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AN INVENTORY CONTROL MODEL FOR PRODUCT RETURNS

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ABSTRACT

In recent years, the sales of consumer electronics have increased rapidly. Manufacturers introduce the state of the art technologies in quick succession. As a result, the volume of the returned end-of-life (EOL) products has grown significantly [1]. Often these EOL products are still in excellent working conditions (functional). Customers return them because various marketing programs create an aura of "must have" sense in the minds of customers or because of the favorable incentives offered by service providers or manufacturers to acquire upgraded products. Thus, disassembly facilities are often faced with an overwhelming number of returns that is beyond the actual demand of these items. The appropriate management of the reverse supply chain, specifically in terms of inventory control, then becomes more complicated. In this paper, we address the issue of managing the inventory generated in the disassembly facility that is beyond the forecasted demand and propose an inventory control model to minimize its impact. An example is considered to illustrate the approach.

INTRODUCTION

The environmentalists have always demanded that companies should take end-of-life (EOL) products back and manage them in an environmentally conscious manner. EOL products can be remanufactured, reused, recycled, or disposed of. However, because of the uncertainty in quantity and quality of items taken back, planners have often felt discouraged to engage in such initiatives. Other factors that inhibit them from engaging in such activities include: less vertical integration, lack of efficient recovery process, and questionable profitability.

Due to much rigid environmental legislation and the understanding of economical and environmental benefits from minimizing the use of virgin resources, many corporations have started to comprehend the importance of the recovery process and are taking serious steps in restructuring their supply chain processes to meet the new regulations such as limitations on waste disposal and recycling requirements. The idea behind it is to allow the use of materials and parts more than once before it is finally discarded [2]. Thus, effective supply chain management is vital in gaining a competitive edge over other corporations [3]. Supply chain management "involves functions such as production, purchasing, materials management, warehousing, inventory control, distribution, shipping, and transport logistics" [3]. However, the take-back process is much more environmentally friendly than the traditional supply chain process as it "closes the loop" of the supply chain process and transform the end of life (EOL) items into new serviceable products. This new portion of the supply chain is known as Reverse Supply Chain and together they are known as Closed-Loop supply Chain.

The management of reverse supply chain is challenging compared to regular supply chain because it is much more reactive and much less visible [4]. Examples include, changing demand rates, multiple demand sources, variety of products, and logistical complications. Yet another challenge is offered by inventory control and value management of EOL products. Due to the

disparity between demands for parts and materials and their yields, the planner faces economical constraints (holding and transaction cost of excess inventory) and physical constraints (capacity and space limitations) when trying to make an informative decision of how many products to take back and when to take them back. Our research focuses on developing an inventory control policy of an on-hand inventory of returned items and disassembled parts such that profit is maximized.

The returned EOL products are disassembled into separate parts and materials. For large quantities of returned products, the best way to disassemble them is to do it on a disassembly line that consists of several disassembly workstations [5]. Workstations tend to experience different accumulation rates as well as different depletion rates because of differences in yields and demands. Such differences create "uncertainties" in inventories and space requirements at the workstations. It is therefore necessary to develop a method to determine an appropriate inventory policy. In most cases, the disassembly system ends up with on-hand inventory in excess of what is needed. In this paper we obtain the appropriate pricing of disassembled parts and associated costs such as transaction costs, holding costs, and recovery costs. We develop a static approach where the liquidation time is predetermined and a dynamic approach that depends more on the number of items (quantity) on hand. We propose an inventory control policy that tracks the total accumulated cost of on-hand items and measure its effect on the system's profit.

INVENTORY CONTROL IN REVERSE LOGISTICS

One of the most challenging issues in reverse logistics in general and in disassembly line in particular, is the inventory management of returned items and disassembled parts. In previous research we proposed a linear programming model to balance the inventory of returned items while satisfying the demand. Yet, the system still ends up with excess on hand inventory (OHI) of disassembled parts that is in excess of what is needed. The challenge is to determine the optimal liquidation batch sizes for each item type in conjunction with suggested OHI. In addition, the costs associated with the processes are different and should be compared and prioritized based on some appropriate criteria. For example, it might be more desirable to dispose of hazardous materials quickly (incurring some cost) rather than carrying them in inventory for a potentially large profit in the future but at a risk of incurring a greater loss due to the possibility of contamination of other parts [6]. Timings of such decisions are critical because all items kept in inventory incur holding costs and carry a risk of obsolescence. Other items could cost more to hold rather than their actual remaining values.

