Inventory Models for Manufacturing Process with Reverse Supply Chain

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BY

RABINDRA NARAYAN MAHAPATRA

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA - 769008, INDIA

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Dedicated to

My

Family

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA, INDIA

Dr. Bibhuti Bhusan Biswal
Professor and Head
Department of Industrial Design
NIT, Rourkela

CERTIFICATE

This is to certify that the thesis entitled "**Inventory Models for Manufacturing Process with Reverse Supply Chain**" being submitted by **Rabindra Narayan Mahapatra** for the award of the degree of Doctor of Philosophy (Mechanical Engineering) of NIT Rourkela, is a record of bonafide research work carried out by him under my supervision and guidance. He has worked for more than three years on the above problem at the Department of Mechanical Engineering, National Institute of Technology, Rourkela and this has reached the standard fulfilling the requirements and the regulation relating to the degree. The contents of this thesis, in full or part, have not been submitted to any other university or institution for the award of any degree or diploma.

(**Dr. B. B. Biswal**)

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ABSTRACT

Technology innovation leading to development of new products and enhancement of features in existing products is happening at a faster pace than ever. This trend has resulted in gross increase in use of new materials and decreased customers' interest in relatively older products leading to the deteriorating conditions of the environment due to the reduction of non-renewable resources and steady increase in the land fill of waste. This has forced organizations and communities to consider recovery alternatives such as reuse, repair, recycle, refurbish, remanufacture and cannibalize, rather than discarding of the products after end of life.

Products are retuned back or become redundant because either they do not function properly or functionally they become obsolete. The sources of these returns are Manufacturing returns, Distribution returns and Customer returns. The product recovery options in reverse supply are Repair, Refurbish, Re-manufacture, Cannibalize and Recycle. The main difference between the options is in the reprocessing techniques. Where Repair, refurbishing, and remanufacturing are involved in the up gradation of the used products in quality and/or technology with a difference with respect to the degree of up gradation(repair involves the least, and remanufacturing the largest),the cannibalization and recycling are involved in using parts ,components and materials of the used products.

Although much is being disused on the different recovery options still a lot of research remains to be done for improvement of the currently available techniques. In this context the present work focuses on remanufacturing option of recovery process for return items which is the most advanced and environmentally friendly production processes in use. Therefore the broad objectives of the present work are to deal with the different models of remanufacturing either new or existing for adding new features to it and making it simple and more user oriented, to develop deterministic models using direct manufacturing and remanufacturing for profit optimization, to develop and deal with probabilistic models of inventory with demand fluctuation using direct manufacturing and remanufacturing.to select and recommend a tool for predicting various critical parameters associated with the Reverse supply chain (RSC).to make these models usable to achieve maximum advantages by reutilization of resources integrating the upstream and downstream chains.

For the effective implementation of remanufacturing in Reverse supply chain, the entire work has been arranged in different chapters to present the distinct aspects of the research. Models are developed with special reference to remanufacturing. These models proposed helped in minimizing the gaps existing in the RSC in the

present scenario. The different models proposed for RSC are discussed on the basis of deterministic and probabilistic approaches. Although a lot of assumptions are intentionally made to make the models deterministic, still these models have its own identity in satisfying the needs of RSC. Two models are being discussed under deterministic approach. These models tries to find out the amount of new product supply to the market, the amount of remanufactured products supply to the market, the amount of products returned from the market and the amount of waste. Pertinent data from industry have been considered to prepare the models. The model variables are tested with adaptive-network-based fuzzy inference system (ANFIS), where the testing of the actual out come and desired outcome is done by using ANFIS. One of the proposed models is picked up to predict the critical parameters associated with RSC using remanufacturing.

Although the models dealing with the deterministic RSC models are simple still it becomes difficult to deal with a situation where there is a fluctuation of demand in the market, which is a common phenomenon. Therefore, it becomes inevitable to use the probabilistic approach for sorting out it. The aim is to deal with probabilistic models of inventory and models are proposed where the uncertainty due to fluctuation of demand and uncertainty in the return rate of used products is taken care of by using the safety stock. The determination of the safety stock is done on the basis of service level approach. The model variables are optimized using mathematical models considering the profit maximization.

The contribution of the present work is directed towards the environmental benefits. The manufacture of durable goods is one of the major contributors to the GNP of all developed countries. It employs large amounts of human resources, raw materials and energy. The raw materials and energy in the production of durable goods have been continually depleted. Many durable products are disposed in landfills at the end of their useful lives as well. The landfill space has been decreasing and the price charged by the landfills is increasing at a faster rate. This becomes an environmental concern. Remanufacturing, as discussed earlier is one of the predominant product recovery option for the return products. With respect to quality it is considered to be as good as new ones but with a lower cost of conversion. Therefore, focusing on remanufacturing option of product recovery not only decreases the depletion rate of virgin raw materials and rate of land fill but also contributes much towards the GDP as well as GNP. The models proposed in this work are simple and can be practically implemented to get benefits from the return items and still satisfying the market demand for sustainable production.

