

# OPTIMIZATION OF DEMAND BASED REMANUFACTURING COST ESTIMATION MODEL

Dr. L.K.TOKE<sup>1</sup>, Prof. A.D.LOKHANDE<sup>2</sup> Prof. P.V. Fegade<sup>3</sup>

<sup>1</sup>. Asso. Prof., S.S.G.B.C.O.E &T, Bhusawal.

<sup>2</sup>. Asst. Prof., M.I.T, Pune.

<sup>3</sup>.Asst. Prof. S.S.G.B.C.O.E &T, Bhusawal

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**Abstract** - Remanufacturing is the act of returning an end of life product to new condition with a warranty equivalent to new product. Remanufacturing is the only option that requires a full treatment process like new manufacture to guarantee the performance of the finished object. It is more appropriate for products that are technologically mature and where a large fraction of the product can be reused after refurbishment. Remanufacturing industries are related to the earthmoving, automotive parts, electronics, medical devices and information technology. The essential requirements for remanufacturing are sourcing end of life products, inspection, disassembly, component testing, remediation, repair or replacement, reassembly, assembly, testing and dispatch. Remanufacturing businesses have developed in response to a business opportunity. Remanufacturing is a technically feasible, environmental benefits and economically profitable.

Remanufacturing has tremendous impact on India, it will affect severely its growing industry and large based consumers. The paper is focused on factors responsible for remanufacturing products. We have described the manufacturing and remanufacturing policy for the main scenario provide an approximation of the probability distribution used to determine the amount and rate of collected products present an algorithm for calculating the optimal manufacturing and remanufacturing capacities. We have developed a simple solution to estimate demand based remanufacturing cost.

**Key Words:** Life cycle, Remanufacturing, Reduce, Reuse and Recycle.

## 1. INTRODUCTION

The remanufacture of automotive engines, gearboxes and other components prospered in the situation of lack of materials during the Second World War. Remanufacturing started with the help of small independent companies providing cheap replacement parts. Vehicle Manufacturers excepted this business opportunity for many years. It has

viewed as a dirty part of the industry that lacked the glamour of new car production and marketing. In the USA, while remanufacturing is a major business, Original Equipment Manufacturers (OEMs) still remain relatively disengaged and account for less than five percent of total remanufacturing activity (Guide Jr., 2000). In Europe, OEMs have discovered the aftermarket potential for remanufactured products and many are now involved (Seitz and Peattie, 2004). In the route of creating huge wealth, manufacturing industry has consumed the resources and energy in the earth and seriously polluted the environment. Sustainable development is the way to save resource and improve environment with the help of "4R" rule (Reduce, Reuse, Recycle and Remanufacture). "4R" rule is the important measure to get the goal. Remanufacturing is the industrialization of high tech maintenance of the waste and worn out productions. It is one of the most active factors in "4R". Remanufacturing is the process of disassembly of products during which time parts are cleaned, repaired or recycled then reassembled to sound working conditions. Remanufacturing is a process of recapturing the value added to the material when a product is first manufactured then it is used for remanufacturing the components and spare parts. Remanufacture returns a used product to new like condition. A product may be remanufactured with or without brand or product identity. Finally, Remanufacturing is a series of manufacturing steps are acting on an end of life part or product which is in order to return it like new or better performance with warranty. (Fig.1) shows the basic Remanufacturing Process (Steinhilper, 1998).

### 1.1 Benefits of Remanufacturing process:

The benefits of remanufacturing process related to cost savings are as follows.

- The cost is lower than an equivalent new product.
- It creates high skill, high value added jobs compared to other waste management practices.
- Levels of occupational safety and hygiene are higher than in the recycling and waste management industry.
- It is estimated to employ 50,000 people in the UK. (about the same as the recycling industry)
- It is a reuse option, sitting near the top of the waste hierarchy.
- It shows high levels of resource efficiency.

- g) It uses fewer resources and important in reducing rare materials or materials where the supply is not certain.

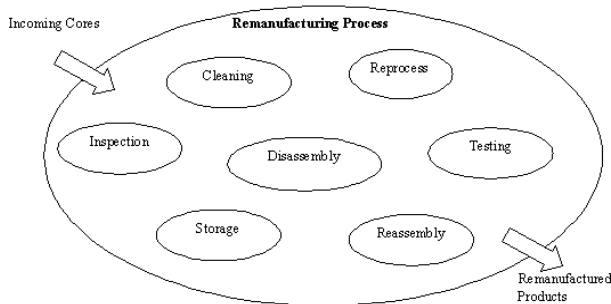


Fig.1 Basic Remanufacturing Process

### 1.2 Remanufacturer:

The remanufacturers are almost every industrial sector whether original equipment manufacturers, contractors or independents. Remanufacturers are an ingenious, valuable and largely unrecognized set of companies determined by an apparent grip of the economic value of their services. Top flight remanufacturers are characteristically flexible and adjustable in coping with the business environment and the manufacturing task. Most describe themselves as service providers.

