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Coordination of manufacturing, remanufacturing and returns acceptance in hybrid manufacturing/remanufacturing systems

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ABSTRACT

This paper deals with the coordination of manufacturing, remanufacturing and returns acceptance control in a hybrid production-inventory system. We use a queuing control framework, where manufacturing and remanufacturing are modelled by single servers with exponentially distributed processing times. Customer demand and returned products arrive in the system according to independent Poisson processes. A returned product can be either accepted or rejected. When accepted, a return is placed in a remanufacturable product inventory. Customer demand can be satisfied as well by new and remanufactured products. The following costs are included: stock keeping, backorder, manufacturing, remanufacturing, acceptance and rejection costs. We show that the optimal policy is characterized by two state-dependent base-stock thresholds for manufacturing and remanufacturing and one state-dependent return acceptance threshold. We also derive monotonicity results for these thresholds. Based on these theoretical results, we introduce several relevant heuristic control rules for manufacturing, remanufacturing and returns acceptance. In an extensive numerical study we compare these policies with the optimal policy and provide several insights.

1. Introduction

During the last two decades, quite some attention has been paid to the problem of jointly controlling the manufacturing of new products and remanufacturing of returned products. In addition to the joint control of manufacturing and remanufacturing, another important issue is whether or not to accept returns. There are many situations in practice where controlling the returns acceptance can result in considerable cost savings, especially when the costs related to accepting a return are high. These costs may include, among others, transportation costs (related to the collection of returns), stock keeping costs, and recovery costs.

In this paper, we consider the hybrid system shown in Fig. 1. When a product is returned, it can be either rejected, or accepted and placed in a remanufacturable inventory, where it is assumed that in principle all accepted returns can be remanufactured. The finished good inventory can be replenished by manufacturing new products or remanufacturing accepted returns.

Manufacturing, remanufacturing as well as returns acceptance decisions can be based on different data. Two important data in this context are the finished good inventory position (I) and the remanufacturable inventory position (R). More precisely, I denotes the number of products in the finished good inventory plus the products actually being manufactured or remanufactured minus backlogs and R denotes the number of products in the stock of accepted returned products not yet remanufactured.

We address the problem of jointly controlling manufacturing, remanufacturing, and returns acceptance control in a setting with stochastic processing times and finite capacities. The structure of the optimal policy is characterized helping us to design simple heuristic control rules for manufacturing, remanufacturing and returns acceptance. In a numerical study, we compare these heuristic control rules with the optimal rules.

The setup of the rest of the paper is as follows. Section 2 provides a literature review and points out our contributions to the literature and practice. In Section 3 the assumptions of our queueing control model are detailed. The structure of the optimal policy is derived in Section 4. In Section 5 we present several heuristic control rules for manufacturing, remanufacturing and returns acceptance. Then we compare them numerically with the optimal policy. The paper ends with a brief summary of the main results.

2. Literature review

The literature review focuses on the setting of Fig. 1 with two distinguished inventories: the remanufacturable inventory and the finished good inventory. We do not review papers where the

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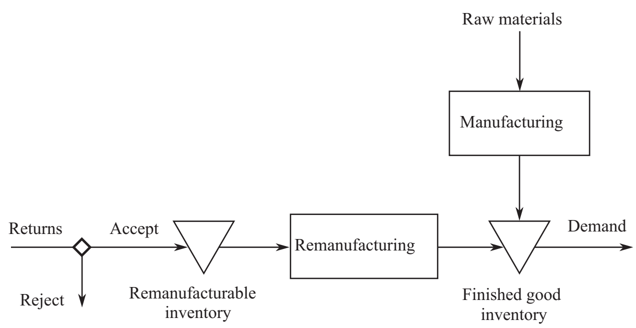

Fig. 1. Hybrid system with manufacturing, remanufacturing and returns acceptance.

remanufacturable inventory is not modelled explicitly. For instance Fleischmann et al. (2002) assume that returns can be re-used immediately as new products. In such a situation, the problem can usually be reduced to a single-dimensional problem where decisions are based only on the finished good inventory position. We also restrict our survey to papers assuming stochastic demands and returns. For exhaustive reviews, we refer the reader to Rubio et al. (2008) and Ilgin and Gupta (2010).

We begin with papers that investigate the structure of the optimal policy. In a periodic-review setting, Inderfurth (1997) studies a problem where returns can be accepted or rejected and unsatisfied demand is backlogged. When the manufacturing time and the remanufacturing time are equal (and constant), he proves the optimality of an (S_m, S_r, S_a) policy with S_m the manufacture up to level, S_r the remanufacture up to level, and S_a the accept (returns) up to level. The manufacturing decision and the acceptance decision are based on the aggregate inventory $(I+R)$ while the remanufacturing decision is based only on the inventory position I. More precisely, this policy states to manufacture if and only if (iff) $I+R<S_m$, remanufacture iff $I<S_r$ and accept returns iff $I+R<S_a$. To emphasize the link between decisions and data, we denote this policy by $(S_m[I+R], S_r[I], S_a[I+R])$. We will use similar notations in the rest of this section. If the procurement time exceeds the remanufacturing time by one period, Inderfurth (1997) characterizes the optimal policy for the special case where the accepted returns are remanufactured directly without waiting. For systems with a remanufacturable inventory and non-identical manufacturing and remanufacturing times, the optimal policy has not yet been characterized. Before Inderfurth, Simpson (1978) had characterized the optimal policy for the case with zero manufacturing and remanufacturing times.

