Incoming Shipment Optimization

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***Abstract*— Successful remanufacturing of electronic devices must meet the challenges of continuously falling prices for new models, short life cycles, disassembly of unfriendly designs and prohibiting transport, labor and machining costs in high-wage countries. Companies that specialize in remanufacturing must optimize their activities in order to be profitable. For the planning of shipments, an optimization model is introduced. Uncertainties regarding quantity and conditions of IT products, availability of shipments, and processing times are considered.**

Keywords—Linear Optimization; Production Programming Planning; PC Remanufacturing

I. Introduction

A. Reverse Logistics

Reverse logistics has received considerable attention over the past few years due to the potential value recovery from the used products. The focus on reverse logistics is on waste management, material recovery (recycling), and parts/product recovery (through remanufacturing). Although remanufacturing offers the potential for maximizing profits, the remanufactured products face competition from new products thus turning the investment on product recovery into a risky investment [1].

The remanufacturing of expensive, long-living investment goods has been extended over the past few years to include many consumer goods with relatively short life cycles and low values. Reusing goods allows compliance with required recovery rates and quantities as well as special treatment requirements as prescribed by European legislation with the directive on Waste of Electrical and Electronic Equipment (WEEE) which requires the recycling or reuse of a minimum of 4 kg per person per year [2] [3].

Remanufacturing is often done by the OEM (Original Equipment Manufacturer) in which case the reverse logistics are often integrated into new distribution models such as leasing or “pay per use” with remanufacturing strategies. Remanufacturing is also done by third parties who are not the product manufacturer.

B. Remanufacturing Computers

During remanufacturing, computers (laptops, PCs, servers) are separated into individual components. These components include the motherboard, hard disk drive and random-access memory.

The motherboard is a printed circuit board that holds and allows communication between many of the elements of the system including the CPU and RAM. The motherboard will generally include expansion capabilities which can be used to connect additional components to the system (for example, network cards, hard drives, and graphics cards). During the remanufacturing process the CPU is not removed from the motherboard such that if the motherboard or CPU are broken the motherboard is considered not to be useable and both are recycled.

The hard disk drive (HDD) is a data storage device used for storing and retrieving digital information. The HDD is built from one or more rigid rapidly rotating discs covered with a magnetic coating. The discs are paired with magnetic heads attached to an actuator arm that read and write data to the magnetic surface. Some computers contain alternative technologies for storing data such as solid-state drives (SSD) and solid-state hybrid drives (SSHD) which use integrated circuit assemblies as memory to store data persistently. For simplicity, in this paper we treat all hard drives the same.

Random-access memory (RAM) is a form of data storage used in computers to store frequently used instructions to improve the speed of a system. RAM allows data to be read and written at speeds that are orders of magnitude faster than HDD. However, RAM is both more expensive than HDD and does not store data persistently and therefore computers will generally have much less RAM than HDD memory.

C. Literature Review

The problem of collection of used products has been discussed and several solutions have been suggested. These solutions include optimizing the location of collection points for returning used products [4], combining the collection of used products with retail activity [5], and the outsourcing reverse logistics activities [6] [7] [8] [9]. It has been suggested that outsourcing is more suitable when returns are more variable [10]. In this paper, we look at a use case of a company that does third-party reverse logistics.

Solutions to reverse logistics problem need to take into account the modularity of the products being collected [11] [12]. In addition, the implications of product modularity on closed-loop supply chains has been discussed [13]. The products analyzed in this paper are made of multiple modules where each module is treated as an individual entity.

The handling of the variety of parts received through reverse logistics and the handling of the multiple inventories that are created (used parts, new parts, etc.) is an issue for which researchers have suggested alternative procurement and inventory control strategies [14] [15]. A variety of inventory control policies to handle the supply and demand of used products is also discussed [16] [17]. This paper relies on a central inventory which stores all the parts that pass through the system.

The economics of the remanufacturing of computers is discussed [18] and a framework for analyzing profitability is suggested [19]. A generic remanufacturing plan for mobile phones is suggested [20].

II. CASE STUDY

For this case study, we evaluated the methodologies used by the All Trade Group (ATG) for treating used IT equipment. Based on the results of our evaluation we created a model which finds which orders to take for optimal profit. Due to the variety of equipment that ATG deals with we simplified our model by only relating to personal computers (PCs).

