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Optimal ordering, issuance and disposal policies for inventory management of perishable products

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ABSTRACT

Perishables, such as packed fresh food and pharmaceutical products (a.o. blood products), typically have a fixed shelf life set by a fixed use-by date or sell-by date. Despite their limited life time, orders in practice are usually based on the stock level irrespective of the ages of the products in stock. The management of inventories of such products can be improved by applying stock-age dependent ordering, issuing, and disposal policies.

This paper investigates cost reductions that can be achieved by an optimal stock-age dependent ordering, issuing, or disposal policy as obtained by Stochastic Dynamic Programming. Orders are made before the uncertain demand is revealed. When demand turns out to be relatively low, a disposal policy enables to get rid of excess (old) stock. Disposal decisions are an understudied area, but may be relevant to retailers for which displaying the freshest items is of high importance. Also blood banks prefer not to issue products that are about to expire as transfusion of younger blood products is more effective. This paper fills a research gap identified in Karaesmen et al. (2011): the paper appears to be the first to report optimal stock-age dependent disposal decisions, both under a base stock policy and under optimal stock-age dependent ordering. Results of optimal stock-age dependent ordering, disposal, and issuance are compared to a base stock policy, which is commonly used in practice.

Under FIFO issuance, the added value of an optimal disposal policy is high. An optimal disposal policy in combination with optimal ordering reduces the average costs only when issuing old products is penalized, e.g. by selling at a discounted price. Under LIFO issuance, an optimal disposal policy has significant impact when orders are set by a BSP, but not under optimal stock-age dependent ordering. When no penalty or discount applies, disposals reduce costs only in case of suboptimal ordering, e.g. by a BSP.

1. Introduction

The inventory control problem of perishable products consists of (at least) three optimization problems: the problem of determining an optimal order policy, an optimal issuing policy, and an optimal disposal policy. In a periodic review setting, the order policy prescribes how much to order. The issuing policy, in the literature also called the picking, dispatching, or withdrawal policy, sets the order in which products are taken from the shelf to meet the demand. The disposal policy prescribes how many products to remove from stock. In many studies, order policies are limited to base stock policies and issuing policies are either FIFO (=oldest first) or LIFO (=youngest first), or mixtures of FIFO and LIFO. Usually the disposal policy is to dispose products when the expiration date has exceeded, but one may decide to dispose prematurely some products, that is before the expiry date has elapsed. Practical reasons for disposing products prematurely are the following: (1) a retailer who sells at a high market segment likes to display only the freshest products, (2) the value of old products is perceived lower by customers, and thus the retailer provides a discount to the sales price, and (3) blood banks and hospitals may want to dispose the oldest blood products if stock levels are high, as transfusing younger blood products is more effective. The disposal decision does not result in much additional product waste, if the disposed products are kept behind in a back storage to meet the demand in case one runs out of stock, or when disposed products are sold at another market. In our analysis we have not included the selling of disposed products.

In this paper the focus is on a product with a fixed maximal shelf life of m days, after which a product cannot be sold. When information is available about the ages of the products in stock, an optimal policy is the so-called stock-age dependent. Nevertheless, in practice one finds mostly stock-level dependent policies, which

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do not minimize the operational and managerial costs of an inventory system. Many Automated Store Ordering (ASO) and Computer Assisted Ordering (CAO) systems apply base stock policies (BSP), also called the order-up-to S policies, for setting periodically the order quantity irrespective of the ages of the products in stock. We study how much one may improve the inventory control by stock-age dependent issuance or disposal, without changing such ordering systems, and compare the results with the case of optimal stock-age dependent ordering. We check the added value of a disposal policy by computing and simulating a combined ordering and disposal policy and an optimal ordering policy with no premature disposals.

Recently, Haijema (2011) shows that stock-age dependent issuance may not be FIFO in a lost sales inventory system. This result was first shown in Pierskalla and Roach (1972). In some cases of relatively high stock levels, it appears to be optimal to not issue the oldest products but to let them expire as this reduces holding cost and increases sales revenues by selling less products at discounted prices. Optimal issuance may result in less shortages without generating more outdating. Apparently optimal issuance results in a better timing of disposing of products. An optimal disposal policy is easier to implement than an age dependent issuing policy, as a disposal decision is made only once a day, whereas depending on the context the issuing decision is made multiple times a day. Moreover, stock-age dependent issuance is only applicable in cases in which the picking of products is controlled, like at blood banks and hospitals. In supermarkets the store manager has no full control on the issuing policy, as customers take products from the shelf themselves: their picking order is a mixture between FIFO and LIFO. By mirroring products on the shelf, i.e. display the oldest products at the front of the shelf, and keeping the freshest products in the back storage, store managers force the picking order to become close(r) to FIFO.

