ECONOMIC ANALYSIS AND GTA MODELLING FOR JUSTIFICATION OF REMANUFACTURING

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CERTIFICATE

This is to certify that the report entitled **“Economic Analysis and GTA modelling for justification of Remanufacturing”** submitted by **Srishti Sabharwal** (Roll No.:12/PRD/2010) in partial fulfillment for the award of Masters of Technology in Production Engineering from Delhi Technological University, is a record of bonafide project work carried out by her under my supervision and guidance.

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ABSTRACT

Remanufacturing is the process of product recovery in which old products at the end of their lives are procured from the customers and transformed into a condition and functionality, which is as good as that of a new product. Designing of a system for remanufacturing requires consideration of several factors like design for disassembly, various costs involved, quality issues etc. Developing a product recovery system and modelling a reverse logistic network are the initial steps in determining the suitability of remanufacturing for any system. To study the cost effectiveness of remanufacturing, various techniques have been used like, mixed integer programming, quantitative models and algorithms. Such kinds of studies include various costs like procurement, inventory, refurbishing, assembly/disassembly, transportation etc. However, the economy of remanufacturing not only depends upon the above, but also on the capacity of remanufacturing and also whether there is demand for remanufactured products. The main aim of this project has been to understand the various reverse logistic issues of remanufacturing, to study the market forces and decision making attributes. Based on these, different analytical tools have been applied for economic analysis of remanufacturing and to decide whether the company should go for remanufacturing or not.

This thesis comprises of seven chapters. The first chapter introduces the concept of remanufacturing, discusses the various product recovery operations and explains the basics of this technique. The next chapter gives an insight into the significant literary works on remanufacturing and the various tools used for the analysis of remanufacturing system. Chapter 3 discussed the recordings of a survey conducted to understand the customer perception about remanufactured products in order to determine the parameters on which they judge a product and to recommend improvements in the same. The observations on their preferences were analysed and certain strategies were proposed to increase the market for such products. Chapter 4 explains a decision support system (DSS) developed using C++ programming to determine the implementation of remanufacturing in a system. The

DSS is also used to show the effect of various parameters on the overall cost of remanufacturing, thus helping in weighing their criticality relative to each other. Chapter 5 is dedicated to applying another mathematical tool called the graph theoretic approach (GTA) to compute the range cost effectiveness index for remanufacturing. Using this technique a highly accurate model has been developed by inclusion of both qualitative and quantitative parameters. Chapter 6 consists of a case study of an inkjet printer to show the cost advantage of remanufacturing for the product .Chapter 7 states the results and conclusions drawn from this study.

Keywords: Remanufacturing, reverse logistics, economic analysis, decision support system, graph theoretic approach, cost effectiveness index.

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CHAPTER 1

INTRODUCTION

Remanufacturing is defined as the process of converting used, returned products into ‘like new’ components. It involves complete disassembly of the used product and recovering its various parts to bring them to functionality as good as a new part or sometimes even better. The process of remanufacturing captured the western markets right in the 1990’s primarily due to the stringent environmental laws being practiced there. Some of these included the European Union’s directive on Waste from Electrical and Electronic Equipment (WEEE), Universal Waste Rule (1995) of North America. and Japan’s Extended Producer Responsibility (EPR) (Thierry et al., 1995; Fleischmann et al., 1997; Dekker et al., 2000; Doppelt and Nelson, 2001; Guide and Wassenhove, 2003). Apart from these laws the green consciousness among the customers also invoked a feeling of take back responsibility among the manufacturers in the west. The Indian market, however, is still not so well versed with this idea of remanufacturing. Lack of awareness and consciousness among customers and inadequate facilities at the industrial end seem to be the primary reasons behind this. However, due to its tremendous economic benefit, like high profit margins with minimum resource utilization, the remanufacturing genre is gradually seeping into the Indian corporate sector as well. Some of the industries and name-brand companies that support recoverable manufacturing include: diesel engines (Caterpillar), disposal cameras (Kodak), copiers (Xerox and Canon), furniture (Miller SQA) and cell phones (Motorola) (Jayaraman et al, 2008). Other products include printers, machine tools and even computers.

1.1 Product recovery and reverse supply chain

Closed-loop supply-chain channels are distribution systems that include activities supporting both the forward flow of goods from the manufacturer to the consumer as well as the reverse flow from the consumer to the manufacturer. The forward channel is relatively straightforward and well understood. The reverse supply chain is difficult to implement owing to the complexity and uncertainty of events associated with it.

Reverse logistics involve managing the receipt, handling and disposition of returned merchandise. That is, it is a supply chain starting from the customer and ultimately reaching the original equipment manufacturer (OEM). The reverse logistics functions are comprised of a set of unique, complicated and time-sensitive tasks (Dowlatshahi, 2005). The first step of a reverse logistic chain is the collection of old discarded products from the customers and storing them in inventories for procured parts called collection centres. These old discarded products can be subjected to three disposition options: reuse, remanufacture or recycle. In the reuse option, the product can be resold without any further processing. This would be the case if a product was returned because the consumers changed their mind about their purchases and the product was in good condition. In the remanufacturing option, the product enters the reverse channel at the fabrication stage where it is disassembled, remanufactured, and reassembled to flow back through the forward flow channel as a remanufactured product. This option is exercised if goods with defects are returned or if goods which have run their useful lives can be remanufactured. In recycling, the last disposition option, the product enters the reverse value channel in the raw-material procurement stage where it is used with other raw materials to produce new products. In recycling, the identity and functionality of products and components is lost (Jayaraman et al., 1999; Guide et al., 2000).

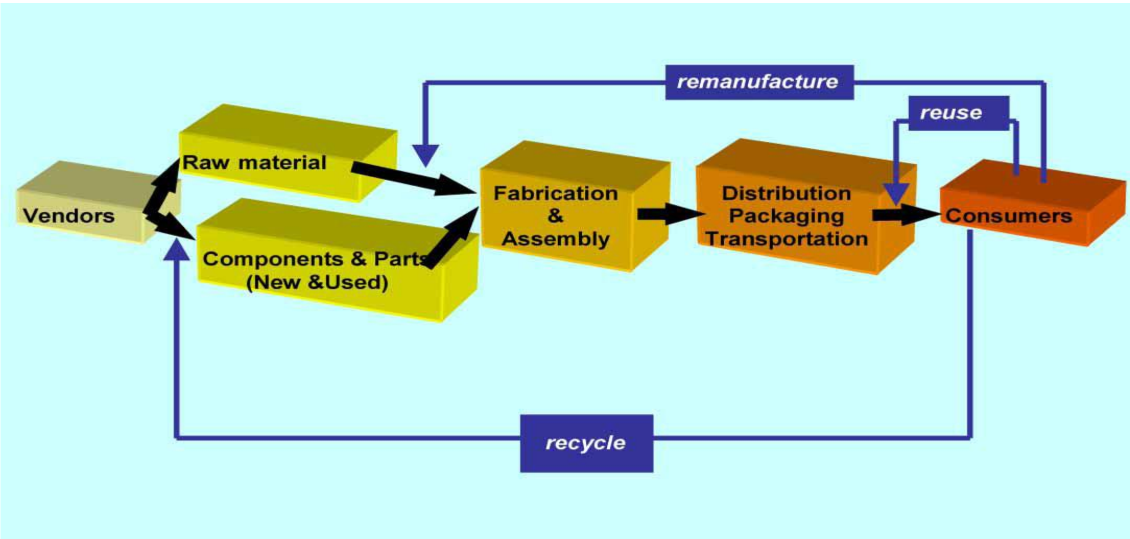


Figure1.1. Various disposition policies for product return (Jayaraman et al, 2008).

Extending the value chain to include recovery operations, such as recycling, reuse, and remanufacturing adds an additional level of complexity to value chain design and a new set of strategic and operational issues. These issues arise from two fundamental problems: uncertainty associated with the recovery and replacement process with regards to quantity, timing and quality of returns; and the process associated with collection and transportation of used products. Table 1.1 shows the key differences between reverse logistics and forward supply chains across different factors such as environmental, design, logistics and forecasting.

Factors	**Reverse logistics recoverable value chains**	**Traditional (forward) value chains**
Environmental focus	Focus is to prevent post production waste from occurring.	Focus is on pre-production and pollution prevention / remediation.
Design	Remanufactured products have to be designed for easy disassembly. While this may add some cost up-front, the payoff will occur during product's second, third or fourth life cycles.	Focus is on environmentally conscious design, fabrication and assembly.
Low Fashion	Remanufacturing is mostly used in heavy industrial applications where customers care more about performance rather than looks.	Novelty is a key marketing issue. While performance is most definitely an order winner, it pays to be fashionable in most industries.
Logistics	Forward and reverse flows. Uncertainty in timing and quantity of returns.	Focus on open forward flow. No need to handle returns. Demand Driven flows.
Forecasting	Need to forecast both the availability of core and demand for end products.	No need for parts forecasting. Focus on Forecasting end products only.

Table 1.1. Key differences between reverse logistics and forward supply chain (Guide et al, 2000).

During the nascent years of the study of the field of remanufacturing, the benefits were largely seen as cost driven; however, with growing understanding about the environmental and waste reduction aspects in customers, the process of adopting remanufacturing is being driven by demand and consumer preferences. While markets often prefer remanufactured products owing to the recycled components in the products, increasingly, resellers have been finding that certain niche (secondary) markets may also prefer remanufactured products because the price per unit is lower.

1.2 Reverse logistics of remanufacturing

Designing the logistics of a reverse supply chain requires planning and control of aspects like procurement, production and inventory. The primary issue in developing a product recovery network is the redesign of the system and incorporation of product collection and recovery centers and warehouses. Also, the capacity of the remanufacturing system is built in accordance with the demand for such products. Other fundamental factors which can affect the effective implementation of remanufacturing are the quantity, quality and frequency of return of the old products; availability of market for such products and feasibility of collection and transportation of returns to the remanufacturing centre. If the initial cost of setting up the desired infrastructure is catered to, then remanufacturing is one of the most profitable and ecologically beneficial techniques of manufacturing.

In the process of remanufacturing, the used products are procured from the customers at the end of their life cycles. They are taken to disassembly site where they are completely dismantled into their constituent parts. Each of these parts is then inspected to determine their feasibility for recovery. Some items which cannot be recovered are sent to scrap dealers for recycling. The remaining parts are cleaned and refurbished, damaged parts are repaired or sometimes even replaced. Technological upgradation of some parts or modules is also possible during the remanufacturing process. Finally, these recovered parts are reassembled and final testing is done to check the functionality of the remanufactured product. It should be in conformance with the original product specifications to enable them to compete with the new products in the market. On meeting these criteria they are then re-dispensed into the market. The product flow cycle in remanufacturing is depicted in Fig 1.2 on the next page.

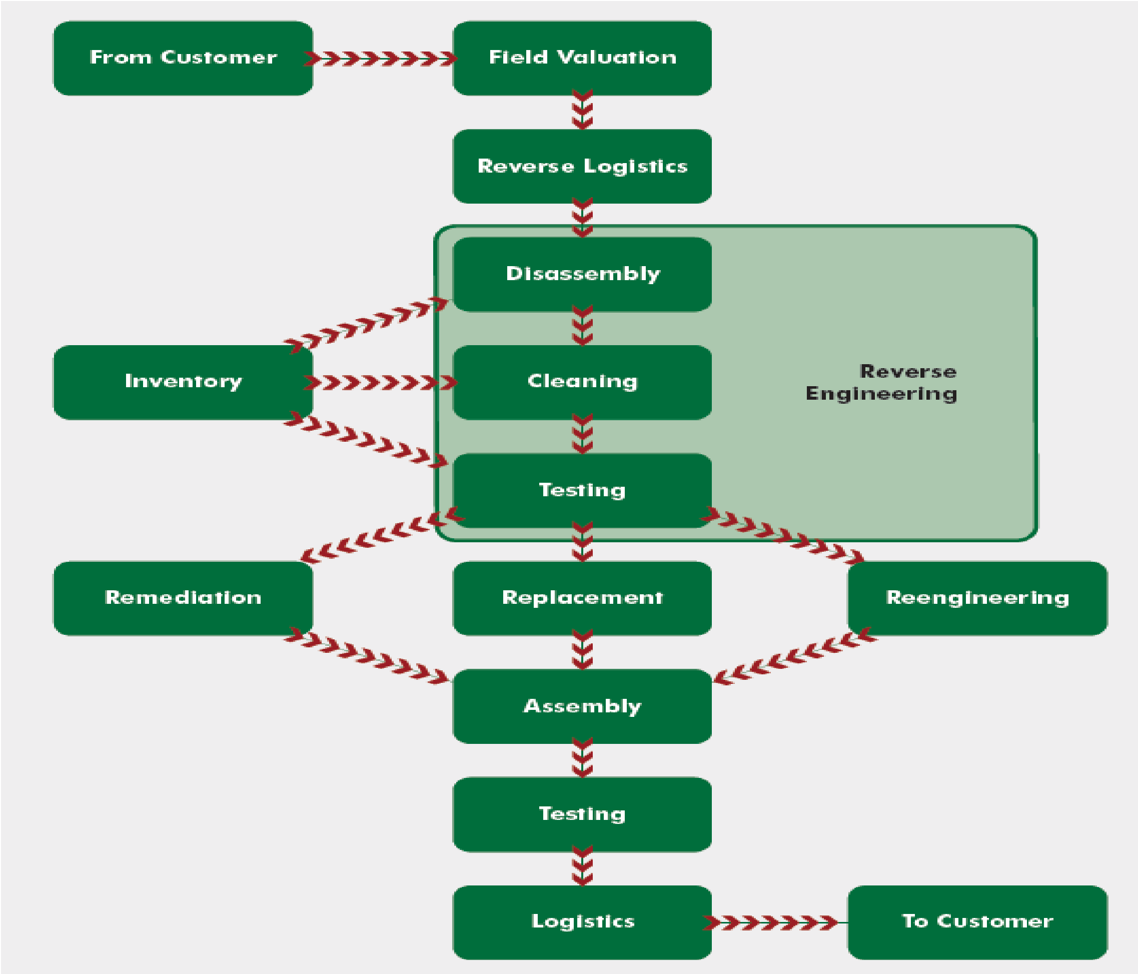


Figure 1.2 .Flow diagram showing product recovery network in remanufacturing (Parker et al, 2007).

Efficient management of all the above activities offers opportunities in terms of cost and lead time reductions and improved quality, the latter by employing a unanimous view on quality at the source. Competition today implies that quality, time and cost must be improved successively in order to stay profitable. This is accentuated in industries with high product introduction rates and large volumes over short product life cycles. A sense of strategic flexibility must also be incorporated in such business environments. Of all the issues, the most important issue for starting any system is its economy. Despite the high initial investment required for building up the infrastructure and equipment for remanufacturing, any manufacturer will go for this only if eventually, there is a considerable cost saving in remanufacturing products than in manufacturing new ones.

To study the cost effectiveness of remanufacturing, various techniques have been used like, mixed integer programming, quantitative models and algorithms. These studies incorporate various costs like procurement, inventory, refurbishing, assembly/disassembly, transportation etc in the analysis. However, the economy of remanufacturing not only depends upon the above, but also on the capacity of remanufacturing and also whether there is demand for remanufactured products. To device an appropriate model for determining the cost effectiveness of remanufacturing, the first step is to list out and evaluate the various parameters affecting the remanufacturing cost. Based on these parameters, the model is then formulated. The above approach has been followed in this study for assessing the economic viability of remanufacturing for different products.

1.3 Objectives of the study

The main objective of this study is to analyze the concept of remanufacturing from the economic point of view.

i. Firstly, a survey was conducted to gain perception of the customers about remanufactured products in different product categories. They were asked questions related to their preferences for remanufactured products, their desired attributes in such a product and the cost they are willing to pay for it. Based on it, an analysis was done.
ii. Next, a decision support system (DSS) was developed using C++ programming. The program was based on quantitative parameters prevalent at different stages of remanufacturing and affecting the overall cost. It can be used to decide whether a product should be remanufactured or not based on cost criteria. This DSS was then modified to determine the effect of different parameters on the overall cost of remanufacturing and their optimum values have been obtained.
iii. To take into account the qualitative parameters as well in the cost analysis, a graph theoretic approach (GTA) was used to calculate the cost effectiveness index for remanufacturing. This technique helped in obtaining a more precise model, as it is based on both quantitative and qualitative parameters, their interdependence and their impacts on the overall judgement criteria.
iv. Finally, a small case study was conducted on remanufacturing of inkjet printers. In this the price of remanufacturing a printer was calculated. It was then compared to the price of a new printer and relevant conclusions were drawn.

CHAPTER 2
LITERATURE REVIEW

Although remanufacturing is an emerging trend in the manufacturing sector and is a comparatively new technique, significant literature is present to give valuable information on its various facets. Different researchers have carried out case studies or developed models to study issues like procurement uncertainty, inventory, environmental issues, marketing strategies, benefits, barriers and strategic factors. Some of the eminent works are stated below.

2.1 Reverse logistic issues in remanufacturing

Lund and Skeels (1983) pointed the following issues for implementation of remanufacturing: (1) product selection, (2) marketing strategy, (3) remanufacturing technology, (4) financial aspects, (5) organizational factors, and (6) legal considerations. Kroon at al. (1995) discussed the reverse logistics of returnable containers. Carter and Ellram (1998) presented a literature review on reverse logistics and suggested some critical factors in the reverse logistics process. Stock (1998) suggested methods of development and implementation of reverse logistics programs. Fleishmann et al. (2000) characterized the logistic network for product recovery.

De Toni and Tonchia (2001) classified the performance measures broadly into two categories– cost performances and non – cost performances. Former included costs to purchase, manufacture, distribute, cost of waste, returns, obsolescence and productivity. The latter comprised of measures like time, quality and flexibility. Meade and Sarkis (2002) presented a framework to manage product returns in reverse logistics by focussing on product ownership data, average life cycle of products, past sales, forecasted demand and likely impact of environmental policy measures. Robotis et al. (2004) illustrated the use of remanufacturing as a tool to serve secondary markets. The options of reuse and remanufacturing were weighed and analysed for a reseller.

S.Dowlatshahi (2005) put forward a strategic framework for design and implementation of remanufacturing in a reverse logistics environment. He has discussed the five strategic factors involved in the process namely- cost, quality, customer service, environmental concern and political / legal concern. Ijomah et al. (2007) developed guidelines for robust design for remanufacturing and to enhance product remanufacturability. Fitness for use, design for disassembly/ remanufacturing were some of the factors. They also suggested the incentives for remanufacturing (like environmental concerns, green credentials, less resource utilization) and the technical and non technical barriers for remanufacturing (lack of technology, poor disassemblability, use of less durable materials, poor customer perception, throwaway culture, low demand etc.). Mutha et al. (2009) gave a paper on strategic network design for reverse logistics and remanufacturing using new and old product modules. They put forward the idea of allowing only a portion of capacity in warehouses, RPC's and factories for reverse logistics. By segregating the capacities, companies would have flexibility to produce new or remanufactured products as per the demand.

Atasu et al. (2008) analyzed remanufacturing as an important marketing strategy. They provided an alternative and somewhat complementary approach that considers demand-related issues, such as the existence of green segments, original equipment manufacturer competition, and product life-cycle effects on the profitability of remanufacturing. Jayaraman et al. (2008) discussed the role of information technology in the reverse supply chain.

2.2 Remanufacturing - models and case studies

Bayindir et al. (2003) proposed a model to evaluate inventory costs in a remanufacturing environment. They investigated the possible benefits of remanufacturing in inventory-related costs. Jayaraman et al. (2003) suggested models and solutions for the design of reverse distribution networks. Beamon and Fernandes (2004) developed a model to decide how many warehouses and collection centres should be open for storing procured products, which warehouses should have sorting capabilities and how much material should be transported between each pair of sites. The multi-period integer programming model used the present worth method to jointly analyze investment and operational costs involved.

