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Surendra M. Gupta
Northeastern University

Srikanth Vadde
Northeastern University

Sagar V. Kamarthi
Northeastern University

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Contact Information

Dr. Surendra M. Gupta, P.E.
Professor of Mechanical and Industrial Engineering and
Director of Laboratory for Responsible Manufacturing
334 SN, Department of MIE
Northeastern University
360 Huntington Avenue
Boston, MA 02115, U.S.A.

(617)-373-4846 **Phone**
(617)-373-2921 **Fax**
gupta@neu.edu **e-mail address**

<http://www.coe.neu.edu/~smgupta/> **Home Page**

DISPOSAL DECISIONS UNDER PREDETERMINED PRICING POLICIES

Srikanth Vadde, Dept. of MIE, Northeastern University, (617) 373-7635, srikant@coe.neu.edu
Sagar V. Kamarthi[†], Dept. of MIE, Northeastern University, (617) 373-3070, sagar@coe.neu.edu
Surendra M. Gupta, Dept. of MIE, Northeastern University, (617) 373-4846, gupta@neu.edu
([†]Corresponding author)

ABSTRACT

The economic progress of product recovery facilities (PRFs) is often bogged down by the inventory imbalances arising from the hard-to-predict arrival rates of discarded products and the stochastic demand trends for the recovered components. In spite of adopting an effective pricing policy – a strategy to minimize inventory fluctuations – the inventory levels may skyrocket when there is an unexpected surge in the quantity of discarded products. Under this scenario PRFs have two options: either to dispose the surplus items or to stock them in anticipation of the future demand. This paper is concerned with PRF's optimal disposal decisions when the actual demand and the forecasted demand go out of sync, rendering the existing price policy suboptimal. The problem is modeled as a stochastic dynamic programming model. The analysis of the optimal disposal policy indicates that disposal is preferable when the carrying cost exceeds the disposal cost.

INTRODUCTION

The recent surge in the amount of discarded products and their environmental impact has led to legislations mandating manufacturers to take back discarded products. The overarching motive of these regulations is to require that the original equipment manufacturers (OEMs) accept the end of life products and encourage them to carry the environmentally benign activities such as, product reuse, recycle, and proper disposal. IBM's Global Asset Recovery Services [1], AER Worldwide [2], NuKote [3], and ReCellular [4] are good examples of product recovery facilities (PRFs). They face many daunting challenges which could dent their financial progress: (a) expensive and skilled labor required for product recovery operations; (b) uncertainty in the timing and quantity of discarded products arriving at the PRFs; (c) fleeting inventory levels of recovered components resulting from the unpredictable disposal of products and stochastic demand; (d) holding costs of surplus inventory; (e) lost sales due to stockouts; (f) disposal cost of leftover and obsolete inventory; (e) “fire-fighting” inventory clearance strategies such as promotional sales, discounts, markdowns, and donation to charities; (f) competition from OEMs, and (g) restrictive environmental regulations. Of all the challenges, inventory levels have a more telling effect on the revenue of PRFs. Uncertainty is induced into inventory management of PRFs by the unpredictable customer rate of product disposal, discarded product quantity, and arrival time at the facility. The uncertainty could lead to extremities of both kinds, too low inventory levels and too high. Both these states of inventory are detrimental to the profits of PRFs. A perpendicular rise in inventory levels could increase the carrying and subsequently the disposal costs. On the other hand, backorders could result in stockout situations. If inventory levels continue to remain high for longer periods of time obsolescence could catch up on the components [5] mitigate their sales opportunities. In case components become obsolete, the revenue from selling them as recyclable material could be smaller than their reuse revenue.

Appropriate pricing of components in inventory is one of the effective ways to address these challenges [5-9]. This strategy has a twofold impact: it facilitates inventory control and enhances the profit margin. In spite of adopting a clearance-friendly pricing policy, inventory levels may go beyond the desirable limits when, (a) there is an unexpected surge in the quantity of discarded products; and (b) there is inadequate demand for components. Although PRFs can adopt pricing policies which dynamically adjust prices according to the on-hand inventory level, implementing such policies involves cost to relabel products with updated prices and cost of communicating the updated prices to customer [10]. Moreover, implementing such a policy at a short notice may be difficult from an operational perspective. This work proceeds with the assumptions that, PRFs do not dispose product returns when they arrive unexpectedly, instead they are subject to product recovery operations; and PRFs do not implement a dynamic pricing policy.