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D_1	Demand rate of new product [unit/time]
D_2	Demand rate of remanufactured product [unit/time]
c_1	Unit manufacturing cost for new product [Rs/unit]
c_2	Unit manufacturing cost for remanufactured product [Rs/unit]
α	Return rate of end-of-use products
P_1	Unit price of new product [Rs/unit]
P_2	Unit price of remanufactured product [Rs/unit]
Q_h	Number of units holding the product [units]
Q_s	Number of units of new product supply to the market [units]
Q_m	Number of units of remanufactured product [units]
Q_r	Number of units of return for end-of use products [units]
Q_w	Number of units of waste product [units]
a_1	Maximum units of sales of new product [units]
a_2	Maximum units of sales of remanufactured product [units]
b_1	Price sensitive to the customer for new product [Rs/unit]
b_2	Price sensitive to the customer of remanufactured product [Rs/unit]
γ	Sensitivity to price difference[units/Rs]
c_b	Unit buy back cost [Rs/unit]
s	Scaling factor
d	Demand rate
p	Production rate
C_1	Cost of holding inventory per item per unit time
C_2	Setup cost per production run for remanufacturing
C_3	Cost of setting up a production from raw materials
q	Number of items manufactured per run
q^1	Number of items remanufactured per run

t_1	Time Interval for the production run from raw materials
t_1^1	Time during which the stock is building
t_1^{11}	Time during which there is no production but consumption of inventory
I_m	Maximum level of inventory at the end of "t_1^1
t_2	Time during which the remanufactured items are consumed.
K^1	Remanufacturing rate.
q	Manufactured quantity during the cycle.
K	Rate of production (units/year).
R	Rate of consumption (units/year).
T_1	Time for which there is production/procurement as well as consumption.
T_2	Time in which there is only consumption and the stock level comes down to zero.
T_3	Time for which the production/procurement starts again realizing the back orders till the stock level comes back to zero.
r	The number of returned items collected from customers in unit time (units/time)
p	Capacity of the remanufacturing process (units/time)
d	Demand of finished products/serviceable(units/time)
C_s	Set up cost for the remanufacturing process (Rs/setup)
C_o	Ordering cost for new items (Rs/order)
C_{h1}	Inventory holding cost for the returned items for remanufacturing (Rs/unit/time)
C_{h2}	Inventory holding cost for the newly manufactured items (Rs/unit/time)
T	Cycle time.
t	Time after which remanufacturing initiates.

Abbreviations

SCM	Supply Chain Management
MRP	Material Requirement Planning
B2B	Business to Business
B2C	Business to Customer
OEM	Original Equipment Manufacturer
EOL	End of Life
SCOR	Supply-Chain Operations Reference
VRCD	Vehicle Recycling Development Center
DFD	Design for Disassembly
APRA	Auto Parts Remanufacturers Association
QM	Quality Management
SCQM	Supply Chain Quality Management
ESCM	Environmental Supply Chain Management
ETO	Engineer to Order
TCT	Transaction Cost Theory
TQM	Total Quality Management
BOSC	Build-to-order Supply Chain Management
SMEs	Small and Medium Enterprises

Chapter 1

INTRODUCTION

1.1 Overview

Over the past decade, there has been an increasing emphasis on supply chain management as a vehicle through which firms can achieve competitive advantage in markets. A large number of examples in the 1990s show how companies have made large investments to streamline their supply chains in order to improve customer satisfaction and increase their internal productivity. As Christopher [1] states, it is not actually individual companies that compete with each other now a days; rather, the competition is between rival supply chains. The supply chains that add the most value for customers with the lowest cost in the chain make up the winning network of individual companies.

Supply chain management offers an integrated philosophy for managing organizations purchasing and distribution processes based on a marketing perspective. Supply chain management is a homogenous management concept. The overall objective of supply chain management is to contribute to improvements in the company's bottom line or profitability. Related objectives include reducing the costs mainly by reducing the inventory level and increasing the revenues by improving customer service through coordination and integration along the material flow, win-win relationships and end customer focus. These imply that in order to achieve the objectives of supply chain management individual companies should coordinate and integrate their activities with other companies along the material flow in win-win relationships and focus their joint effort on the end customer. The supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer request. In addition to the manufacturer and suppliers, supply chain includes transporters, warehouses, retailers and customers. All the functions, fulfilling the customer request are included by the supply chain within the organization. The functions like new product development, marketing, operations, distribution, finance, and customer service are encompassed within these functions. In order to maximize the total profitability, supply chain management coordinates the management of flows between and within the stages of supply chain.

Supply chain management is the integration and management of supply chain organizations and activities through cooperative organizational relationships, effective business processes, and a high level of information sharing to create high performing value systems that provide member organizations sustainable competitive advantage.

Supply chain can be thought of the involvement of one player at each stage of the organization. In real case scenario, the material flow in manufacturing organization is a transaction between several suppliers to several distributors creating a supply chain network. Therefore, it is more accurate to use supply network or supply web to define the organization of supply chain, as shown in Fig. 1.1.

