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## **A STOCHASTIC INVENTORY MANAGEMENT APPROACH IN THE DISASSEMBLY LINE PORTION OF REVERSE LOGISTICS**

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### **ABSTRACT**

Reverse logistics is a critical topic that has captured the attention of government, private entities and researchers in recent years. This increase in the concern was driven by current set of government regulations, increase of public awareness, and the attractive economic opportunities. As a result, 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 [1]. Because of the unique problems associated with reverse supply chain and the complex nature of the reverse logistics activities, numerous studies have been carried out in this field. One of those crucial areas is inventory management of end-of-life (EOL) products. Previously, we have assumed deterministic data for demand, supply, and line yields when modeling the inventory problem along the disassembly line. In this paper, we model uncertainty in the data with probability distribution to be accurate thus covering all possible inputs. The definition of the problem will remain the same as before.

### **INTRODUCTION**

Environmentalists have always demanded Original Equipment Manufacturers (OEMs) to be more involved and be responsible for their products at the end of their life cycles. However, the uncertainty factor that is associated with the disassembly operations discourages OEMs from participating in such programs. Also, Original Equipment Manufacturers are becoming less vertically integrated and rather focused in their core business [2]. Inventory management and the appropriate handling of the returned items contribute to the performance of the reverse logistics systems. That means, knowing what type of items to take back and disassemble, when to disassemble, and when to keep items on hand or dispose them, are very important to the profitability of disassembly operations. The take-back program could possibly cause financial drain to OEM if not managed well and if the concerns raised above are not addresses effectively. Thus, an efficient yet cost effective system needs to be implemented to appropriately manage the overwhelming number of returns.

The strategic and management aspects of reverse supply chains are challenging compared to regular (forward) supply chains because they are much more reactive and much less visible [3], [4]. Yet another challenge is offered by inventory control and value management of EOL products. Two major constraints are of concern when discussing inventory related issues in the reverse logistics context. In particular, the disassembly line portion of the reverse logistics has to address: i) economical constraints (holding and transaction cost of excess inventory) and ii) physical constraints (capacity and space limitations) [5]. Our research focuses on developing

an inventory control policy of an on-hand inventory of returned items and disassembled parts such that total cost of the system is minimized.

In a couple of previous papers [6], [7], we modeled deterministic and probabilistic parts of the problem using linear programming and dynamic programming respectively. The uncertainty portion was modeled by assuming that only a certain percentage of the returned items are good for disassembly and the remaining items are either disposed of or recycled. In other scenarios considered, such items could satisfy other demands that did not have strict product quality requirements. In this paper, we have modeled uncertainty in the data by a probability distribution. The idea is to allow flexibility by accommodating all possible inputs. In addition, by allowing this variability in the input, the disassembly line capacity is required to be flexible and adjusted based on the need of space [8]. Our model focuses on the space along the line. Such approach is more realistic as the behavior of the returned items changes from period to period and strict advance planning is not possible. The goal is to have an agile model that is reactive and flexible. The model utilizes multi-period stochastic dynamic programming to solve the problem. A numerical example is considered to illustrate the approach.

## **UNCERTAINTY BEHAVIOR OF EOL PRODUCTS**

The uncertainty behavior of the returned EOL products is due to different reasons. The age of product that is being returned and how long it has been used in the market widely affect the quality of parts/subassemblies that can be recovered. Also, the nature of the working environment these products were used in and the amount of wear cause the parts quality to deteriorate rapidly even if the product has been introduced to the market recently. Given these factors, we can assume that not all returned EOL products can be send to disassembly facilities. Some EOL products could be disposed off at the inspection station, while other that pass inspection will have different quality levels and will contain different parts with probabilistic yields. This probabilistic nature of the problem will make it more difficult for planners to estimate the on hand inventory at any given time period, safety stock, and space required to keep extra units for future demand.