Kim et al. (2006) proposed a mathematical model using mixed integer programming for maximizing the total cost savings in remanufacturing by optimally deciding the quantity of parts to be processed at the remanufacturing facilities and the number of parts to be purchased from subcontractor. The sensitivity analysis to determine the effect of capacity of disassembly site on the remanufacturing cost has also been done. Agarwal et al. (2006) suggested an Analytical Network Process (ANP) based approach for modeling of remanufacturing system. Pishvaee et al. (2009) gave a stochastic optimization model for integrated forward/reverse logistics network design.

Mukherjee and Mondal (2009) gave analysis of issues relating to remanufacturing technology by discussing the case of an Indian photocopier company. Nenes et al. (2010) presented a case study to discuss the inventory control policies for inspection and remanufacturing of returns. Ghorushi et al. (2011) presented a detailed modeling framework developed for the cost benefit analysis of the take back process. Matsumoto and Umeda (2011) illustrated the remanufacturing practices in Japan. Their paper consisted of significant literature review of the previous studies and case studies on remanufacturing of products like photocopier machines, automobile parts, single use cameras and printer cartridges. Rahman and Subramanian (2011) identified important factors for recycling of computers. Availability of resource, coordination and integration of recycling tasks and the volume and quality of recyclable materials, were considered as critical for computer recycling operations. Also, factors such as government legislation, incentive and customer demand were found to be the major drivers.

2.3 Graph theoretic approach (GTA)

This is an important mathematical technique which uses digraphs and matrices for comparative and cumulative analysis of parameters affecting a system. The graph theoretic approach finds application in many fields like physics, mathematics, engineering, operations research etc. In this study, it has been used for calculating the cost effectiveness index of remanufacturing system. To understand the graph theoretic approach and its applications, some of the literary works related to it have been listed below.

Gandhi and Agrawal (1994) used the graph theoretic approach for system wear evaluation and analysis using attributes like micro and macro geometry, environmental conditions etc. Wani and Gandhi (1999) used the graph theoretic approach for development of maintainability index for a manufacturing system. Gandhi and Agrawal (2002) used the digraph and matrix approach for the failure mode and effect analysis (FMEA) of hydraulic and mechanical systems. Jangra et al. (2011) used GTA for the performance evaluation of carbide compacting die manufactured by wire EDM by evaluating factors like work material, machine tool, tool electrode, geometry of die and machining operation.

Al- Hakim et al. (2000) have used this approach to represent a product and define the relationships between its components. The approach presented in the paper provided a more refined visualisation of the energy flow and is applicable to numerous designs including sliding gears, clutches, overrunning clutches and flywheels, amongst others.Venkata Rao and Padmanaban (2006) used this for comparison and selection of industrial robots.

Upadhyay et al. (2007) applied the graph theory and matrix algebra for structural modelling and analysis of intelligent mobile learning environment. They used GTA as a mathematical analytical tool to capture the notion of structural model as the basis to analyze characteristics of performance, quality and reliability of software architecture. Goyal et al. (2010) combined the GTA with fuzzy theory for the comparison and selection of the most suitable advanced manufacturing system from a set of alternatives based on several parameters like costs, quality and flexibility of the system. Pishvaee et al. (2010) gave a graph theoretic algorithm for supply chain network design with direct and indirect shipment. Raj et al. (2010) developed a digraph and matrix model for studying the intensity of barriers in the implementation of FMS. Yadav et al. (2010) applied the digraph and matrix approach for selection of a power plant by taking into account its operational and economic parameters

The above literatures have served as useful guidelines and knowledge base for the further course of work in this project.

CHAPTER 3
CUSTOMER PERCEPTION ON REMANUFACTURING

With growing emphasis on complete customer satisfaction, the customer has become the king for any business. The products are designed, developed and marketed keeping in mind the needs of the customers. Before introducing any new product into the market, it is imperative to seek the customer inputs. Even after the introduction of a product, regular market surveys are conducted by the company to grasp the changing trends in the customer outlook. Remanufactured products are also comparatively new elements in the manufacturing sector. While the use of second hand products has been prevalent for decades, the essence of remanufactured goods is still to be captured by the Indian markets. Hence, before adopting this technique, it is important for any manufacturer to gain an insight into the customer perception on remanufactured products.

3.1 The survey

To achieve the above objective, a survey was conducted to know the perception and awareness of the common man on the concept of remanufacturing and remanufactured products. The aim of this survey was to provide guidelines to the remanufacturers about the needs and demands of the customers and their outlook towards such products. To carry out the survey, a questionnaire was prepared on remanufactured products. The questionnaire comprised of a set of questions for remanufactured products of different product categories. The product categories were based on the monetary value, the strategic value and place of use of the product. Five products were selected namely printer cartridge, electrical home appliances, personal computer, automobile/automobile parts and industrial machinery/medical equipment. The different categories in which these products lie based on the criteria mentioned above has been shown as a grid in Table 3.1 on the following page. The grid will help in understanding the overall product domain and will later be used for correlating the product attributes with the people’s judgement and the inferences drawn from the survey. The symbols used in the grid stand for the following: L- Low, M – Medium, H- High, D- Domestic, I- industrial.

Product	Monetary value	Strategic importance	Place of use
Printer cartridge	L	L	D/I
Electrical home appliances	L	L	D
Personal computer	M	L	D/I
Automobile/auto parts	H	H	D
Industrial machinery/ medical equipment	H	H	I

Table 3.1 Grid showing different product categories

The questions were framed keeping in mind the following main objectives:

- To know the preferences of the people for remanufactured products under different product categories.
- To determine the attributes which people would look for in the remanufactured products in order of importance.
- To gain information about the maximum price the people are willing to pay for remanufactured products.

Before handing out the questionnaire, people were briefed about the concept of remanufacturing, it claims of equivalent quality, warranty and significantly lower price. The people chosen for the survey were randomly selected from different genres and sectors. They comprised of college faculty members, people with industrial experience doctors, M.Tech students, management students etc. having mixed knowledge and preferences. Once the survey was conducted, an indepth analysis of the observations was done to arrive at relevant conclusions.

3.2 Observations from the survey

The observations have been made product wise as well as criteria wise to get a holistic view of the scenario at the customer end. First, talking about the preferences of the customers for remanufactured products .The observations regarding the same, for the five products have been depicted in the column chart in Fig. 3.1.

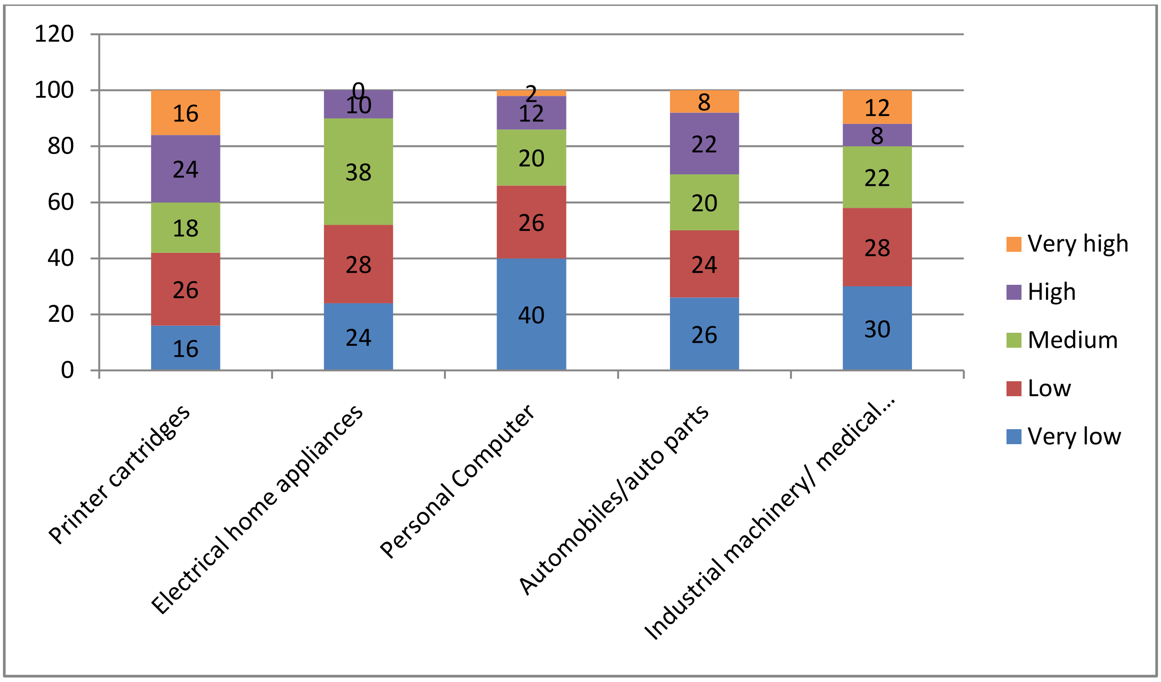


Figure 3.1 . Percentage preferences of people for different categories of remanufactured products.

It can be observed that for all the products majority customers have low to very low preference. Only in the case of printer cartridges the percentage of people having high to very high preference (40 % combined) is comparative to those having low to very low preference (42% combined). While for electrical home appliance majority people (about 38 %) have medium preference for remanufactured products. For other products like PC, automobiles and industrial machinery people have quite low preferences.

Next talking about the characteristics desired by people if they go for a remanufactured product in order of importance or criticality. A set of six attributes were given to them and they were asked to rate them based on its importance for them in a particular product. The most sought after trait was to be rated 6, the least be rated 1 and likewise. The attributes were:

1. Quality / Functionality of the product
2. Cost / Cost saving as compared to a new product
3. Aesthetics/ Looks of the product
4. Reputation / Brand value of the remanufacturer
5. Green credentials / Environment friendliness of the product
6. Feedback from peers about such products

These factors were chosen because they serve as the main deciding criteria for any product selection by a customer. From the survey, it was observed that for all the product categories, the quality of the product and the cost/ cost saving were the paramount criteria for judgement and selection. Next was the reputation/ brand value of the remanufacturer. Least important were feedback from peers, aesthetics of the product and environmental friendliness (in decreasing order respectively). The cumulative rating of the people for different parameters for each of the five products individually is given below in the form of pie charts.

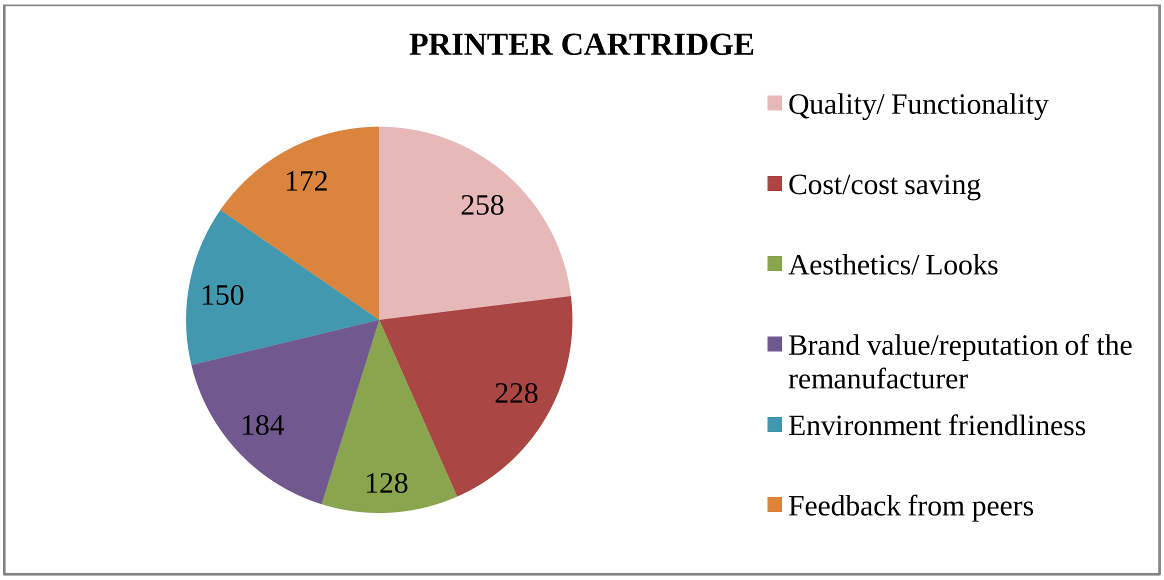


Figure 3.2. Total scores of various parameters for printer cartridge.

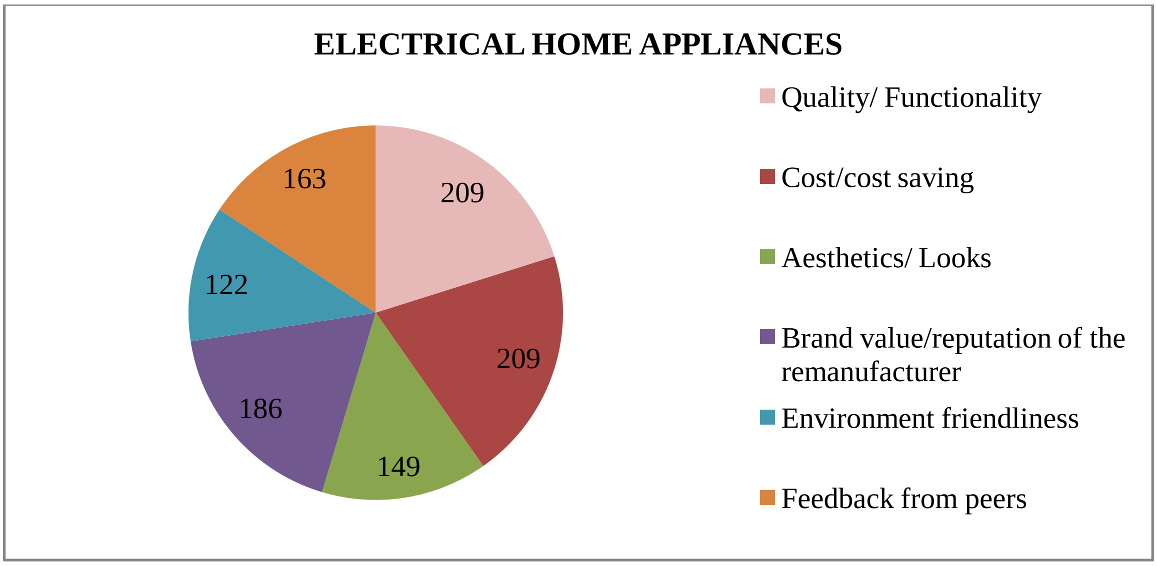


Figure 3.3. Total scores of various parameters for electrical home appliances.

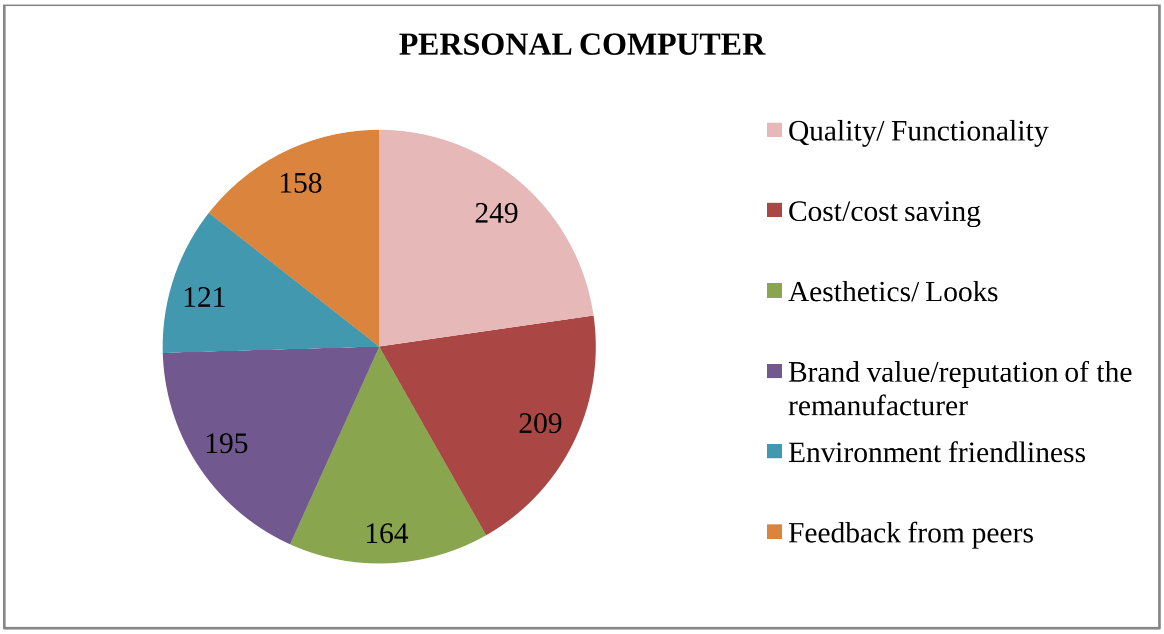


Figure 3.4. Total scores of various parameters for personal computer.

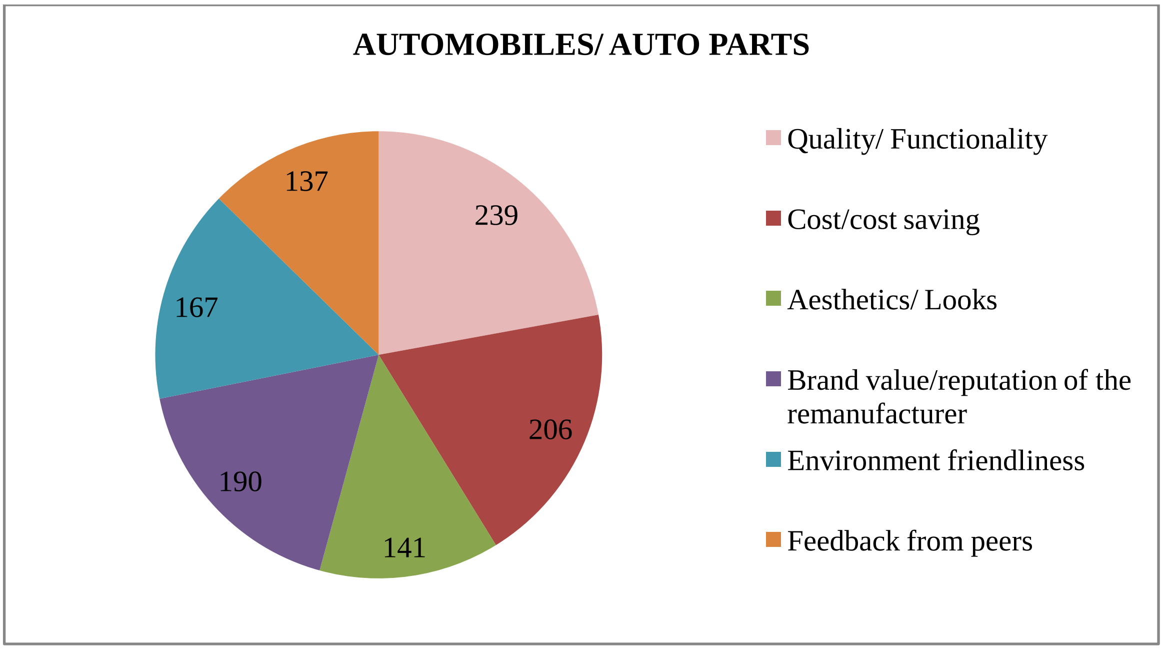


Figure 3.5. Total scores of various parameters for automobiles/auto parts.