They need to be capable of the important factors are sourcing end of life products, inspection, classification, disassembly, component testing, remediation, repair or replacement, reassembly, assembly, testing and dispatch.

### 1.3 Product Life Cycle:

A product is considered remanufactured if its primary components come from a used product. The used product is dismantled to the extent necessary to determine the condition of its components. The used products components are thoroughly cleaned and made free from rust and corrosion. All missing, defective, broken or substantially worn out parts are either restored to sound, functionally good condition or they are replaced with new, remanufactured, sound, functionally good used parts. To put the product in sound working condition such as machining, rewinding, refinishing or other operations are performed as necessary. The product is reassembled and a determination is made that it will operate like a similar new product. Product life cycle is an important aspect to be studied from remanufacturing and recycling point of view. Material, energy and manpower consumption along with environmental impact aspects were subjects of interests. (Fig.2) describes the life cycle of a product. (John Sutherland, 2002)

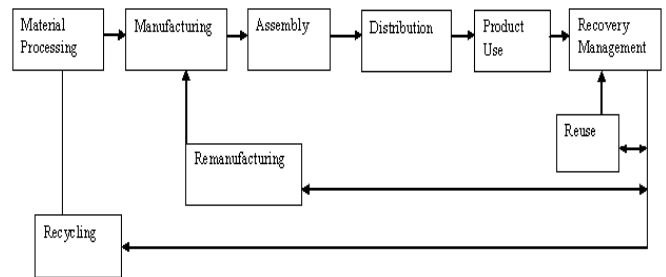


Fig.2 Life Cycle of a product

The different steps are involved in the life cycle of a product

1. Material processing involves extraction and raw materials. Extraction is done from earth's crust and liquid petroleum, woods for paper and rubber based products. Material extraction consumes energy and creates wastes in processing and resulting in retreating resources. Recycling is always preferable to avoid environmental trouble that material extraction requires. Recycling takes less energy than extraction and reduces the amount of landfills.
2. Manufacturing involves processing raw material into parts. These parts and processing techniques are quite diverse based on product performance characteristics. Manufacturing process consumes considerable amount of energy and manpower. In many cases toxic wastes and harmful bi-products are generated.
3. The assembly process involves putting different manufactured parts together manually or by automated. The assembly process can be a very complex especially where large numbers of parts are involved e.g. automobile, computers. Assembly of the product consumes energy and manpower.
4. Product-use is putting product to its intended use which might involve energy consumption, wear and tear of product and its component. In some cases products use might result into generation of pollutants e.g. automobiles, refrigeration units.

Product end of life is the first stage for remanufacturing. For a product to be remanufactured it is important to have all know how to incorporate resources to rebuild the product. Product end of life hierarchy in Allocca (2002) is categorized in six broad categories.

1. Reuse: Reuse is the used trading of the product for use as originally designed. Automobiles and its spare components are the best examples of reuse. The products those are build for longer life span like 10 to 20 years or more are feasible for reuse. Extended product life is one of the suitable alternatives to eco design but it is not a solution. Rapid change in consumer's taste makes it more difficult to build such products. Rate of growth of technology constantly triggers feasibility. Computers are examples of no longer in use due to faster growth in model design changes.
2. Service: Servicing is increasing product life by replacing worn out parts or rebuilding some product's part in order to make it functional for longer duration. Servicing is preferred for products those are huge in size and shape. Earthmovers

and houses are the products where servicing is suitable through economic perspective and is widely used. It is profitable practice for both consumers and industries.

3. Recycling with disassembly: Recycling reclaims material streams useful for applications in same or different products. Disassembly into material fraction increases the value of the materials recycled by removing material contaminants hazardous material or highly valuable components. Recycling with disassembly is feasible for products with homogeneous materials. Products designed for recycling with disassembly are becoming widely popular. Paper and aluminum products are now fully recycled. This is economically feasible and profitable option.

