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# INVENTORY BALANCING OF POST-USAGE COMPONENTS OF A DISASSEMBLY LINE

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## ABSTRACT

In recent years, disassembly has gained a lot of attention due to its role in efficiently recovering valuable materials, parts, and subassemblies from end of life (EOL) products. This is due to the rigid environmental legislation, the economical and environmental benefits from reusing primary materials instead of virgin resources and the increase in environmental awareness and concerns of the consumers. However, the practice of recovering components and materials is challenging, as there are many associated complications that are unique to the disassembly process such as monitoring and controlling the inventory of core products and disassembled parts and the ability to satisfy demand from on hand inventory. Due to the disparity between demands for parts and their yields, there are many inventory problems that arise during the disassembly line balancing process. In this paper, we address the balancing of the inventories generated at various workstations of a so called “balanced” disassembly line.

**Keywords:** Disassembly line, Inventory control, End of life products, Inventory balancing, optimization

## INTRODUCTION

In today’s fast moving market, many of consumer products are subjected to disassembly (demanufacturing) and remanufacturing [1]. Thus the establishment of disassembly and remanufacturing facilities are necessary to handle the overwhelming number of products retrieved every year. According to a forecast, almost 50 million computers are expected to be discarded every year in the U.S. alone. So, for these facilities to be profitable, we have to develop models and techniques to help optimize their operations. Of course, recovery of value from an EOL product can only occur if the components can be easily extracted and subsequently sold at a profit [2]. In the U.S. most original equipment manufacturers (OEMs) have no interest in collecting used products and recovering components, in the absence of mandatory take-back legislation. This dissuades them from taking ownership of the life-cycles of their products [3]. Some of the factors that encourage such behavior are: i) Less vertical integration, ii) Significant uncertainties of quality and quantity of returned items, iii) Lack of efficiency of the product recovery process, and iv) Questionable profitability from product recovery [1].

Based on the aforementioned argument, an opportunity exists for smaller companies to enter the arena of product recovery by establishing stand alone facilities which, because of their smaller sizes, can operate on smaller scale, assume greater risks and have the flexibility to be “agile” to adapt to different products. However, there are many challenges associated with a disassembly line. Table 1 summarizes some of the differences between an assembly line and a disassembly line [4].

Table 1: Assembly Line vs. Disassembly line

<b>Characteristics</b>	<b>Assembly Line</b>	<b>Disassembly Line</b>
Process Flow	Convergent	Divergent
Condition of components	known	unknown
Inventory Challenges	Low-Moderate	High
Degree of Uncertainty	Low	High
Demand	Last Station	All stations

In this paper, we address the problem of balancing the inventories generated at each workstation of a disassembly line. This research, and future research, will address the balancing issue and suggests how to manage excess inventories and minimize their impact on the performance of the disassembly line and maximize its profitability. The objective is to find the right balances such that the demands are satisfied and the costs are minimized. An example consisting of a simple PC module is considered to illustrate the approach.

### **PROBLEM DEFINITION**

One of the most challenging issues faced by a disassembly (demanufacturing) facility is the management of its inventory. In reverse logistics environment the control and monitoring of incoming and outgoing products and parts are more difficult than traditional methods in a supply chain network. The inventory problem in the reverse supply chain network stems from the disparity between the demand for disassembled components/materials and the actual line yields. Workstations tend to experience different accumulation rates as well as different depletion rates because of differences in their demands. Such differences create “uncertainties” in inventories and space requirements at the workstations. It is therefore necessary to develop a method to determine appropriate inventory levels, their upper and lower bounds, and ways to handle and maintain work-in-process (WIP) at suitable levels.

Most of inventory related issues addressed in the disassembly literature ignore the uncertain characteristics stemming from the probabilistic returns, the quality of returned items, varying recovery rates, changing demands and the logistical needs to support the disassembly facilities.

Because of the differences in flow rates (in and out) disassembled components start piling at the sorting area designated at each workstation. In some cases, this behavior does not interfere with the work because of the component(s) size and quick turn over. In other cases, the accumulation of inventory could block the workstation. The unexpected behavior of products returns or the sudden change in demand levels could lead to excess or shortage in inventory levels. The challenge is to manage the inventory of disassembled components to satisfy demand and carry minimum amount of components on hand during all time.

The inventory problem discussed here is unique because it only investigates the effect of inventory accumulation at the workstation, which is separate from the actual inventory that is stored at the warehouse facility. The goal is to keep optimum stock of each component type at each workstation.