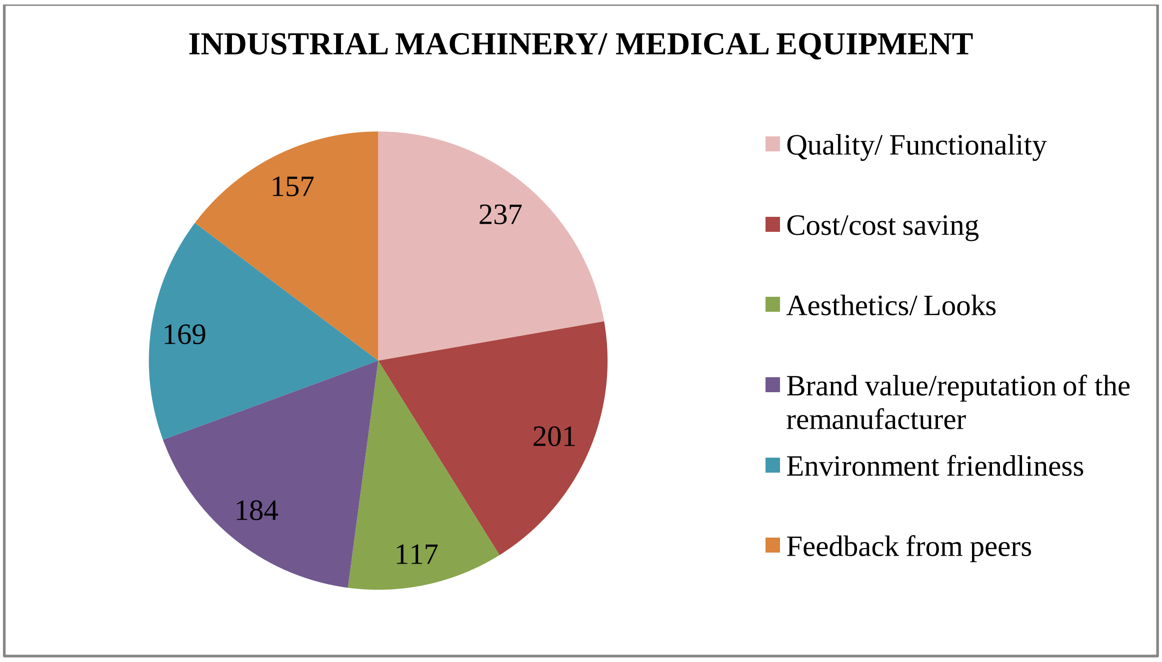


Figure 3.6. Total scores of various parameters for industrial machinery/ medical equipment.

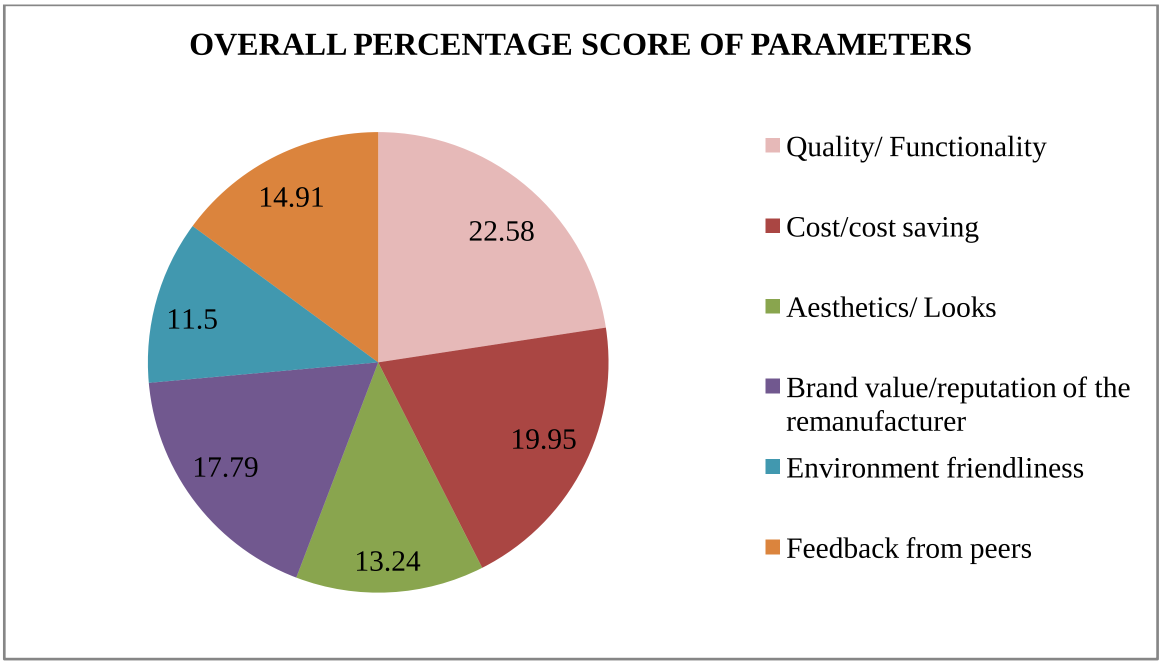


Figure 3.7. Overall percentage scores of various parameters for all products combined.

We can observe from the above figures that the common trend for all product categories is the highest score for quality followed by cost. Among the least important are aesthetics for printer cartridges, automobiles and industrial machinery and environment for electrical home appliances and personal computers.

The third criterion for evaluation was the maximum percentage price that people are willing to pay for remanufactured products. The range of price options given was from 40% to 90% the price of a new product. Based on the feedback from all the customers, results for each of the five products have been indicated below.

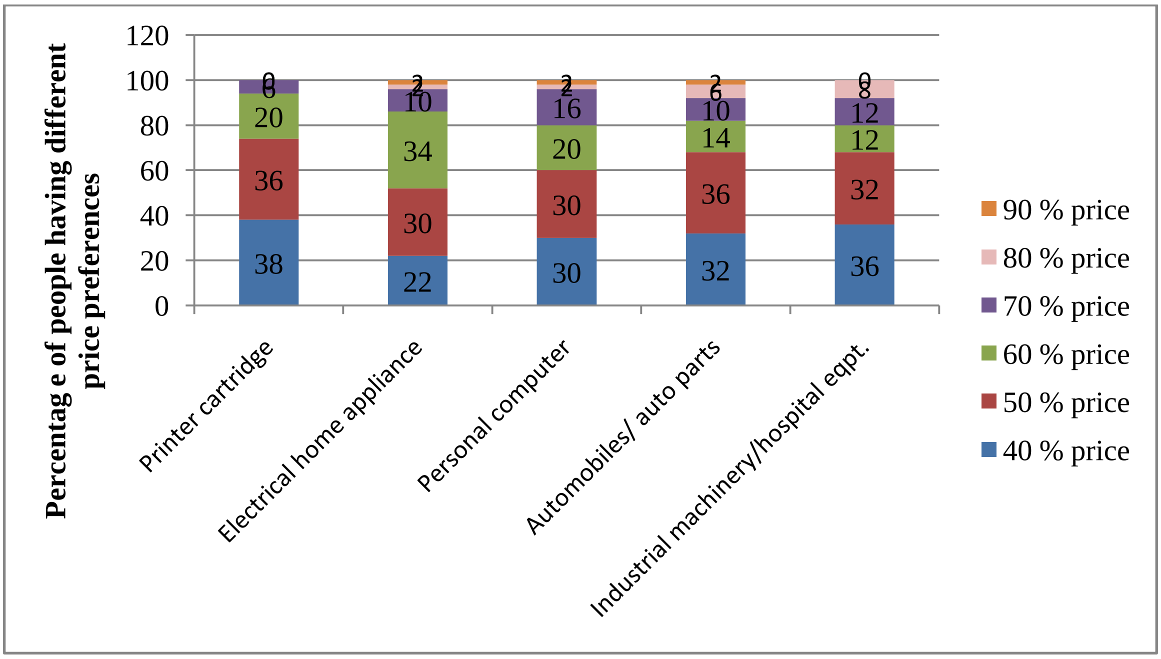


Figure 3.8. Percentage preferences of customers regarding prices of different remanufactured products.

It can be seen that for printer cartridges and industrial machinery maximum people want to pay 40% the price of a new product. For PC and automobile they can offer 50 % while for electrical home appliances upto a maximum of 60%. For more strategic products like PCs, automobiles and industrial machinery/ medical equipment, the percentage of people willing to pay between 70- 90% the price are higher as compared to for low value products like printer cartridges.

This observation was at the individual product level. However, for an overall picture and better understanding, the average value of the percentage prices has been calculated for all the products and is represented in Fig. 3.9.

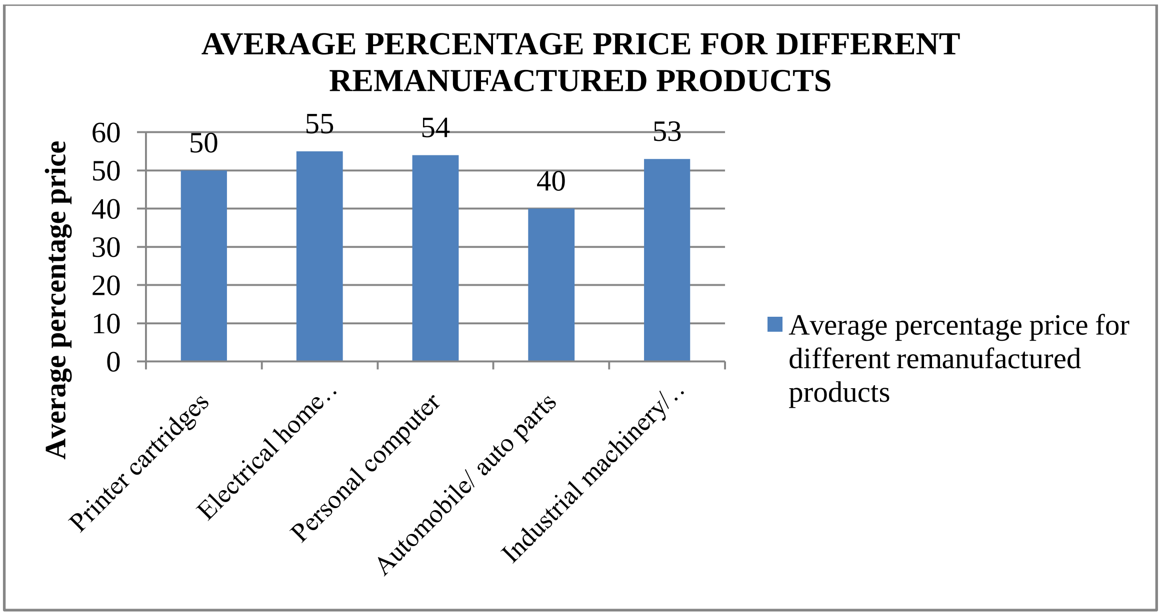


Figure 3.9. Average values of percentage prices that people are willing to pay for remanufactured products in the above product categories

It can be observed that most of the people would like to pay between 40-50% the price of a new product. Although the remanufactured products already are much cheaper as compared to new ones, still this perception shows the low credibility of a remanufactured product in the eyes of the customers.

3.3 Analysis and inferences from the survey

Based on the results obtained in the survey, the inferences drawn about the customer perception on remanufactured products have been discussed below. Also, certain strategies which can be adopted by remanufacturers to overcome the setbacks have been proposed.

1) First with regard to the preferences of customers for remanufactured products, most of the people prefer remanufactured products only for low cost items like printer cartridges and medium preference for domestic goods like electrical home appliances. For more expensive products like automobiles and industrial machinery, people are still hesitant to go for remanufactured products. This implies that people are not ready to experiment with or adopt a new technique for costly goods due to lack of faith in such products.

   Proposed strategy: Create more awareness among people about remanufactured products and their benefits through good advertising. Offer incentives like discounts, free trial period initially to gain customer confidence and ensure good product quality to develop more clientele

2) Talking next about the parameters that people look for while deciding on remanufactured products. For all product categories, quality/ functionality of the product has been rated the highest followed by cost/ cost saving while purchasing such products. This is a positive sign as it means customers would be ready to spend little more that if equivalent quality is provided as a new product. Moreover, price of a remanufactured product is generally 30-40% lower than its new counterpart. So, their second criterion is also met with remanufacturing. Now, moving on to the least rated parameters. Overall, the environment friendliness has been of the lowest importance, except for products like automobiles and industrial machinery, for which people have given higher weightage to the products green credentials over certain other parameters. This poor approach towards environmental degradation and energy saving is the main cause behind low preference of remanufactured products. Another parameter which has received low rating is the product aesthetics. This is an encouraging fact for remanufacturers, as in such products main focus is on functionality and quality while aesthetics are not given much importance. Feedback from peers is also of less importance for people while decision making. It means people rely more on self knowledge and trial, which can be a motivational factor for remanufactured products. Brand value and reputation of the remanufactures also holds certain value for people while deciding.

   Proposed strategy: Generating more green awareness among people and enforcing stricter laws in this regard like western countries. Also, people should be informed about the energy conservation and waste reduction at the manufacturing level and not only at the working level. As reputation of the remanufactures is also a judgement criterion for people, it is proposed that the original equipment manufacturers (OEMs) should adopt this technique as compared to local resellers. This way people will tend to have more faith in such products and their proclaimed benefits.

3) The third basis for gaining customer perception was the price they are willing to pay for remanufactured products. Majority of the people want to pay only 40-50% the price of a new product for these. For strategic and expensive products where functionality and safety is very important, people are ready to shell out 60-70 % the price and some even upto 80%, but such people are very few in number. The primary reason behind this is that people consider remanufactured products to be at the same level as second hand products and hence do not want to pay more.

   Proposed strategy: Imparting knowledge about the difference between a second hand reusable and a remanufactured product will help people understand the value addition that goes into the product during remanufacturing. As a result, they will value the 20- 30% cost saving obtained by purchasing a remanufactured product.

Following the above proposed steps will help remanufacturers gain customer faith and change their current perception to some extent. It will help bring out more people to atleast try these new technology products. However, the customer today is smart and educated. So, in the end it would be the product's efficient functionality and upto the mark quality that will sustain it in the market amongst competent new products.

CHAPTER 4
DECISION SUPPORT SYSTEM FOR REMANUFACTURING

A decision support system (DSS) is a computer-based information system that supports business or organizational decision-making activities. DSSs serve the management, operations, and planning levels of an organization and help to make decisions, which may be rapidly changing and not easily specified in advance. DSSs include knowledge-based systems. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from a combination of raw data, documents, personal knowledge, or business models to identify and solve problems and make decisions.

4.1 DSS Architecture

Three fundamental components of DSS architecture are:

1. The database (or knowledge base)

   It is the organized collection of data which forms the base of the DSS. It is present mostly in the form of inputs, user knowledge or expertise and outputs. It may include factors, numbers and characteristics to analyze, inputs requiring manual analysis by the user or transformed data from which DSS "decisions" are generated.
2. The model (i.e., the decision context and user criteria)

   It is a conceptualization which is used to interpret data and give results. A model comprises of a series of relationships between the various inputs, factors, parameters and constraints. These relationships may be mathematical, logical or theoretical. Using these relationships we can find solutions to real life problems. Hence, we can say that a model is nothing but a representation of a real lie situation.
3. The user interface

   It is the space where interaction between humans and machines occurs. The goal of interaction between the user and the system at the user interface is effective operation and control of the system, and feedback from the system which aids the operator in making operational decisions .The user interface includes hardware (physical) and software (logical) components.

User interfaces exist for various systems, and provide a means of:

- Input, allowing the users to manipulate a system
- Output, allowing the system to indicate the effects of the users' manipulation

Hence, an interface helps users to control and assess the state of the system. The users themselves are also important components of the architecture. To develop a decision support system, it is important to first understand the parameters affecting the decision to be taken. In context with remanufacturing, to decide whether to go for remanufacturing or not based on the economic criteria, it is important to know the factors affecting the overall cost of remanufacturing. These have been discussed in the following section.

4.2 Parameters affecting remanufacturing

Based on the extensive literature review and the information gathered from previous studies, the parameters affecting cost effectiveness of remanufacturing can be divided broadly into two categories (De Toni and Tonchia, 2001):

1) *Cost based parameters:* These are the parameters which have a direct relation with the remanufacturing cost. These primarily include the direct cost incurred during the remanufacturing process like the cost of procuring, inventory, refurbishing, subcontracting, disassembly, scrap disposal cost etc.
2) *Non - cost based parameters:* This includes those parameters which have an impact on the cost effectiveness of remanufacturing process and indirectly add to the remanufacturing costs. For instance the quality, flexibility of the system, time, customer demand, capacity of remanufacturing site etc.

As already stated, remanufacturing involves complete disassembly of the old product followed by reconditioning of each of the components to invoke characteristics of new part. Those components which cannot be refurbished are replaced with new parts. The main aim of this study is to determine the extent to which remanufacturing parts is an economically better option over purchasing completely new products. This is dependent on a number of parameters present at the various stages of remanufacturing. The remanufacturing process can be divided into five major stages. A mix of cost and non-cost based parameters exist at each of these stages of remanufacturing. They are discussed in the following pages.

4.2.1. Stage 1: Customer to Collection site

- *Procurement of old products:* There is an uncertainty in the number of parts returned by the customers. Due to the lack of awareness about this concept many people tend to sell the old products to scrap dealers rather than sending it back to the original equipment manufacturer (OEM). Thus, in order to make this process of remanufacturing economically viable, the procurement rate of parts needs to be regularized. Based on the demand, sufficient number of old parts need to be procured beforehand.
- *Cost of procuring parts:* The old products need to be purchased by the OEM from the customers. The price that he has to pay should be such that the economic balance is maintained between the price paid and outcome generated. The end of life products cost around 30% of the original price.
- *Capacity of collection site:* The extent of remanufacturing depends largely upon the capacity of the collection site. This is the initial stage and the numbers of old parts/products which can be stored in the collection sites determine the number of products which undergo further processing.So appropriate number of warehouses with sound capacity should be maintained. This capacity is also dependent on the demand for remanufactured products and the average number of products being collected from customers in unit time.
- *Inventory carrying cost at collection site:* The cost associated with holding the collected parts also adds a major portion to the remanufacturing costs. So a trade off is needed between the capacity to be maintained and the associated inventory carrying cost. Also, owing to the uncertainty in the number of products being procured, a minimum inventory of old products needs to be maintained and thus has an indispensable cost associated with it.

4.2.2 Stage 2: Collection to disassembly site

- *Capacity of disassembly site:* The disassembly is the next stage where products are reduced to their component parts. Hence, an even higher capacity than the collection site would be required. Also each of the sites needs to be segregated into separate areas to keep the products and the different kinds of parts separately for better management. So, this again would add up to the capacity requirement. Setting up the large disassembly sites and suitable infrastructure would require huge initial investment.

- *Design for disassembly and reassembly:* The complexity of the product determines whether it is possible to completely disassemble it or not. Intricate shape, permanent fastening, rust, worn out parts etc may hinder complete segregation of components. This may render remanufacturing as unfavourable and changes of product damage are higher. As a result part recovery will be lower. Same is the problem with reassembly of such products.
- *Sorting capability of disassembly site:* After disassembly, the parts need to be segregated into those which can be remanufactured and those which need to be scrapped. Thus setting up appropriate sorting facilities in these sites is essential. This adds up to the cost as well. Sorting of parts also has a labour cost associated with it which is involved in the process of initial sorting of the products.
- *Percentage of parts recovered:* The percentage of parts recovered from the returned product is another major factor determining the effectiveness of remanufacturing. If part recovery is small then this process will not be economically viable. Higher the percentage rejection of parts at this stage, more will be the number of parts to be subcontracted and thus it will add to the subcontracting cost. Thus, the maximum allowable rejection is to be determined up to which remanufacturing is economically advantageous. Appropriate sensitivity analysis needs to be done for this.
- *Cost of disassembly:* The cost of disassembly is an important cost factor which adds up to the total cost. This cost however is unavoidable as the products to be remanufactured, at first, need to be disassembled completely for inspection and subsequently sorting and refurbishing. It is directly proportional to the number of parts being passed on from collection site at any period of time.