4. Recycling without disassembly: Products with composite material structure are suitable for this option. Automobile tires can be given as an example for recycling without disassembly. The shredded material is separated with chemical processes or simply using magnetic density or other properties of the materials

5. Remanufacturing: As stated in definition in above section. It is a process in which reasonably large quantities of product are brought back into facility and disassembled. Parts from a specific product are not kept with the product but instead they are collected by part type, cleaned and inspected for possible repair and reuse. Remanufactured products are then reassembled on assembly line using those recovered parts and new parts wherever necessary. Remanufacturing is feasible solution for complex assemblies. Products designed through remanufacturing perspective will have much longer lives and will be giving economic advantage for manufacturers.

6. Disposal: This end of life strategy is transferring product to landfill the product without much energy recovery. This is the last option to be practiced for eco design. To consistently perform an environmental impact analysis across all possible ends of life strategies it is necessary to determine a reference point. The reference point can be product in resalable condition or product requires recycling or product requires to be remanufactured.

## 2. LITERATURE REVIEW

A literature review is studied continuously during this research paper in order to better understand the research area as well as to find out what research has been done. Remanufacturing has a long history in the UK across the complete range of industrial sectors. In most of the cases remanufacturing business have been developed in response to a business opportunity, they are producers of durable (usually metal) manufactured assemblies. For example, Caterpillar manufactures engines for large plant and rolling stock. The inherent value of the materials and the cost of production enable this equipment to be remanufactured to new condition. This process saves tens of millions of tones of materials world wide can make more profit than new equipment. It's a lower cost to the end user. T.E Graedel and B.R.Allenby[1995] was explained remanufacturing

involves the reuse of obsolete products by retaining serviceable parts, refurbishing usable parts and introducing replacement components. It is defined as remanufacturing is a process of bringing the used products back to as new condition by performing the necessary operations such as disassembly, overhaul and replacement. According to Guide (2000) a recoverable manufacturing system is characterized by the uncertainty in timing, quantity and quality of returns and the place where to collect them. This uncertainty affects planning performance and production control (Prahinski and Kocabasoglu, 2006) and creates unpredictability in remanufactured product inventories. Rub (2008) analyzed the main characteristics of articles on reverse logistics and Fleischmann and Minner (2003) classified the models for describing systems with reverse logistics in two categories deterministic models [Minner and Kleber (2001) and Choi (2007)] and stochastic models (Fleischmann and Kuik (2003), vander Laan(2004), Buchanan and Abad 1998 and Teunter, 2006). These models are used to determine optimal ordering and inventory policies that manufacturing and remanufacturing capacities are enough to supply the demand. Vlachos (2007), Georgiadis (2006), Georgiadis and Vlachos (2004) presented the dynamic models for strategic remanufacturing and collection capacity planning where these capacities are state variables and a policy is proposed in order to calculate them. Another relevant reference is Souza (2008) which mentioned other sources regarding single period models and used product achievement. Rose and Ishii (1999) was published the remanufacturing is an end of life strategy that reduces the use of raw materials and saves energy while preserving the product value added during the design and manufacturing processes. The concept of product dematerialization that consists of increasing the performance and the lifetime of a material for a unit piece of raw material, remanufacturing and reuse approaches would contribute a) To reduce the climate change issue and other environmental challenges like material extraction or waste amounts. b) To support the development of new consumption behaviors. Remanufacturing processes must be adapted to support existing products that were not designed to be easily remanufactured in most of the cases (Sundin 2001a). So, the remanufacturing process is not optimal leading to costs too high to make the business really profitable (Barker and King 2006, Franke 2006, Sundin 2006). The industrial issue is to develop new products optimizing remanufacturing and reuse strategies. The scientific issues deals with developing design methods of remanufacturable products (Brissaud and Zwolinski 2004, Zwolinski and Brissaud 2006).

Remanufacturing industry is relatively small in developing countries especially in India. If the government were to implement policies to aid in the development of the sector it could improve the economy and help the environment, while leading as one of the few nations with a strong remanufacturing. Remanufacturing is a very labor intensive process through the various stages of breakdown required for advanced products. Partially due to large

number of necessary labor most if not all remanufacturing occurs in the unorganized sector of manufacturing (Mukherjee and Mondal 2008). While the informal sector is important in the growth of an overall economy. India could benefit more from creating a formal remanufacturing sector. The processes of product require would increase a demand for labor thus employing more citizens and help reduce waste in land fills. Moreover, in remanufacturing businesses see profits of up to 20 percent and in the auto industry this is even higher (Mukherjee and Mondal 2008). It is important to note that certain industries such as the remanufacturing of PCs are difficult to start up as they require a high level of technological knowledge that most Indian manufacturing firms do not have. However, success in other industries can create spill over and the continual efforts of R&D can provide the technology necessary for firms to enter these markets. They have completed a case study of a photocopier manufacture in India that offers free service and repair to all customers thus guaranteeing long term contact with consumers. In this way the company can also monitor individual units and present a buy back scheme to a customer when the separate machine components still have viability for remanufacturing. Introducing that will force industries to remanufacture, while providing information and logistical support for firms will start India on a path of greater product recovery. However, these policies would only apply to existing firms and not aid in the development of new remanufacturing firms. Through grants, low interest loans and information support the government could facilitate the creation of more remanufacturing firms. These firms could be linked to various companies focusing solely on the process of stripping down old products allowing OEMs to receive the components ready to build with. Depending on the market structure this out sourcing may be more cost effective for a firm especially smaller OEMs with limited human capital.

