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Control of a production–inventory system with returns under imperfect advance return information

S.D.P. Flapper [a], J.P. Gayon [b,*], S. Vercraene [b]

[a] Technische Universiteit Eindhoven, P.O. Box 513, 5600 MB Eindhoven, Netherlands
[b] Laboratoire G-SCOP, Grenoble Institute of Technology, 46 Avenue Félix Viallet, 38031 Grenoble Cedex, France

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ABSTRACT

We consider a production–inventory system with product returns that are announced in advance by the customers. Demands and announcements of returns occur according to independent Poisson processes. An announced return is either actually returned or cancelled after a random return lead time. We consider both lost sale and backorder situations. Using a Markov decision formulation, the optimal production policy, with respect to the discounted cost over an infinite horizon, is characterized for situations with and without advance return information. We give insights in the potential value of this information. Also some attention is paid to combining advance return and advance demand information. Further applications of the model as well as topics for further research are indicated.

1. Introduction

During the last 15 years a lot of attention has been paid to so called closed-loop supply chains, reverse logistics, product recovery, both in practice, as in academic literature, see e.g. Dekker et al. (2004) and Rubio et al. (2008). In this context, also attention has been paid to forecasting the reverse flows. Available publications use delivery/purchase information to forecast returns, see e.g. Yuan and Cheung (1998), sometimes taking into account information on actual returns, see e.g. de Brito and van der Laan (2009).

In this paper we neglect the use of the above information, but focus on return information supplied by the owner/user of a product after the initial delivery, purchase of this product. We study situations where customers have to announce the return of a product. Advance return information/advance supply information (ARI/ASI) is among others required in practice for warranty returns, commercial returns, buy back contract returns, returns due to wrong delivery. An important reason for the above is to prevent unnecessary or incorrect returns. See e.g. Boykin (2001) for a general description of the return material authorization process and the support offered for this process by SAP. Other examples of using ARI concern information related to the end of lease contracts, when the lessee has to indicate some time before whether or not (s)he will continue the contract or buy the leased product.

A number of authors paid already attention to the value of advance information in the context of product recovery, including the recent contribution by Khawam and Hausman (2009) with an up-to-date review of the literature in this field. Our paper differs from the above paper in a number of aspects including the origin of supply uncertainty, a finite production capacity, a continuous review of the inventory position, random lead times and lost sales.

We adopt a make-to-stock queue framework to model production capacity and uncertainty with respect to production, returns and demand. A make-to-stock queue refers to a make-to-stock system where the supply process is modeled by servers producing products one by one. Make-to-stock queues have been used to investigate issues such as stock allocation (de Véricourt et al., 2002), production scheduling (Zhao et al., 2008), dynamic pricing (Gayon et al., 2009b) and multi-echelon coordination (Veatch and Wein, 1994). A few make-to-stock papers include product returns (see e.g. Heyman, 1977, Gayon and Dallery, 2007). However, none of them investigates the use of ARI. Our modeling of imperfect ARI is close to the modeling of imperfect advance demand information (ADI) introduced by Gayon et al. (2009a). In the latter paper, the customer announces his intention to buy a product but the actual ordering takes place after a stochastic demand lead time, with a cancellation probability. In this paper, we assume that the customer announces his intention to return a product where the actual return occurs after a stochastic return lead time, with a return cancellation probability. ADI and ARI have opposite impacts on production control. For ADI, production is planned when there are many pending orders. For ARI, production is not planned when there are many pending returns. Because of the increasing use of ADI, we also pay some attention to the combined use of ARI and ADI.

* Corresponding author. Tel.: +33 4 76 57 47 46; fax: +33 4 76 57 46 95.
E-mail addresses: s.d.p.flapper@tue.nl (S.D.P. Flapper), jean-philippe.gayon@grenoble-inp.fr (J.P. Gayon), samuel.vercraene@grenoble-inp.fr (S. Vercraene).

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The rest of the paper is setup as follows. First, we describe the situation that we study as well as the objective function to be optimized. Next, we derive the optimal production policy for lost sales situations for an infinite horizon. Via numerical experiments we determine the sets of parameter values for which ARI may be useful. Next we show that the model developed for the lost sales situations can be amended to deal with backlog situations. We also derive the optimal production policy when both ARI and ADI are used. Then we explain how our model can be used for other applications than product returns. Finally we briefly summarize our main findings and indicate some interesting extensions of the model presented here.

2. Problem description

In this paper we focus on situations where individual products are produced and returned. Products that are returned are as good as new, and are stored in the stock of serviceable products together with the products that the company produces new.