- *Inventory carrying cost of disassembly:* Disassembly site at any point of time would carry a much higher inventory than any other site. It would include the whole products, the subassemblies, individual parts, parts to be scrapped etc. Thus each of these would ultimately increase the total inventory carrying cost. This is a major cost component at disassembly site and needs to be minimized.
- *Idle cost of disassembly:* As remanufactured products are not in continuous demand till now, the disassembly site may remain idle for certain periods of time. This would keep adding to the fixed costs without any output. The idle time could also be due to slow processing and bottlenecks in disassembly line. Hence, aim should be to maximize machine utilization and minimize idle time. Use of automation techniques along with proper planning and scheduling could help in attaining this objective.

4.2.3 Stage 3: Disassembly to Refurbishing site

- *Capacity of refurbishing site:* The number of parts which can be refurbished in a given period of time depends upon this. The facilities and infrastructure available at the site for reconditioning and transforming the old parts determine its capacity. Proper cleaning and refurbishing can enable a part to be reused for two to three times.
- *Cost of refurbishing:* This includes the processing cost of repair and rework, labour cost, cost of auxiliaries, cost of scrapping the waste parts etc. The work in progress inventory cost is also covered in this. This is the most significant operation which actually helps in restoring the component to a new like condition.
- *Quality of refurbished parts:* The significance of refurbishing only persists if the refurbished parts are of comparable quality to original parts. The quality may be judged primarily in terms of conformance of specifications of remanufactured products to virgin products and proper functionality. Hence, this is another important parameter to be kept in mind while remanufacturing as the customer expects the same quality level.
- *Performance of refurbished parts:* The performance of each of the refurbished components should be as good as the original components. Then only the

final remanufactured product could be considered competent enough with the new product. Performance would indirectly be dependent on the quality of the parts and the efficiency of the refurbishing process.

- *Idle cost of refurbishing site:* As the refurbishing process is preceded by complete disassembly of the product followed by sorting of the parts, there may be times when the refurbishing equipments remain idle for a certain period. This will increase the cost of maintenance of these equipment, fixed costs of site, labour cost etc without any output. Hence, a smooth flow of parts from disassembly to refurbishing site as well as within the refurbishing site needs to be maintained to minimize idle costs and make refurbishing more economical.

4.2.4 Stage 4: Assembly site

- *Cost of assembling:* This would include the processing cost, labour cost, maintenance cost of the equipment being used in assembly line etc. Assembly requires great labor skill to ensure proper matching of the new and refurbished parts.
- *Cost of subcontracting parts:* Those parts which are not refurbishable are procured from an outside vendor. Also, some spare parts or buffer stock needs to be maintained to account for larger number of rejections at various stages. As the cost of subcontracting parts is usually high it has a significant impact on the total remanufacturing cost. So, the aim should be to acquire better quality of returns to minimize the rejection of parts as a result of which lesser number of parts will have to be subcontracted.
- *Inventory carrying cost at assembly site:* The cost of holding work in progress inventory, spare parts, unassembled components and assembled products mainly add up to the inventory carrying cost at assembly site. Like any other site, this need to be minimized by avoiding bottlenecks and carrying out frequent inspects to minimize rejections, thus minimizing the need for spare parts.
- *Inspection cost of assembled product:* Before being shipped back to the customer, the remanufactured product needs to be thoroughly inspected to ensure that its quality and performance are comparable to a new product. Apart from that the part should be environment friendly and aesthetically

satisfactory. Only if these criteria are fulfilled that the process of remanufacturing would be considered successful.

4.2.5. Stage 5: Customer zone

- *Availability of clientele for remanufactured product:* The successful and profitable execution of remanufacturing would depend largely on the demand for these products or in other world an available market for these. Customers should be made more aware of this concept to generate demand. Moreover, with the enforcement of stricter environment laws and growing green consciousness among people, the demand for remanufactured products is bound to rise.
- *Customer satisfaction:* The customer satisfaction is the primary aim of any business. The remanufactured product should be capable of performing the same functions as a new product and meeting diverse customer needs. The features and variations of remanufactured products should be compatible with those of original product. This increases the customer acceptability. They should be easy to maintain and the service centres should be readily available. Only then will the customer go for these products.
- *Competition with new product:* The remanufactured product can score over the new product on grounds of lower price, green credentials due to lower energy consumption than required for making a new product. Some companies like Fuji have eliminated the difference between new and remanufactured products by using a mix of old and new parts as a rule. This helps in reducing the competition.

From the above discussion, it can be concluded that the economic advantage of remanufacturing would pertain only if the above factors are controlled and an optimum trade off level is attained between purchasing new products and remanufacturing them. Also a sensitivity analysis of the different parameters can be done to determine which have greater impacts and which do not. The effectiveness of remanufacturing lies in the utilization of existing manufacturing resources, processes, technology and knowledge for remanufacturing with an aim of improving the system design and its implementation. The parameters at the different stages are represented diagrammatically in Fig. 4.1

COLLECTION SITE	DISASSEMBLY SITE	REFURBISHING SITE	ASSEMBLY SITE	CUSTOMER ZONE
• Procurement of old products • Cost of procuring parts • Capacity of collection site • Inventory carryin cost	• Capacity of disassembly site • Design for disassembly • Sorting capability and sorting cost • Percentage of parts recovered after disassembly • Cost of disassembly • Inventory carrying cost	• Capacity of refurbishing site • Cost of refurbishing • Quality of refurbished parts • Performance of refurbished parts • Idle cost of refurbishing site	• Cost of assembly • Cost of subcontractin-g • Inventory carrying cost • Inspection cost	• Availability of customers for remanufactu-red products • Customer satisfaction • Competition with new product

Figure 4.1. Parameters affecting remanufacturing process

4.3 Decision support system for remanufacturing

In the present work, a decision support system has been developed to enable any user to determine the cost of remanufacturing a product. The DSS generated is a computer program based on C++ programming language for economic evaluation of the remanufacturing process. Using this program any manufacturer can determine whether remanufacturing a particular product will be economically viable for a particular product or not and can according take the decision of going for remanufacturing or not. All he needs to do is to enter the approximate values of the various parameters as prompted by the program. The program will perform the necessary mathematical operations and show the result as whether the user should go for remanufacturing or not go for it. Hence, it is a very interactive, user friendly decision support system.

4.3.1 The program algorithm

The basic algorithm or logic used in the program has been discussed below in a step wise manner.

1) *Criteria for decision making*

   The criteria to decide whether the manufacturer should go for remanufacturing or not is based on the comparison between the cost of new product and that of the remanufactured product. If remanufacturing price per product is lower we go for it.

2) *Inputting the various parameters and decision variables*

   This is the preliminary step where the user has to first enter the values of demand of remanufactured products and the products procured from customer in a given period of time. The DSS provides two options to the user for entering the demand. He can enter the demand either in absolute value or as a percentage of demand for new products. Similarly, he can enter the products procured either in absolute value or as a percentage of products sold in a specific period of time previously. Next the user is prompted to enter the values of parameters for calculation of transportation cost (i.e., capacity per vehicle used for transportation and cost per vehicle), cost of old product procured from customer, cost of a new product, sorting cost per product, disassembly cost per product, inventory carrying cost per unit for a specific period of time, refurbishing cost per part, inspection cost per part, cost of subcontracting per part and assembly cost per product. The next set of inputs comprises of other variables like the number of sub – parts per product, percentage rejection of parts at the various stages i.e., after initial sorting, after inspection of disassembled parts, and after inspection of refurbished parts.

   Based on these inputs, the program carries out the logical steps to proceed further.

3) *Mathematical Calculation and logical operations*

   Once the inputs have been entered, the work of the computer begins. Based on the formulae and relations specified in the program the computer calculates the various costs involved at different stages, the parts rejected at various stages, the number of parts subcontracted from the vendor and ultimately the total remanufacturing cost is obtained. This cost is then compared with the cost of a new product to draw conclusions.

4) *Decision Making*

   This is the final step for which the entire DSS has been formulated. After the calculations and comparisons have been done, the system gives the final decision as output. It releases a statement as "Go for remanufacturing" or "Do not go for remanufacturing".

4.3.2 Program Code

Given below is the program code in C++ language which is used as a decision support system for economic evaluation of remanufacturing process.

```
// Program for economic evaluation of remanufacturing process
#include<iostream.h>

#include<conio.h>

int main()

{

clrscr();

// DEFINING THE DECISION VARIABLES AND PARAMETERS

float option, dem, percentdem, demnew, prodsold, percentsold, prodproc,
cap_veh, n, R1, r1,r2,P_rej,P_left,p_left1,p_left2,p_pur;

float Cnew, Cold, Cveh, Cinv, Cdiss, Csort, Crefur, Cassem, Cinsp, Csubcon ,
Creman;

float TCtrans,TCproc,TCinv,TCdiss,TCsort,TCinsp1,TCinsp2,TCsubcon,
TCassem, TCrefur, TCreman;

// ENTERING THE VALUES OF DIFFERENT DECISION VARIABLES AND
PARAMETERS

cout<<"Options to enter demand for remanufactured products :"<< endl;

cout<<"1 to enter demand in numbers" << endl;

cout<<"2 to enter demand as percentage of demand for new products" <<
endl;

cout<<"Enter your option for demand input :"<< endl;

cin>>option;
```

```
if (option==1)

{

cout<<"Enter the value of demand :"<< endl;

cin>>dem;

}

else

if (option==2)

{

cout<<"Enter demand for new product :"<< endl;

cin>>demnew;

cout<<"Enter percentage of demand for remanufactured products :" << endl;

cin>>percentdem;

dem =percentdem/100*demnew;

}

cout<<"Option to enter old products procured from consumers:"<< endl;

cout<<"1 to enter products procured in actual value"<< endl;

cout<<"2 to enter as a percentage of products sold in the chosen period of time “ << endl;

cout<<"Enter option ;" << endl;

cin>>option;

if (option==1)

{

cout<<"Enter the number of products procured :"<< endl;

cin>>prodproc;

}

else

if(option==2)

{

cout<<"Enter the number of products sold in the chosen period of time: " << endl;
```

```
cin>>prodsold;

cout<<"Enter the percentage of products procured from customers:"<< endl;

cin>>percentsold;

prodproc= percentsold/100*prodsold;

}

cout<<"Enter the price of a new product:"<< endl;

cin>>Cnew;

cout<<" Enter the price of old product paid to consumer:"<< endl;

cin>>Cold;

cout<<"Enter the cost per vehicle chosen for transportation:"<< endl;

cin>>Cveh;

cout<<"Enter the capacity of one vehicle in terms of the number of products it
can carry:” << endl;

cin>>cap_veh;

cout<<"Enter the initial sorting cost per product:"<< endl;

cin>>Csort;

cout<<"Enter the cost of disassembling per product:"<< endl;

cin>>Cdiss;

cout<<"Enter the inventory carrying cost per unit:"<< endl;

cin>>Cinv;

cout<<"Enter the cost of inspection per part:" << endl;

cin>>Cinsp;

cout<<"Enter the cost of inspection per part:" << endl;

cin>>Cinsp;

cout<<"Enter the refurbishing cost per unit:"<< endl;

cin>>Crefur;

cout<<"Enter the assembly cost per product:"<< endl;

cin>>Cassem;

cout<<"Enter the cost of subcontracting per unit:"<< endl;

cin>>Csubcon;
```

```
cout<<"Enter the number of subparts of the product:"<< endl;

cin>>n;

cout<<"Enter the percentage of products rejected at initial sorting:"<< endl;

cin>>R1;

cout<<"Enter the percentage of parts rejected after disassembly:"<< endl;

cin>>r1;

cout<<"Enter the parts rejected after refurbishing :"<< endl;

cin>>r2;

//CALCULATION OF VARIOUS COSTS

TCtrans=(prodproc*Cveh)/cap_veh;

If ( prodproc < cap_veh)

{

TCtrans = Cveh;

}

TCproc= (prodproc*Cold) + (TCtrans);

cout<<"The total cost of procuring"<< prodproc <<"product is:" <<TCproc <<
endl;

TCsort = Csort*prodproc;

cout<<"The total sorting cost is: "<<TCsort<< endl;

P_rej =(R1/100)*prodproc;

P_left= prodproc - P_rej;

TCdiss =P_left * Cdiss;

cout<<"The total cost of disassembling the products is :"<<TCdiss<< endl;

TCinv = n*P_left*Cinv;

cout<< " The total inventory carrying cost is :" << TCinv << endl;

TCinsp1 = n*P_left*Cinsp;

cout<<" Total cost of inspecting the parts after disassembly :"<<TCinsp1<<
endl;

p_left1= (1- (r1/100)) *n*P_left;

cout<<" Parts remaining after inspection of disassembled parts: "
<<p_left1<<endl;
```

```
TCrefur = p_left1*Crefur;

cout<<"Total cost of refurbishing:" <<TCrefur<<endl;

TCinsp2 =p_left1*Cinsp;

cout<<"Total cost of inspection after refurbishing is : "<<TCinsp2<<endl;

p_left2 = (1- (r2/100))*p_left1;

cout<<" Parts left after inspection of refurbished parts:"<<p_left2<<endl;

p_pur = (n*dem) - p_left2;

TCsubcon =p_pur*Csubcon + TCtrans;

cout<< " Total cost of subcontracting new parts for assembling :"<<
TCsubcon<< endl;

TCassem = dem * Cassem;

cout << " Total cost of assembly is : "<<TCassem << endl;

TCreman= TCproc + TCsort +TCdiss + TCinv+ TCinsp1 + TCrefur + TCinsp2
+ TCsubcon +TCassem;

cout<< "The total cost of remanufacturing is:" <<TCreman << endl;

Creman = TCreman/dem;

cout<<"Cost of remanufacturing per product is: "<< Creman<< endl;

cout << " Cost of a new product is: " << Cnew << endl;

if (Creman< Cnew)

{

cout <<"Remanufacturing is a more economical option. Go for
remanufaturing."<< endl;

}

else

cout <<" Remanufacturing is less economical than buying new products. Do
not go for remanufacturing “<< endl;

getch();

}
```

The meaning of the different variables used in the above program is given in Appendix at the end.

4.3.3 Tables of Input / Output

The execution of the above program is shown by taking the example of remanufacturing a mobile phone. The values of different parameters used in this example are for demonstrative purpose to show the working of the program. Some of these are based on hypothetical assumptions (like demand, products procured, capacity per vehicle and the percentage rejections at various stages) while some are based on knowledge and research (like price of new product, old product, processing costs etc.).The values of the input parameters were entered on being prompted for the same when the program was run. The inputs entered step by step during the execution of the program have been collectively tabulated in Table 4.1

Variable name	**Value**
Demand	1000
Products procured	600
Price of new product	3000
Price of old product	900
Cost /vehicle for transportation	200
Capacity /vehicle (no. of products)	600
Sorting cost/product	15
Disassembly cost/product	7
Inventory carrying cost/unit	40
Inspection cost/part	60
Refurbishing cost/unit	25
Assembly cost/product	9
Subcontracting cost /part	100
Number of subparts	5
% rejection at initial sorting	10
% rejection after disassembly	20
% rejection after refurbishing	15

Table 4.1 . Table showing values of variables entered by the user

Based on the above inputs, the outputs were generated by the program. The outputs comprise of the various processing costs, the parts at rejected and recovered at different stages and the total cost of remanufacturing per product. The above outputs are shown in the next table.

Output parameter	**Value**
Total cost of procurement	540200
Total sorting cost	9000
Total cost of disassembly	3780
Total inventory carrying cost	108000
Total cost of inspection 1	162000
Parts remaining after inspection 1	2160
Total cost of refurbishing	54000
Total cost of inspection 2	129600
Parts left after inspection 2	1836
Total cost of subcontracting	316600
Total cost of assembly	9000
Total cost of remanufacturing	1332180
Cost of remanufacturing/product	**1332.18**
Selling price of new product	3000
Cost of manufacturing a new product (considering 40% profit margin)	**2143**

Table 4.2 . Table showing the output generated by the DSS

Comparing the costs of manufacturing and remanufacturing from the last and third last rows of the output table, the price of a remanufactured product is much less than the price of a new product (one- third in this case). So, the DSS would show the message "REMANUFACTURING IS A MORE ECONOMICAL OPTION. GO FOR REMANUFACTURING".

If however in some case the cost of remanufacturing is more than the cost of a new product then the DSS would show the opposite message. This way the decision support system can be successfully used for determining the economic viability of remanufacturing.

4.4 Effect of parameters on the cost of remanufacturing

As already discussed in the previous sections, the remanufacturing cost is affected by different parameters. Some of these are qualitative while others are quantitative in nature. The parameters which can be quantified have been used to develop the computer program discussed above. It is very important to analyse their impact on the remanufacturing costs and determine the optimum values upto which we can increase them while maintaining the economic viability of the process. To achieve the above objective, the program can be modified slightly to serve as a means for determining the effect of certain process parameters on the overall cost of remanufacturing.

4.4.1 The modified program algorithm

The basic program remains the same as discussed in section 4.3.3. The only difference is the use of “FOR LOOP”. The initial program statements for defining the decision variables and parameters shall remain intact. Next, would be the code lines for inputting the values of all the parameters and decision variables except the one whose effect is to be analysed. After this, the “for loop” is applied to vary the parameter under study within a given range. The steps for calculation of various costs and the overall remanufacturing cost are included within this loop. Also, instead of demanding the output for each of the processing costs, the loop will comprise of output statement for only the final cost of remanufacturing. The end statements which compare the cost of remanufactured product and new product and print the decision statement shall be omitted in this case. Instead the output would comprise of a series of output statements showing value of the parameter and the total remanufacturing cost corresponding to that value. For example, to determine the effect of products procured on the overall remanufacturing cost, the loop will be as given below. This loop is used where the products procured are taken as a percentage of products previously sold.

```
for(percentsold = 5; percentsold <= 80; percentsold ++)
{
    prodproc= percentsold/100 *prodsold;
    TCtrans= (prodproc*Cveh)/cap_veh;
    If (prodproc < cap_veh)
    {
    TCtrans = Cveh;
    }
    TCproc= (prodproc*Cold) + (TCtrans);
    cout<<"The total cost of procuring"<< prodproc <<"product is:" <<TCproc <<
    endl;
    TCsort = Csort*prodproc;
    cout<<"The total sorting cost is: "<<TCsort<< endl;
    P_rej =(R1/100)*prodproc;
    P_left= prodproc - P_rej;
    TCdiss =P_left * Cdiss;
    TCinv = n*P_left*Cinv;
    TCinsp1 = n*P_left*Cinsp;
    p_left1= (1- (r1/100)) *n*P_left;
    TCrefur = p_left1*Crefur;
    TCinsp2 =p_left1*Cinsp;
    p_left2 = (1- (r2/100))*p_left1;
    p_pur = (n*dem) - p_left2;
    TCsubcon =p_pur*Csubcon + TCtrans;
    TCassem = dem * Cassem;
    TCreman= TCproc + TCsort +TCdiss + TCinv+ TCinsp1 + TCrefur + TCinsp2
    + TCsubcon +TCassem;
    Creman = TCreman/dem;
    cout<< “For percentage product procured =” <<percentsold<<"The cost of
    remanufacturing per product is:  is:" <<TCreman << endl;
}
```

Keeping all other parameters constant, the parameter to be studied is varied within a given range of values, on similar lines as shown above and the corresponding cost of remanufacturing for each of the values is calculated using the “for loop”. The output obtained is then tabulated and graphs of remanufacturing cost v/s parameter are plotted.

4.4.2 Tabulated results for effect of different parameters

The above program has been applied to study the effect of the following parameters:

1) Percentage rejection of parts during remanufacturing
2) Percentage of old products procured from the customers
3) Various processing costs namely –
    - Inventory carrying cost
    - Inspection cost
    - Refurbishing cost
    - Disassembly cost
    - Sorting cost
    - Subcontracting cost
    - Cost of old product

The results obtained for each one of them shall be discussed one by one. The values of all other inputs used for execution of the program are same as given in section 4.3.4.