A. The Remanufacturing Process

1) Shipment

ATG arranges for the shipment of used IT equipment from a company. The cost of the delivery is paid by ATG. The shipment is received by the sorting center which is responsible for receiving shipments, documentation of paid shipments, configuration and qualification of the equipment received, and entering the equipment into the inventory.

2) Receiving Process

As shipments of pallets come in they are weighted, documented (photographed and filed) and the arrival of all the equipment is verified. Depending on the contents of the shipment the equipment is either immediately recycled or is sorted for further treatment (the content is only sorted if it has potential resale value).

3) Sorting Process

The equipment in the shipment is identified and sorted into different equipment categories (servers, PCs, laptops, printers, monitors, etc.). The equipment is then sorted into individual components for testing. Certain components will be recycled already in this stage if they do not have potential resale value.

4) Testing Process

Each type of equipment has separate testing processes to make sure that all the components that it contains work properly. Any component that is found to be faulty is sent to be recycled. Components that are found to work properly are put in the inventory if they have potential resale value.

B. Model

Based on the above process we modeled the remanufacturing process (Figure 1/Table 1). This allows us to fully calculate the revenue earned for each shipment. Each shipment is based on an order from a company. When deciding if to order the equipment from the company an estimation of the equipment to be received is made.

FIGURE I. PC REMANUFACTURING PROCESS

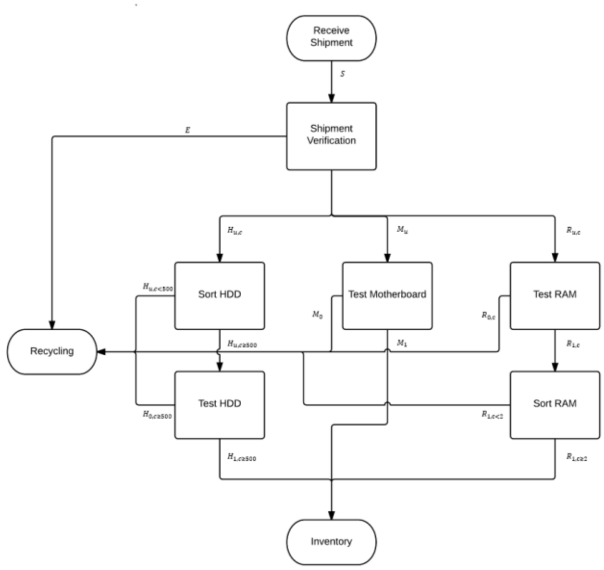

TABLE I. DEFINITION OF VARIABLES

Variable	Definition
Xj,d	Decision variable: to order j on day d
Aj,d	Availability of order j on day d
S	Quantity equipment in Shipment
E	Quantity of electronic waste to be recycled
R	Quantity of RAMs
M	Quantity of Motherboards
H	Quantity of HDDs
D	Delivery cost
π	Profit
π	Profit
W	Wages
u	Useable (1/0)
c	Capacity (GB)
j	Order number
d	Day of delivery
α	Amount of time to treat electronic waste
β	Amount of time to treat HDD
γ	Amount of time to treat a motherboard
δ	Amount of time to treat RAM
n	Number of potential orders
r	Part going to recycling
i	Part going to inventory

The profit for each shipment is divided into the profit that can be received for each product that can be reused (and is thus stored in the inventory) and the profit gained for recycling the materials of the equipment that can't be reused (Table 2). Based on the above we define a target function to maximize ATG's revenue.

(1)

$$MAX[\sum_{d=1}^{7}\sum_{j=1}^{n} \begin{matrix} X_{j,d} * (\pi_{\mathrm{Er}} * E_j \\ +\pi_{\mathrm{Hr}} * \left(H_{j,u,c<500} + H_{\mathrm{j},0,c\geq 500}\right) + \pi_{\mathrm{Hi}} * H_{\mathrm{j},1,c\geq 500} \\ +\pi_{\mathrm{Mr}} * M_{\mathrm{j},0} + \pi_{\mathrm{Mi}} * M_{\mathrm{j},1} \\ +\pi_{\mathrm{Rr}} * \left(R_{\mathrm{j,0,c}} + R_{\mathrm{j,1,c<2}}\right) + \pi_{\mathrm{Ri}} * R_{\mathrm{j,1,c\geq 2}} \\ -D - W * \left(\alpha E_j + \beta H_{\mathrm{j}} + \gamma M_{\mathrm{j}} + \delta R_{\mathrm{j}}\right)) \end{matrix}]$$

