REVENUE MANAGEMENT FOR RETURNED PRODUCTS IN REVERSE LOGISTICS

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Abstract — Returned products take a considerable part in logistics. Recovering the returned products is one of the management issues of manufacturing companies. As an element of reverse logistics, product recovery encompasses several options, i.e., remanufacturing, repair, refurbishing, cannibalization and recycling, which are classified based on the degree of disassembly and the quality level of the recovered product. Difference in quality levels of recovered products draw different prices in the secondary markets. This situation gives rise to revenue management, i.e., to set the prices of recovered products of different quality levels such that the total revenue is maximized. One of the decision problems is the location of collection and inspection points in order to minimize the cost of reverse distribution. In our framework, we include preliminary inspection, that requires physical checking etc. and needs no substantial investment, at the collection points, and detailed inspection at the remanufacturing facility. In this paper, we modify the pricing model of Subrata Mitra to maximize the expected revenue from the recovered products. Numerical example is included for illustration.

Keywords — Reverse logistics, product recovery, revenue management, pricing model, supply chain

INTRODUCTION

Reverse logistics stands for all operations related to the reuse of products and materials. It is the process of moving goods from their typical final destination to the purpose of capturing value, or proper disposal. Normally, logistics deal with events that bring the product towards the customer. In the case of reverse, the resource goes at least one step back in the supply chain. For instance, goods move from the customer to the distributor or to the manufacturer [1]. Reverse logistics is more than just returns management. It is all activities related to returns avoidance, gatekeeping, disposal and all other after-market supply chain issues [2]. Returns management, however, increasingly being recognized as affecting competitive positioning, provides an important link between marketing and logistics. A typical framework for reverse logistics involves three main operation steps: Collecting the returned products from users, inspecting the collected products, and finally recovering or disposing the products. Reverse logistics management addresses a number of processes that have a direct or indirect impact to cost of quality. The development and implementation of a diagnostic tool to fully identify and measure this impact can indicate the way improvement of reverse logistics management may lead to final cost reduction through reduction of cost of quality. Fassoula [3] developed such a tool which is process oriented and provides cost functions for selected processes.

Product recovery is an element of reverse logistics, which is a broader term and encompasses collection, transportation, inspection and sorting, inventory management, and production planning and scheduling of returned products. There are various product recovery options, i.e., remanufacturing, refurbishing, repair, cannibalization, and recycling, which are classified based on the degree of disassembly and the quality level of the recovered product.

Remanufacturing is the process of restoring the quality level of a used product to that of a new product. It is the process of disassembly and recovery at the module level and, eventually, at the component level. It requires the repair or replacement of worn out or obsolete components and modules. Parts subject to degradation affecting the performance or the expected life of the whole are replaced. Remanufacturing differs from other recovery processes in its completeness. A remanufactured machine should match the same customer expectation as new machines.

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Remanufacturing is a high-grade product recovery option where the product is disassembled top art
level, all modules and parts are inspected and repaired or replaced if necessary and the product is upgraded to an as new quality level [4].

Remanufacturing provides the customer with an opportunity to acquire a product that meets the original product standards at a lower price than a new product. The flow of materials and products in this environment occurs both from the customer to the remanufacturer (reverse flow), and from the remanufacturer to the customer (forward flow). Since most of the products and materials may be conserved, essentially this forms a closed-loop logistics system. Jayaraman et al. [5] presented a 0-1 mixed integer programming model that simultaneously solves for the location of remanufacturing/distribution facilities, the transshipment, production, and stocking of the optimal quantities of remanufactured products.

Refurbishment (restoration) is the process of major maintenance or minor repair of an item, either aesthetically or mechanically [6].

Repair is the process of replacing the damaged or corrupt parts of the product. It is to restore the product to a sound or good state after decay, injury, dilapidation, or partial destruction. A repair is something that we do to mend a machine, building, piece of clothing, or other thing that has been damaged or is not working properly.

Another product recovery option is cannibalization, where a limited set of reusable parts are recovered and used as spare parts or for the production of new products. Cannibalization is the process (act) of removing parts from (an object, machine, etc.) to be used in another one.

Recycling means reprocessing of waste to recover reusable material. It is the act of processing used or abandoned materials for use in creating new products.

