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How to set the holding cost rates in average cost inventory models with reverse logistics?

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Abstract

Among both inventory theorists and practitioners, it is common use to include an opportunity cost rate in the holding cost rate. In that way, the cost of capital can be roughly incorporated in an average cost (AC) inventory model. The traditional way for calculating the opportunity cost rate is to multiply the interest rate (or discount rate) by the marginal cost for producing/ordering an item. For single source inventory systems with only forward logistics, this method is easy to use, and leads to near-optimal policies from a discounted cash flow (DCF) point of view. For inventory systems with reverse logistics, however, the method is no longer straightforward. In this paper we compare different methods for calculating the opportunity cost rates of returned non-serviceable, remanufactured, and manufactured items. We discuss which method gives the best results for a specific reverse logistics model with setup costs, non-zero lead times, and disposal.

Keywords: Inventory control; Remanufacturing; Costing

1. Introduction

The discounted cash flow (DCF) approach is generally considered to be the 'right' approach for determining optimal policies (see, for instance Grubbström [3]). However, inventory theory is dominated by the average cost (AC) approach. The AC approach is often simpler, but it only roughly incorporates the cost of capital, i.e. the opportunity cost. The traditional approach for including the cost of capital in an average cost (AC) model is to add the interest rate (or discount rate) times the marginal cost for ordering/producing an item to the out-of-pocket holding cost rate. In single source models with only forward logistics this is straightforward and produces good results. Recent reviews on this topic are provided by Klein Haneveld and Teunter [4] and Corbey et al. [1].

As we shall discuss below, however, setting the holding cost rates is less straightforward in models with reverse logistics. Reverse logistics is the collective noun for logistic environments with reuse of products and materials. Possible cost reductions, more rigid environmental legislations, and environmental concerns have led to increasing attention for reverse logistics in the recent past. A particular type of reuse is remanufacturing. After remanufacturing, an item is considered to be

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as good as new. A number of authors have proposed quantitative models for inventory systems with remanufacturing. An excellent review is provided by Fleischmann et al. [2]. Most models consider three types of stocked items: non-serviceable items, i.e. returned items that are not yet remanufactured, remanufactured items, and manufactured items.

With respect to setting the holding cost rates, the following questions arise in models with remanufacturing. When remanufacturing is cheaper than manufacturing, should the opportunity holding cost rate for remanufactured items then be smaller than that for manufactured items? Note that this would lead to identical manufactured and remanufactured items with different holding cost rates. And should we include opportunity costs in the holding cost rate for returned items that are not yet remanufactured? In what follows, we will address these questions.

The remainder of the paper is organized as follows. In Section 2 we list the notations that we use. In Section 3 we propose five different methods for setting the holding cost rates in a model with reverse logistics. In Section 4 we present a specific reverse logistics model, that we will use for comparing these five methods. It is a continuous review model with stochastic demand and return of items, and fixed positive lead times for manufacturing and remanufacturing. Costs are incurred for (re)manufacturing items, placing a (re)manufacturing order, backordering, and for disposing items. The goal is to find the optimal policy that is characterized by the order quantities for manufacturing and remanufacturing, the reorder levels for manufacturing and remanufacturing, and the dispose-down-to level. The results are reported in Section 4.4, and their robustness is discussed in Section 5. We end with some conclusions in Section 6.

2. Notations

We use the following notations:

λ	demand rate
r	recovery rate
c_m	marginal cost for manufacturing one item
c_r	marginal cost for remanufacturing one item
c_d	cost for disposing one item
K_m	setup cost for manufacturing
K_r	setup cost for remanufacturing
h	out-of-pocket holding cost rate
h_n	holding cost rate for non-serviceable items
h_m	holding cost rate for manufactured items
h_r	holding cost rate for remanufactured items
p	backorder cost rate
L_m	lead time for manufacturing
L_r	lead time for remanufacturing
α	continuous interest rate
Q_m	order quantity for manufacturing
Q_r	order quantity for remanufacturing
s_m	reorder level for manufacturing
s_r	reorder level for remanufacturing
s_d	dispose-down-to level.

3. Five methods for setting the holding cost rates

The five methods that we propose for setting the holding cost rates h_n for non-serviceable items, h_r for remanufactured items, and h_m for manufactured items are listed in Table 1. Each holding cost rate is always the sum of the out-of-pocket holding cost rate h and some opportunity cost rate that depends on the method that is used and on the interest rate α. In the remainder of this section, we will discuss each of the five proposed methods separately.

All methods consider the costs for collecting returned items to be fixed. Hence, these costs are not included in the opportunity cost rates. Furthermore, all methods ignore the costs associated with transporting a returned non-serviceable item to either its stocking location, or to the disposal facility.

Method 1: $h_n = h$, $h_r = h + \alpha c_r$, $h_m = h + \alpha c_m$

Ignoring the costs associated with transporting a returned non-serviceable item to its stocking location, no 'value is added' to a returned item. Therefore, there is no cost of capital associated with stocking a non-serviceable item. Hence, $h_n = h$. Remanufacturing a non-serviceable item costs c_r. Hence, the capital tied up in a remanufactured item is $0 + c_r = c_r$, which gives $h_r = h + \alpha c_r$. Finally,

Table 1
Five methods for setting the opportunity holding cost rates for inventory models with reverse logistics

Method	1	2	3	4	5
$h_n – h$	0	0	$\alpha(-c_d)$	$\alpha(-c_d)$	$\alpha(c_m - c_r)$
$h_r – h$	αc_r	$\alpha((1-r)c_m + rc_r)$	$\alpha(c_r - c_d)$	$\alpha((1-r)c_m + r(c_r - c_d))$	αc_m
$h_m – h$	αc_m	$\alpha((1-r)c_m + rc_r)$	αc_m	$\alpha((1-r)c_m + r(c_r - c_d))$	αc_m