Simpson (1978) and Inderfurth (1997) consider a situation where they allow to dispose accepted return from the remanufacturable inventory. For both models, the optimal policy structure shows that the disposal option is only used when the returns arrive in the stock and not later. This makes these models equivalent to our model with respect to returns acceptance control.

Li et al. (2010) generalize the results of Simpson (1978) by including fixed manufacturing costs and fixed disposal costs. The optimal policy orders a quantity S_m-I-R when $I+R$ drops below the reorder point s_m and disposes $I+R-s_a$ returns (or at least R returns if $I+R-s_a<0$) when $I+R$ rises above the disposal point s_a. DeCroix (2006) extends the results of Inderfurth (1997) to a multi-stage serial system where products are remanufactured at the upstream stage.

In what follows, we review papers focussing on heuristic policies. Kiesmüller (2003) investigates the problem with non-equal manufacturing and remanufacturing times. She proposes two heuristic policies assuming that all returns are accepted that we can denote by $(S_m[I'], S_r[I])$ and $(S_m[I+R], S_r[I'])$. She defines a modified inventory position I' that takes into account only part of the products being actually manufactured.

In a continuous-time review setting, van der Laan and Teunter (2006) assume that demand and returns occur according to independent Poisson processes. They include setup costs for manufacturing and remanufacturing. The times for manufacturing and remanufacturing are assumed to be equal. They investigate two heuristic policies where all returns are accepted. The $(s_m[I], Q_m, Q_r)$ policy orders a quantity Q_m when the inventory position I drops below the reorder point s_m. The remanufacturing is controlled by a push policy: as soon as there are Q_r products in the remanufacturable stock, these products are sent to remanufacturing. The authors compare this policy with a pull remanufacturing policy $(s_m[I], Q_m, s_r[I], Q_r)$, with s_r the reorder point for remanufacturing products. The authors provide approximate formulas for the optimal values of the different parameters and compare them to the optimal parameter values in a numerical study.

Van der Laan et al. (1996b) study a model with the option of rejecting returns upon arrival. The manufacturing time is constant while remanufacturing is operated by a finite number of servers with exponentially distributed times. There is a setup cost for manufacturing and no setup cost for remanufacturing. The authors propose an $(s_m[I+R], Q_m, S_a[R])$ push remanufacturing policy and derive an analytical expression for the average cost. Van der Laan et al. (1996a) generalize the above policy via an $(s_m[I+R], Q_m, S_a^1[I+R], S_a^2[R])$ push remanufacturing policy. For a system with remanufacturable stock holding cost, returns are accepted if both $I+R<S_a^1$, and $R<S_a^2$ hold. This returns acceptance policy resembles the Kanban generalized policy proposed by Liberopoulos and Dallery (2003).

Van der Laan and Salomon (1997) consider a model with correlated demand and return processes, demand and return inter-occurrence times being Coxian-2 distributed. The authors compare the $(s_m[I], Q_m, Q_r, S_a[I])$ push remanufacturing policy with the $(s_m[I], Q_m, s_r[I], S_r, S_a[R])$ pull remanufacturing policy, where the system remanufactures S_r-I products if $I \le s_r$. Teunter and Vlachos (2002) complement the numerical study of this model. In a multi-echelon setting, Aras et al. (2006) consider a two stage problem with remanufacturing at the downstream stage.

Korugan and Gupta (2000) have investigated very briefly the same setting as ours, proposing a Kanban policy. However, neither theoretical results nor numerical results are presented in this work.

We now summarize our contributions with respect to the literature. Our first contribution is the characterization of the optimal policy for the setting described in Section 1. We prove that the optimal policy, minimizing discounted or average costs, is characterized by two state-dependent base-stock thresholds for manufacturing and remanufacturing and one state-dependent returns acceptance threshold. We also derive several monotonicity results for these thresholds. To the best of our knowledge, only Simpson (1978), Inderfurth (1997), and Li et al. (2010) have derived optimality results for the setting of Fig. 1. However, they assume constant times and infinite capacities for manufacturing and remanufacturing while we assume stochastic processing times and finite capacities. Our second contribution is the comparison of heuristic policies with the optimal policy. We restrict our attention to heuristics that are consistent with our theoretical monotonicity results. Most of these heuristic policies have been studied in the literature in different contexts but have not been compared with the optimal policy. Designing from scratch efficient heuristics that jointly control manufacturing, remanufacturing and acceptance is a difficult task. To deal with this difficulty, we first consider heuristic policies where only one of the three controls (manufacturing or remanufacturing or returns acceptance) is a heuristic and the two other controls are set optimally given this heuristic control. It allows us to derive insights about the relevance of various heuristics for the three types of control. Based on this analysis, we derive insights on several heuristics that jointly control manufacturing, remanufacturing and acceptance.