Remanufacturing is the most valuable product recovery option since here the value added to the product can be obtained. Remanufacturing and refurbishing options bring more value to the manufacturer than the other options. Recently, remanufacturing has been receiving growing attention for various reasons. First, government legislations require manufacturers to assume responsibility of their products after use either for disposal or for reuse, and encourage them to incorporate as many recyclable materials as possible in their products to reduce waste. Second, customers have become more environment-conscious. This creates a pressure for the corporations to adopt “green” manufacturing practices, including the reuse of discarded products, for enhanced corporate image and competitive advantage. Finally, remanufacturing is also gainful from the economic point of view. The cost of remanufacturing is typically 40–60% of the cost of manufacturing a new product with only 20% of the effort [1]. This is more attractive in the sense that the remanufactured product is of the same quality as a new product, and sold with the same warranty [7]. Also, since the same product is sold more than once, there is considerably less pressure for pricing the product when it is sold for the first time [8]. Remanufacturing is practiced in many industries, including photocopiers, computers, telecommunication equipment, automotive parts, office furniture and tires. Annual sales of remanufactured products are in excess of $53 billion, and more than 73,000 U.S. firms are engaged in some form of remanufacturing [2]. AT&T and Xerox have saved $100 million in 19 months and $20 million per year, respectively, by remanufacturing used products [9][2]. In practice, all remanufactured products might not be sold because of skepticism about their quality and unsold units need to be disposed of. Also, there might be more than one quality level of the remanufactured products, which could draw different prices in the secondary markets. This situation gives rise to revenue management, i.e., to set the prices of remanufactured products of different quality levels such that the total revenue is maximized [13].

**REVENUE MANAGEMENT**

Returned products are collected at various collection points, and after preliminary inspection, if found recyclable, are transported back to the manufacturer or a third-party remanufacturing facility. Otherwise, they are disposed of. At the remanufacturing facility, the returned products are subjected to detailed inspection, based on which it is decided whether they could be remanufactured or have to be disposed of. The products that go through the remanufacturing process have to be sold in the secondary markets, and the cycle is repeated. Remanufactured products, which could not be sold, have to be disposed of. Ideally, the reverse logistics activities have to be integrated with the normal manufacturing activities of a firm, but this adds to the complexity of the system since there is a high
level of uncertainty in terms of the timing, quantity, and quality of the returned products. One of the
decision problems is the location of collection and inspection points in order to minimize the cost of
reverse distribution. Should inspection be carried out at the collection points or at the remanufacturing
facility? If inspection is carried out at the collection points, it will reduce the unnecessary
transportation of otherwise useless products. But at the same time a substantial investment may have
to be made for installation of sophisticated inspection equipment at all the collection points. For
inspection at the remanufacturing facility only, there will be economies of scale in terms of investment
in inspection equipment. Surely, there is a trade-off in between these two inspection alternatives, and
this should be determined prior to revenue management stage.

The Revenue Management model considers the problem faced by a seller who owns a fixed and
perishable set of resources that are sold to a price sensitive population of buyers. In this framework
where capacity is fixed, the seller is mainly interested in finding an optimal pricing strategy that
maximizes the revenue collected over the selling horizon. Motivation for this work is the pricing
policies that are today, more than ever before, a fundamental component of the daily operations of
manufacturing and service companies. The reason is probably because price is one of the most
effective variables that managers can manipulate to encourage or discourage demand in the short run.
Price is not only important from a financial point of view but also from an operational standpoint. It is
a tool that helps to regulate inventory and production pressures.

Revenue management for returned products has not been addressed in literature so far. Jayaraman
et al. [10] gave an integer programming formulation of the reverse distribution problem and a heuristic
methodology that was very promising in terms of solution quality. Fleischmann et al. [11] first
considered the integration of forward and reverse distribution, and gave a generic integer
programming formulation. They took two cases of photocopier remanufacturing and paper recycling,
and showed that there is potential for cost savings if one undertakes an integrated view rather than a
sequential design of the forward and reverse distribution networks. In both the papers, the decision
variables were the flows and the locations of the collection centres and remanufacturing facilities. In
[11], the locations of plants and warehouses were the additional decision variables.

