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Allocation of external returns of different quality grades to multiple stages of a closed loop supply chain

Rabindranath Bhattacharya [a,*], Arshinder Kaur [b,c]

[a] Chennai Business School, Chennai, India
[b] Department of Management Studies, Indian Institute of Technology, Madras, India
[c] School of Information Systems, Curtin Business School, Curtin University, Australia

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ABSTRACT

A single period multistage closed loop supply chain (CLSC) is presented here considering simultaneous manufacturing of new products and remanufacturing of customer returned used products. The quantity of used products in reverse supply chain considered in the model is a fraction of the new products manufactured in the forward supply chain. Used products of known quantity are pulled from end customers as per quality grades. Products are assumed to be mechanical in nature and remanufacturer has to pay different acquisition prices for different quality grades of return. The groups of graded products based on the acquisition prices are thus sorted and sent to stages of CLSC earmarked for them as per demand for repairing/recycling of raw materials. After repairing/refurbishing and recycling at each stage of reverse supply chain the used parts/products become part of forward supply chain. In this paper, a nonlinear maximizing profitability function for CLSC has been formulated for the system with a price dependent demand for *n*-stages. The decision variables are selling price of product and percentage return of graded used products entering into different stages. A numerical example for a three stage model illustrates the method followed by managerial insight.

1. Introduction

Forward supply chain (FSC) ensures an efficient and effective production of new products/parts and delivery of the same to the customers. Similarly a reverse supply chain (RSC) comprises of activities involving acquisition, collection, delivery, reprocessing of the used parts/products to recover left over market value or dispose it of Pochampally and Gupta [1]. The integration of forward and reverse supply chain is termed as closed loop supply chain (CLSC). Another definition in this connection was given by Guide and Wassenhove [2] which is: the design, control, and operation of a system to maximize value and dynamic value recovery throughout the life of the returns of different types and quantities. Radhi [3] defined each process of reverse supply chain as follows:

- Reuse is the process of directly reusing the product with cosmetic repairs apart from cleaning and checking.
- Recycling is the process of recovering raw materials where the shape of the material changes.
- Cannibalization is the process of reusing good parts and components that are recovered from used products.
- Repair or reconditioning is accomplished by restoring out of specification products to working conditions but *not to as good as new condition*.
- Remanufacturing and/refurbishing is the process of transforming or restoring the condition of the used parts to its original condition *as good as new*.

Although remanufacturing of products was going on for quite some time general overview of remanufacturing and product recovery is presented by [4–6]. In the nationwide assessment of remanufacturing, Nasr et al. [7] reported average profit margin of 20% for the remanufacturing firms which directly employ three hundred and fifty thousand workers in USA. Product recovery management encompasses the management of all used and discarded products, components and materials that fall under the responsibility of a remanufacturing company. The objective of all product recovery management (PRM) is to recover as much of the economic (and ecological) value as reasonably possible, thereby reducing the ultimate quantities of waste [6]. Ferguson et al. [8] opined that insofar as remanufacturing requires different competencies than

* Corresponding author. Tel.: +91 7044199555; fax: +91 4422574552.
E-mail address: rabindranath.bhattacharya@yahoo.com (R. Bhattacharya).

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manufacturing whether to enter the remanufacturing is a similar question to whether to enter any new business.

Remanufacturing focuses on value added recovery, rather than just materials recovery, i.e., recycling [5]. In remanufacturing, used products can range in condition from slightly used with only minor cosmetic blemishes to significantly damaged and requiring extensive rework [9]. The critical operating decision for remanufacturing is to establish a proper sorting policy given variable conditions of returns just to understand which product is to be reused or which one to be repaired and which one to be recycled ultimately.

It has been a practice for quite some time on the part of manufacturers or remanufacturers to pay lowest acquisition prices for collection of old used products of worst quality class from customers and highest price for best quality class. Clearly, remanufacturing cost is assumed to increase as product condition worsens [9]. However, it would not be practical for anybody to fix price for each product being collected according to its condition. In order to overcome the problem, organizations generally assign a fixed number of quality grades of the returns and assign acquisition prices according to the quality grades for the entire range of collected products. Each price is assigned to a group of products having similar nature of defects and where remanufacturing/repairing cost in a reverse supply chain (RSC) centre would lie within a narrow band. For example, for a three stage closed loop supply chain (CLSC), grade one may mean products with virtually no parts replacement but requires a touch up or tweaking or testing to bring it to shape.