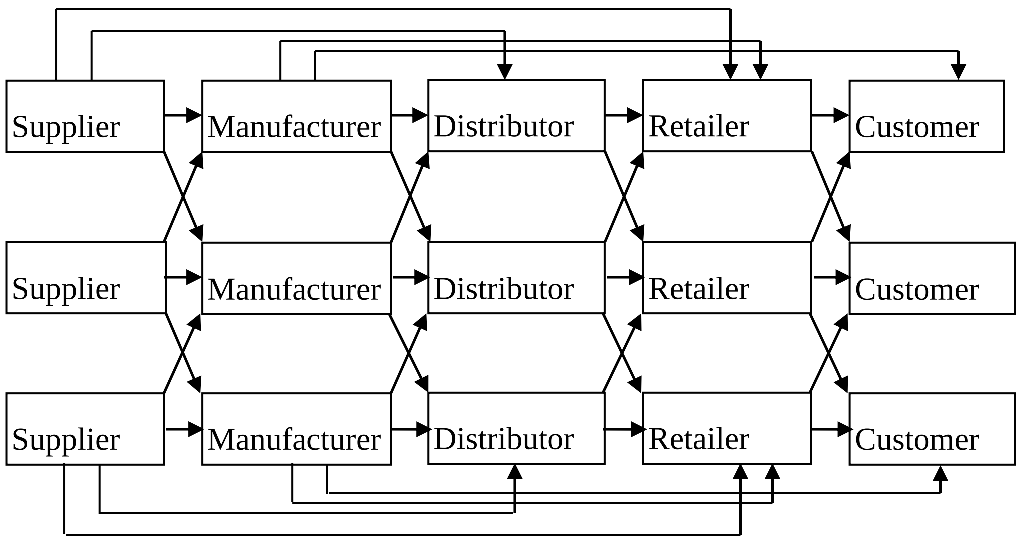


Figure 1.1: Stages of supply chain.

Directly or indirectly, the supply chain includes all the events, in fulfilling the customer request. SCM entangles challenges in developing trust and collaboration among supply chain allies, identifying best practices that can facilitate supply chain process alignment and integration, and successfully implementing the latest collaborative information systems and Internet technologies that drive efficiencies, performance, and quality throughout the supply chain. Network design in supply chain and demand forecasting in a supply chain are the main role in supply chain management. Industries and organizations in any supply chain must make decisions individually and collectively regarding their actions in five specific areas:

- **Production***:* What products does the market would like? How much and when of which products should be produced? This activity includes the creation of master production schedules that take into account capacity planning, workload balancing, quality control, and equipment maintenance management.

- **Inventory**: How much and when? What inventory should be stocked and when at each stage in a supply chain? How much inventory should be held as raw materials, semi- finished goods, finished goods and work in process? The primary purpose of inventory is to act as a cushion against uncertainty in the supply chain. As holding inventory can be expensive, hence the optimal inventory levels and reorder points are much important.

- **Location**: Where should facilities for inventory storage and manufacturing be located? What are the most cost efficient locations for manufacturing and inventory storage? Whether existing facilities be used or new ones built? These decisions determine the possible paths available for product to flow through for delivery to the end user.

- **Transportation**: Transportation refers to the movement of inventories from one location to another as it makes its way from the beginning of a supply chain to the end users. Most of the manufacturers & retailers have an intention to use state of the art supply chain management to reduce inventory & warehousing costs while speeding up delivery to the end customer. Air freight and truck delivery are generally fast and reliable but they are expensive on the other hand. Much less expensive methods like, Shipping by sea or rail but it usually involves longer transit times and more uncertainty. This uncertainty must be compensated for by stocking higher levels of inventory. Which mode of transportation to be used and when the key to success in field of supply chain management.

- **Information**: This particular area is related to data collection and information sharing. How much data should be collected and how much information should be mutual? Precise and timely information holds the guarantee of better coordination and better decision making. Without good information, people can never make effective decisions about what to produce and how much, about where to locate inventory and how best is to transport it.

1.2 Process views of a supply chain

The organization of Supply chain is a network of processes and flows taking place between and within different stages and optimize it to fill the customer need for a product.

The processes executed in a supply chain can be viewed in two different ways.

1. Cycle View: The processes in a supply chain network are divided into a number of cycles and each cycle is accomplished at the interface between two consecutive stages in the network.
2. Push/Pull View: Different processes in the supply chain are divided into two categories depending on whether they are initiated in response to the customer requirement (make to order) or expecting the customer requirement (make to stock).The make to order initiated by customer order are the pull processes and make to stock in anticipation of customer order are the push processes.

1.2.1 Cycle view of supply chain processes

All supply chain processes can be broken down into the following four process cycles considering the five stages of a supply chain shown in Fig 1.2[2],

- Customer order cycle
- Replenishment cycle
- Manufacturing cycle
- Procurement cycle

Each cycle is executed at the interface between two consecutive stages of the supply chain. It includes four detectable cycles within five stages which depends on the type of organization. In a grocery supply chain, the retailer maintains stock of finished goods and places renewal orders with distributor that includes all four cycles but in contrast to it, Dell bypassing the retailers and distributors, sells directly to the consumers. The six sub processes per cycle is given below

- Supplier stage that markets the product
- Buyer’s stage that places order
- Supplier stage that receives order
- Supplier stage that supplies order
- Buyer stage that receives supply

- Buyer returns reverse flows to supplier or the third party.

In each cycle, the sub-processes are linked in a definite way that starts with the supplier marketing the product to customers. The buyer then places an order which is received by the supplier. Then the supplier supplies the order that is received by the buyer. Some of the products or other recycled materials may be returned by the buyer to the third party or supplier. The cycle of activities is repetitive. The final aim of the buyer, within each cycle is to guarantee product availability and to accomplish economies of scale in ordering a product.