The profitability of reuse activities is affected by uncertainty regarding the quality of returned
products. The quality of returns becomes known only after the transportation of the products to the
recovery site. Zikopoulos and Tagaras [12] examined a reverse supply chain consisting of two
collection sites and a refurbishing site, which faces stochastic demand for refurbished products in a
single-period setting, and proved that the expected profit function has a unique optimal solution
 procurement and production quantities) and derived the conditions under which it is optimal to use
only one of the collection sites.

Apart from other researchers who approached to revenue management problem from cost
minimization point of view, Mitra [13] developed a distinctive pricing model to set the prices of
remanufactured products of different quality levels such that the total revenue is maximized.

In this paper, we do a minor modification on the pricing model developed by Mitra [13] to
maximize the expected revenue from the recovered products. Instead of disposal cost, we added
revenues from selling scraps in the model where the preliminary inspection is included at the
collection points that requires physical checking etc. and needs no substantial investment, and detailed
inspection at the remanufacturing facility. Numerical example is given for illustration.

**PROBLEM DEFINITION**

Regarding the product recovery options of remanufacturing and refurbishing Mitra [13] defined
the problem in the following way. There is an inventory of manufactured products and remanufactured
products of two quality levels. Consider remanufactured products which are “as good as new” and
refurbished products which are of lower quality. The number of units in inventory for each class of
products is obtained from an appropriate inventory control model. The number of units of refurbished
products exceeds the number of units of remanufactured products since generally the returned products
are of low to medium quality and it may be economically unviable to remanufacture them. It is
assumed that there is enough demand in the primary market so that all manufactured products will be
sold. However, for remanufactured and refurbished products, the probabilities of selling are expressed
as decreasing (linear) functions of prices and availabilities such that not all units will be sold. The
assumption is that as the availabilities increase, the probabilities of selling individual items will decrease. Though the probabilities are decreasing functions of prices and availabilities, demands are decreasing functions of prices and increasing functions of availabilities. It is assumed that an unsold remanufactured product can always be sold at the price of a refurbished product, and an unsold refurbished product has to be disposed of at a certain cost. Given the problem definition, the objective is to determine the prices of the remanufactured and refurbished products such that the total revenue is maximized.

**MODEL FORMULATION**

Before describing the model, let us introduce the following notations.

\[ p_1 \] price of remanufactured products

\[ p_2 \] price of refurbished products

\[ x_1 \] available units of remanufactured product

\[ x_2 \] available units of refurbished product (>\(x_1\))

\[ X_1 \] remanufacturing capacity of the manufacturer

\[ X_2 \] refurbishing capacity of the manufacturer

\[ K_i \] sensitivity parameters (> 0) (\(i = 1, 2, 3\))

\[ d \] cost of disposal of a refurbished product

\[ R \] expected revenue from remanufactured and refurbished products

In this model, the probability of selling of a remanufactured product is given by \((1-(p_1/P_1))(1-(x_1/K_1X_1))\) where \(P_1\) is the maximum price that can be charged at which the probability of selling becomes zero. Hence, demand or the expected number of units of remanufactured product sold is given by \((1-(p_1/P_1))(1-(x_1/K_1X_1))x_1\). It is seen from the expression that demand is a linearly decreasing function of price for a given number of available remanufactured units. Also, it can be shown that demand is a concave function of availability for a given price and the maximum of the function occurs at \(K_1X_1/2\). If we restrict \(K_2\geq2\), we can ensure that within the range of \(x_1\) demand is an increasing function of availability with decreasing returns to scale, which means demand grows more rapidly with availability in the initial phase of introduction of remanufactured products. But the growth rate tapers off as more and more remanufactured products become available in the market [13].

