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Production under periodic demand update prior to a single selling season: A decomposition approach

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Abstract

This paper focuses on dynamic, continuous-time production control problems in the fashion industry. Similar to the classical news-vendor problem, we consider a single product-type and the cumulative demand for items is not known until the end of the production horizon and therefore must be forecasted. Since there are periodic updates before a single selling season, actual demand during a period of time can only be determined by the end of the period. If the overall demand is overestimated, excessive inventory holding and production costs are paid and surpluses are sold at low prices at the end of the production horizon. If it is under-estimated, then sales are lost. The objective is to dynamically determine production orders which minimize overall expected costs. Since the optimal feedback for such a problem is characterized by thresholds evolving with time and system states, there is a significant computational burden in determining them. With the aid of the variational analysis and a decomposition, we derive a closed-form solution for the thresholds. A numerical study carried out to compare the decomposition and straightforward simulation-based solutions indicates the high accuracy of the suggested approach while the computational burden is dramatically reduced.

Keywords: Production control; Systems dynamics

1. Introduction

Inventory management is a key business function for companies operating with inventories that may quickly become obsolete, spoil, or have a future that is uncertain beyond a single period. This paper is motivated by the problem arising in fashion industry or in companies, which supply various garment accessories for production of fashion industry goods. The demand for these accessory items is unknown prior to a selling season. Once the season starts it is too late to produce, since fashion good manufacturers cannot halt their production to wait for deliveries. To prevent loss of sales and clients, accessory manufacturers tend to keep large stocks of end items. This, however, ties up sizeable amounts of capital.

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Forecasting demand is an efficient way of reducing uncertainty and excessive inventories and manufacturers will expend much time and effort at professional exhibitions of leading fashion designers in attempt to foresee future trends and accessory needs in the upcoming season. In addition catalogs and samples are periodically sent to fashion good manufacturers in order to update demand forecasts and get advance orders.

A typical approach to incorporating demand uncertainty is to assume a random but known and stationary distribution for the demand in each demand period. Porteus (1990) gives examples of this approach which commonly results in base stock models. In practice, these models are applied, for example, to fashion or seasonal products by large international apparel brands when the products are characterized by the supply lead-time comparable to the length of the selling period (Fuloria and Wadhwa, 1995). In this paper, since we focus on this type of seasonal goods, we assume that demand is independent (stationary) across time, as is the case in many other studies devoted to seasonal goods (e.g., Bitran et al., 1997; Federgruen and Heching, 1999; Feng and Gallego, 1995; Gallego and van Ryzin, 1994).

The problem under discussion fits the well-known class of single-period inventory models, which are frequently referred to as news vendor or newsboy problems. An extensive literature review on various extensions of the classical newsboy problem and related inventory control models can be found in Khouja (1999) and Silver et al. (1998). Although the importance of extensions to models with more than one period to prepare for the selling season has been stressed in this literature, only problems with one additional order or urgent reorder have been solved (see, for example, Veinott, 1966 and Wright, 1969). Lau and Lau (1998) considering a single-period newsboy type product which can be ordered twice during a period, show that the decision is substantially more complicated than for the simple one-order-per-period newsboy problem typically solvable with a base stock policy (ordering up to a certain level). They suggest several heuristic decision rules. Murray and Silver (1966), Hausman and Peterson (1972), Bitran et al. (1986) and Matsuo (1990) consider a number of sub-periods to prepare for the selling season. These models commonly utilize special product and demand parameters to optimize operations over each sub-period. This results in either a stochastic mixed-integer or dynamic programming. Since both outcomes pose significant computational problems, heuristics are commonly suggested. The heuristics provide various computational shortcuts based on (i) limiting the ability to adjust production in response to demand updates, (ii) reducing a multi-period problem to a single period problem or to a number of simplified problems (multi-phase heuristics), and (iii) replacing stochastic programming with a deterministic integer programming.

In contrast to these periodic review models with finite horizons, there is a stream of research studies on the use of base stock policies with advance demand information (BSADI) for continuous review of production/inventory systems operating over an infinite planning horizon. Policies of this type have been investigated in a number of papers (see, for example, Hariharan and Zipkin, 1995; Toktay and Wein, 2001; Karaesmen et al., 2004; Wijngaard, 2004). Ozer and Wei (2004) address periodic review, capacitated, finite and infinite horizon production faced by a manufacturer who has the ability to obtain advance demand information. They show that for such production systems, even when fixed costs are zero, base stock levels or thresholds evolve over time with a system's state. This radically affects the computational burden for a straightforward, backward induction algorithm that they use to numerically solve the problem. Consequently, developing simple-to-calculate, closed forms for the thresholds to provide a good approximation of the optimal solution is a challenging contribution to both engineering and operations research literature.

In this paper we deal with a capacitated system operating over a finite planning horizon. Similar to the above newsboy type papers, we consider inventory costs incurred only by the end of the planning horizon (single-review). In contrast to what appears in the literature, this paper derives a closed form solution for thresholds evolving over a continuous-time finite horizon under periodic demand updates. As a result, heavy numerical computations of the thresholds can be avoided. The derivation of the closed form solutions is accomplished with a decomposition method. The general problem presented in Section 2 is decomposed into two sub-problems. First, a lower bound is derived by minimizing the expected cost over all possible realizations without imposing the non-anticipativity condition (Section 3). This implies that the control which could provide such a cost on-line does not always exist. Then we consider an on-line control at a time point; impose non-anticipativity (which increases the expected cost found at the first step) at this time point; and apply a small control variation to minimize the change in the cost function. The minimization results in a feedback policy (Section 4). Section 5 presents an example. As shown in our simulation results (Section 6), this lower