INVENTORY AND VALUE MANAGEMENT OF EOL

Problem Description

Products disassembly and recovery is a complex problem. One of the issues in the reverse supply chain is inventory control and management of EOL products. Returned products arrive to disassembly facilities at different rates. Demands for disassembled parts and subassemblies occur at different rates and at all workstations. Disassembly facilities have no control over the quantity, quality, and flow of these EOL products. These products have different quality levels depending on the different environments they have been operating in. The main goal is to satisfy the demand for these products and items from the EOL products returns. Any excess demand is outsourced from an outside supplier. Because of the disparity between the demand and the line yields this will create uncertainty of the inventory levels of items that should be kept on hand to

cover for any future uncertainty. Such disparity will create a "fluctuation" of the amount of inventory to keep on hand, and when to liquidate it. In previous research, we introduced a linear programming model that minimizes the total cost of the system while satisfying the demand. However, the system tends to accumulate the EOL products which are disposed of when they reach a critical level. Nevertheless, by discounting the prices on current inventory, one might be able to slow down the rate of accumulation. Yet, we are also faced with a demand source capacity regarding the quantity the customers can purchase and a storage space limitation at the disassembly facility. We illustrate the problem graphically in figure 1.

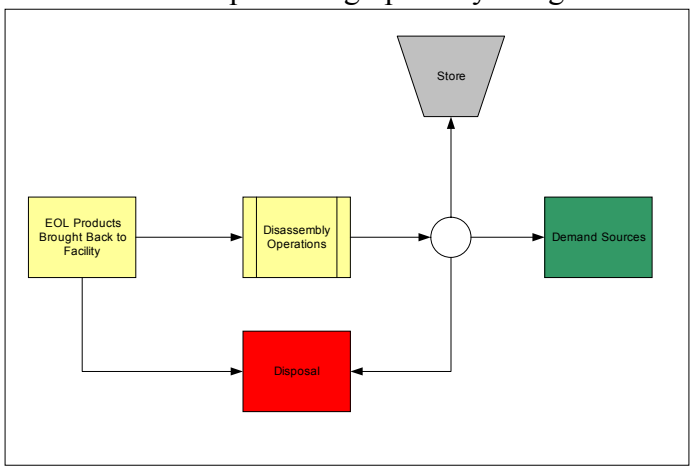

FIGURE 1
Graphical representation of the process

Problem Definition

After performing disassembly operations on returned EOL products, inventory of different items will start to pile up. Disassembled parts are being used to satisfy the demand and any shortage is being outsourced from an outside suppliers. In some case we will have an excess inventory beyond the demand. Appropriate management of this excess inventory is crucial to minimize the overall cost of the system and maximize its profit.

Problem Assumptions

1. There is a single product with three quality levels, and static deterministic inventory
2. Demand and returns are constant and known.
3. OHI is given and is different from period to period (Remaining after demand is satisfied)
4. There are zero inventories at the end of last period (end of planning horizon).
5. The price change is non-linear.

Problem Objective Function

The objective is to maximize the profit of the sub-system, which is revenue (money collected from the sales of the disassembled parts/subassemblies), minus the associated cost (transaction cost, holding cost, transferring-to-storage cost). The goal in this type of situation is to determine the minimum inventory we can hold before we decide to liquidate/dispose excess inventory.

METHODOLOGY AND PROBLEM FORMULATION

Notations

Known Parameters

$C^{dc}_{i,k,t}$ Cost to dispose one unit of core type *i*, with quality level *k*, in period *t*

$C^{diss}_{j,t}$ Cost to dispose one unit of subassembly *j*, with quality level *k*, in period *t*

$C^{holc}_{i,k,t}$ Cost to hold one unit of core type *i*, with quality level *k*, in period *t*

$C^{hols}_{j,k,t}$ Cost to hold one unit of subassembly type *j*, with quality level *k*, in period *t*

$C^{trac}_{i,k,t}$ Cost of transaction associated with selling one unit of core type *i*, with quality level *k*, in period *t*

$C^{tras}_{j,k,t}$ Cost of transaction associated with selling one unit of subassembly/ part type *j,* with quality level *k*, in period *t*

$P^{c}_{i,k,t}$ Price of core product type *i*, with quality level *k*, in period *t*

$P^{s}_{j,k,t}$ Price of part/subassembly type *j*, with quality level *k*, in period *t*

$Q^{ohic}_{i,k,t}$ Quantity of on hand inventory of core type *i*, with quality level *k*, available in period *t*

$Q^{ohis}_{j,k,t}$ Quantity of on hand inventory of subassembly/part type *j*, with quality level *k,* available in period *t*

w_i Amount of space consumed by one unit of core type *i*

w_j Amount of space consumed by one unit of subassembly/part type *j*

CAP^{dem}_{n} Demand source *n* capacity in terms of cubic units

CAP^{stgc}_{i} Storage facility capacity of core products type *i*

CAP^{stgs}_{j} Storage facility capacity of subassembly/part type *j*

Decision Variables

$Q^{liqc}_{i,k,t}$ Quantity of core product type *i*, with quality level *k*, liquidated in period *t*

$Q^{liqs}_{j,k,t}$ Quantity of subassembly/part type *j*, with quality level *k*, liquidated in period *t*