To model the probability of selling of refurbished products, the same logic can be applied. However, there is an issue that needs to be addressed. According to the problem definition, an unsold remanufactured unit can be disposed of at the price of a refurbished unit, and hence this would impact the probability of selling of refurbished products. From the expression for demand for remanufactured products, it is seen that the number of unsold remanufactured products increases linearly with price, but exponentially with availability. Hence, the impact of availability of remanufactured products would be much more effective than the impact of their price on the probability of selling of refurbished products. In fact, it is assumed that the increase in the number of unsold remanufactured units due to increase in its price is absorbed by the manufacturer by bundling the units with separate service provisions. The effective prices of remanufactured units thus sold approximately equal those of refurbished units, and the attractive offers are promptly lapped up by customers since the prospective customers of refurbished units are price-sensitive and they look for cost-effective utilization of these products. It can be assumed that the increase in price of remanufactured units would virtually have no impact on the probability of selling of refurbished units. On the other hand, the increase in availability of remanufactured units would definitely have an impact. Accordingly, the probability of selling of refurbished products is defined as \((1-(p_2/P_2))(1-(x_2/K_2X_2))(1-(x_1/K_3X_1))\) where \(P_2\) (<\(P_1\)) is the maximum price that can be charged. \(K_2\geqK_1\) means thereby the availability of remanufactured products would impact the probability of selling of remanufactured products more than the probability of selling of
refurbished products, which is consistent with the situation. Hence, demand or the expected number of units of refurbished product sold is given by 
\((1 - \frac{p_2}{P_2})(1 - \frac{x_2}{K_2X_2})(1 - \frac{x_1}{K_1X_1})x_2\). Following the same logic as in the case of remanufactured products, here also if we restrict \(K_2 \geq 2\), we can ensure that within the range of \(x_2\) demand is an increasing function of availability with decreasing returns to scale [13].

Now, \(R\) can be expressed as follows:

\[
R = \left(1 - \frac{p_1}{P_1}\right) \left(1 - \frac{x_1}{K_1X_1}\right) x_1 p_1 \\
+ \left[1 - \left(1 - \frac{p_1}{P_1}\right) \left(1 - \frac{x_1}{K_1X_1}\right)\right] x_1 p_2 \\
+ \left(1 - \frac{p_2}{P_2}\right) \left(1 - \frac{x_2}{K_2X_2}\right) \left(1 - \frac{x_1}{K_3X_3}\right) x_2 p_2 \\
- \left[1 - \left(1 - \frac{p_2}{P_2}\right) \left(1 - \frac{x_2}{K_2X_2}\right) \left(1 - \frac{x_1}{K_3X_3}\right)\right] x_2 d.
\]

The objective is to maximize \(R\) given that \(p_1 (p_2)\) lies between 0 (0) and \(P_1 (P_2)\). It can be shown that if \(d\) is less than \(P_2\), the value of the objective function can always be improved by making the prices satisfy their lower bounds and \(p_1\) satisfy its upper bound. However, the same cannot be inferred for the upper bound of \(p_2\), and derivation of the condition under which \(p_2\) satisfies its upper bound is not straightforward. Hence, the concavity of the objective function is to be checked and the optimal values of \(p_1\) and \(p_2\) are to be determined, and if \(p_2\) exceeds \(P_2\), it is set \(p_2 = P_2\) [13]. In practice, disposal of a refurbished product usually does not bring a cost, instead some revenue occurs due to the selling of its scrap. Thus, by incorporating this case into the last part of the objective function (as a positive contribution), we can have a more realistic model for revenue optimization.

**NUMERICAL EXAMPLE**

Currently there is a manufacturing base for notebook (laptop) computer makers in Turkey. Some of these devices are being imported as well. There are also organized collection programmes and recyclers of used notebooks. Customers usually exchange their old notebooks for newer models at the dealers’ or service providers’ facilities. Dealers, authorized by the manufactures, then sort the used notebooks based on their age and quality, and accordingly either upgrade or repair. The upgraded notebooks are sold through the same sales channels as the new ones with the same warranty but at a reduced price. The repaired notebooks, on the other hand, are sold through different sales channels in the markets for used notebooks at substantially reduced prices without any warranty. The price-quality differentials between upgraded and repaired notebooks make these two markets independent of each other in the sense that a quality-conscious buyer of upgraded notebooks will never look for a lower-quality repaired notebook and a price-sensitive buyer of repaired notebooks cannot afford to buy a higher-priced upgraded notebook.

