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Omega 34 (2006) 571–584
omega
The International Journal of Management Science
www.elsevier.com/locate/omega

Determination of recovery effort for a probabilistic recovery system under various inventory control policies

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Available online 5 March 2005

Abstract

In this study we investigate the desired level of recovery under various inventory control policies when the success of recovery is probabilistic. All the used and returned items go into a recovery process that is modelled as a single stage operation. The recovery effort is represented by the expected time spent for it. The effect of increasing recovery effort on the success probability together with unit cost of the operation is included by assuming general forms of dependencies. Alternative to recovered items, demand is satisfied by brand-new items. Four inventory control policies that differ in timing of and information used in purchasing decision are proposed. The objective is to find the recovery level together with inventory control parameter that minimize the long-run average total cost. A numerical study covering a wide range of system parameters is carried out. Finally computational results are presented with their managerial implications.

Keywords: Probabilistic recovery; Inventory control

1. Introduction

As a consequence of the increased awareness on the scarcity of resources and diminishing raw materials, recovery of used products has become an important issue for manufacturers in the past years. In many countries there are laws and law proposals obliging manufacturers to take back their products after their useful life to re-use. Designing recovery systems that bring the used items into an as-good-as new condition has been taking attention of many researches with diverse backgrounds. In this study our main aim is to investigate the desired level of recovery effort in the economical sense.

In addition to environmental benefits, product recovery is typically seen as a cost reducing strategy. However, having a recovery practice requires new planning applications; mainly coordinating the traditional purchasing/production sources with recovery options due to the fact that they are used to satisfy the same demand stream. In recent years a vast amount of academic knowledge has been accumulated in coordinating these decisions. de Brito [1, p. 43] provides an up-to-date and extensive review of the literature.

One of the issues not investigated in detail is the fact that the recovery process is not perfect in the sense that not all of the items can be successfully recovered. To the best of our knowledge, imperfect recovery is only investigated by Ferrer [2]. Under a deterministic demand, single period setting, he examines a number of distinct situations about the information on the failure of recovery. He includes a number of serial recovery operations and identifies the value of having the yield information in early stages of recovery. In addition the importance of the responsive suppliers as alternative to imperfect recovery is shown by numerical experimentation.

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doi:10.1016/j.omega.2005.01.015

Our study, aiming to investigate the desired level of recovery is motivated by an industrial practice in a European refinery (Rijneveld [3]). An important class of items in the inventory consists of expensive, slow moving parts that have high supplier lead time. The system is also subject to returns which cannot be used as-good-as new ones and have to go through a recovery process. The recovery process consists of a set of testing and fixing operations, starting with roughest to the detailed ones. Typically the recovery process is considered to be economical. Therefore the objective of the recovery shop is to maximize the number of recovered items, consequently they have the tendency for practicing recovery into finest detail. Currently, company's purchasing and recovery decisions are not coordinated. Since while making purchasing decisions the returns are not taken into account in a formal way, the recovered items cause inventory accumulation for the serviceables that are used to satisfy demand. As most of these items are slow moving, their effects can be substantial in holding costs. Besides, the objective of maximizing throughput of recovery may not be appropriate considering the effect of increasing recovery effort on the success probability of recovery and costs.

The main objective of our study is to investigate the desired level of recovery effort for such a system. Our approach integrates tactical and operational decision making. We consider specification of recovery effort (that can be considered as a system design issue) and purchasing decisions (that is traditionally an operational decision) in a coordinated manner. For the sake of generality and simplicity, we model recovery as a single stage operation with some unit cost and lead time. We consider the expected time spent in recovery operation, i.e., associated expected lead time, as a measure of the amount of recovery effort and focus on the case where the probability of successful recovery increases as the expected lead time increases, i.e., the amount of effort put into recovery. Increasing the expected lead time of recovery operation can be considered as performing further disassembly, testing and fixing operations, in other words increasing the number of steps that get to be more detailed. We also include the effect of increasing recovery effort on associated unit cost.

We assume that all of the items completing their usage time (which is stochastic with a known probability distribution) return to the system. We further assume that information on the number of items currently in use is always available. In several practical cases one observes both a 100% return rate and availability of information on the number of items currently in use. For instance consider a specific tool that is occasionally used by service engineers in the maintenance and repair of a certain machinery and that is prone to damage during the use. Whenever a need for use arises, the engineer requests the tool and after the use (s)he returns it. In general, the usage time is stochastic and the quality level of the used tool is not as-good-as new. Similarly, you can think of any commercial product where all of the customers return the products at the end of the useful life time as obliged by legislation or sales agreement. In these cases it is important to keep track of the number of items currently in use, in order to monitor the inventory system correctly. We assume that all of the issues and return information are perfectly recorded. Moreover the number of items currently in use is known.

For the system described above we propose four distinct inventory control policies, and the desired level of recovery is investigated under different system conditions: expected life time of the product, expected supplier lead time, unit purchasing cost, sensitivity of success probability and unit cost to the increase in expected lead time of the recovery operation.

The outline of the paper is as follows: In Section 2, the technical assumptions are given together with model formulation. In Section 3, the results of the numerical study are presented. Finally managerial insights gained by the study and the effect of employed assumptions are discussed in Section 4.

2. Model development and formulation

In this section we discuss the specifications of the considered environment in detail. The environment is described in Section 2.1, modeling of recovery operation is discussed in Section 2.2. In Section 2.3 system costs are given. Proposed inventory control policies are discussed in Section 2.4, and a generic steady-state cost function is derived in Section 2.5. The notation summarized in Table 1 is used throughout the article.

2.1. Demand and supply processes

We consider a single item inventory system facing stochastic demand. There are two supplies for the system; brand new items purchased from an outside supplier and recovered used items. All items completing their usage return to the system and go over a recovery operation which is imperfect; with a certain probability p the used item is brought to an as-good-as new condition, otherwise it is lost. A simple sketch of the system is given in Fig. 1.

We assume that the demand process is Poisson with rate λ in accordance with representing a slow moving item. Unsatisfied demand is completely backordered. Each item demanded is returned after use where the duration is stochastic with a known distribution. This means that either the customers are the employees of the firm, or there is a sales agreement or a legislation dictating 100% take-back. The information on the number of items currently in use is always available. Regardless of its age, each returned item goes into the recovery operation after which it is brought to an as-good-as new condition with a certain probability. Recovered items are perfectly substitutable for the brand new ones supplied from an outside vendor. Supplier lead time for the new items is assumed to be stochastic with a known