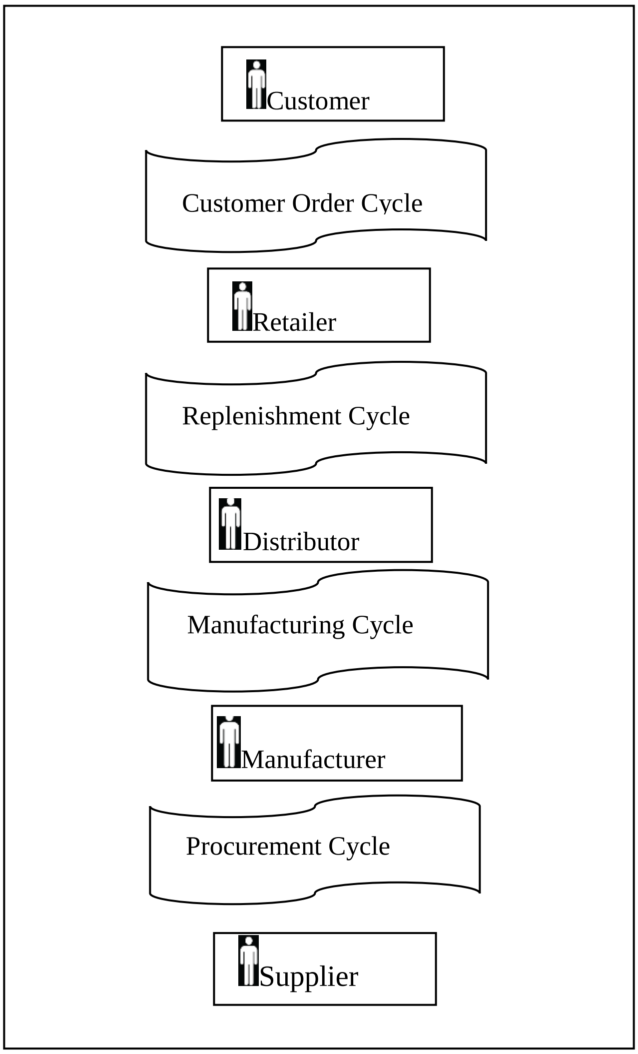


Figure 1.2: Cycle view of supply chain process.

In the process of forecasting the customer order and cost of receiving the order the responsibility of the supplier lies in fulfilling the order in time while taking care of the efficiency improvement and truthfulness of order replenishment process. The reduction of cost of receiving process is worked out by the buyer. To manage reduction of cost and meet environmental objectives, reverse flows are encouraged. Each cycle has the identical basic sub processes with a few key differences between different cycles. Demand, being external to the supply chain is uncertain. In order cycle the uncertainty lies in the order placement but it can be forecasted on the basis of policies framed by a supply chain network

1.2.2 Push/Pull view of a supply chain processes

All processes in a supply chain fall into one of the two categories depending on the timing of their execution in response to the demand of the end user. In the pull type processes, execution is initiated in response to the end user's order (make to order). But in the push type processes, execution is initiated in anticipation of end user's orders (make to stock). The pull processes are executed with a definite demand as the customer requirement is known, whereas the push processes are accomplished with an uncertain demand scenario as the demand has to be forecasted. As the pull processes react to the actual requirement of the customers, these are referred as reactive processes. Push processes are rather speculative in nature and referred as speculative processes as they respond to the speculative/forecasted demand. A clear demarcation in a supply chain between push and pull processes of L.L. bean is shown in fig. 1.3.The operational environment of push and pull processes lies in the uncertainty and certainty of the customer demand respectively. The pull system is easy to operate from the supply chain point of view. However there are certain restrictions imposed on the push system in the form of inventory and the capacity decision.

The execution of all processes in customer order cycle in L.L.Bean [2] takes place after the customer arrives. Hence all the processes in the customer order cycle are Pull processes. The fulfilment of the order takes place from the product in inventory. The processes in the replenishment cycle are performed in anticipation of the market demand thus a push processes.

The scenario is completely different in Dell [2] where customized computers are built to order.

There is no reseller or distributor in the network and Dell sells directly to the customers.