In addition to the expansion of remanufacturing firms the government much helps in the creation of a market willing to buy remanufactured products. A mass campaign to promote the "like new" quality of remanufactured goods at almost half the cost would increase the domestic consumption of remanufactured goods and make companies more competitive in the market place. Moreover, remanufactured goods could be exported to other nations such as the members of ASEAN where a majority of the population would appreciate the availability of cheap but reliable goods. Western consumers may be adverse to the idea of remanufactured goods but it is likely that the environmental and economic benefits to buying remanufactured products will open up more foreign markets for Indian firms. Overall the positive environmental impact and the profits to firms would aid in the development of the economy expanding exports while bolstering the domestic sector. In this paper we study a production system with constant demand and returns for a single product. We focus in determining the optimal manufacturing and remanufacturing capacities.

## 2.1 Current Status of Remanufacturing Industry

In an investigation of remanufacturing industries presents some practical examples of issues that have been addressed in the remanufacturing. The proposed work involves extensive research on remanufacturing industry. The issues are described some of the problems facing remanufacturing industry.

**Low price:** Remanufacturing has a role of producer responsibility. From abroad, remanufacturing is a low cost import for improving quality goods. The relatively high UK labor cost content of remanufactured goods. It is a cheaper to purchase new than recondition. Remanufacturing is used to compete in markets where price is the only basis for competition, unless a low cost source of labor is available. However, this does not rule out competition from low-cost, well-organized and networked remanufacturers who can credibly intermediate between suppliers and purchasers of goods.

**Customer's opinion:** Remanufacturing is not a magic bullet for production industries. View of remanufactured goods as second-class can limit sales growth. For example, fashion oriented lifestyle or status products are cars, white goods, and attire. Even business to business transactions suffer without strong standards for the remanufacturing process. **Keeping changes:** In some cases, independent operators should undertake costly reverse engineering functions to determine specifications. Skill shortages limit capacity to remanufacture where rate of technological change or environmental efficiency gain from new design is high. The most sustainable strategy may not be remanufacturing. In such cases recycling and design for recycling is a sensible step.

**Potential:** Remanufacturing has the potential for greater contribution to sustainable consumption. There are different steps that all stakeholders take to enable. A starting point is that elimination of legal impediments such as rejection of contact to manufacturer design information, exclusion of remanufactured components in new goods and redefinition of what constitutes waste. Removal of these would increase competition and force evolution of improved services including remanufacturing.

## 2.2 Exemplary Industrial Practices for the Remanufacturing in the World and India.

1. **Office furniture:** Office furniture includes tables, chairs, pedestals and bookcases. The data provided by Durham are broken down into these product categories enabling a detailed analysis of each product type. Approximately 165,000 tones of office furniture are thrown away annually from British businesses. Some of this will be the result of wear and tear but the majority is in perfect working order and its disposal is largely due to changes in fashion, variations in staff levels or whole office moves. It has been estimated that over half of the office furniture sent to landfill each year is re-useable. Based on



conversations with remanufacturers under current market conditions. The savings of furniture between 25% - 50% can be made on each item of furniture.