The highest price could be paid for such range of products for collection from the customers since the remanufacturing cost will be the least. Similarly, grade two means products with major repair with replacement of parts without completely dismantling the products. The second highest price could be paid for such range of products. The worst grade of quality means products with worst condition where some parts after dismantling may be scrapped but manufacturers would be more interested in salvaging costly raw material by recycling the same internally or externally to convert them into say ingots like aluminium alloys and zinc. The raw material ingots could be then used again for producing the components in the first stage in forward supply chain (FSC). Lowest acquisition prices could be paid for such products since the recycling cost would be the highest among all the costs of RSC entities. In our paper the number of stages of the CLSC matches the number of quality grades fixed initially and each stage would handle then one quality grade of materials distributed from collection centre. We find similar assumption by Ketzenberg et al. [10] who assumed that disassembly sequence is the reverse of assembly sequence and both the processes can run parallel or mixed.

We find somewhat similar application (excluding recycling) adopted by the dealers of old cars in India who pay for the collection of old cars based on the kilometres run, registration month and year and condition of the old car like fair, good and very good. Here the dealers of old cars first assess the grades/quality class of the cars brought by the seller and the maximum price that could be paid for the corresponding class based on a cost matrix provided by the management. Management fixes sale price of the remanufactured car based on the expected remanufacturing cost and cost of acquisition of the products. These products, unlike our model, are however never mixed with the new cars and sold through separate network of dealers dealing with only old cars like *True Value* (http://www.marutitruevalue.com/buy.aspx) owned by Suzuki and *First Choice*, owned by Mahindra and Mahindra (http://www.mahindrafirstchoice.com) in India. Automobile ancillaries who are manufacturing parts like water pumps, oil pumps, fuel pumps, timing cover, oil sump, cylinder blocks, cylinder heads and gear box castings use aluminium alloy ingots for manufacturing these items through high pressure, low pressure and gravity casting process. Since raw material cost for such products are very high compared to prices of other parts assembled together, manufacturers would prefer salvaging the raw materials rather than scrapping the used products as experienced by one of the authors during his tenure in a leading group of companies in India. Real challenge therefore lies in determining the proportion of returned materials (grade wise) expected to be handled by each stage of RSC, running in parallel with FSC, out of total return of used products. Subulan et al. [11] proposed a fuzzy model for designing and implementation of spent battery collection and recovery systems to maximize collection of used batteries.

The research objective here is to take a holistic view of the situation and identify optimum decisions maximizing the profitability of a multi-stage CLSC in a single period. The decisions are:

- What should be the optimum sale price of the new products in a CLSC?
- What percentage of a known external return percentage of different quality grades should get pulled optimally by the corresponding stages in RSC for processing?
- Under what conditions the optimum distribution is likely to be disturbed?

2. Literature review

The publications on CLSC were found in many areas like networking and distribution, integrated manufacturing–remanufacturing, acquisition, overall structure, planning and control, inventory control, collection, review papers, strategy apart from case studies. These literatures were published in all major cited journals in the world and numbers are growing year by year. This shows the importance of remanufacturing. Since our paper is related to inputs, processing and price of the final product we concentrate in the corresponding areas only.

2.1. Acquisition

There are two primary systems for obtaining used products from end users/customers for *reuse*: (1) *market driven system* and (2) *waste stream system* [12]. In European *waste stream driven approach* the remanufacturer passively accepts whatever comes to him and the manufacturer concentrates mainly in on grading and disposition activities. Management does not have much role to play in controlling the *quality as well quantity* of the inputs. This happened because the producers were mandated by laws in many countries in Europe and many states of USA to collect EOL and EOU products from customers and take them back for reuse instead of dumping them. Since the law is very stringent the producers often are left with a large unsorted inventory (nuisance value) of varying quality. The management is forced to look for *cost minimization* instead of taking profit maximization as objective function. The high level of variability makes this remanufacturing facility difficult to plan, control and manage [13]. Yield factor plays a major role here which affects profitability of the system.

But the *market driven system* works on motivation. The customers/end users are *motivated by financial incentives* to part with used products and the remanufacturer in turn is able to *control the quantity and quality* of inputs as these are now conditioned by certain standards. Market driven systems are common in United States because of the profitability of remanufacturing [5]. As a result of this, the variability of process time and routing would be reduced, inventory would be less, labour utilization gets better and planning and control gets simplified. In a nutshell this system is more cost efficient and more productive. Management always would, in these circumstances, take a holistic view of the situation and the objective would be mainly *profit maximization*. Products are procured/pulled

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