Effect of Percentage Rejection of Parts

The percentage of parts which would be rejected or scrapped at different stages of remanufacturing is quite probabilistic in nature. The aim is to determine to what extent of percentage rejection remanufacturing would be economically viable. The impact of this parameter on the total cost of remanufacturing is also affected by the cost of subcontracting parts from the outside vendor. The point of optimality would vary with difference in cost of purchasing new parts. That’s why the graphs of remanufacturing cost v/s percentage rejection have been plotted for different values of subcontracting costs.

The “for loop” was run for percentage rejection between 0 % to 80 % for three different costs of subcontracting ne parts (Rs. 100, 300 and 400). The corresponding values of the cost of remanufacturing for each of the cases have been recorded in a tabular form.

Percentage rejection	Cost of remanufacturing/ product (Csub =100)	Cost of remanufacturing/ product (Csub=300)	Cost of remanufacturing/ product (Csub=400)
0	1291	1859	2089
10	1295	1912	2169
20	1299	1964	2248
30	1303	2017	2328
40	1307	2070	2408
50	1311	2122	2487
60	1315	2175	2567
70	1319	2228	2647
80	1323	2280	2726

Table 4.3 Effect of percentage rejection of parts on the cost of remanufacturing/product

Using the above table, the following curves were plotted.

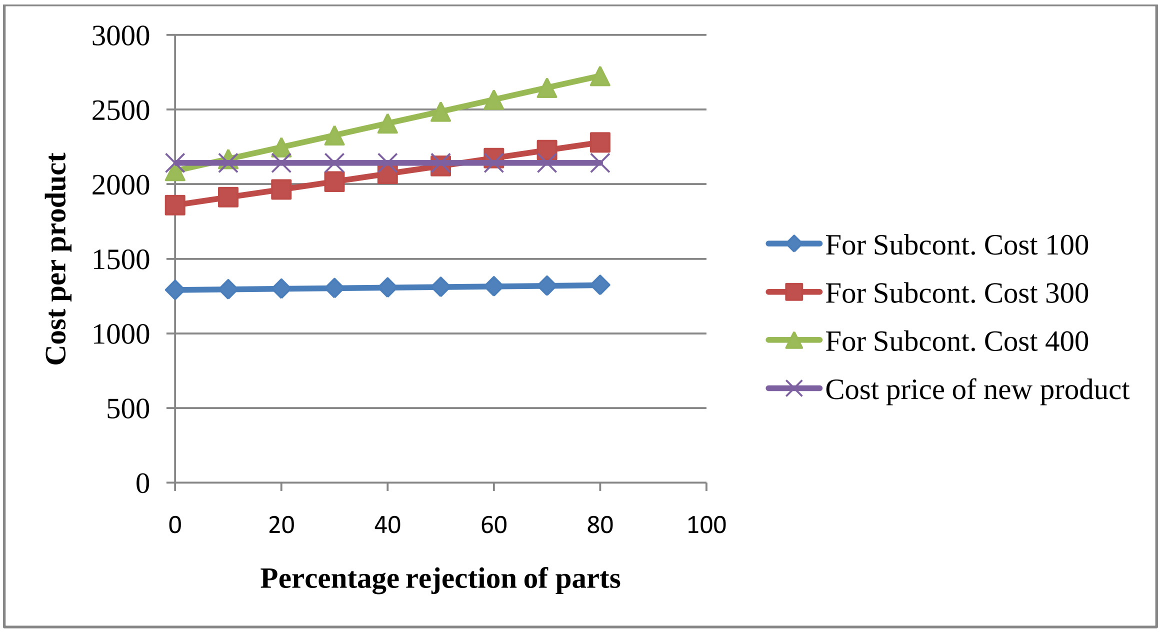


Figure 4.2. Remanufacturing cost v/s percentage rejection of parts (for different values of subcontracting costs)

Analysis of curve: With increase in percentage rejection the cost of remanufacturing increases. However, the effect of the cost of subcontracting is noteworthy. As the cost of subcontracting is increased (as shown in third and fourth column), the remanufacturing cost per product rises more rapidly than when it is low (as shown in red and green curves). Hence, for lower values of subcontracting costs (like for cost of subcontracting = Rs 100 as shown in blue curve), the graph is nearly flat. So, we can go for remanufacturing even at higher levels of percentage rejection. But as the cost of subcontracting new products rises, the remanufacturing cost approaches the cost of new product at a faster pace thus limiting its applicability beyond a certain point. The optimal value of percentage rejection for cost of subcontracting Rs 300 is 50% while that for subcontracting cost Rs 400 is 15%.

Effect of Products Procured

The number of products procured is another factor which has uncertainty attached to it. However, as it forms the basic raw material for remanufacturing, it is essential to obtain sufficient number of products to meet the demand. The purchasing of old products from customers is associated with a significant amount of procurement cost. If less number of products are procured, then less number of remanufacturable parts would be obtained and so a larger number of new parts will have to be purchased from vendor thus adding to the cost of subcontracting. Hence, it is important to determine the optimum value of percentage procurement where the costs are balanced. These results are based on the same inputs as given for the base program. The only difference is that the products procured are taken as a percentage of products sold before in a certain time period in this case and the value of products sold has been input as 2500. The results obtained are given below.

% products procured	Cost of remanufacturing /product
5	701
10	892
15	1084
20	1276
25	1467
30	1659
35	1851
40	2042
45	2234
50	2426

Table 4.4 Effect of percentage of products procured on the cost of remanufacturing.

Based on the table the following graph was plotted.

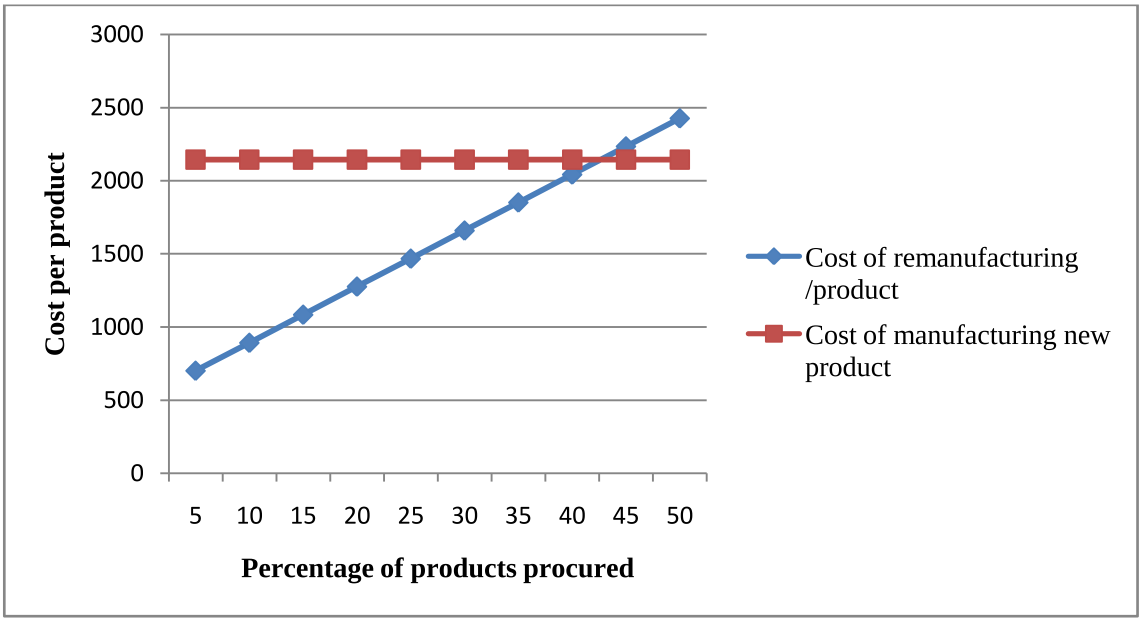


Figure 4.3 Remanufacturing cost per product v/s percentage of products procured.

Analysis of curve: It can be seen from the curve that the cost of remanufacturing remains economical upto a percentage procurement of around 42.5%. It means that upto this value the cost of procurement is less dominant than cost of purchasing new parts. But for higher percentage procurement than this, the price paid for purchasing old product as well as the transportation cost would overshoot the cost saved by purchasing lesser number of new parts (subcontracting cost) and the cumulative result would be an increase in remanufacturing cost beyond the optimum limit.

<u>Effect of Processing Costs</u>

It is quite evident that with increase in the processing costs, the cost of remanufacturing would increase. Hence, the more important aspect to analyse here is the relative effect of the different costs to determine which costs have more profound effect on the overall cost over others. The program was run within the ranges in which the costs usually lie. The curves obtained were then extrapolated to attain the optimum values. However, more importantly, the slopes of each of the processing cost curves were calculated to judge which of the processing cost have a sharper effect on the total cost of remanufacturing. Following are the tables and graphs for the different processing costs mentioned before.

a) <u>Inventory carrying cost</u>

Inventory cost/unit	Remanufacturing cost /unit
40	1331
50	1358
60	1385
70	1412
80	1439
90	1466
100	1493

Table 4.5 Effect of inventory carrying cost on the cost of remanufacturing.

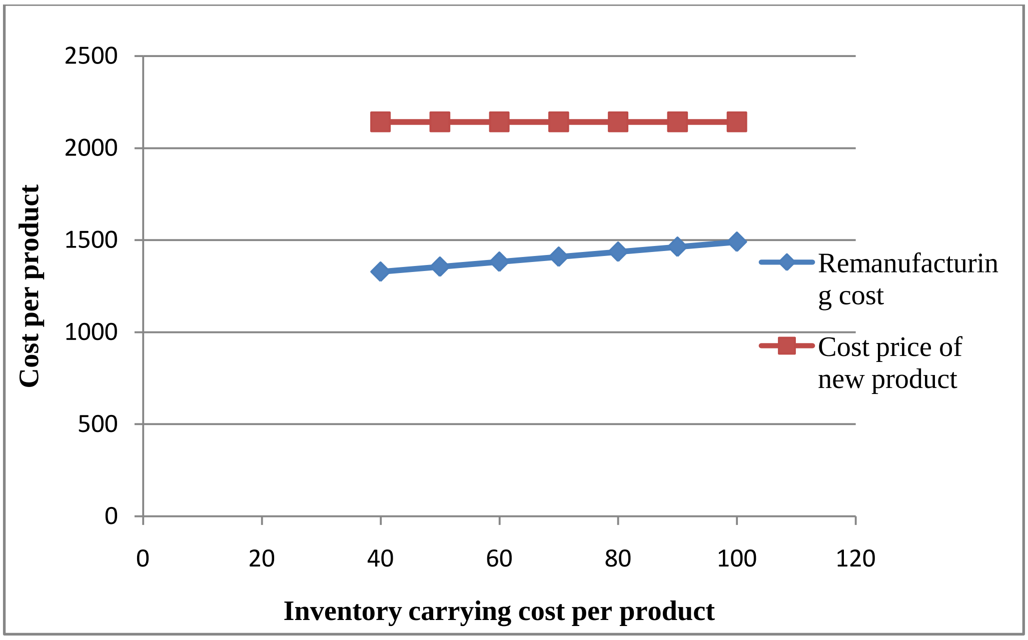


Figure 4.4 Remanufacturing cost v/s inventory carrying cost

Slope of curve = 2.7

Maximum feasible inventory carrying cost (on extrapolation) for economic remanufacturing = Rs 342

b) Inspection cost

Inspection cost/unit	Remanufacturing cost/unit
60	1331
70	1381
80	1429
90	1477
100	1526
110	1574
120	1623

Table 4.6 Effect of inspection cost on the cost of remanufacturing.

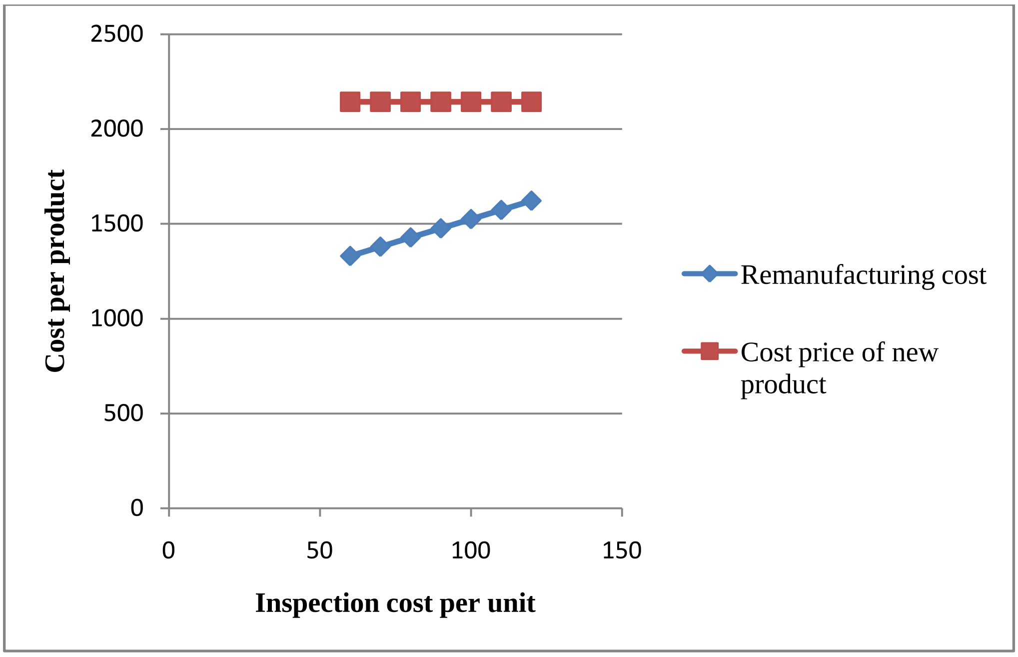


Figure 4.5 Remanufacturing cost v/s inspection cost

Slope of curve = 4.9

Maximum feasible inspection cost (on extrapolation) for economic remanufacturing = Rs. 226

c) <u>Refurbishing cost</u>

Refurbishing cost/unit	Remanufacturing cost/unit
25	1429
35	1450
45	1472
55	1493
65	1515
75	1537
85	1558

Table 4.7 Effect of refurbishing cost on the cost of remanufacturing.

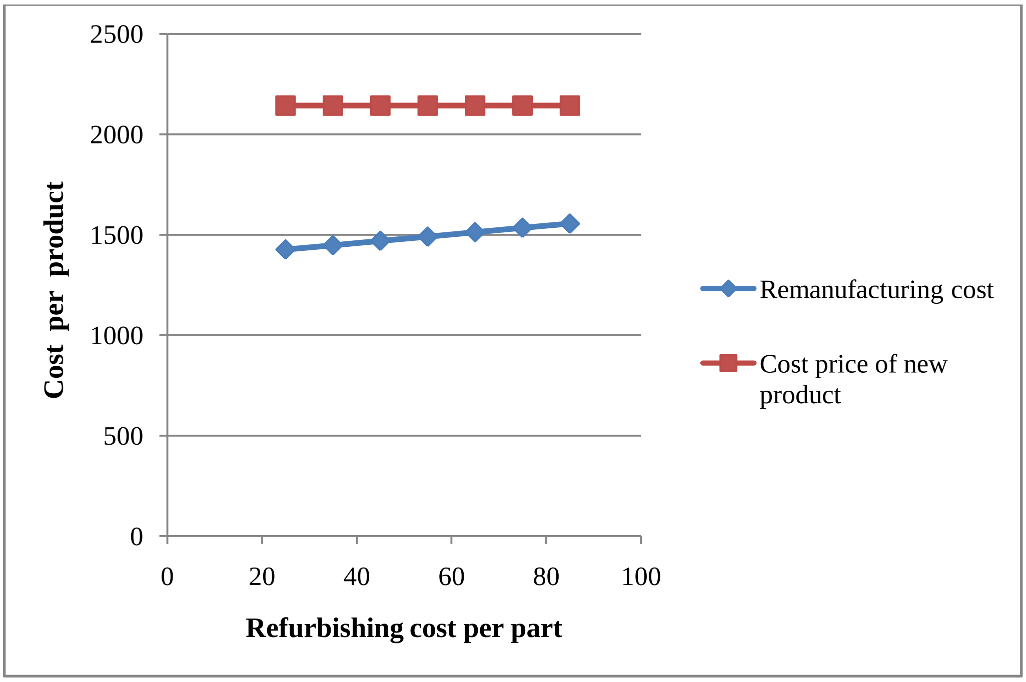


Figure 4.6 Remanufacturing cost v/s refurbishing cost

Slope of curve = 2.1

Maximum feasible refurbishing cost (on extrapolation) for economic remanufacturing = Rs. 363

d) Disassembly cost

Disassembly cost/unit	Remanufacturing cost/unit
7	1429
9	1432
11	1435
13	1437
15	1441
17	1443
19	1447

Table 4.8 Effect of disassembly cost on the cost of remanufacturing.

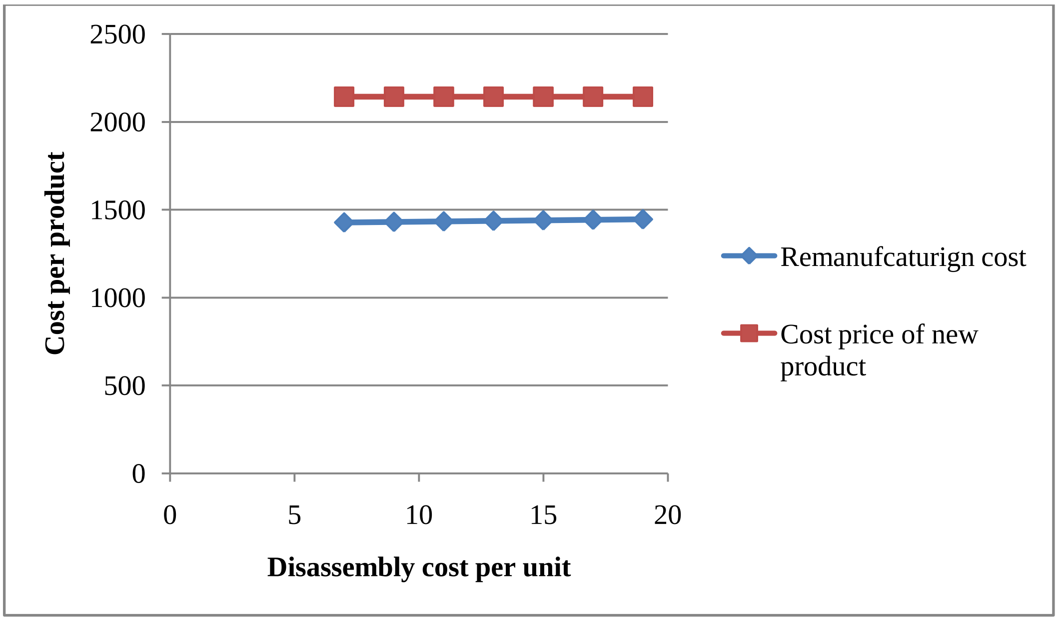


Figure 4.7 Remanufacturing cost v/s disassembly cost

Slope of curve = 1.5

Maximum feasible disassembly cost (on extrapolation) for economic remanufacturing = Rs. 483

e) <u>Sorting cost</u>

Sorting cost/unit	Remanufacturing cost/unit
15	1429
25	1435
35	1441
45	1443
55	1453
65	1459

Table 4.9 Effect of sorting cost on the cost of remanufacturing.