2. **Printer cartridges:** Printer cartridges provide the ink to enable printing on both ink-jet and laser printers. The cartridges for these products are incompatible but there is significant remanufacturing activity for both types. Most office-based printers are based on toner technology. The cost differential between new and remanufactured printer cartridges ranges from 20% to 50%.
3. **Laptops/desktops:** Although the pace of technological change means that older laptops are usually unsuited for use within a modern office environment, the return channels for unwanted and warranty returned products mean that laptops which are only one or two months old are being resold as remanufactured with a full manufacturers warranty. Most of the major Original Equipment Manufacturers (OEMs) and suppliers offer remanufactured and refurbished products, meaning that there is a large and active market for the sale of remanufactured and refurbished laptops. Remanufacturing is generally only undertaken with newer products hence procuring remanufactured products will still ensure that high-quality products are being sourced. The price differential depends upon the age of equipment being offered, but nearly new or current models will typically be in the range 65-75% of the cost of new; these will be sourced from overstock.
4. **Servers:** Most office-based businesses, schools and other organizations have an internal IT infrastructure. This normally consists of workstation computers, typically desktops and laptops which are supported by a server that operates over a network. The server is used to provide network services to users, for example network data storage, network routing, email hosting and file hosting. In many ways the equipment is similar to the more familiar desktop computers, using processors, memory and hard disks amongst other components. Remanufacturing costs associated with server equipment are dependent on the equipment, its age and its specification as well as market demand for that product. A similar price range can be expected to that commanded by laptops. The calculations described below will assume an average saving of approximately 25%.
5. **Vehicle maintenance:** The automotive sector is traditionally an area in which remanufacturing has flourished. Over 50 different components are commonly remanufactured. These are typically high value and require a good level of technical expertise and knowledge to manufacture and remanufacture. Product includes engine and engine components, drive train, rotating electrics, turbo chargers, air conditioning and electronics.
6. **Photocopiers and other opportunities:** There is a strong market in remanufactured photocopiers and printers. Due to the decreasing costs associated with lower volume models, the remanufacturing process is limited to higher value enterprise models. The process is performed by both

independent remanufacturers and also a variety of original equipment manufacturers, the most widely quoted being Xerox, but others such as Lexmark offer similar services. Remanufacturing is an important business tool used by these organizations to reduce capital costs on many of their service contracts which involve the sale of a service (printed paper) rather a printer is as mentioned above; remanufacturing is common practice on larger printers and photocopiers. Due to costs associated with the remanufacturing process smaller cheaper products are rarely remanufactured. As a general rule the cost savings for higher value remanufactured photocopiers will be greater.

Remanufacturing is an effective method for prevention of environmental hazards, material wastage and excessive energy consumption. While analyzing the current status of the Indian remanufacturing industry one thing is clear that it's disorganized nature which is due to the lack of proper planning while formalizing perfect strategies. Not a single company has produced a strategy that could have guided them towards popularizing their remanufactured products in an ever developing market. Whatever, data is available which is developed to attract companies from other sectors. It is either the corporate that uses remanufactured cartridges or a small group which understands the IT peripherals. There are over 30,000 remanufacturer in the business of refilling and remanufacturing across the country employing more than 5 lakh people. Out of it 70 remanufactures and 300 refillers in the country can be called serious remanufactures with quality brands, proper manufacturing facilities and trained manpower. As per estimates, the Indian cartridge market is estimated at around Rs 1,400 crore, growing annually at 30 percent. Of the 30 percent less than 10 percent is contributed by alternative supplies like compatibles and remanufactured products. The presences of big remanufacturer are Black Magic, Amkette and Lipi Data Systems.

Now with the emergence of international remanufacturer, Indian remanufactures are optimistic about the industry. Foremost among them is Cartridge World one of the world's largest retail chains selling remanufactured products through 1,500 franchise outlets. The retailer has aggressive plans for India and plans to open 50 stores by the end of the current financial year and 250 stores by 2010. Aggressive plans for India have also been devised by Static Control Components (SCC). The company makes some 13,000 different parts including drums, ink, casings and chips for 1,200 different toners and cartridges. They have two offices in India, Delhi and Mumbai. They have planned to open in more cities soon with big investments lined up for our various initiatives here.

Remanufacturing is a business opportunity worldwide and the business of waste is the most beneficial and effective. India is the second most populated country in the world; a need is identified for remanufacturing a last twenty years and a half ago. The country is still trying to strike into the vast potential of the industry. Among various

information technology products, recycled and remanufactured products were receiving maximum attention worldwide when India decided to follow its peers. International remanufacturers are fixed a position and turned it into their success story. Indian remanufacturers are making a slow start to come into terms with it and thus the industry is still in its early years according to leading Indian remanufacturers.

Keeping environmental and cost factors in mind, people started cartridge remanufacturing in a big way. The Indian remanufacturing industry continues played a marginal role and even after more than a decade of existence it is organized and find out effective strategies by Shalimar Cartridges, the Indian cartridge remanufacturing industry, MP Colour Prints Ltd. The marginal role played by the Indian remanufacturing industry is primarily due to lack of organization and negative end user perceptions. According to estimates, genuine compatibles and remanufactured products account for less than 10 percent of the total inkjet cartridges and laser toners sold. Refilled and remanufactured products constitute just 20 percent of printer consumables. Of these 8 out of 10 cartridges are being refilled. Black Magic Toners is one of the leading domestic remanufactured cartridge makers in India.