$Q^{remc}_{i,k,t}$ Quantity of core product type *i*, with quality level *k*, remaining at end of period *t*

$Q^{rems}_{j,k,t}$ Quantity of subassembly/part type *j*, with quality level *k*, remaining at end of period *t*

Problem Formulation

Max R= $\sum_i \sum_k \sum_t P^{c}_{i,k,t} * Q^{liqc}_{i,k,t} + \sum_j \sum_k \sum_t P^{s}_{j,k,t} * Q^{liqs}_{j,k,t} - \sum_i \sum_k \sum_t C^{trac}_{i,k,t} * Q^{liqc}_{i,k,t}$

- $\sum_j \sum_k \sum_t C^{tras}_{j,k,t} * Q^{liqs}_{j,k,t} - \sum_i \sum_k \sum_t C^{holc}_{i,k,t} * Q^{remc}_{i,k,t} - \sum_j \sum_k \sum_t C^{hols}_{j,k,t} * Q^{rems}_{j,k,t}$

Subject to

$$Q^{liqc}_{i,k,t} + Q^{remc}_{i,k,t} \le Q^{ohic}_{i,k,t}, \forall i,k,t \qquad (1)$$

$$Q_{j,k,t}^{liqs} + Q_{j,k,t}^{rems} \le Q_{j,k,t}^{ohis}, \forall j,k,t \quad (2)$$

$$\sum_i \sum_k w_i * Q_{i,1,t}^{liqc} + \sum_j \sum_k w_j * Q_{j,1,t}^{liqs} \le CAP_1^{dem}, \forall t \quad (3)$$

$$\sum_i \sum_k w_i * Q_{i,k,t}^{liqc} + \sum_j \sum_k w_j * Q_{j,k,t}^{liqs} \le CAP_2^{dem}, \forall t, k \ne 1 \quad (4)$$

$$\sum_i \sum_k Q_{i,k,t}^{remc} \le CAP_i^{stgc}, \forall t \quad (5)$$

$$\sum_j \sum_k Q_{j,k,t}^{rems} \le CAP_j^{stgs}, \forall t \quad (6)$$

All variables $\ge 0, \forall i, j, k, t$

NUMERICAL EXAMPLE

The inventory model in this paper is an extension model of our previous research [6]. Previously, we developed a linear programming model to simulate the accumulation of inventory on hand. Demand sources were: direct reuse, recycling, and disposal. We took in consideration the environmental regulations. In this model we introduced two demand sources: remanufacturing, which only takes good quality items, and refurbishing which takes average and/or imperfect quality items. The data and the results are presented in tables 1 and respectively.

Table 1

Data used for on hand inventory of EOL

Part/Subassembly Type	Quality Level	Space Req.	Profit/Unit	Holding C.	Transaction C.
Core Type 1	Good	0.625	$37.00	$3.70	$1.50
	Average	0.625	$23.00	$2.30	$1.50
	Imperfect	0.625	$17.00	$1.70	$1.50
Part Type 1	Good	0.1	$13.00	$1.00	$0.75
	Average	0.1	$10.00	$1.30	$0.75
	Imperfect	0.1	$8.00	$0.70	$0.75
Part Type 2	Good	0.2	$8.00	$0.50	$0.75
	Average	0.2	$4.00	$0.55	$0.75
	Imperfect	0.2	$3.00	$0.20	$0.75
Part Type 3	Good	0.25	$7.00	$0.33	$0.75
	Average	0.25	$5.00	$0.40	$0.75
	Imperfect	0.25	$2.00	$0.13	$0.75

The model was run over five periods and analyzed using Lingo 8 and a spreadsheet. Due to limited space, only results from period 4 are presented in table 2.

The objective function value is calculated to be **$178,770.80**. The objective function value did not account for a small fraction of end of period inventory that could be either disposed of or transferred to a remote storage facility. Note that the system has a tendency of liquidating higher value items more often and keep lower valued ones on hand. This is because that demand can be satisfied by any quality level available, and by liquidating a higher value items faster it results in a reduction in carrying cost and an increase in the performance level of the system, and eventually the system's overall profit.

Table 2
Results from period 4

Period	Type	Quality	OHI	Liq	Rem	Acc. Inv	Dispose	Actual Inv.	Extra . Inv.
Period 4	Core Type 1	Good	526	526	0	0	0	0	0
		Average	714	707	7	7	0	7	0
		Imperfect	456	0	456	456	456	650	194
	Part Type 1	Good	225	225	0	0	0	0	0
		Average	456	456	0	0	0	0	0
		Imperfect	125	125	0	0	0	0	0
	Part Type 2	Good	222	222	0	0	0	0	0
		Average	369	0	369	369	0	369	0
		Imperfect	222	0	222	222	222	750	528
	Part Type 3	Good	121	121	0	0	0	0	0
		Average	231	0	231	231	0	231	0
		Imperfect	156	0	156	788	38	750	594

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