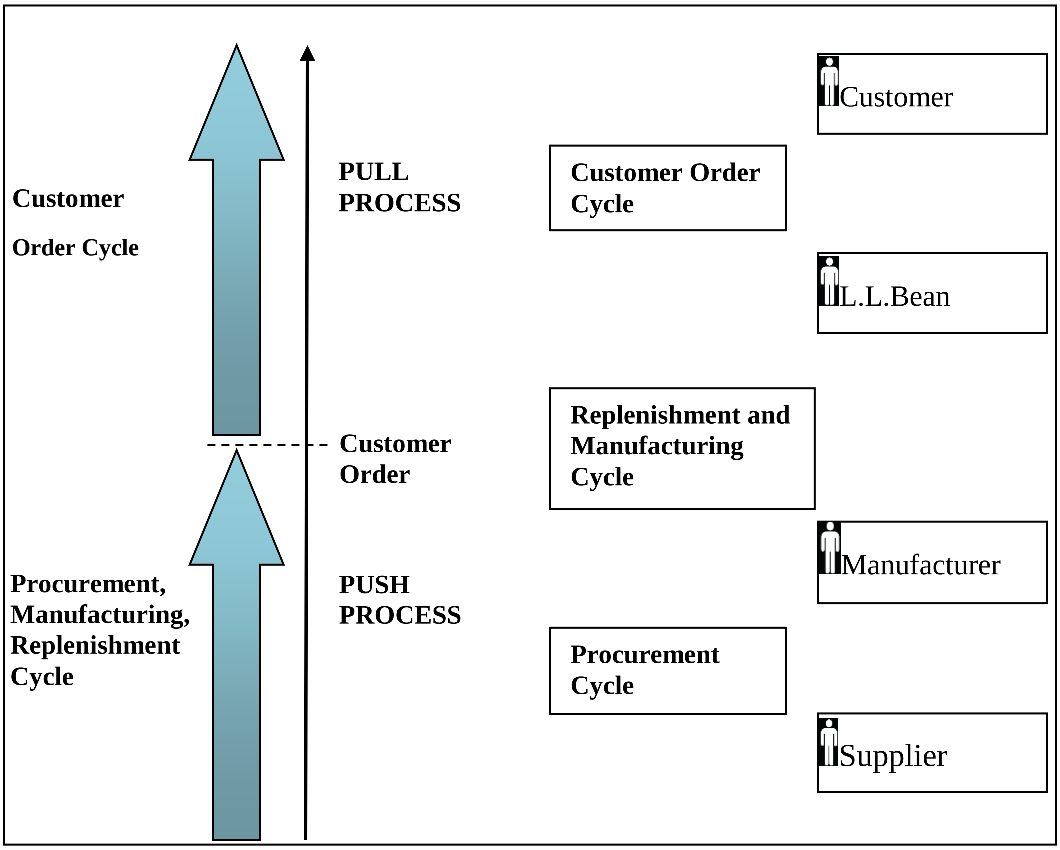


Figure 1.3: Push/Pull Processes for the L.L.Bean Supply Chain

Demand is filled from production and not from the finished product inventory. Dell operates on two cycles as shown in Fig 1.4

- Customer order and manufacturing cycle and
- Procurement cycle.

At Dell, all the processes in the Customer order and manufacturing cycle are thus pull processes as they are triggered by customer arrival. The push processes are the processes related to procurement cycle as they are in response to the demand forecast.

A push/pull view of supply chain is very useful when considering strategic decisions relating to supply chain design. To match the supply and demand effectively, the goal of the organization is to identify an appropriate push/pull boundary.

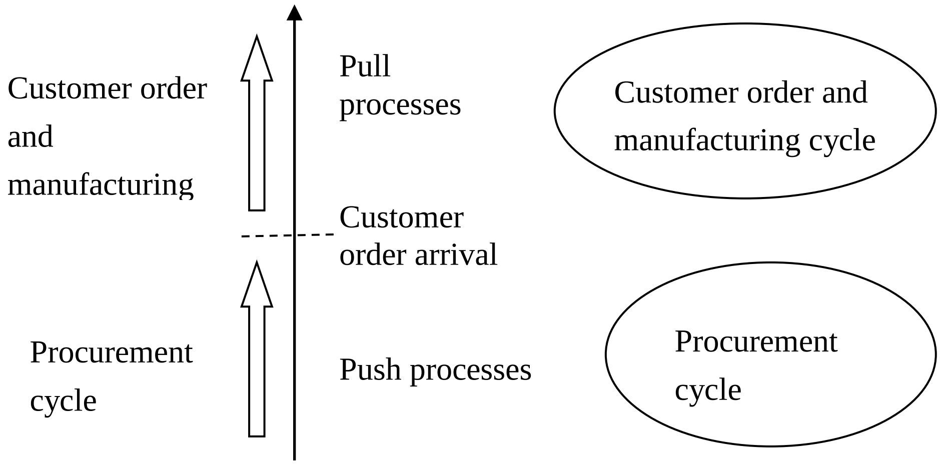


Figure 1.4: Push/Pull processes for Dell supply chain for customized PCs

1.3 Reverse supply chain

The weakening conditions of the environment, reduction of non-renewable resources, and the constantly increasing land fill of waste have forced organizations and communities to consider recovery alternatives such as reuse, repair, recycle, refurbish, remanufacture and cannibalize, rather than discarding of the products after end of life. In order to facilitate and support the recovery process, the basic pattern of the entire supply chain needs to be redefined so that related environmental concerns can be minimized. Therefore the reutilization of resources and integration of the upstream and downstream chains is highly essential.

Since long, firms are rigorous on getting products and services to the market and the amount of scientific assistance as well as business practices for the forward supply chain are largely explored. Contributions exploring the potential of the reverse flow from a practical point of view are relatively little. Whilst the tools and techniques like MRP, bullwhip effect, just-in time, lean production, mass customization, delayed product differentiation have been extensively explored both from a theoretical and operational point of view, a very few attempts has been made pertaining to the reverse supply chain, imparting the same knowledge. In evaluating reverse logistics tasks, the focus has traditionally been in minimizing costs ensuring a reasonable customer service and satisfaction. Over time, the recognition of the increasing value of products and technology created in the field at the end of the direct supply chain and the impact of the environmental legislation has forced companies to focus on different types of recovery programs.

1.4 Product returns: the various routes

In general, products are retuned back or become redundant because either they do not function properly or functionally they become obsolete. Therefore it becomes important to know the return reasons with usual supply chain stages starting with manufacturing, distribution and finally product reaching the customer. Therefore the returns can be divided under three heads like manufacturing returns, distribution returns and customer returns.