India has been more into refilling than remanufacturing. The cost is a major deciding factor, as people are unwilling to pay 75 percent of the price of the OEM product Indian Cartridge Recyclers and Remanufactures Association (ICRRA). This is trying to bring all relevant people to a single platform. It's aiming to impart awareness about the advantage and necessity of remanufactured cartridges but the association has yet to attain national importance. In a country with a population of more than one billion and a booming economy, it has attracted number of industry remanufacturers which convinced them to expand its base by incorporating more people and increasing the number of members.

### 3. REMANUFACTURABLE PRODUCT PROFILES

Table I. List of Remanufactured Products

Sr. No.	Product	Sr. No.	Product	Sr. No.	Product
A)	Household appliance	D)	Office material	G)	Others
1.	Washing machine	12.	Photocopier	24.	Musical Instruments
2.	Refrigerator	13.	Telephone	25.	Tyre
3.	Television	14.	Mobile	26.	Aircraft Parts
B)	Medical Equipment	15.	Phone	27.	Compressors
4.	Medical Equipment(X ray)	16.	Fax	28.	Robots
5.	Hospital Equipment	17.	Printer	29.	Bakery Equipment
C)	Car component	18.	Toner Cartridges	30.	Electrical Apparatus
6.	Vehicle parts	19.	Office Furniture	31.	Waste plastic
7.	Engine	E)	Computer Material	32.	Gaming Machines

8.	Alternator	F)	Machine
9.	Starter	20.	Textile machine
10.	Gear box	21.	Floor cleaning machine
11.	Universal joint	22.	Tractor
		23.	Pallet truck steam machine

When designing a product, the question of its end of life is raised and a remanufacturing approach has to be considered. So, we have proposed to develop methods and tools to evaluate whether the remanufacturing strategy is feasible. To construct this expertise, we have characterized what is a remanufacturable product. Then we have identified what the most relevant criteria to establish categorizations of products that are currently successfully remanufactured. To characterize a 'remanufacturable product' a sample of existing products successfully remanufactured are studied. (See Table I).Based on the previous discussion, most of the current applied remanufacturing systems focus on the economic profit by disassembling the returned products and reusing their parts for the purpose of service or marketing their products. Economic profit is only a part of the advantages that result from a remanufacturing system over other implemented systems. It is suggested that remanufacturing process model of product take back system will be introduced. It emphasizes integrating the environmental, economic and social dimensions of sustainability as an approach industrial sustainability achievement.

### 4. PROBLEM DESCRIPTION

The problem considered in this paper is related to manufacturing and remanufacturing product capacities. Before discussing details of the optimized solution related to manufacturing and remanufacturing product capacities. We describe the manufacturing and remanufacturing policy for the main scenario provide an approximation of the probability distribution used to determine the amount and rate of collected products present an algorithm for calculating the optimal manufacturing and remanufacturing capacities in this section.

#### 4.1 Analysis of manufacturing and remanufacturing product capacities

We consider that produces and sells a single product. The product can be returned to the industry once it has completed its useful life. The collected units are remanufactured and resold as new or disposed. This method has the following important features:

1. The time scope is discrete with periods of equal length.
2. The industry makes the decisions at the end of each period.
3. The demand D (units/period) is known and same in

each period.

- It is a just in time production system (JIT), so there should be no inventories.

The system has unknown and limited manufacturing and remanufacturing capacities namely 'X' and 'Y' units per period which will be calculated by minimizing costs. It is assumed that a) X and Y do not change over time. b) There is sufficient capacity to supply the demand, i.e.  $X + Y \geq D$ . c) If  $X \leq D$  &  $Y \leq D$ . Because never will be used capacities is greater than D in order to supply the demand. 'Cpf' is the production fixed cost. 'Crf' is the remanufacturing fixed cost. The production costs of the production system and the remanufacturing system are composed of fixed costs 'Cpf' and 'Crf' (which depend on the installed capacity and do not vary provided that the production capacity remains constant) and variable costs (per unit of output) cpv and crv. It is assumed that Cpf is an increasing function of X and Crf is an increasing function of Y.

The return of the product has the following characteristics.

- The end of usage of the product occurs between periods T1 and T2 after it is sold. 'pi' is the probability that the end of usage of the product occurs 1 period after it is sold. ( $i = T1 \dots T2$ ).
- 'r' is the probability of an end of usage product being returned and collected. Therefore, the probability that a unit sold in period t will be collected in period t+i is  $r \cdot pi$ .
- There is only one quality type for collected products. Therefore, each unit of collected product undergoes the same remanufacturing process.
- A remanufactured product has the same usage expectancy and return quality as a manufactured product.
- Each collected unit has a cost of crv.
- The cost of disposing of collected units is zero.