Casper Computer is one of the leading notebook manufacturers in the country. The selling price of a new average capacity notebook is around $1200 (vat included). Upgraded versions of secondhand notebooks of this kind are sold at $1000, whereas the price for repaired secondhands is just $700. Those secondhand notebooks that cannot be upgraded or repaired are disposed as scrap. Scrapped notebooks are recycled (recovered) at around $150 each. Capacity of the manufacturer for both upgrading and repair operation is 500 units. Given the above information including the sensitivity parameter values as 1, 2, 3, and the available units of upgraded and repaired notebooks as 100 and 200 respectively, the proposed (modified) pricing model can be used for determining optimal prices for upgraded and repaired secondhand notebooks and the expected revenue thereof.

The model parameters and their values are stated below.
When we run this nonlinear model with the given data, we reach at the following optimal result.

**Optimal prices**

- $p_1$: $812.608$
- $p_2$: $625.225$

**Maximum revenue:** $1.0304E+5$

Of course, expected revenue can vary against alternative values of model parameters ($P_1$, $P_2$, $d$, $X_1$, $X_2$, $x_1$, $x_2$, $K_1$, $K_2$, $K_3$). According to the changing conditions (with specific sets of data) the model can be used dynamically to determine the new prices to be charged and the expected revenue thereon. When the model is run for different values of parameters for any case, the following decisions are to be derived [13]. As the maximum price increases, the probability of selling at a given price and availability also increases, thereby the expected revenue increases with the maximum price that can be charged. The expected revenue increases with $x_1$. Since according to the assumption made in the model, the unsold upgraded products can at least be appraised at the price of repaired products, it is expected that the revenue will increase with the availability of remanufactured products.

The expected revenue also increases with increase in $x_2$. With increase in the availability of repaired products, more are more of the same will have to be disposed of, which will slightly increase the revenue. We can infer that as the ratio $x_1:x_2$ improves, the revenue is also expected to increase. The expected revenue increases with increase in the disposal value, which is obvious from the model.

It is evident that as the value of $K_i$ ($i = 1, 2, 3$) increases, the expected revenue also increases. $K_i$ represents the sensitivity of selling probability to availability. As $K_i$ increases, the selling probability becomes less sensitive to availability, and as a result demand, and hence the expected revenue, increases. In particular, $K_3$ represents the sensitivity of selling probability of repaired products to the availability of upgraded products. With increase in $K_3$, the selling probability of repaired products becomes less sensitive to the availability of upgraded products, which results in higher expected revenues [13].

It is assumed in the model that the probability of selling was a linear function of price, given availability. A sensitivity analysis was performed by Mitra [13] on the developed non-linear analytic model by making the probability of selling a concave function of price for a given number of available units. It resulted such that when the price was on the lower side, the probability of selling decreased slowly with increase in price, but when the price was on the higher side, the probability of selling declined sharply with price increase.

**CONCLUSION**

Product recovery is one of the reverse logistics activities, which has gained importance in recent years due to government legislations and increasing awareness among people to protect the environment and reduce waste. Researchers have put in a lot of effort so far for developing inventory models in the context of reverse logistics. In all these models it was implicit that recovered products (basically the remanufactured ones) were sold along with new products in the primary markets at a price equal to or less than that of new products to satisfy customer demand. Cost minimization rather than profit maximization has become the objective of these reverse logistics inventory models. Whereas, the sale of recovered products was not so easy because of two reasons. First, customers were skeptical about the quality of recovered products, which limited the purchase of all these ones. Second, due to different quality levels of recovered products, it was expected to set different prices on these products in the secondary markets. Thus, revenue management for recovered products appeared to be an important subject, which has not been looked into so far. In this paper, we have discussed the matter in the context of recycled notebooks in Turkey, with numerical example, to maximize the expected revenue. We have selected two quality levels for illustration, namely upgraded and repaired products. The model can be generalized for any number of quality levels, though with an increase in complexity of the problems.
In the context of the notebook computer industry, when the average replacement period of notebooks is decreasing very rapidly due to introduction of newer models, the market will be swamped with quite new laptops of sufficiently high grade of quality, which can be easily upgraded and resold in the primary and secondary markets. This is also true for other type of recyclable products, i.e., photocopiers, mobile phones, white goods, television sets, etc. This means huge business opportunity for the original equipment manufacturers as well as the third-party remanufacturers. Thus, as product recovery activities get intensified, revenue management programs will be needed more.

REFERENCES