When it becomes necessary for PRFs to control the inventory of recovered components, they have two choices: either to dispose or to stock in anticipation of the future demand. The decision depends on the holding cost, disposal cost, inventory level, and the forecasted demand. Disposals may not always be attractive; penalties could be incurred when the disposed quantity exceeds the regulated limit imposed by environmental regulations.

This research is aimed at answering the question, “what is the optimal quantity of items to dispose from recovered component inventories under a predetermined pricing policy?” This issue is addressed for a scenario that PRFs could encounter – the forecasted demand and actual market demand are so out of sync that the prices determined based on forecast demand would become suboptimal for the actual demand.

PREVIOUS RESEARCH

In the chronicled literature most research articles address disposal issues for items in recoverable inventory that stock discarded product returns. When these products are subjected to product recovery operations the ensuing components are stocked in serviceable inventories. Disposals from serviceable inventories may become necessary for products which normally require substantial product recovery operations and whose components have different demand patterns even though an effective price policy is in effect.

van der Laan and Salomon [11] determined the optimal reorder point, order quantity, and disposal quantity for an inventory system where returned products are first repaired and stocked to satisfy the demand. Inderfurth [12] addressed the disposal decisions when the product returns and the demand are stochastic. Inderfurth *et al.* [13] addressed the issue of allocating the returned products to the various remanufacturing options available and the ensuing disposal issues. van der Laan and Salomon [14] determined the optimal quantities to remanufacture, dispose, and procure for a product recovery system with push and pull production strategies. Teunter and Vlachos [15] determined the disposal quantity of returned products using simulation. Beltran and Krass [16] analyzed a variant of the dynamic lot sizing problem with backorders and excess inventory disposals. Guide *et al.* [17] developed optimal disposal strategies for returned products by basing their decision on the time to process returned products in the facility.

ANALYTICAL MODEL

PRFs usually post prices using a forecasted demand function which is normally determined by factoring in the current market conditions and historical demand data. The actual and the forecasted demand could be out of sync when the market dynamics influence or alter the customer purchase decisions. When this happens, the prices posted by PRFs could become suboptimal consequently the inventory may not be cleared as expected. Here, it is assumed that PRFs do not revise their price policy to optimality. In this section, the optimal disposal decision under such a situation is determined. Before delving into the modeling of the problem the setting of the problem is first presented.

A PRF starts off the selling horizon, which is equally divided into $N - 1$ periods, with a certain inventory level. In any period, the following sequence of events takes place in that order. Inventory (serviceable inventory) is replenished, then the orders are fulfilled, and finally the disposal decision is made. The replenishment quantity, price, and demand are assumed to be known for every period. PRFs have to abide by a disposal regulation which restricts the quantity of serviceable inventory disposed to landfills to a pre-specified limit. On violation of the regulation a penalty is imposed. When demand exceeds the on-hand inventory the PRF does not entertain any backorders. It is assumed that the PRFs' inventory capacity is finite and the replenishment quantity cannot exceed this capacity limit.

This problem is best modeled by dynamic programming techniques [17] – the stages are represented by the $N - 1$ periods of the selling horizon, the state variable is the inventory level of remanufactured components in each period, and the decision variable is the disposal quantity in each period. Let s_i be the inventory at the beginning of stage i , with $0 \leq s_i \leq M$, where M is the inventory capacity. The inventory level at the beginning of the next stage is $s_{i+1} = \max\{0, s_i + r_i - \lambda_i - w_i\}$ where r_i , λ_i , and w_i respectively represent the replenishment quantity, demand, and disposal quantity in period i . It is assumed that the replenishment quantity is known for all periods. Let the price policy be $\{p_1, p_2, \dots, p_{N-1}\}$ in the selling horizon which is already predetermined. Let d_i be a random variable that represents the demand in stage i . For modeling purposes, assume that d_i follows a Poisson distribution. The expected demand when u units are available in inventory is,

$$\bar{\lambda}_i(u) = \sum_{j=0}^{u-1} jP_j + u \sum_{j=u}^{\infty} P_j \quad (1)$$

where, $P_j = \frac{e^{-\mu_i} (\mu_i)^j}{j!}$ and μ_i is the mean demand arrival rate, and $\bar{\lambda}_i$ is the expected demand in stage i .

