose similar models to analyze customer delay costs.

Other research focuses on the use of quoted lead-time as a competitive strategy. Weng (1996) considers an MTO manufacturer facing two types of customers: (i) lead-time-sensitive customers who are willing to pay a higher price for a shorter lead-time and (ii) lead-time-insensitive customers who are willing to wait. In a queueing setting the author studies the joint decision on customer acceptance rates and quoted lead-times which would maximize profit. Using queueing and semi-Markov decision processes, Duenyas and Hopp (1995) investigate different cases of dynamically quoting lead-times to customers in the manufacturing environment, assuming that the probability of the customer placing an order decreases as the lead-time quoted increases.

More recently, Altendorfer and Minner (2011) consider the problem of finding the optimal planned lead-times and production capacities for each stage of a two-stage MTO manufacturing system, so that the total inventory holding and customer order tardiness cost are minimized. Using M/M/1 queuing systems to model the problem, they present a general solution approach and study the influence of customer required lead-time on optimal planned lead-time. Chaharsooghi, Honarvar, Modarres, and Kamalabadi (2011) investigate the role of flexibility in price, lead-time and delivery in the MTO environment, where limited production capacity under a stochastic demand function is allowed. They develop a stochastic programming model to determine the price, lead-time and production amount in each period for various demand classes with different sensitivities to lead-time and price. However, these papers do not consider the dependencies between quoted lead-time and demand.

Hill and Khosla (1992) are probably the first to study the impact of lead-time reduction on demand where demand is formulated as a log-linear (Cobb–Douglas) function of actual lead-time and price. The authors also assume operating cost to be lead-time-sensitive. The firm's objective is to maximize profit by appropriate selection of decision variable values: price and lead-time. This deterministic model puts demand in a log-linear relationship with lead-time and price, but does not consider the impact of demand variability and system congestion as stochastic models do. In most of the analytic models related to uniform guaranteed lead-time, a queueing model is used to describe the manufacturing or service facility. In order to characterize optimal decisions, the authors usually perform analytical comparative statics (e.g. they study changes in profit before and after a change in some underlying parameters) and provide numerical results and managerial insights on the effect of operating characteristics on the optimal strategy of a firm. Such a model is proposed by So and Song (1998): the mean customer demand is expressed as a Cobb–Douglas function of lead-time and price. The objective is to maximize the profit per unit time by optimal choice of not only lead-time and price but also capacity, subject to reliability constraint that ensures a pre-specified service level.

In a model similar to that of So and Song (1998), Palaka, Erlebacher, and Kropp (1998) also use queuing theory to analyze pricing and lead-time decisions, but the lead-time and price-dependent demand function is assumed to be linear. A further difference is that they explicitly consider inventory and penalty costs to capture the impact of quoted lead-time on the cost side. So (2000) extends So and Song's work to a multi-firm model, in which he analyzes how firms select the best price and lead-time decisions in the presence of competition (i.e. each firm can react to the other's action) and how different firm and market characteristics affect the optimal strategy. In Ray and Jewkes (2004) demand is expressed as a linear function of market price and guaranteed lead-time. Their work is distinguished from others in that market price is modeled as a function of lead-time and unit operating cost as a function of mean demand rate. Ray and Jewkes (2004) study lead-time and capacity decisions. They consider the trade-off between capacity and the lead-time guarantee while assuming that the firm can increase its capacity to reduce lead-time but must be able to ensure a

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