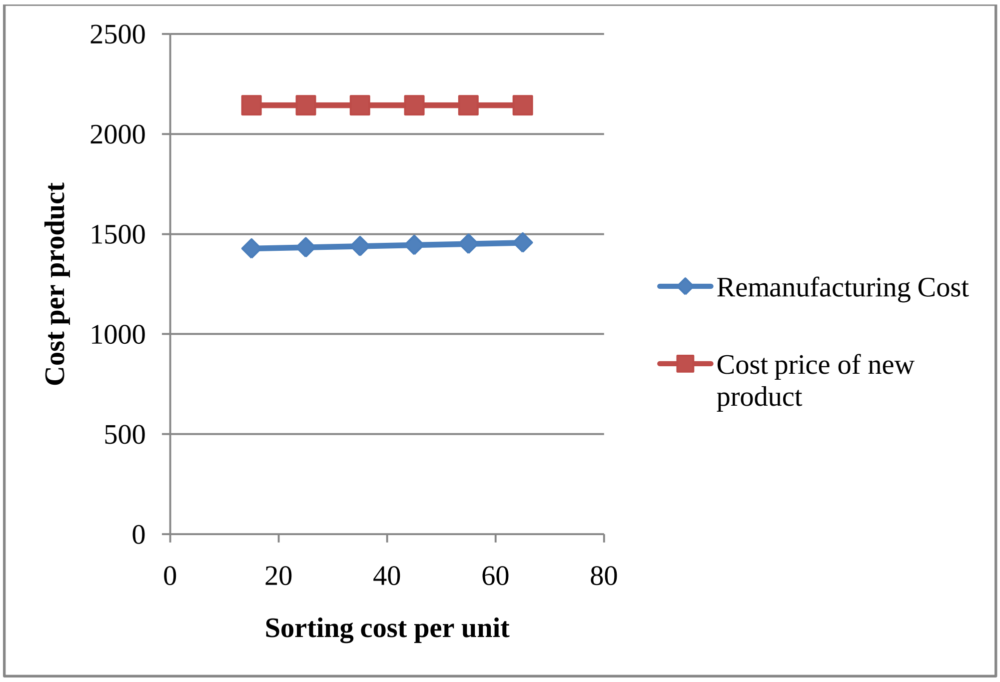


Figure 4.8 Remanufacturing cost v/s sorting cost

Slope of curve = 0.6

Maximum feasible sorting cost (on extrapolation) for economic remanufacturing = Rs.1205

f) <u>Subcontracting cost</u>

Subcontracting cost /unit	Remanufacturing cost/unit
100	1429
150	1587
200	1745
250	1903
300	2061
350	2220
400	2378

Table 4.10 Effect of subcontracting cost on the cost of remanufacturing

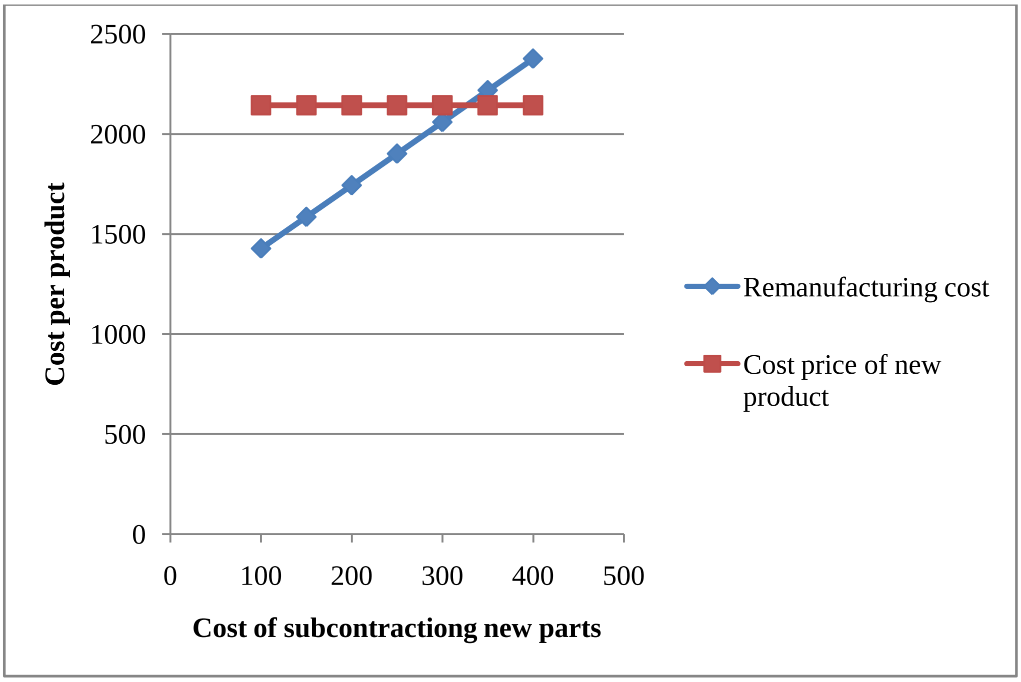


Figure 4.9 Remanufacturing cost v/s subcontracting cost

Slope of curve = 3.1

Maximum feasible subcontracting cost (on extrapolation) for economic remanufacturing = Rs. 326

g) <u>Cost of old product</u>

Cost of old product /unit	Remanufacturing cost/unit
600	1151
700	1211
800	1271
900	1331
1000	1391
1100	1451
1200	1511

Table 4.11 Effect of cost of old product on the cost of remanufacturing

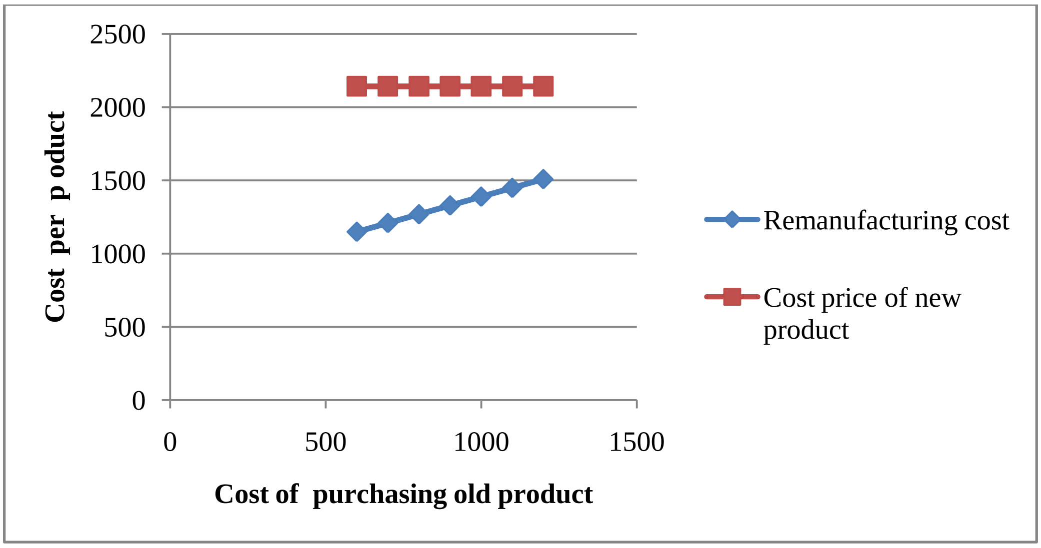


Figure 4.10 Remanufacturing cost v/s cost of old product.

Slope of curve = 0.6

Maximum feasible refurbishing cost (on extrapolation) for economic remanufacturing = Rs 2253

Analysis of all the processing cost curves: It is quite evident that, the increase in any of the above costs will lead to an increase in the cost of remanufacturing. However, the effect of each of these relative to each other can be determined by comparing the slopes of each of the curves. The curves with a higher slope indicate that those costs inflict a greater change in cost of remanufacturing per unit change in cost or in other words remanufacturing costs are more sensitive to the changes in those costs which show larger slopes. Based on this criterion the costs are listed below.

Cost Type	Slope
Inspection cost	4.9
Subcontracting cost	3.1
Inventory carrying cost	2.7
Refurbishing cost	2.1
Disassembly cost	1.5
Procurement cost	0.6
Sorting cost	0.6

Table 4.12 Slopes of different cost curves

Thus, a stricter control over costs of inspection, subcontracting, inventory and refurbishing need to be maintained as compared to disassembly, procurement and sorting costs to keep remanufacturing costs within economically viable limits.

The model developed in this chapter can be used by decision makers to check the viability for any product before investing in remanufacturing. Also, this DSS can serve as a cost controlling tool to keep a check on the different processing attributes during remanufacturing.

CHAPTER 5
GRAPH THEORETIC APPROACH

Graph theoretic approach is a powerful decision making method which has been in use since 1736. Graph theory has served an important role in the modelling of systems, network analysis, functional representation, conceptual modelling, diagnosis, etc. In GTA, the relationship between different variables is represented in the form of a digraph (directional graph) and matrix. Their interdependence on each other as well as their individual contribution to the system is assigned numerical values and an overall index is calculated. This index is then used for the self analysis of the system or the comparative analysis of two or more system to select the best alternative. There are some other techniques like Analytical Network Process (ANP) and Analytical Hierarchy Process (AHP), which are based on the similar idea of parametric interrelationship. However, AHP does not capture the interdependence of variables while ANP does not include the hierarchy among them .GTA has no such limitations (Raj et al., 2010) and hence can be used in a variety of fields.

With guidelines from the literatures mentioned in chapter 2, the digraph and matrix approach has been implemented in the remanufacturing system, to calculate its cost effectiveness index. However, to apply this technique, first it is important to classify the parameters at the system and sub-system level based on which digraphs and matrices shall be formed.

5.1 Classification of remanufacturing attributes for GTA

On the basis of literary work conducted by experienced researchers, it has been determined that the successful implementation of remanufacturing in a system is dependent upon a number of attributes or parameters. These parameters can be broadly categorised into four main groups:

- Procurement parameters (P_1)
- Processing parameters (P_2)
- Material recovery parameters (P_3)
- Marketing parameters (P_4)

5.1.1. Procurement parameters

In remanufacturing, the first step is procurement of old products from the customers. These products form the basic raw materials for further processing. The parameters can be broadly classified as:

1) *Number of old products procured from the customers:* The number of old products obtained from the customer, is highly uncertain in nature. Due to the lack of awareness about this concept many people tend to sell the old products to scrap dealers rather than sending it back to the original equipment manufacturer (OEM). Owing to the large variability of this parameter, it is very important to forecast and analyse the average percentage procurement and the corresponding demand for the remanufactured product. Only if the requirement can be met, should remanufacturing be implemented. Customer returns are estimated at 6% of sales and may be as high as 15% for mass merchandisers and up to 35% for catalogue and e-commerce retailers (Dowlatshahi, 2005). Customers are encouraged to return the old products to the original equipment manufacturer (OEM) by offering them several incentives like cash , discounts, transportation costs etc.(Ghoreishi et al., 2011) . Mukherjee and Mondal (2009) illustrated certain policies adopted by companies to encourage return of the product by the customer to the OEM. For instance, every new machine that is sold is expected to be serviced and maintained at the cost of the company until its end-of-life (10 years approx.). However, the cost of consumables, required for maintenance service is to be borne by the customer .This policy enables the company to maintain a logbook of all the sold and installed machines, and also maintain a close relationship with its customers through a strong network of service centres all over the country. The companies also initiate the 'exchange offer' and 'buy-back' scheme to facilitate returns.
2) *Price paid to the customer for the old product*: The price paid to the customer depends upon the condition of the product at the time of take back. The price is set in such a manner that the economic balance is maintained between the price paid and outcome generated. The end of life products are generally procured at one-fourth to one-third of the original price.
3) *Quality of products procured*: Another aspect of procurement includes the quality of old product. Both these factors are dependent upon the duration of

use and the service conditions of the product. A good quality return fetches a higher price to the customer and in turn offers higher part recovery to the remanufacturer. Robotis et al. (2005), in their paper have illustrated the interactions between procurement and remanufacturing decisions. They have also investigated the impact of uncertainty associated with demand in secondary markets on the influence of the flexibility provided by remanufacturing. According to them, when the reseller can remanufacture used products, the reseller prefers to procure a lower number of units from the suppliers as he can upgrade the used products which do not match the required levels of quality by the market by remanufacturing. Their second inference is that, when the cost per unit of remanufacturing is lower, the cut-off quality level that a product should have in order to be remanufactured is lower.

4) *Transportation cost:* The cost of transporting the product from the customer to the remanufacturing site is another procurement sub parameter. Transportation costs to move materials are proportional to the distance travelled and the quantity transported and is one of the dominant costs. The objective here is to avoid the transportation costs incurred by transporting rejected products to warehouses. This should promote the existence of collection centres, proximal to customers, where used products can be inspected and rejected products can be sorted and disposed (Beamon et al., 2004). Hence, a baseline quality inspection at the customer site can help save a lot of transportation cost.

5.1.2 Processing parameters

Once the old products reach the remanufacturing facility, they undergo a series of operations or processes to recover the parts and bring them back to new like functionality. It is very important to design the network and build up adequate infrastructure to facilitate product recovery.

1) *Capacity of the remanufacturing system:* The capacity of the system in terms of availability of remanufacturing resources, technology and processes is a very important parameter. It also includes the capability of the available resources to bring the product back to a state comparable to the virgin product. Fleischmann et al. (2001) have analysed two approaches to achieve

this. One approach is to add reverse flow capabilities to an already existing forward network (sequential design). Another approach is to redesign the network including simultaneously forward and reverse flows (integral design). Stock (1998) stated that the full utilization of current equipment, labour, and facilities should be given first priority in order to minimize the overall product cost and the total cost of a reverse logistic (RL) system. Therefore, the overall success of a RL system in terms of strategic cost is largely determined by the effective utilization of current resources. This could also mean that products selected for RL operations must fit into, and be compatible with, the overall product strategy of the firm (Dowlatshahi, 2005).

2) *Operating cost:* Unlike reuse where the product can be used more than once in the same form after cleaning or reprocessing and recycling which involves material recovery without conserving any product structure, in remanufacturing, discarded products are completely disassembled through a series of industrial process in factory environment. Usable parts are cleaned, refurbished, and put into part inventory. Then the new product is reassembled from the old and, where necessary, new parts to produce a fully equivalent and sometimes superior in performance and expected lifetime to the original new product (Lund, 1998). All these processes namely disassembly, sorting, refurbishing, inspection and reassembly impart an operating cost on the system which needs to be strategically monitored and controlled. This cost includes labour cost, maintenance cost of machinery etc.

3) *Inventory carrying cost:* The products procured, the parts under recovery operations as well as the new parts purchased are stored in the warehouse till the entire process is completed. As a result, a holding cost is to be incurred by the company called as the inventory carrying cost. This is another integral parameter, as some inventory will always be present, mainly due to the uncertainty in demand and procurement associated with this new technique. Nenes et al. (2010) have stated some inventory control policies for inspection and remanufacturing of returns. In their paper, they have investigated alternative policies for a system where both demand of new products and returns of used products are stochastic. The expected cost of each policy for a real application problem is computed and the best policy is proposed. Gou et al. (2008) developed an algorithm for determining the optimal economic

delivery batch size for the local collection points as well as the optimal handling batch size for the centralized return centre in order to minimize the long-run average cost for the open loop reverse supply chain.

4) *Flexibility of the system:* We have already discussed that in remanufacturing; the old product is disassembled completely to the level of its smallest components. As a result, these parts after reconditioning can be used in different products. For example, some parts of an old Maruti Alto can be used in remanufacturing a Maruti Swift owing to similarity of components and make. This imparts flexibility to the system with regard to variety in the final product being made from the same old product. However, to meet the above goal, flexibility within the remanufacturing process is essential. Manufacturing flexibility is widely recognized as a critical component to achieve a competitive advantage in the market and improve an organization’s capability to respond to customer demands without incurring excessive time and cost penalties (Oberoi et al., 2008). Implementing FMS requires capital investment and maintenance costs initially but in the long run it reduces lead time, improves product quality and hence reduces the overall production cost.

All the above parameters are very important from the processing aspect and directly affect the cost effectiveness of remanufacturing.

5.1.3 Material recovery parameters

As remanufacturing is a product and part recovery process, the amount and quality of material recovered from the old discarded product is of utmost significance. After disassembly, the individual parts are inspected to determine their initial condition. The parts which are recoverable are sent for further processing and others which are damaged or worn out beyond repair are scrapped. The components which are remanufacturable undergo various refurbishing, reconditioning, repair and reuse operations to make their condition as good as that of a new component.

1) *Percentage of parts recovered:* The percentage of parts recovered from the product depends to a large extent on the product design. The product design should be such that it can be easily disassembled without damaging any component and the individual parts are accessible for reconditioning. The design issues and the part access problems were discussed by Ijomah et al.

(2007). Green product design has received much attention recently, because product design significantly influences the cost of disassembly, component inspection and repair, remanufacturing and recycling (Chung and Wee, 2008). The second factor affecting part recovery is the quality of the remanufacturing process. The technology, tools and machinery being used should be of such a standard, that they bring the degraded parts to an acceptable level of functionality. With reference to cost effectiveness, the fraction of parts recovered is a very important parameter, as it directly affects the other material recovery parameters. Hence, in order to make the process economical, our aim should to be recover maximum parts possible

2) *Cost of scrap disposal:* Scrap reduction in desirable not only from economic point of view but also from environmental point of view. The main aim of remanufacturing is to minimize waste and conserve energy. Different forms of waste products require different disposal techniques as per the industrial norms. This adds tremendous cost to the overall production operation. Hence, it is very important to try and retain maximum possible parts. One time investment in good quality machines and facilities to enhance recovery is more profitable than repeatedly incurring heavy cost of scrap disposal.
3) *Cost of purchasing new parts:* This factor is also dependent upon the product recovery capacity of the system. Those products which are discarded during the process need to be replaced with new ones. The cost of subcontracting new parts also affects the overall cost of remanufacturing. The more expensive a new part is the greater burden it will add to the production economy of the system. On the flip side, if the cost of purchasing new parts in not very high for some component, while the cost of machinery required for bringing the component to the desired quality level is very high, then we can straight away go for the new part as that will save more cost. Yen-Chun Jim et al., 2006 have highlighted this aspect in their research paper on the study of reverse logistics in the publishing industry: China, Hong Kong and Taiwan. They have stated that the loss on material cost is far less than the manpower spent on processing in the publishing sector. Thus, instead of making effort to process returned goods, logistics firms or publishers may consider discarding the returned goods directly.

From the above discussion we can infer that, it is an interlinked set of parameters which collectively control the material recovery aspect of remanufacturing.

5.1.4 Marketing parameters

Identification of the market for remanufactured products and components can be very hard, basically because of the difference in customer's perception on quality and costs between used and new products (Majumder and Groenevelt, 2001).As remanufacturing is a comparatively new technique in the industrial sector, its marketing aspect plays a pivotal role in its acceptability among the customers and its sustainability in the competitive manufacturing sector.

1) *Availability of market:* Availability of market or a customer segment for remanufactured products is very important to ensure sufficient returns for the company. Otherwise, the company would end up in a loss. The right kind of publicity and advertising approach would bring in a greater clientele for these products. Factors like less wastage and energy conservation impart a greener image to remanufactured products and helps promote them. Moreover, remanufactured products have warranties equal to that of new alternatives and may also involve upgrade of a used product beyond the original specification (Ijomah et al., 2002). All these incentives at a lower price can help develop a suitable market for these products.
2) *Competition with other products:* Another attribute is competition with the other products. Atasu et al., 2008 explored the potential of remanufacturing as a strategic marketing tool with a major impact on the firm's competitive advantage. They identified the profitability conditions for remanufacturing by considering the following important characteristics of a remanufactured product:

   (i) The remanufactured product is typically a natural low-cost alternative to the new product.

   (ii) Remanufactured products usually have lower valuation from regular consumer segments.

(iii) Remanufacturing has a green image because it reduces waste generated and reuses old material. As such, it provides high value to a relatively small (albeit growing) green consumer segment.

(iv) A remanufactured product usually has the same functionality as a new product.

3) *Final product quality/ functionality:* The final product quality/ functionality should conform to the product's original quality standards and product performance. Customers usually expect the same level of quality from the manufacturer regardless of the nature of the product. The poor quality of remanufactured/ recycled products can adversely affect the reputation and possibly the sales of the firm's virgin products (Dowlatshahi, 2005).

4) *Advertising cost:* The cost of advertising is another marketing parameter which directly affects the cost of remanufacturing. Initially, large scale advertising is required to make the people aware of the benefits of remanufactured products. This will add to the overall cost of remanufacturing. However, this cost can be compensated for, by offering good quality products and after sale services. Complete customer satisfaction will ensure that the company's clientele is maintained and that the customers will recommend these products to others as well. As a consequence, the company can now cut down on the advertising cost, thus making the overall process more cost effective.