TABLE II. DIVISION OF EQUIPMENT

Equipment to be Recycled		
Electronic Waste	E	Electronic waste received (kg)
Hard Drives	$H_{u,c<500}$	HDDs with a capacity smaller than 500 GB
	$H_{0,c\geq 500}$	HDDs that don't work (with a capacity larger than 500 GB)
Motherboards	M_0	Motherboards that don't work
RAM	$R_{0,c}$	RAM that does not work
	$R_{1,c<2}$	RAM that works with a capacity smaller than 2 GB
Equipment to be Resold		
Hard Drives	$H_{1,c\geq 500}$	HDDs that work with a capacity larger than 500 GB
Motherboards	M_1	Motherboards that work
RAM	$R_{1,c\geq 2}$	RAM that works with a capacity larger than 2 GB

The decision whether to ship a specific order (j) on a given day (d) is defined using the boolean variable $X_{\mathrm{j,d}}$ with $X_{\mathrm{j,d}} = 1$ indicating the we are shipping order j on day d and $X_{\mathrm{j,d}} = 0$ indicating that we are not. $A_{\mathrm{j,d}}$ defines the boolean parameter indicating whether order j is available on day d for shipping. Order j can only be shipped on day d if $A_{\mathrm{j,d}} = 1$.

(2) $X_{\mathrm{j,d}} \in \{0,1\}\ \forall \mathrm{j,d}$

(3) $\sum_{d=1}^{7} X_{\mathrm{j,d}} \in \{0,1\}\ \forall \mathrm{j}$

(4) $A_{\mathrm{j,d}} \geq X_{\mathrm{j,d}}\ \forall \mathrm{j,d}$

Each type of equipment takes a different amount of time to go through the remanufacturing process. We therefor define a coefficient for each type of equipment (Table 1). The amount of equipment processed daily is therefore limited by the amount of manpower staffed by ATG.

(5) $\sum_{j=1}^{n} \alpha E_{j,d} + \beta H_{\mathrm{j,d}} + \gamma M_{j,d} + \delta R_{j,d} <$ $\mathrm{DAILY\_WORK\_HOURS}\ \forall \mathrm{d}$

ATG provides delivery services to collect the shipments from the companies giving the equipment. The number of shipments received each day is therefore limited by the number of trucks in ATG's fleet. For simplicity, we assume that each truck can deliver up to one shipment each day.

(6) $\sum_{j=1}^{n} X_{j,d} \leq NUMBER\_OF\_TRUCKS\ \forall \mathrm{d}$

III. Example

In our example, we assume that ATG works for two days each week and that there are 8 hours of work that can be done at the company per day (DAILY_WORK_HOURS=8). In addition, we assume that ATG has two trucks (NUMBER_OF_TRUCKS=2). In our example, we have five orders where each order has an estimated profit and hours of work needed to process the order (Table 3). The availability of the orders for shipment is also defined (Table 4).

TABLE III. ORDER AVAILABILITY

Orders	Day 1	Day 2
Order 1	1	1
Order 2	1	1
Order 3	1	0
Order 4	1	0
Order 5	1	1

TABLE IV. ORDER DETAILS

Orders	Profit	Hours of Work
Order 1	1,900	7
Order 2	1,300	3.6
Order 3	1,250	3.5
Order 4	2,250	7.5
Order 5	200	0.8

The decision of which orders to ship process each day is limited by hours of work per day (constraint 5), shipments per day (constraint 6) and product availability (constraint 4). To maximize profits (Constraint 1) ATG will take on day one order #2 and order #3. Although there are enough hours of work to also process order #5 the order will not be taken due to the limit of two orders per day (constraint 6). On day two ATG will take order #1 and order #5 (order #4 is more profitable but is not available on day two (constraint 4)). The results can be seen in the following table (Table 5).

TABLE V. ORDER SHIPMENT RESULTS

Orders	Day 1	Day 2
Order 1	0	1
Order 2	1	0
Order 3	1	0
Order 4	0	0
Order 5	0	1

IV. Conclusion

In this paper, we evaluated the remanufacturing process at ATG. Based on the process we proposed a model to allow optimization in planning future shipments. We suggest future work that would consider the stochastic nature of the size of orders and that would consider the option of fitting multiple orders into one truck. In addition, future work can include analysis of a variety of equipment, optimization of prices, and finding historical data on orders to create more exact examples.

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