If we assume that there is no product recovery. The optimal inventory policy is such that the inventory costs are zero. Therefore, the costs for each period would be  $Cpf(D) + cpv \cdot D$ . When products are collected and remanufactured the company can sell units from either the original production system or the remanufacturing system.

Since there is an inherent degree of uncertainty in the availability of returns. We analyze a scenario, there is a supplier with sufficient capacity that enables the industry meet all demand with a cost per unit of cs, it is assumed that cs is greater than cpv and crv.

#### 4.2 Manufacturing and remanufacturing product capacities

The optimal manufacturing and remanufacturing capacities are calculated by minimizing the expected value of the cost in each period according to the following process. First, for each pair of manufacturing and remanufacturing capacities we calculate the minimum expected cost by a system with these capacities (to do this we must determine

for each pair of capacity values the optimal manufacturing and remanufacturing policy and calculate the expected value of the cost associated with the optimal policy). Next, in order to determine the optimal capacities we choose the capacities associated with the minimum of the expected costs calculated in the previous step.

The costs by the industry during each period depend on the quantity of goods manufactured, collected and remanufactured by the industry and on the goods purchased from the supplier. These amounts will be limited by the installed manufacturing and remanufacturing capacities and by the quantity of collected product which is a random value.

##### 4.2.1 Manufacturing and remanufacturing policy

The manufacturing and remanufacturing policy is obtained by solving the mathematical calculations shown below the manufacturing and remanufacturing capacities X and Y. The units of product collected during each period 'd' [Minimum]  $c = Cp f(X) + Cr f(Y) + cpv \cdot x + crv \cdot y + cs \cdot (D - x - y) + crc \cdot d$

The conditions are as a)  $x + y \leq D$ , b)  $x \leq X$ , c)  $y \leq \min\{Y, d\}$ ,  $x, y \geq 0$

Where 'x' and 'y' are the quantities of product to manufacture and remanufacture respectively.

The optimal solution depends on the values of d, X, Y & D and also on the relation between crv and cpv.

- When  $crv < cpv$  there are three cases.
  - If  $d < D - X$ , The company meets total demand using the alternative supplier. The optimal values and costs are:  $x=X, y=d$   
Now,  $c = Cp f(X) + Cr f(Y) + (cpv - cs) \cdot X + cs \cdot D + (crv - cs + crc) \cdot d$
  - If  $D - X \leq d \leq Y$ , The optimal values and costs incurred are  $x=D-d, y=d$   
Now,  $c = Cp f(X) + Cr f(Y) + cpv \cdot D + (crv - cpv + crc) \cdot d$
  - If  $d \geq Y$ , The returns are higher than Y. The optimal values are  $x = D-Y, y=Y$   
Now,  $c = Cp f(X) + Cr f(Y) + cpv \cdot D + (crv - cpv) \cdot Y + crc \cdot d$
- When  $crv \geq cpv$  we have two cases:
  - If  $d < D - X$ . The optimal values and costs are  $x=X, y=d$   
Now,  $c = Cp f(X) + Cr f(Y) + (cpv - cs) \cdot X + cs \cdot D + (crv - cs + crc) \cdot d$
  - $D - X \leq d$ , the optimal values and cost are  $x=X, y=D-X$   
Now,  $c = Cp f(X) + Cr f(Y) + (cpv - crv) \cdot X + crv \cdot D + crc \cdot d$

##### 4.2.2 Probability distribution of collected product quantity

The quantity of product collected during a given period from the quantity of product sold in the nth previous period. The Binomial distribution  $f(k) = n Ck pk(1-p)^{n-k}$ , [ Bin(D, r·pn) ]

Where, P<sub>n</sub> - Probability that the product will come to the end of its useful life during the nth period after its sale. r - Probability that the product will be returned. D - Quantity of product sold during the nth previous period.

The quantity of product collected during a given period is equal to the sum of the collected products from each of the previous periods. The probability value will be d is denoted by p(d).