Disassembly line inventory problem is defined as follows: A disassembly line is designed to disassemble one type of product that has  $n$  components. Disassembly task times, cycle time, precedence relationships and demand are known. However, there is uncertainty associated with the quality and the quantity of recovered components and/or subassemblies. The objective is to balance the inventory generated from each workstation by siphoning off the components materials disassembled by providing a proper flow to demand sources, thus minimizing the disparity between the actual demand and line yield (deviation) and/or optimizing some measure of performance. Figure 1 show an example of a disassembly line with components recovered in different rates.

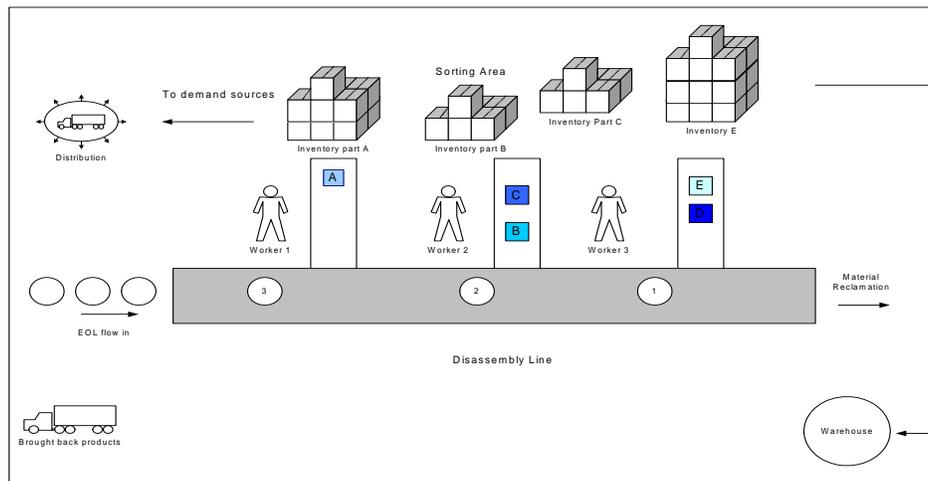


Figure 1. Disassembly line diagram with product recovery,  $WS=3$  and  $n=5$

Each part/subassembly is disassembled in one and separate workstation. At each workstation there exists two storage bins: Recoverable bin to store disassembled parts and recyclable bin for parts that do not pass the inspection. Parts disassembled are assumed to be sent directly to demand sources. Excess parts are either kept at the storage bin if there is enough space or sent to the storage facility.

Our research will investigate this behavior and the effect of some restrictions of the line specifications such as available bin space at the workstations, minimum on hand inventory required at each bin, and a limit on disposal volume per day, etc on how to balance the inventory. The proposed methodology will be further validated in future research and under different scenarios and compared to other approaches.

## DISASSEMBLY INVENTORY MODEL WITH LINE RESTRICTION

Workstations in a disassembly line are the entities where disassembly operations take place. Each product is routed through all workstations and is delayed a predefined cycle time to allow worker to perform required actions. Then, disassembled part or subassembly is placed in a recoverable bin (storage bin) if it passed the inspection, otherwise it will be collected in a recyclable bin (storage bin).

The balance of the product will be sent to a down stream workstation until all parts are disassembled. In this paper, we will study the inventory problem of disassembled components and we will develop a simple model to balance the inventory at workstations in such way that the utilization of the spaces is similar and demand is satisfied.

The disassembly line has  $M$  workstation, with maximum capacity of  $W$  cubic units per bin per workstation. Each component type disassembled on the line consumes a certain amount of space  $w_i$  [5]. At any pointy in time the following relation must hold true:

$$\lambda_i * w_i \leq W \dots\dots\dots (1)$$

Where  $\lambda_i$  is the amount of inventory of part type  $i$  at the specified recoverable bin (storage bin) any given point in time. At the end of period the following must hold true:

$$I_i * w_i \leq W \dots\dots\dots (2)$$

By assuming that each workstation have a limited bin space that can carry a maximum inventory up to  $I_i^*$  components, where  $I_i^*$  is the maximum inventory of type  $i$  at the workstation, then

$$I_i^* = W / w_i \dots\dots\dots (3)$$

Assuming that recovery rate of each component type is given by  $\gamma_i$ , where  $i=1, 2, 3\dots n$  and  $i$  is the number of components in the core product. Also, assuming that  $1-\gamma_i$  represents the disposal rate of part type  $i$ .