1.4.1 Manufacturing returns

Manufacturing returns encompass all those returns for which the need for recovery of components or products is identified during the production phase. This occurs for a number of reasons. left over raw materials, intermediate or final products not passing through quality checks and have to be reworked and products left over during production, or by-products resulting from production are the major reasons for manufacturing returns. The raw material surplus and production leftovers represent the ‘product not-needed’ category, while quality-control returns fit in the do not function category. Hence, manufacturing returns include:

- Raw material surplus
- Quality-control returns
- Production leftovers/by-products

1.4.2 Distribution returns

Distribution/supply returns refers to all those returns that are triggered during the distribution phase. It refers to stock adjustments, commercial returns, product recalls, and functional returns. A stock adjustment is the redistribution of stocks in the supply chain. Stock adjustments can occur between warehouses or shops for example in the case of seasonal products [3]. B2B commercial returns are all those returns for which a buyer has a contractual option to return products to the seller [4]. This can refer to wrong/damaged deliveries or to unsold products that retailers or distributors return to, e.g. the wholesaler or manufacturer. The latter includes out-dated products. This includes the products having a very short shelf life (perishable items) like, pharmaceutical products and food items. While the stock adjustments occur within a company, the commercial returns involve more than one company alone. Product recalls are products recollected because of safety or health problems with the products, and are initiated by the manufacturer or a supplier, and not the customer [5]. Product recalls fall in ‘distribution returns’ as they are usually initiated during this phase and they are anyway specially demanding with respect to distribution. Finally, there are products for which their inherent function makes them go back and forward in the chain. One can suggest calling these as ‘functional returns’. An obvious example is distribution carriers like pallets: their function is to carry other products and they can serve this purpose several times [6, 7]. Summarizing, distribution returns comprehend:

- stock adjustments
- B2B commercial returns
- product recalls and
- Functional returns (distribution items/carriers/packaging).

1.4.3 Customer returns

The customer returns comprises of returns initiated by the customers once the product has reached the final customer. This happens due to a number of reasons.

- B2C commercial returns (reimbursement/other guarantees),
- warranty returns,
- Service returns (repairs, spare-parts, etc.),
- end-of-use returns, and
- End-of-life returns.

As much as possible, the reasons have been listed according to the life cycle of a product. B2C commercial returns, like reimbursement guarantees, give customers the opportunity to change their minds about purchasing when their needs or expectations are not met (usually shortly after having received/ acquired the product). The list of underlying causes is long. For Reverse Logistics, questionnaires like why, what, how and who plays a vital role in finding out the causes of return. Independent of the underlying causes, when a customer returns a new product, benefiting from a money-back-guarantee or an equivalent, there lies the presence of B2C commercial returns. The next two reasons, warranty and service returns, refer mostly to an incorrect functioning of the product during use, or to a service that is associated with the product and from which the customer can benefit. Initially, customers benefiting from a warranty can return products that do not (seem to) meet the promised quality standards. Sometimes, these returns can be repaired. Otherwise, a customer may get a new product or his/her money back after which the returned product can be recovered. After the warranty period has expired, customers can still benefit from maintenance or repair services, but they no longer have the right to get a substitute product for free. Products can be repaired at the customer's site or sent back for repair. In the former case, returns commonly occur in the form of spare parts, since in advance it is hard to know precisely which components are going to be needed for the repair. End-of-use returns refer to those situations where the user has a return opportunity at a certain life stage of the product. This refers to leased products and returnable containers like bottles, but also to returns to second-hand markets as the one of Biblio find, a division of Amazon.com for used books (see Amazon.com, online). Finally, end-of-life returns refer to those returns for which the product as such is at the end of its economic or physical life. They are either returned to the OEM because of legal product-take-back obligations, or other companies like brokers, collect them for value-added recovery. Summarizing the typology 'return reasons' for reverse logistics in the three stages of a supply chain: manufacturing, distribution, and customer.

One should note however that the distinction between these three stages might be factitious. In practice it is not always easy to pinpoint exactly where manufacturing ends and distribution starts, as value may be added when some sort of distribution has already begun.

Recovering parts for reuse, repair, recycle, refurbish, remanufacture and cannibalize are the examples of reverse logistics having an attractive business opportunity and emphasizing sustainability. "…by ignoring the efficient return and refurbishment or disposal of product, many companies miss out a significant return on investment". Way back 1970; the supply chains were busy in fine-tuning the logistics of products from raw material to the end customer. Now also the Products are still streaming in the direction of the end customer but an increasing flow of products is coming back to the manufacturer. This is taking place for a wide range of industries. The major industries coming under this covers pharmaceuticals, electronic goods, beverages, sponge iron etc. the automobile industry is demanding the change in the physical and virtual supply chain to facilitate end-of-life recovery [9]. It is not surprising that the Reverse Logistics Executive Council has announced that US firms have been losing billions of dollars on account of being ill prepared to deal with reverse flows [10]. The return as a process was recently added to the Supply-Chain Operations Reference (SCOR) model, stressing its importance for supply chain management in the future[11]. There is a trend of recycling that is stretching out worldwide, involving all the layers of supply chains in various industry sectors. As some performers in the chain have been forced to take products back, others, attracted by the value in the used products return have positively done so. With much less ambiguity, reverse Logistics has become a key competence in the field of supply chain.

Though the inception of Reverse supply chain germinated out from long time ago, the very term is difficult to trace with precision and accuracy. Synonymous terms like Reverse Channels or Reverse Flow already appear in the scientific literatures way back in the seventies, but predominantly related with recycling [12, 13].During the next decade, the definition was inspired by the movement of flows against the conventional flows in the supply chain, as put by Lambert and Stock [14]. In the early nineties, a more logical and formal definition of Reverse logistics, a subset of reverse supply chain was put together by the Council of Logistics Management, stressing the recovery aspects of reverse logistics [15-18]. Logistics has been defined as that part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point-of-origin to the point-of-consumption in order to meet customers' requirements. Reverse logistics has been defined as the movement of product or materials in the opposite direction for the purpose of creating or recapturing value, or for proper disposal [19]. The reverse flow may consist of both product and packaging, and both have been studied in the literature.