All the above parameters and their sub parameters have been listed in Fig. 5.1 below. These will be used in the upcoming sections to calculate the cost effectiveness index (CEI) for remanufacturing using the Graph Theoretic Approach.

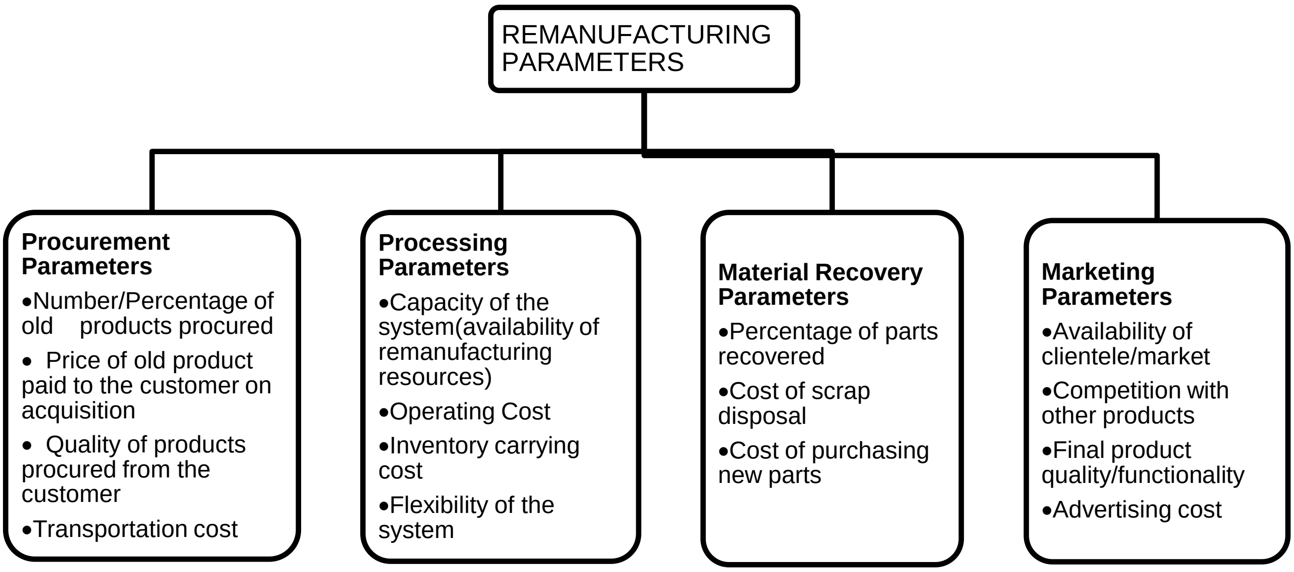


Figure 5.1. Parameters and sub parameters affecting the cost effectiveness of a remanufacturing system.

5.2 GTA for remanufacturing system

GTA has been applied for a remanufacturing system by taking into account the primary attributes of the system; namely procurement, processing, recovery and marketing parameters. Each of these is further divided into sub parameters to analyse the complex system at the smaller parametric levels and then evaluate their cumulative effect on the overall system. Based on these attributes, their sub attributes and their interdependencies a single numerical index is calculated called as the cost effectiveness index (CEI). This index signifies whether implementing remanufacturing will be an economically viable option or not.

5.2.1 Methodology for digraph and matrix development

a) A digraph consists of a number of nodes and directed edges connecting the different nodes. The number of nodes is equal to the number of system parameters being considered in the model. If a parameter 'i' has a relative importance over parameter 'j', then a directed edge or arrow is drawn from node 'i' to node 'j' and vice - versa. This way the inter-relationship between different parameters is indicated. However, as the number of nodes increases, the digraph becomes complicated and difficult to comprehend. Hence, it is translated into a matrix.

b) Based on the digraph, a square matrix is developed. In the matrix, the diagonal element D_{ii} indicates the importance or contribution (also called as inheritance) of the i^{th} parameter on the overall system index. The off- diagonal elements, a_{ij}'s, indicate the relative importance of one parameter over the other. In other words, they are an indicative of the parametric inter-dependencies.

The values of D_{ii}'s and aij's can be obtained from the Tables 5.1 and 5.2 given below:

Qualitative measure of attributes	**Assigned value of D_i**
Exceptionally low	1
Extremely low	2
Very low	3
Below average	4
Average	5
Above average	6
High	7
Very high	8
Extremely high	9
Exceptionally high	10

Table 5.1 Quantitative values assigned to attributes

Qualitative measure of interdependence of attributes	**Assigned value of a_{ij}**
Very strong	5
Strong	4
Medium	3
Weak	2
Very weak	1

Table 5.2 . Quantitative values assigned to interdependence of attributes

c) Both the digraph and matrix are not unique as they change if the order of nodes is altered. To develop a unique representation, the permanent function of the matrix per (E) is computed. The permanent function is a standard matrix function based on combinatorial mathematics. It is similar to computing the determinant of a matrix except that all the negative signs are replaced by positive ones. This ensures that each term of the multinomial function is able to contribute to the overall system evaluation and none of the terms loses its significance due to negative sign. The permanent function of an M X M matrix is represented as given below (Rao, 2007) :

$$\text{per}(J) = \prod_{i=1}^{M} A_i + \sum_{i=1}^{M-1} \sum_{j=i+1}^{M} \cdots\cdots \sum_{\substack{M=t+1 \\ \ldots,\, M \neq pus}}^{M} (a_{ij}a_{ji}) A_k A_l A_m A_n A_o \ldots A_t A_M$$

$$+\sum_{i=1}^{M-2} \sum_{j=i+1}^{M-1} \sum_{k=j+1}^{M} \underset{l=1}{\cdots\cdots} \sum_{\substack{M=t+1 \\ k,\, \ldots,\, M \neq pus}}^{M} (a_{ij}a_{jk}a_{ki} + a_{ik}a_{kj}a_{ji}) A_l A_m A_n A_o \ldots A_t A_M$$

$$+\Big[\sum_{i=1}^{M-3} \sum_{j=i+1}^{M} \sum_{k=i+1}^{M-1} \sum_{l=i+2}^{M} \cdots\cdots \sum_{\substack{M=t+1 \\ k,l,\, \ldots,\, M \neq pus}}^{M} (a_{ij}a_{ji})(a_{kl}a_{lk}) A_m A_n A_o \ldots A_t A_M$$

$$+\sum_{i=1}^{M-3} \sum_{j=i+1}^{M-1} \sum_{k=i+1}^{M} \sum_{l=j+1}^{M} \cdots\cdots \sum_{\substack{M=t+1 \\ k,l,\, \ldots,\, M \neq pus}}^{M} (a_{ij}a_{jk}a_{kl}a_{li} + a_{il}a_{lk}a_{kj}a_{ji}) A_m A_n A_o \ldots A_t A_M\Big]$$

$$+\Big[\sum_{i=1}^{M-2} \sum_{j=i+1}^{M-1} \sum_{k=j+1}^{M} \sum_{l=1}^{M-1} \sum_{m=l+1}^{M} \cdots\cdots \sum_{\substack{M=t+1 \\ k,l,m,\, \ldots,\, M \neq pus}}^{M} (a_{ij}a_{jk}a_{ki} + a_{ik}a_{kj}a_{ji})(a_{lm}a_{ml}) A_n A_o \ldots A_t A_M$$

$$+\sum_{i=1}^{M-4} \sum_{j=i+1}^{M-1} \sum_{k=i+1}^{M} \sum_{l=i+1}^{M} \sum_{m=j+1}^{M} \cdots\cdots \sum_{\substack{M=t+1 \\ k,l,m,\, \ldots,\, M \neq pus}}^{M} (a_{ij}a_{jk}a_{kl}a_{lm}a_{mi} + a_{im}a_{ml}a_{lk}a_{kj}a_{ji}) A_n A_o \ldots A_t A_M\Big]$$

$$+\Big[\Big(\sum_{i=1}^{M-3} \sum_{j=i+1}^{M-1} \sum_{k=i+1}^{M} \sum_{l=j+1}^{M} \sum_{m=1}^{M-1} \sum_{n=m+1}^{M} \cdots\cdots \sum_{\substack{M=t+1 \\ k,l,m,n,\, \ldots,\, M \neq pus}}^{M} (a_{ij}a_{jk}a_{kl}a_{li} + a_{il}a_{lk}a_{kj}a_{ji})(a_{mn}a_{nm}) A_o \ldots A_t A_M$$

$$+\sum_{i=1}^{M-5} \sum_{j=i+1}^{M-1} \sum_{k=j+1}^{M} \sum_{l=1}^{M-2} \sum_{m=l+1}^{M-1} \sum_{n=m+1}^{M} \cdots\cdots \sum_{\substack{M=t+1 \\ k,l,m,n,\, \ldots,\, M \neq pus}}^{M} (a_{ij}a_{jk}a_{ki} + a_{ik}a_{kj}a_{ji})(a_{lm}a_{mn}a_{nl} + a_{ln}a_{nm}a_{ml}) A_o .. A_t A_M$$

$$+\sum_{i=1}^{M-5} \sum_{j=i+1}^{M} \sum_{k=i+1}^{M-3} \sum_{l=i+2}^{M} \sum_{m=k+1}^{M-1} \sum_{n=k+2}^{M} \cdots\cdots \sum_{\substack{M=t+1 \\ k,l,m,n,\, \ldots,\, M \neq pus}}^{M} (a_{ij}a_{ji})(a_{kl}a_{lk})(a_{mn}a_{nm}) A_o \ldots A_t A_M$$

$$+\sum_{i=1}^{M-5} \sum_{j=i+1}^{M-1} \sum_{k=i+1}^{M} \sum_{l=i+1}^{M} \sum_{m=i+1}^{M} \sum_{n=j+1}^{M} \cdots \sum_{\substack{M=t+1 \\ k,l,m,n,\, \ldots,\, M \neq pus}}^{M} (a_{ij}a_{jk}a_{kl}a_{lm}a_{mn}a_{ni} + a_{in}a_{nm}a_{ml}a_{lk}a_{kj}a_{ji}) A_o \ldots A_t A_M\Big)\Big]$$

+-------

Where ‘pus’ in the above term stands for previously used subscripts. The above term for an M X M matrix consists of M+ 1 group of terms, each representing the measure of attributes and their relative importance loops. The first group represents the cumulative measure of all M attributes. The second group is absent as there is no self-loop in the digraph. The third group contains 2-attribute relative importance loops and measures of (M-2) attributes. Each term of the fourth group represents a set of a 3- attribute relative importance loop, or its pair, and measures of (M-3) attributes. The fifth group contains two sub-groups. The terms of the first sub-group is a set of two 2-attribute relative importance loops and the measures of (M-4) attributes. Each term of second sub-group is a set of a 4-attribute relative importance loop, or its pair, and the measures of (M-4) attributes. The sixth group contains two subgroups. The terms of the first sub-group is a set of a 3-attribute relative importance loop, or its pair, and 2-attribute relative importance loop and the measures of (M-5) attributes. Each term of the second sub-group is a set of a 5-attribute relative importance loop, or its pair, and the measures of (M-5) attributes. Similarly other terms of the equation are defined (Rao, 2007).

This permanent function is the desired numerical index based on which further analysis is done and conclusions are drawn.

5.2.2 Digraph, matrix and permanent function of a remanufacturing system

Following the methodology discussed above the digraph for the remanufacturing system will contain four nodes corresponding to the four main system parameters i.e., procurement, processing, recovery and marketing which directly affect the cost effectiveness of the system. The digraph for the overall system is shown in Fig. 5.2.

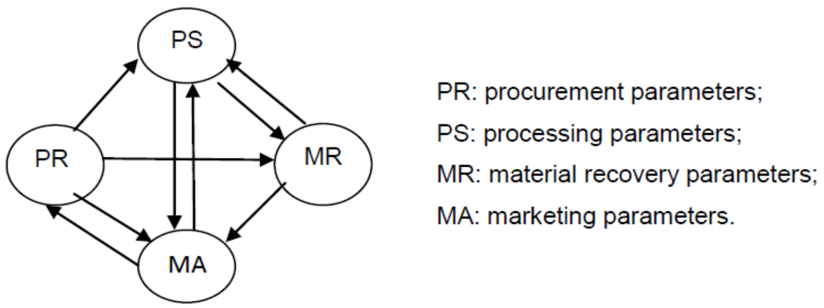


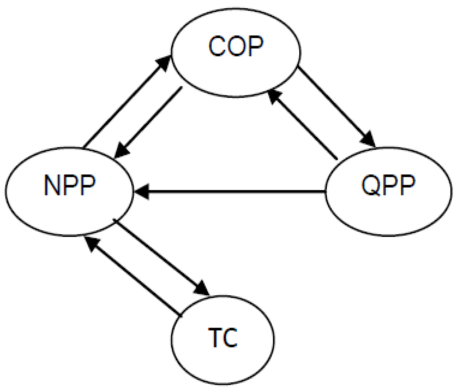
Figure 5.2. Digraph for remanufacturing parameters

The directed edges shown in the digraph indicate that the procurement parameters have direct effect on the processing parameters but the latter does not directly affect the former. Similarly, it can be seen that the processing and recovery parameters are mutually interdependent and so are the procurement and marketing parameters and the processing and marketing parameters. Likewise, the inter-relationship between other parameters can be interpreted from the digraph. This digraph is now translated into a corresponding matrix. The value of the diagonal and the off-diagonal elements is taken from tables 1 & 2 based on previous literatures and the author's own judgement skills. In a matrix, the off -diagonal element a_{ij} indicates the quantitative effect of parameter 'i' on parameter 'j'. Hence, if there is no arrow from a particular node ‘i’ to a node ‘j’ then the corresponding value of a_{ij} in the matrix would be written as zero. Hence the matrix for the overall system parameters is as given in Fig. 5.3.

$$\begin{bmatrix} & PR & PS & MR & MA \\ PR & D1 & 5 & 5 & 4 \\ PS & 0 & D2 & 4 & 3 \\ MR & 0 & 4 & D3 & 3 \\ MA & 4 & 4 & 0 & D4 \end{bmatrix}$$

Figure 5.3. Matrix of main system parameters

Here we have not written the values of diagonal elements. These values will be obtained from the permanent functions of the sub-parameter matrices. So, next we draw the digraphs and the corresponding matrices of the various sub - parameters listed in Figure 5.1.They have been illustrated in Fig. 5.4 to Fig. 5.7.



$$\begin{bmatrix} & NPP & COP & QPP & TC \\ NPP & D11 & 5 & 0 & 5 \\ COP & 3 & D12 & 3 & 0 \\ QPP & 3 & 4 & D13 & 0 \\ TC & 3 & 0 & 0 & D14 \end{bmatrix}$$

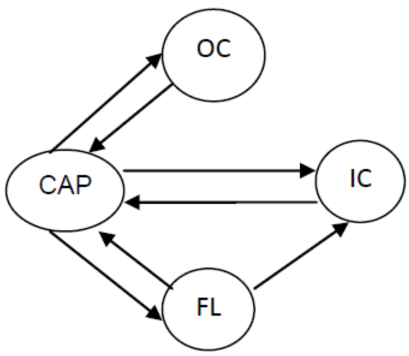
NPP: number of old products procured;

COP: cost of old product;

QPP: quality of products procured;

TC: transportation cost.

Figure 5.4. Digraph and matrix of procurement parameters



$$\begin{bmatrix} & CAP & OC & IC & FL \\ CAP & D21 & 5 & 4 & 3 \\ OC & 3 & D22 & 0 & 3 \\ IC & 2 & 4 & D23 & 0 \\ FL & 3 & 5 & 4 & D24 \end{bmatrix}$$

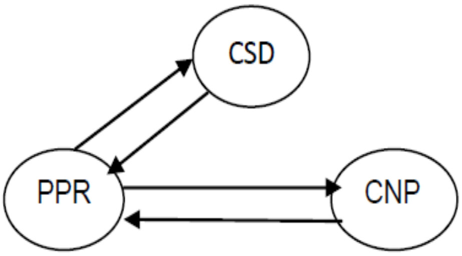
CAP: capacity of remanufacturing system;

OC: operating cost;

IC: inventory carrying cost;

FL: flexibility of the system.

Figure 5.5. Digraph and matrix of processing parameters



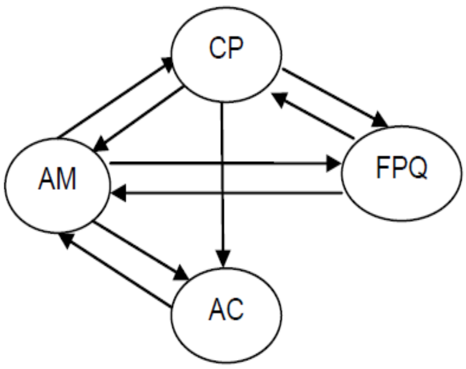
$$\begin{bmatrix} & PPR & CSD & CNP \\ PPR & D31 & 5 & 4 \\ CSD & 3 & D32 & 0 \\ CNP & 2 & 0 & D33 \end{bmatrix}$$

PPR: percentage of parts recovered;

CSD: cost of scrap disposal;

CNP: cost of purchasing new parts.

Figure 5.6. Digraph and matrix of material recovery parameters



$$\begin{bmatrix} & AM & CP & FPQ & AC \\ AM & D41 & 5 & 4 & 5 \\ CP & 3 & D42 & 4 & 4 \\ FPQ & 4 & 5 & D43 & 0 \\ AC & 5 & 4 & 0 & D44 \end{bmatrix}$$

AM: availability of market for remanufacturing;

CP: competition with other products;

FPQ: final product quality;

AC: advertising cost.

Figure 5.7. Digraph and matrix of marketing parameters

Now we shall compute the permanent function for each of the sub - parameter matrices. To do so, we require the values of the diagonal elements for each of the matrices. For a generalized case, we will compute the maximum and minimum values of the permanent function for each of the sub- parameters. To obtain the maximum values, we substitute all the diagonal elements with value 10, as that is the maximum value it can take (from Table 5.1) and correspondingly for obtaining the minimum values of the permanent function, we substitute all D_{ii}'s as 1 (from Table 5.1).The computed values of the maximum and minimum permanent function for each of the sub –parameters are listed in Table 5.3.

Parameter	Maximum value	Minimum value
Procurement	41130	268
Processing	16080	402
Material Recovery	1230	24
Marketing	23676	1869

Table 5.3 Maximum and minimum values of permanent function for the sub parameter matrices

Now the final step is to compute the range of the cost effectiveness index (CEI) for the overall system. For the maximum possible value of CEI we substitute the diagonal elements in the main matrix (shown in Fig. 5.3) with the maximum values of permanent functions for the corresponding parameters (from Table 5.3).

$$CEI_{max} = \begin{bmatrix} & PR & PS & MR & MA \\ PR & 41130 & 5 & 5 & 4 \\ PS & 0 & 16080 & 4 & 3 \\ MR & 0 & 4 & 1230 & 3 \\ MA & 4 & 4 & 0 & 23676 \end{bmatrix} = 1.9260101 \times 10^{16}$$

Similarly, the minimum value of the CEI is computed by substituting the D_i's in the above matrix with the minimum values of the permanent function for each of the parameters (from Table 5.3).

$$CEI_{min} = \begin{bmatrix} & PR & PS & MR & MA \\ PR & 268 & 5 & 5 & 4 \\ PS & 0 & 402 & 4 & 3 \\ MR & 0 & 4 & 24 & 3 \\ MA & 4 & 4 & 0 & 1869 \end{bmatrix} = 4.840891 \times 10^{9}$$

Hence, we obtain that the range of cost effectiveness index for a remanufacturing system is 4.840891×10^9 to 1.9260101×10^{16}.