Disassembled parts are used immediately to satisfy the demand sources. Then, any shortages are secured through a third party supplier in case of extra parts carried beyond the demand is stored in storage facilities until they are needed to satisfy future demand, or maybe disposed off is their carrying/holding costs exceeds its worth. All these costs compared to remaining value of parts kept in inventory and what potential future profit it could generate makes the planning more complex. Hence, the inventory model should account for these variations when planning the space required for items to keep on hand, and for how long. To model such space design changes, the model uses Stochastic Programming techniques. Its goal is to adapt and optimize the changing storage space requirements for multiple parts and subassemblies over multiple time periods after the demand has been satisfied. This should minimize cost associated with holding, transferring, and liquidating inventory. In the next section, problem definition and description will be given.

## STOCHASTIC PROGRAMMING APPROACH TO EOL PROBLEM

### Problem Description

One of the issues when discussing the inventory management and control problem in Reverse Logistics is the space utilization of disassembled end-of-life (EOL) core products and disassembled parts/subassemblies. After performing disassembly operations, the different demand sources are satisfied and any excess inventory is either sent to storage facilities or kept along the disassembly workstations. Thus, planner has to make the decision of how much to keep vs. how much to liquidate, if any. If decided to keep a certain level of On Hand Inventory (OHI), an advanced planning of the space will be needed based on future demand and supply of EOL products. The accumulation of these items and any associated extra carrying and holding costs should be justified, otherwise it's more economically sound to dispose e

### Problem Definition

When planning for disassembly operations some constraints are taken into accounts which are physical and economical constraints. Physical constraints include demand sources capacities, disassembly line storage space area, and warehouse storage space limitations. Economical constraints include holding cost, return acquisition costs, carrying costs (handling operations, potential obsolescence and spoilage costs, and insurance and taxes). For the scope of this paper, space planning is an important element of the physical constraints that will determine how much space should be allocated for certain items, and in which period to allocate it. This decision should be based on demand and supply of items. In other words, the space allocation should be flexible to adapt any fluctuations in supply and demand of end-of-life (EOL) products, as well as the quality of these items and its line yields.

### Problem Assumptions

1. There is a single product with three parts and three quality levels
2. All products returned are disassembled, thus storage for core is negligible
3. All associated costs remain constant during each period
4. Demand and supply are stochastic and follow a probability distribution
5. Planning horizon is two periods ( $t=2$ )

### Problem Objective Function

The objective is to adapt and optimize the changing storage space requirements for the disassembly workstations for multiple parts/subassemblies over multiple time periods. This space configuration should minimize all associated costs such as holding costs, transaction costs, and disposal costs.

In this paper, analysis of the inventory control problem in the disassembly context will be discussed and solved using a multi-period stochastic programming technique with resources (SPR). In this formulation some of the data in both the objective functions and in the constraints are given by probability distribution to allow variation in the input. "The fundamental idea behind this type of problem is the concept of resource, which is the ability to take corrective action after a random event has occurred". The methodology will provide a tool for the decision maker to take corrective actions as needed and when needed on current on hand inventory and expected future returns on end-of-life (EOL) products.

## PROBLEM FORMULATION AND METHODOLOGY

### Notations

I	Set of core products that are eligible for disassembly
J	Set of parts/subassemblies that are disassembled
K	Quality levels of EOL products
T	Time period

### Known Parameters

$C_{i,k,t}^{dc}$	Cost to dispose one unit of core type $i$ , with quality level $k$ , in period $t$
$C_{j,t}^{diss}$	Cost to dispose one unit of subassembly type $j$ , with quality level $k$ , in period $t$
$C_{i,k,t}^{holc}$	Cost to hold one unit of core type $i$ , with quality level $k$ , in period $t$
$C_{j,k,t}^{hols}$	Cost to hold one unit of subassembly type $j$ , with quality level $k$ , in period $t$
$C_{i,k,t}^{trac}$	Cost of transaction associated with selling one unit of core type $i$ , with quality level $k$ , in period $t$
$C_{j,k,t}^{tras}$	Cost of transaction associated with selling one unit of subassembly/ part type $j$ , with quality level $k$ , in period $t$
$Q_{i,k,t}^{ohic}$	Quantity of on hand inventory of core type $i$ , with quality level $k$ , available in period $t$
$Q_{j,k,t}^{ohis}$	Quantity of on hand inventory of subassembly/part type $j$ , with quality level $k$ , available in period $t$
$Q_{i,k,t}^{retc}$	Quantity of core product type $i$ , with quality level $k$ , returned in period $t$
$Q_{j,k,t}^{rets}$	Quantity of subassembly/part type $j$ , with quality level $k$ , returned in period $t$
$Q_{i,k,t}^{liqc}$	Quantity of core product type $i$ , with quality level $k$ , liquidated in period $t$
$Q_{j,k,t}^{liqs}$	Quantity of subassembly/part type $j$ , with quality level $k$ , liquidated in period $t$
$Q_{j,k,t}^{dems}$	Demand for subassembly/part type $j$ , with quality level $k$ , 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 $j$
$w_{j,t}^{wss}$	Amount of space allocated at workstation for part type $j$ in period $t$
$w_{j,t}^{out}$	Amount of space allocated in outside storage facility for part type $j$ , in period $t$
$w_{j,t}^{out}$	Amount of space limited to certain disposal limit set by government regulations