In summary, the definition of Reverse supply chain has changed over time, starting with a sense of "wrong direction." going through an overemphasis on environmental aspects, coming back to the original pillars of the concept, and coming finally to a widening of its scope. For other discussions on the evolution of the definition of Reverse supply chain put forth by Fernandez [20] can be referred.

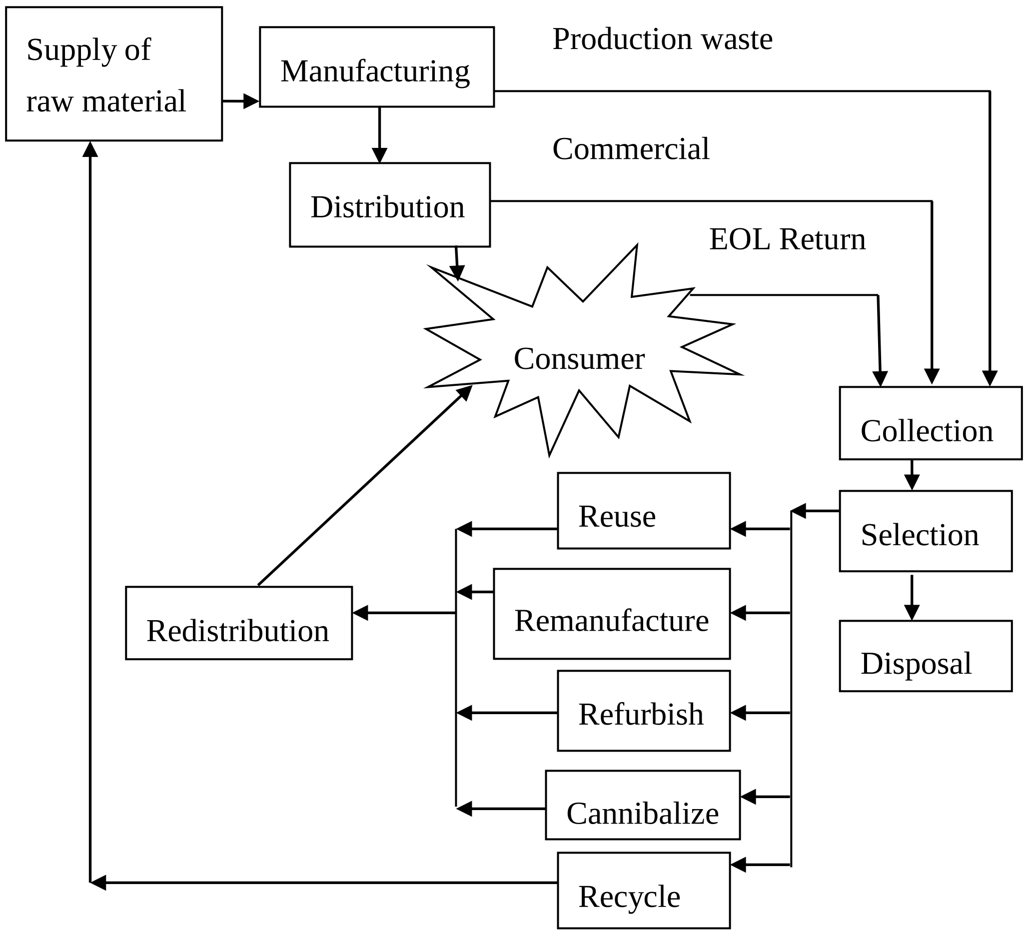


Figure 1.5: Framework of reverse supply chain

1.5 The Forward Supply Chain vis-à-vis Reverse Supply Chain

There lie a lot of differences between Forward and Reverse supply chains that rationalize the development of different theories for each region. For the scope of this work, the focus is mainly based on the analysis for the operations management issues of Reverse supply chain. It is worth noting that, all the organizational areas may be affected by the introduction of a Reverse supply chain system into a company. To investigate the differences between forward and reverse Supply Chain the following areas of work are being considered:

- Location theory and logistics network design
- Forecasting
- Inventory control
- Production /Remanufacturing
- Disassembly operations
- Reverse Distribution.

1.5.1 Location theory and logistic network design

This research area comprises of all the design of the reverse network. Primarily, it is concerned with the optimization of the location and capacity of the facilities and the flow of goods between them as well. The demands and operational costs are considered inputs to the location models in the conventional models. Since the secondary markets, disposal facilities, etc. also receive the product of the company in Reverse supply chain, the demands are located not only at one side of the chain but in both. Krikke [21] considers some elements that differentiate the Reverse supply chain network design from the forward one:

"Forward logistics systems are pull systems, while in reverse supply chain there is a combination of push and pull, due to the fact that there are clients on both sides of the chain, namely the disposer and the re-user. In forward logistics, only customer markets need to be served and the entire logistic chain, including suppliers (the 'equivalent' of disposers), adjusts itself to it. As a result of the extended producer responsibility, the amount of waste supplied to the reverse supply chain system (the push) cannot be influenced in the long run and has to be matched with demand (the pull). Disposal can serve as an escape route for unwanted waste, but the amount of disposal is limited by legislation."

Opposing to the divergent nature of forward supply chain, the reverse supply chain networks are both converging and diverging in nature. The return flows in the reverse supply chain are diverted into different processes like Repair, refurbishing, remanufacturing, cannibalization and recycling where the discarded/returned/EOL products are transformed into materials, components and secondary products. In contrast to it, in the forward supply chain there is the production unit where transformation takes place which serves as a source in the forward network.