The total expected value of combined manufactured and remanufactured products from the industry is called P<sub>mr</sub> and P<sub>mr</sub> is calculated by,

$$P_{mr} = D - \sum_{d=0}^{D-X} (D - X - d)p(d)$$

When r·P<sub>n</sub> is sufficiently small. We can approximate the probability distribution of collects from a given period to a Poisson distribution (f(k) = λke<sup>-λ</sup> / k!) with parameter D, r, P<sub>n</sub>. Therefore, the total amount of product units collected during a given period follows a Poisson distribution λ with parameter r·D (since the sum of P<sub>n</sub> is '1'). In this case we can

$$P(d) = \frac{e^{-rD}(rD)^d}{d!}$$

obtain

We have discussed the optimal manufacturing and remanufacturing policy in the above section. We can determine the expected value of cost function by using the following relations.

$$E[C_e(d)] = \sum_{d=0}^{\infty} c(d)p(d)$$

Both the cases are the non-linear problems.

Case I - When Cr ≤ Cpf the equation becomes,

$$E[C_e(d)] = C_{pf}(X) + C_{rf}(Y) + \sum_{d=0}^{D-X} [(C_{pf} - C_s)X + C_sD + (C_{rf} - C_s + C_{rc})d]p(d) + \sum_{d=D-X}^Y [C_{pf}D + (C_{rf} - C_{pf} + C_{rc})d]p(d) + \sum_{d=Y}^{\infty} [C_{pf}D + (C_{rf} - C_{pf})Y + C_{rc}d]p(d)$$

By rearranging the terms the equation becomes,

$$E[C_e(d)] = C_{pf}D + C_{rc}E(d) + C_{pf}(X) + (C_s - C_{pf}) \sum_{d=0}^{D-X} (D - X - d)p(d) + C_{rf}(Y) - (C_{pf} - C_{rf})[Y - \sum_{d=0}^Y (Y - d)p(d)]$$

Where, E(d) is the expected value of d = r·D.

We can define the following functions for determining the optimal solution

$$f_1(X) = C_{pf}(X) + (C_{sf} - C_{pf}) \sum_{d=0}^{D-X} (D - X - d)p(d)$$

$$f_2(Y) = C_{rf}(Y) - (C_{pf} - C_{rf})[Y - \sum_{d=0}^Y (Y - d)p(d)]$$

$$f(X, Y) = C_{pD} + C_{rc}rD + f_1(X) + f_2(Y)$$

Therefore, the desired values of X and Y are the solution of the following problem

[Minimum] f(X, Y)

Where, X ≤ D, Y ≤ D, X+Y ≥ D, X, Y ≥ 0.

Case II - When Crf ≥ Cpf The equation becomes,

$$f_1(X) = C_{pf}(X) + (C_{pf} - C_{rf})X + (C_s - C_{rf}) \sum_{d=0}^{D-X} (D - X - d)p(d)$$

$$f_2(Y) = C_{rf}(Y)$$

$$f(X, Y) = C_{rf}D + C_{rc}rD + f_1(X) + f_2(Y)$$

With the help above approximation, we have determined the probability distribution which is used to find the amount and rate of collected products. An optimization based procedure is applied to solve the manufacturing and remanufacturing capacities. We have developed a simple solution to estimate cost of manufacturing and remanufacturing products.

## 5. CONCLUSION

This paper has described the nature of remanufacturing and the principle of remanufacturing that affect its successful implementation. These are mainly technical, business and economic in nature. However, the type of organization has a significant impact upon the ability to remanufacturing. Remanufacturing and life cost are impacted by expenses related to disassembly, reassembly and probability of process failure. We would like to suggest that industry should work by operating in a cyclical manner and moving forward not just into materials recovery, but also into a value added recovery that recaptures most of the surrounded value that entered a product during its initial manufacture. As shown in this paper, the remanufacturing process of a product take back system, movement towards a zero waste system and sustainability is achieved. This paper highlights some of the most visible business and economic related to affect remanufacturing. The important factors required to establish the remanufacturing industries are solid waste management, environmental condition, high skilled workers, economical condition, reduced price, investment and motivations.

The products take back system in the remanufacturing using powerful tools, which is a less than the current manufacturing process. Ultimately, by product take back system the overall resource demand and environmental impact would be diminished and industrial practice would move toward industrial sustainability. The remanufacturing process includes the consumer buys as well the product's service, but at the end of life of the product it is returned to the producer and the products embedded value is recovered. Remanufacturing is feasible solution for complex assemblies. Products designed through remanufacturing perspective will have much longer lives and will be giving economic advantage for manufacturers. We have described the manufacturing and remanufacturing policy for the main scenario provide an approximation of the probability



distribution used to determine the amount and rate of collected products present an algorithm for calculating the optimal manufacturing and remanufacturing capacities. An optimization based procedure is applied to solve the manufacturing and remanufacturing capacities.

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