5.3 Applicability of this model

In the above analysis, the graph theoretic approach has been used to obtain the range of the cost effectiveness index (CEI) for a remanufacturing system. Using this technique has enabled the inclusion of both quantitative and qualitative parameters in the model, which has enhanced the accuracy of the model manifold. The CEI has been calculated using the permanent function of a matrix. If the value of CEI obtained is closer to the maximum value, it indicates that remanufacturing can be suitably implemented with considerable cost saving. On the other hand, if the value of CEI lies closer to the minimum value, it means remanufacturing will have poor cost effectiveness for that particular product and hence should not be implemented. The mathematical model shown in this chapter is a demonstrative example and is applicable to a particular scenario and for the given set of parameters as taken in this paper. This work done can be used as a guideline to develop a model, which can prove to be a strategic decision making tool for production managers to decide upon the introduction of remanufacturing in their systems.

CHAPTER 6
REMANUFACTURING OF AN INKJET PRINTER: A CASE STUDY

The concept of remanufacturing has been discussed in detail in the previous chapters. A number of models and techniques have been discussed to check economic implementation of remanufacturing. This chapter deals with applicability of remanufacturing. Remanufacturing can be used for a number of products, mostly for those where functionality of the product weighs much more than the aesthetics. One such product is a printer. Printers essentially comprise of four main parts – the print head, the paper feed assembly, the cartridges and the stepper motor. In addition to refilling of cartridges, which is being done on a large scale, the other parts too can be remanufactured. This chapter provides a case study to propose that remanufacturing of an inkjet printer is a more economical option than purchasing a new one. The cost computations for remanufacturing a printer has been done and comparisons drawn with the price of a new printer to arrive at the stated results.

6.1 Remanufacturing of an inkjet printer – Background study

To elaborate upon the benefits and drawbacks of the remanufacturing process, the example of an inkjet printer has been taken up. Using this product, a detailed discussion on the forces promoting and opposing remanufacturing will be done in this section. For the past several years, the practice of remanufacturing printer ink and toner cartridges is being carried out in countries like Japan and United States, by companies like Hewlett - Packard, Canon, Epson, Ecoria and Dell (Matsumoto and Umeda, 2011). Cartridge is a low value product. However, this practice can be extended to the entire printer to broaden the prospects of remanufacturing and to increase the profits. Printers have a regular customer base comprising of printout shops, offices, business units and personal households. The life of a printer is around 5-7 years and it generally requires servicing once or twice a year. With time, as the condition of the components deteriorates, the need for replacement and hence the cost of servicing increases. Purchasing a printer at a high price and also bearing the service charges occasionally, will eventually add burden on the consumers' pockets. To overcome this, the company can propose an alternate option to the customers. The company can initiate 'exchange offers' and 'buy-back' schemes. Customers are given the choice of getting their old units replaced by new and upgraded models through 'exchange offers' or simply selling the old units to the company through buy-back scheme. The company is directly benefited by the economic advantage of discontinuing the service to old machines. Now instead of disposing, these collected returns are remanufactured by the company (Mukherjee and Mondal, 2009). The customer will get a remanufactured printer with the same performance level and at a much lower price. Also, the company can provide free servicing throughout the life of the remanufactured printer. This will not only help the company maintain good customer relations but also enable it to keep a close track of the shelf life of their device, thereby ensuring a regular acquisition of returns.

The printer essentially comprises of four main components – the print head, the paper feed assembly, the cartridges and the stepper motor. Each of these parts generally does not undergo major damage or wear during the life of a printer. Hence, their functionality can be conveniently recovered with little refurbishing. Components like the stepper motor and other auxiliary elements like fasteners, retainers etc. which generally replaced, can be purchased at low prices. Overall, the remanufacturing of printers can be economically implemented. Talking about the market forces, the primary factor for starting this business is procurement of sufficient returns. One of the factors to promote product return has already been mentioned above (exchange and buy back offers). Other means to encourage returns from customers is advertising the green image associated with remanufactured procured. Not only the quantity but the quality of returns also plays a major role in increasing the efficiency of remanufacturing. Better quality of returns ensures higher recoverability and reduces the cost of purchasing new parts for replacement. To avoid processing and transportation of bad quality returns, an initial visual inspection is done at the site of procurement. Information regarding the duration of service, frequency of use and maintenance records is also acquired. Once the basic quality check is done, the products are transported to the remanufacturing facility. The cost of transportation is one of the major costs in this process. However, with regularization of returns this cost can be controlled.

Another driving factor is the demand of such products and competition with their ne counterparts. Demand is generated by incentives like lower selling price, equal warranty and good after sales service. Moreover, a market for remanufacturing has been identified majorly in products with lower aesthetic value and higher operational value. It has been observed that the customer segment for new and remanufactured products are separate, thus reducing the risk of cannibalization of one by the other. Once these market forces have been studied, the next aspect is the process optimization. Developing a reverse logistics network with the required infrastructure and facility is paramount. Integrating remanufacturing with the conventional manufacturing system is considered a better option than generating a new system altogether. The reason is that it reduces the investment required and also results in complete utilization of the capacity. A common inventory or buffer stock can also be maintained for both. Remanufacturing is a technologically demanding and labour incentive process. Thus, the tools, equipments and the labour hired for should be highly adept and in sync with the cleaning and refurbishing operations required. The attributes discussed above have been depicted diagrammatically in the figure below.

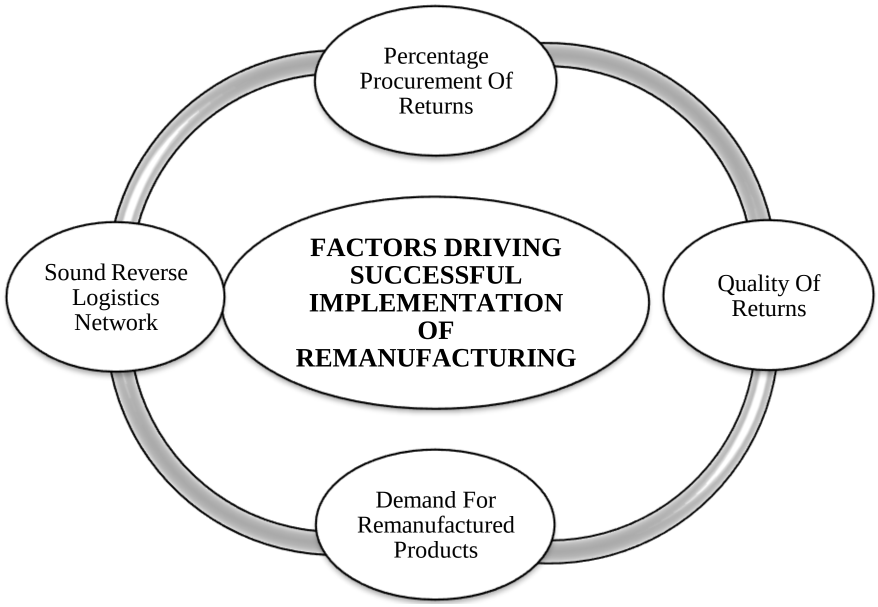


Figure 6.1 Factors driving successful implementation of remanufacturing process

With due consideration to the above parameters, a small hypothetical example of remanufacturing an inkjet printer is discussed below. The aim is to compute and compare the various costs incurred in the process and to show the profitability associated with going for remanufacturing.

6.2 Case study

Like any other business, one of the most important factors affecting remanufacturing is the overall cost. It has already been discussed how remanufacturing can prove to be a highly viable option when it comes to saving costs and gaining profits. However, at the same time it requires capital investment at initial stages and also during the processing of the recovered parts before reselling them. The analysis of remanufacturing with economy as an objective has been done for inkjet printers in this section.

The average selling price of a new inkjet printer in the market is around Rs. 5000. The printer runs for an average life of 6 years. During the lifetime it generally demands servicing atleast 6-7 times (considering the minimum case scenario of once a year). The minimum visit charges for a printer service is around Rs 300 excluding the cost of replacing any parts if needed. Hence, during the entire life of a printer, a user generally has to bear a minimum cost of around Rs. 6800 (i.e. 5000 + 6 * 300).

Now let us consider the option of remanufacturing a printer. An old printer is procured from the customer at 20 - 30 % the price of a new one. The price depends upon the strategic value of the product both from the market and user point of view. Printer is a low value product and thus can be procured from the consumer at a low price of Rs. 900-1000 per printer. This printer is then transported to the remanufacturing facility. Transportation is one of the dominant costs in remanufacturing owing to the scattered nature of the sources of the raw material (old printers in this case). Moreover, it is highly variable in nature and is dependent upon the type of product, number of products and the distance travelled. Thus, it is difficult to assign a definite value to it in a deterministic case scenario. In our study, the cost of transportation will be taken as a lump sum percentage before arriving at the final selling price of the remanufactured printer. Next, coming to the processing aspect. The printer is first thoroughly inspected externally to evaluate the initial condition. This is very important as it will determine the further course of action. This step can also be carried out at the source of procurement to get an idea about the chances of recovery of the parts and avoid the transportation of a bad quality product to the remanufacturing centre. Post inspection, the printer is completely disassembled upto the level of its finest components. The parts then undergo cleaning, repair and other reconditioning operations. The main parts which are strategically valuable from refurbishing point of view are the print head, the paper feed assembly and the cartridges. Rest of the parts like the motor can either be reused or replaced. Once the reworking is done, the parts are reassembled and the final testing is done on the part.

The range of the cost of each of these operations as percentage of price of new product is enlisted in Table 6.1. These have been used as reference for computing the different costs incurred during remanufacturing.

Cost component	**Cost per unit (% price of new product)**
Disassembly	0.23 – 1 %
Inspection	2- 4 %
Refurbishing	0.8 – 4 %
Inventory holding	0.4 – 1 %
Purchasing new parts	1- 10 %
Assembly cost	0.4 – 1.5 %

Table 6.1. Range of different processing cost components

The ranges have been determined by taking into account the economic criteria for remanufacturing. If the costs for multiple processes exceed this range, then they would render remanufacturing uneconomical. Based on the above table, the maximum processing cost shall be computed. An important parameter requiring due consideration here is the percentage of parts recovered during remanufacturing. It is a highly stochastic parameter and varies from product to product; with time period and condition of usage. From various studies and analysis, it has been concluded that remanufacturing can be sustained economically with atleast around 50 - 60 % recovery. With lesser than this recovery, the cost of subcontracting new parts would generally overshoot the cost savings by other means resulting in a higher remanufacturing cost. So, for all further calculation we assume 60 % recovery and 40 % replacement.

The calculation of the various costs and the total cost has been shown in the table below.

Cost component	Cost computation	Total cost per unit(Rs.)
Old product	20/100 * 5000	1000
Disassembly	1/100 * 5000	50
Inspection	4/100 * 5000	200
Refurbishing	0.6 *5* 4/ 100 * 5000	600
Inventory holding	1/100 * 5 * 5000	250
Purchasing new parts	0.4*5*10/100*5000	1000
Assembly	1.5/100*5000	75
Total cost		**3175**

Table 6.2. Cost calculations for different stages of remanufacturing

Hence we see that the total remanufacturing cost amounts to Rs. 3175. Adding an allowance of 10 % for transportation cost and a profit margin of 20 %, the final selling price of the product would be Rs. 4127.

This is around 20 % lower than the price of a new product. This difference in the prices has been obtained on the basis of the maximum cost scenario for remanufacturing. However, often the processing costs in remanufacturing lie on the lower side of the range and the percentage recovery of good components is higher. As the result the selling price comes down to Rs. 3000 - Rs 3500 (30 – 40 % below the price of new product). This profitability of selling price is a clear benefit for the customer. Even for the manufacturers of new printers, the profit margins are lower (only about 10 %) than that for remanufactured printers (20- 30 %). Hence, it can be proposed that printers can be economically remanufactured.

CHAPTER 7
RESULTS AND CONCLUSIONS

7.1 Summary of results

This study highlights the main idea behind a comparatively new concept of product recovery known as remanufacturing. Unlike other product recovery operations like recycle and reuse, remanufacturing involves complete dismantling of the product followed by reconditioning and reassembly. So, it is just like manufacturing, except that the raw materials for this process are the parts and components of the old discarded product. Also, remanufacturing adds greater value to the product than other recovery process and invokes new like characteristics into it. As a result, it is a much beneficial, economical and environment friendly technique.

Just like any other business, remanufacturing is also driven by several factors. The first and the most important being demand. To forecast the demand for any product, the most effective technique is to understand the customer perception about a product. For this purpose a survey was conducted and the customer responses towards remanufactured products under five product categories were recorded. From the survey, it was concluded that the awareness of this concept is still low in the Indian customer segment. They consider it equivalent to a second hand product and hence have low preference for it. According to them quality and cost are the most important criteria, while environment and aesthetics are least important. While all the above are favorable for remanufactured products, poor environmental concern is a setback. Stricter waste reduction and environment conservation laws and regulations are needed in India just like western countries to invoke a green responsibility among the customers. Another conclusion drawn from this survey was that the original equipment manufacturers should take up remanufacturing rather than local manufacturers. This was highlighted from the fact that customers give significant weightage to the reputation of the remanufacturer as well. OEM’s adopting this technique would instill greater faith among customers with regard to the quality and functionality claims of remanufacturing.

Apart from the demand, several other factors related to procurement, processing, material recovery and marketing affect the economy of remanufacturing. These parameters which consisted of both cost based and non- cost based parameters have been elaborated upon in this study. Based on the cost based parameters, a decision support system has been developed. It consists of a computer program generated using C++ programming language for economic evaluation of remanufacturing. That is, this program could be used by a manufacturer to decide whether to go for remanufacturing. The execution of the program was successfully shown with the help of input data pertaining to a mobile phone. The result shown by the DSS in this case was in favour of remanufacturing. As this DSS is highly interactive, easy to understand and execute, it is more user friendly than the other types of models like mixed integer programming or other mathematical algorithms which have been developed in the past.

This DSS was further used to determine the effect of different parameters on the cost of remanufacturing. The computer program was modified by applying a “for loop” in it. With the help of this loop, the parameter under study was varied within a certain range, and the cost of remanufacturing was calculated by the DSS. Based on the output the curves were plotted for each of the parameters. The maximum feasible values of the different parameters for economical remanufacturing were:

1) Percentage rejection of parts: 50% for subcontracting cost of Rs.300 and15% for subcontracting cost of Rs.400.
2) Percentage procurement : 42.5 %
3) Inventory carrying cost: Rs 342
4) Inspection cost: Rs 226
5) Refurbishing cost: Rs 363
6) Disassembly cost: Rs.483
7) Sorting cost: Rs 1205
8) Subcontracting cost : Rs. 326
9) Cost of old product: Rs. 2253

Also, the slopes of the curves of different processing costs were compared and it was inferred that the costs of inspection, subcontracting, inventory and refurbishing have a greater impact on the total remanufacturing cost as compared to disassembly, procurement and sorting costs.

The second technique applied was the digraph and matrix approach for calculating the maximum and minimum cost effectiveness index of remanufacturing system under a given set of attributes at the system and subsystem level. This index signifies whether implementing remanufacturing will be an economically viable option or not. The advantage of using this technique was the inclusion of qualitative attributes in the model by assigning definite scores to them. The range of cost effectiveness index for a remanufacturing system is 4.840891×10^9 to 1.9260101×10^{16}. From this result, the following conclusion can be drawn. If the value of CEI obtained is closer to the maximum value, it indicates that remanufacturing can be suitably implemented with considerable cost saving. On the other hand, if the value of CEI lies closer to the minimum value, it means remanufacturing will have poor cost effectiveness for that particular product and hence should not be implemented. The mathematical GTA model shown in this study is a demonstrative example and is applicable to a particular scenario and for the given set of parameters as taken in this paper. The work done can be used as a guideline to develop a model, which can prove to be a strategic decision making tool for production managers to decide upon the introduction of remanufacturing in their systems.

The last chapter deals with the case study of remanufacturing a printer. This chapter aims at extending the idea of remanufacturing printer cartridges, which is being practiced in Japan, USA and even in India, to the entire printer. To consolidate this claim, the cost of remanufacturing an inkjet printer has been calculated and compared to the cost of a new printer. Based on the computations done, it was observed that the maximum possible selling price of a remanufactured inkjet printer is around Rs.4127 while that of a new inkjet printer is around Rs 5000. This is around 20 % lower than the price of a new product. Moreover, this difference in the prices has been obtained on the basis of the maximum cost scenario for remanufacturing. However, often the processing costs in remanufacturing lie on the lower side of the range and the percentage recovery of good components is higher. As the result the selling price comes down to Rs. 3000 - Rs 3500 (30 – 40 % below the price of new product). This profitability of selling price is a clear benefit for the customer. Even for the manufacturers of new printers, the profit margins are lower (only about 10 %) than that for remanufactured printers (20-30%). Hence, it can be proposed that printers can be economically remanufactured.

7.2 Limitations and scope for future work

Every study has certain limitations due to constraints of research and conditions applied in it.

- This study has been conducted under static deterministic conditions. However, there are several attributes which are highly probabilistic in nature. It is possible to extend this work to dynamic modelling and simulation for a more realistic visualization.
- The sample space chosen for gaining customer perception was limited, covering a narrow stratum of people. The analysis has been done based on the feedback from fixed number of people. The results and trends may vary in a generic or universal scenario.
- Development of the DSS and GTA model in this study are based on a certain set of parameters as mentioned. These are aimed to serve as basic guidelines for understanding the process of remanufacturing for similar products and systems. The parameters can change from one system to another. Hence, the models may need modification or yield varied results accordingly.
- The study is dedicated to the economic aspect of remanufacturing. However, this technique is associated with several social aspects also like environmental conservation, waste reduction etc. There is tremendous scope for future work in these areas.
- Implementation of remanufacturing in the mechanical and heavy industries is yet to be explored. There has not been much research work related to remanufacturing in this sector.

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APPENDIX

Given below is the list of variables used in the C++ program and their meanings.

- **dem -** Demand for remanufactured products
- **demnew –** Demand for new product
- **prodproc -** Number of old products procured from customers
- **percentdem -** The percent value of demand as a percentage of demand for new products
- **prodsold –** Number of products sold in the previous unit of time
- **percentsold -** The percentage of products sold which are procured back
- **cap_veh -** Capacity of one transport vehicle in terms of the number of products it can carry
- **n -** Number of subparts
- **R1-** Percentage of products rejected after initial sorting
- **P_Rej –** Number of products rejected after sorting
- **P_Left -** Number of products left after sorting
- **r1-** Percentage of parts rejected after disassembly
- **r2 -** Percentage of parts rejected after refurbishing
- **p_left1 –** Remanufacturable parts recovered after disassembly
- **p_left2 –** Remanufacturable parts recovered after refurbishing
- **p_pur-** Number of parts subcontracted from outside vendor
- **Cnew –** Cost of new product
- **Cold –** Cost of old product paid to customer
- **Cveh –** cost of one transport vehicle
- **Csort –** Sorting cost per product
- **Cinv –** Inventory carrying cost per part for a specific period of time
- **Cdiss –** Cost of disassembly per part
- **Cinsp –** Cost of inspection per unit
- **Crefur –** Cost of refurbishing per unit
- **Csubcon –** Cost of subcontracting per unit
- **Cassem –** Cost of assembly per product
- **Creman –** Cost of remanufacturing per product

- **TCtrans –** Total cost of transportation
- **TCproc –** Total cost of procurement of old products
- **TCinv –** Total cost of holding inventory for the specific period of time
- **TCsort –** Total cost of sorting the products into remanufacturable and non-remanufacturable
- **TCdiss –** Total cost of dissembling the products
- **TCinsp1 –** Total cost of inspection after disassembly
- **TCrefur -** Total cost of refurbishing the parts
- **TCinsp2 -** Total cost of inspection after refurbishing
- **TCsubcon -** Total cost of subcontracting new parts from a vendor
- **TCassem -** Total cost of assembling the products after remanufacturing
- **TCreman -** Total cost of remanufacturing