We investigate by how much the costs of a base stock policy (BSP) can be improved by an optimal ordering policy, an optimal issuing policy, and an optimal disposal policy. In particular, we are also interested whether an optimal ordering policy can be improved by a combined optimal ordering and disposal policy. Optimal stock-age dependent policies are computed numerically by Stochastic Dynamic Programming (SDP). Throughout this paper, the term 'optimal' policy stands for an optimal stock-age dependent policy as obtained by SDP.

Contribution: This paper is the first paper that studies integrally optimal stock-age dependent ordering, issuing, and disposal policies for perishable inventories. Therefore a Stochastic Dynamic Programming (SDP) model is developed that simultaneously optimizes the ordering and the disposal decision. Numerical experiments provide insights into the impact of stock-age dependent ordering, issuing and disposal policies on costs, waste, and shortages. Besides being of theoretical value, these insights are valuable to the practice of managing inventories of perishable products.

Outline: In the next section, we present related literature on the three optimization problems when dealing with perishable inventory management. The combined problem of optimal ordering and optimal disposal is formulated as a Markov decision problem (MDP) that can be solved by Stochastic Dynamic Programming (SDP) in Section 3. For a broad design of experiments, defined in Section 4, results are presented for both FIFO and LIFO issuance in Section 5. Finally, Section 6 concludes the paper by a discussion and a summary of the main findings and insights.

2. Literature

2.1. Order systems and order policies

In the last (two) decades Automated Store Ordering (ASO) and Computer Assisted Ordering (CAO) systems have become more and more in use to improve the efficiency and the effectiveness of inventory management at retailers (van der Vorst et al., 1998; van Donselaar et al., 2006). Using point of sales data the stock levels in the store are updated automatically, and either an order is placed automatically by an ASO system or an order quantity is proposed by a CAO system. In the latter case the order is to be processed further by a decision maker who is responsible for the ordering process. ASO systems are mainly found at supermarkets and retailers that offer a great variety of products. In settings with a smaller product assortment like blood banks and hospitals a CAO system can be used.

Mechanisms to set an order quantity are ordering policies that take as input the actual stock level (tracked by the system) and any information on future demand (based on historical information on demand realizations and predictions based on promotions). In case stock replenishment happens daily, often traditional periodic review ordering policies are implemented like a BSP. An example of a BSP is to order every weekday d up to an stock level S_d. In case of daily ordering, the review period R, that is, the time between two successive order moments, is 1. In some studies a batch size for ordering is included explicitly: throughout this paper the batch size is set to 1. As most ASO and CAO systems are designed for the inventory management of non-perishables, these systems do not acknowledge the aging of products in stock and thus do not anticipate outdating of old stock. In recent work of van Donselaar et al. (2006), Haijema et al. (2007), Broekmeulen and van Donselaar (2009) and Haijema (2013) new heuristics and ordering policies are proposed to improve the inventory management of perishables through such systems. These policies are not yet (widely) implemented in current ASO and CAO systems, which thus may result in unnecessary outdating of perishable products at retailers.

2.2. Issuing policies

With respect to the issuing policy, most studies found in the literature rely on a simple issuing policy, like FIFO (oldest product first) or LIFO (youngest product first), or a combination of the two. For an overview, see the reviews of Nahmias (1982) and Karaesmen et al. (2011). In case consumers may pick the products themselves, LIFO is a common way of modeling the selection behavior of customers, as many consumers prefer the youngest products available, that are products with the longest use-by-date. Store managers try to influence the selection behavior by putting the oldest product upfront. In case consumers do not pick themselves, products are usually issued by the supplier in the FIFO order as this reduces the number of products that outdate. Although FIFO issuance seems to be intuitively optimal, Pierskalla and Roach (1972) and Haijema (2011) show that in a lost sales inventory system, FIFO issuance may not be cost-optimal when a base stock policy is applied and old products are sold at discounted prices. In Haijema (2011) a Markov decision problem is formulated in which a day is split into multiple time interval, called the epochs. At the end of each epoch products are taken from stock to meet the demand for that epoch. In SDP terminology, the state is the tuple: day of the week, epoch, the number of products in stock in each of the m age categories, and the number of products demanded. The issuing action is the tuple: the number of products to issue from each of the m age categories. Stock is replenished according to a base stock policy, and only at the end of the day products that expire are disposed. The results in Haijema (2011) indicate that it may be occasionally better to dispose some products before they expire. That is, FIFO is not always optimal.

In some studies on the issuing policy, demand is specified per age category and the utility of a product depends on its age. The optimization problem is then to issue such that the long-run utility