The line yield of each component type is calculated as follows:

$$\text{Recoverable bin: } \lambda_i = Q^d * \gamma_i \text{ and } i = 1, 2, 3, \dots, n \dots\dots\dots (3)$$

$$\text{Recyclable bin: } \eta_i = Q^d * (1-\gamma_i) \text{ and } i = 1, 2, 3, \dots, n \dots\dots\dots (4)$$

All recyclables of all part types  $i$  are collected in one storage bin, the recyclable bin, and sold at a predefined price. The mass (or volume) of recyclables can be calculated as follows:

$$\delta = \sum_{i=1}^n \psi_i * Q^d * (1-\gamma_i) \dots\dots\dots (5)$$

Where  $\psi_i$  is the mass to unit (or volume to unit) mapping conversion. Also there is a non negativity constraints on all variables presented above.

Based on that, decision maker can balance the inventory at the workstations so that work is not interrupted due to limited space, and demand source starvation will not occur. The objective is to balance the space consumption so that

$$Iw_1 \approx Iw_2 \approx Iw_3 \approx \dots Iw_n \dots\dots\dots (6)$$

Next we will present our inventory model and how to correct any excess inventory of any part type after satisfying the demand.

## THE MODEL

The Inventory mode in this paper is an extension to a previously proposed model. However, that model did not balance the inventory of each workstation by comparing its levels to other workstations along the line. The model presented here suggests keeping the inventories as low as possible while taking future periods in to account.

The first phase of the model is as follow:

- 1) Assign the following values:  $w_i$ ,  $\gamma_i$  to all components  $n$  of the product disassembled. All products have exactly  $n$  components and  $w_i$  is expressed in cubic unit. The value of  $\gamma_i$  tend to decrease as the age of the product increase.
- 2) At  $t=0$ , set initial inventory bins of all components and recyclable equal to zero , i.e.,  $INV\_A=0$ ,  $INV\_B=0$ ,  $INV\_C=0$ ,...etc
- 3) Calculate the target level inventory of each part type, for all parts  $n$ .
- 4) For the set of possible  $Q^d$  values, where  $Q^d$  ranges between minimum and maximum values do the following:
  - (i) Increase the disassembled quantity of each part by one unit
  - (ii) Update the following values:  $\lambda_i$ ,  $\eta_i$ , and  $U$ . The utilization rate  $U$  can be calculated using the following formula:  $U = I_i * w_i$
  - (iii) If  $\lambda_i \geq D_i - I_i$ , then excess inventory of part  $i$  exists
  - (iv) Else, shortages in supply of part  $i$  exists

The second phase of the model is as follow:

- 1) If  $I_i * w_i \leq W$  , then go to next step. Else, liquidate the current inventory to appropriate level  $S$ , based on specific selling policy that generates the highest profit, while assuring future demand is met and enough space is available for incoming parts
- 2) In case of excess inventory, categorize on hand inventory of parts to three categories: A, B, and C. Class A: Good quality (for reuse, remanufacturing, and recycling), Class B: Good quality after rework (for remanufacturing, and recycling), and Class C: Imperfect quality (for recycling only)
- 3) Using a greedy algorithm, search all possible combinations of mixtures of parts that will generate the higher profit and subject to the following constraints:
  - (i) For each  $i$ , there exists an appropriate level such that  $L \leq I_i \leq U$  , and  $i = 1, 2, 3, \dots, n$
  - (ii)  $I_i * w_i \leq W$  at all times
  - (iii)  $U_1 \approx U_2 \approx \dots \approx U_n$

$$(iv) \quad D_{t+1} \approx E[\lambda_{t+1}] + I_{i,end\_of\_t}$$

## CONCLUSIONS

In this paper we discussed the problem of balancing inventory in a disassembly line. Managing inventory is an important aspect of managing a business and developing the right tools to do so is essential for firms involved in disassembly to ensure profitability. We extended previously reported models to balance the amount of inventory that is stored at the workstation bins along the disassembly line. This model takes the probabilistic nature of the problem into account and offers the ability to consider future demands. It also allows on hand inventory to be categorized into three different categories.

In future research the model will be validated under a multiperiod scenario and results will be compared under different selling policies. However, some parts of the model still need to be developed such as finding the lower and upper bound constraint for the inventory level, and developing the right expression for finding the number of products to be disassembled.

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