The disposal decision arises only when there are leftover components from sale and the disposal cost, C_d , is cheaper than the holding cost C_h , i.e., $C_h > C_d$. Let w_i be the disposed quantity in stage i with $w_i \in [0, q]$, where $q = \min\{D, s_i + r_i - d_i\}$, D being the disposal limit according to the regulation. If however the disposal cost exceeds the inventory carrying cost then the cheaper alternative is chosen. The expected profit earned in stage i is,

$$z_i(s_i, w_i) = p_i \bar{\lambda}_i(s_i + r_i) - C_h(s_i + r_i - \bar{\lambda}_i(s_i + r_i) - w_i) - C_d w_i \quad (2)$$

Using Bellman's optimality principle, the optimal expected profit from stage i through stage $N - 1$ is,

$$J_i^*(s_i) = \text{Max } E \left\{ z_i(s_i, w_i) + \sum_{j=0}^{s_{i+1}} P(j/s_i, w_i) J_{i+1}^*(j) \right\} \quad (3)$$

In equation (3), $P(j/s_i, w_i)$ is the transition probability that the inventory level at stage $i+1$ is j when at stage i it is s_i . The transition probability is computed as,

$$P(s_{i+1}/s_i, w_i) = \begin{cases} P_{s_i+r_i-w_i-s_{i+1}} & \text{if } M > s_i + r_i - w_i \geq s_{i+1} > 0 \\ \sum_{j=s_i+r_i-w_i}^{\infty} P_j & \text{if } M > s_i + r_i - w_i \text{ and } s_{i+1} = 0 \\ 0 & \text{if } M \geq s_{i+1} > s_i + r_i - w_i \end{cases} \quad (4)$$

The optimal disposal quantity in stage i which maximizes equation (3) is,

$$w_i^* = \begin{cases} \min\{D, s_i + r_i - d_i\} & \text{if } C_h \geq C_d \\ 0 & \text{if } C_h < C_d \end{cases} \quad (5)$$

The optimal disposal quantity in each stage is found by choosing the corresponding disposal quantities for $J_i^*(s_i), \forall i=1, 2, \dots, N-1$.

NUMERICAL EXAMPLE

Consider a selling horizon of 5 weeks ($N-1=5$) with the replenishment quantity be $\{4, 2, 1, 2, 2\}$. Let the other parameters be $C_h = \$5$, $C_d = \$4$, $M = 4$ items, $D = 10$ items. Let the mean demand in each period be $\mu = 1$ units per week and the predetermined price policy be $\{\$17, \$15, \$13, \$10, \$6\}$, where each element in the set represents the price posted for a week. The transition probability between states is shown in Table 1 and the optimal disposal policy is shown in Table 2. Also the optimal expected profit at the onset of the selling horizon is shown in Table 2. The expected profit is higher when more items are available in inventory.

Table 1: Transition probability

$s_i + r_i - w_i$	s_{i+1}				
	0	1	2	3	4
0	0.36	0	0	0	0
1	0.36	0.36	0	0	0
2	0.18	0.36	0.36	0	0
3	0.06	0.18	0.36	0.36	0
4	0.01	0.06	0.18	0.36	0.36

Table 2: Optimal disposal policy

$s_i + r_i$	w_1^*	w_2^*	w_3^*	w_4^*	$J_1^*(s_1)$
0	0	0	0	0	0.00
1	0	0	0	0	40.81
2	1	1	1	1	36.82
3	2	2	2	2	20.72
4	3	3	3	3	1.09

CONCLUSIONS

Achieving a proper inventory balance between the recovered components obtained from product recovery operations and the demand for recovered components is crucial for PRFs to prosper economically. This work addressed the question, how much to dispose from recovered component inventories when PRFs already have a price policy in place. This paper determined the optimal disposal policy for a commonly encountered scenario where the existing price policy is rendered suboptimal when the PRFs' forecasted demand differs significantly from the actual demand. Investigation of the optimal disposal policy indicated that disposal is the preferred choice when the cost to dispose is cheaper than carrying items in inventory.

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