### Objective Function

$$\begin{aligned} \text{Min } C = & \sum_j \sum_k \sum_t (C_{j,k,t}^{hols} * w_{j,t}^{wss}) + \sum_j \sum_k \sum_t (C_{j,k,t}^{carc} * w_{j,t}^{out}) + \sum_j \sum_k \sum_t (C_{j,k,t}^{diss} * w_{j,t}^{diss}) \\ & + \sum_j \sum_k \sum_t (C_{j,k,t}^{tras} * Q_{j,k,t}^{dems}) \end{aligned}$$

Subject to

$$Q_{j,t}^{rets} * \gamma_j * \alpha_{j,k,t} = Q_{j,k,t}^{ohis} \quad (1)$$

$$Q_{j,t}^{rets} * (1 - \gamma_j) = Q_{j,t}^{diss} \quad (2)$$

$$Q_{j,k,t}^{rems} = Q_{j,k,t}^{ohis} - Q_{j,k,t}^{dems} \quad (3)$$

$$Q_{j,k,t+1}^{ohis} = Q_{j,k,t}^{rems} + (Q_{j,t+1}^{rets} + \gamma_j + \alpha_{j,k,t+1}) \quad (4)$$

$$w_{j,t}^{wss} + w_{j,t}^{diss} \geq \sum_k Q_{j,k,t}^{rems} * w_j - w_{j,t}^{out} \quad (5)$$

$$w_{j,t}^{out} \leq CAP^{out} \quad , \quad w_{j,t}^{wss} \leq CAP^{wss} \quad , \quad w_{j,t}^{diss} \geq \sum_k Q_{j,k,t}^{rems} - (w_{j,t}^{out} + w_{j,t}^{wss}) \quad (6)$$

$$Q_{j,k,t}^{dems} \leq Q_{j,k,t}^{ohis} \quad (7)$$

### NUMERICAL EXAMPLE

Assume core product  $i=1$  with three parts/subassembly  $j= 3$  (A, B, and C). Product has three quality levels  $k=3$  (working condition, underperforming condition, and malfunctioning condition). Assume the line yields  $\gamma = \{56\%, 27\%, 17\%\}$  respectively for parts A, B, and C. Parts' reliability also follow the following yields: for part A  $\alpha = \{63, 22, 15\}$ , part B  $\alpha = \{55, 31, 14\}$ , and part C  $\alpha = \{41, 24, 35\}$ . The table below represents the end of day balance for parts A, B, and C that will minimize the system overall costs.

Table 1. On hand Inventory at end of period

Period	Subassembly 1	Subassembly 2	Subassembly 3
Period 1	0	170	320
Period 2	0	340	300
Period 3	90	0	130
Period 4	0	80	320
Period 5	0	355	190

The total cost calculated is **12,075.40 USD**.

### CONCLUSION

In this paper, the focus was on space utilization and planning of returned end-of-life (EOL) products along the disassembly workstations. Stochastic programming model with multiple periods was introduced. The goal is to adapt a strategy to allow planner to forecast the space needed for future disassembled parts based on current inventory level, as well as demand and supply for next period. This will allow adjustment to take place accordingly. In case of excess inventory being carried to next period, it can either be sent to a remote storage facility or can be disposed off. The objective is to minimize overall costs, by minimizing inventory level.

Future research will expand on space allocation of parts and the assignment of holding costs based on size and shape of the disassembled parts and subassemblies.

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