We consider an M/M/1 make-to-stock queue for a single item (see Fig. 1). The company can decide at any time to produce this item. The production time is exponentially distributed with mean $1/\mu$. After having been produced, products are stored in the serviceable products inventory. Demand for the serviceable products follows a Poisson process with rate λ. For the moment being, we assume lost sales: Demand that cannot be fulfilled immediately is lost. We will also consider backorder situations (see Section 4).

Besides the single server production mode, the company has an alternative procurement mode where the company receives products from another source that is not under her direct control. These products can not be distinguished from the products produced by the single server. We assume that the company has some advance information on the alternative procurement process.

The alternative source considered hereafter is customers that can return products, although, as we shall indicate in Section 6, the following also holds for other alternative sources. Before returning a product, the customer must announce that he will return the product. The announcements occur according to a Poisson process with rate δ, independently of the demand process. However, not every announced return becomes an actual return. Reasons for this in practice include forgetting to return, not at home at the moment of planned pickup, mind change. We assume that there is a probability p that an announced return is actually returned. There is a probability $q = 1 - p$ that an announced return is cancelled. All actual returns have to be accepted and a return cannot be disposed. Therefore, to guarantee the stability of the on-hand stock of serviceable products, we assume that $p\delta < \lambda$.

We further assume that the time L that elapses between the announcement of a return and its actual receipt (or cancellation) is exponentially distributed with rate γ. This time does not depend on the number of announced returns. Note that a number of the earlier mentioned examples from practice concern situations with a predefined maximum return time. However, in practice, companies deviate from this time for all kinds of reasons, for instance to keep important customers. We make here the same approximation as many other authors, including Yuan and Cheung (1998).

Once received, a return is stored in the serviceable stock and can be sold. The state of the system can be described by $(X(t), Y(t))$ where $X(t)$ denotes the on-hand stock of new and returned products at time t, and $Y(t)$ denotes the number of returns that have been announced but still have not been received or cancelled at time t.

We consider unit production cost, c_p, unit lost sale cost c_l, unit return cost c_r that only has to be paid for actual returns, and unit inventory holding cost per unit of time, c_h. We assume that $c_p < c_l$ in order to have an incentive to produce. The objective of the decision maker is to find a production control policy π minimizing the expected discounted cost over an infinite time horizon. The discount rate is denoted by α. The production control policy specifies, for each state of the system, when to produce. We define $v^{\pi}(x,y)$ as the expected total discounted cost associated with policy π, for initial state $(X(0), Y(0)) = (x,y)$.

We seek to find the optimal policy π^* minimizing $v^{\pi}(x,y)$, where we let $v^*(x,y) = v^{\pi^*}(x,y)$ denote the optimal value function. We restrict our analysis to stationary Markovian policies since there exists an optimal stationary Markovian policy (Puterman, 1994). In the following, we characterize the optimal policy for the case where ARI is used and for the case where ARI is ignored.

3. Lost sales situations

3.1. Optimal policy when ARI is used

When ARI is taken into account, decisions are based on both the on-hand stock of serviceable products, $X(t)$, and the number of announced returns, $Y(t)$. The situation can be modeled as a continuous-time markov decision process (MDP). In order to uniformize this MDP (Lippman, 1975), we assume that the number of announced returns is bounded by M. This is not a crucial assumption since our results hold for any M. We choose a uniformization rate $C = \lambda + \mu + \delta + M\gamma$. The optimal value function can be shown (Puterman, 1994) to satisfy the optimality equations

$$v^*(x,y) = Tv^*(x,y), \quad \forall (x,y),$$

where the operator T is a contraction mapping defined as

$$Tv(x,y) = \frac{1}{C+\alpha}[c_h x + \mu T_0 v(x,y) + \lambda T_1 v(x,y) + \delta T_2 v(x,y) + \gamma p T_3 v(x,y) + \gamma(1-p) T_4 v(x,y)] \quad (1)$$

with

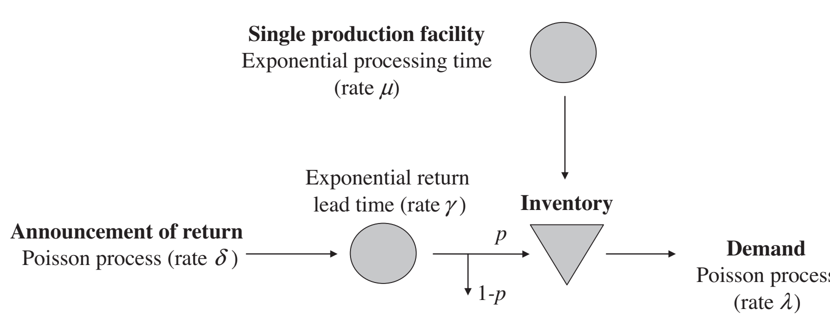

Fig. 1. Inventory system with return flow and ARI.