The transformation process in reverse supply chain tends to be incorporated in the distribution network that covers the whole production process starting from the disposal to reuse. As only a fraction (not properly defined) of the return items are being used, an efficient design, operation and control spread over a high number of stratum. But the forward supply chain usually considers one or two levels.

Fleischmann et al. [22] in addition state the following difference:

"A particularity in the reverse distribution networks is their high degree of uncertainty in supply, both in terms of quantity and quality of used products returned by the consumers. Both are determinants for a suitable network structure since, e.g. high quality products may justify higher transportation costs (and thus a more centralized network structure), whereas extensive transportation of low value products is uneconomical. Moreover, end-markets for recovered products may not be well known, exposing network planning in this context to even more uncertainty."

There is always a uncertainty associated with the product return. Therefore it is difficult to make an assessment to the number and quality of the returned items until it is received. This type of situation makes the design of the logistic network more complex as the details of the demand are not available in advance. One can approximate the quantity of the returned items but the quality of the same remains a question mark.as the worth of the product is influenced by the quality and quantity of the returned items directly; it influences the decision of location and distribution.

One of the major issues in decision making is to stabilize the reverse network. Always there remains a trade-off of the returns through a centralized facility and different facilities close to the client's premise. Another characteristic issue that always puts the management decision in fix is whether to manage the RSC with the same facilities with which the forward supply chain is managed with.

1.5.2 Forecasting

The solution to the problem of forecasting is a difficult task in reverse supply chain. This activity consists in the estimation of the magnitude, timing, location and quality of the returns received. Many a times, returns arise from demand forecasting errors. Again, inaccurate forecasting may lead to some problems that emerge in the reverse supply chain activities. Looking at the other side, the lack of information of some secondary markets makes it difficult to estimate the number of buyers in those markets. Considering some areas like secondary packaging return, forecasting is addressed by considering the system as a closed loop, where the same elements are present in the system and there are some loses at each cycle. This approach helps forecasting since the problem is reduced to estimate the number of units lost at each cycle of the product. For secondary packaging is a good way of forecast, since the idea is to recover the entire package sent. Nevertheless, there is still a lack of established models available in this area.

1.5.3 Inventory control

To manage the return inventory effectively is also considered an important issue. The management of inventory has become more difficult with some identifiable issues when returns are integrated to the manufacturing processes.

- Ambiguity in the quantity of products received may result in excess stock or end up with stock out easily.
- Since the bar code is frequently worsened in returned items, it becomes difficult in identifying some articles.
- The occurrence of the following cases in some segments is frequent. The products with promotional offer are considered as new and dispatched to the market with a new code. At the time of return, without the promotional object these products are merged with the inventory with a different code of a single object. This complication generates problem of inventory balance while dealing with these cases.

Reasons, apart from these are also available to develop new models for the inventory management of the returns: Krikke [21] says that "Inventory management in product recovery situations is particularly different in those which are closed loop. In the remanufacturing environment, the increased system complexity and uncertainty resulting from interactions between forward and return flows, requires adapted control mechanisms". Fleischmann et al. [22] state three differences between reverse and forward logistics inventory control:

- In reverse supply chain, as a consequence of the return flow, the inventory level between new component replenishments is no longer necessarily decreasing but may increase also.
- This loss of monotonicity significantly complicates the underlying mathematical models.
- A possible starting point for a closer analysis of this aspect, are the cash balancing models comprising in and outbound flows.

When returns of goods and remanufacturing options have to be taken into consideration in inventory control situations, two additional sources of complexity appear in the traditional approaches of optimizing stochastic inventory control. Firstly, due to uncertainty of returns, an additional stochastic impact has to be regarded. Secondly, with remanufacturing a second mode of supply of serviceable goods is given, so that coordination with the regular mode of procurement becomes necessary. It can be shown that under these conditions one faces extremely complicated optimal control rules if the lead-times for remanufacturing and regular procurement differ. This holds for both the structure of the control policy and the inventory information necessary for optimal stock adjustment. In this context, the meaning of the inventory position, which is well-defined in traditional inventory control, is no longer evident. In practice, in these situations usually simple (suboptimal) decision rules are applied that only use a few control parameters and additionally do not take into consideration the complexity of defining the inventory position appropriately. For such a simple (4-parameter) control rule it is shown that by determining the inventory position in a proper way the performance of the policy can be improved considerably. This effect is equivalent to using the remanufacturing lead-time as a decision variable which has to be fixed in an optimal way.

1.5.4 Remanufacturing

Disassembly, remanufacturing and reassembly are the three different subsystems that build the foundation of the recoverable manufacturing system. The problems in this area arise as new products are manufactured using three kinds of components in remanufacturing:

- Recovered Components from returned products with uncertainty in quantity.
- Newly purchased Components.
- Contingent to availability and costs, components that can either be purchased new or recovered from returned products.

Krikke [21] shows some reasons for which traditional MRP-systems are not feasible for recovery situations: The primary problem is the bad fit of supply and demand. This is due to the concurrent release of desired and undesired components in the disassembly of returned items. A second most important problem is the compromise between reusing return components and using components outside procurement.

The management, planning, and control of RSC functions have become complex because of six characteristics, Guide et al. [23]. They are:

- The uncertainty in timing and quantity of returns.
- The need to balance demands with returns, that is supply demand balance.
- The necessity to disassemble the returned products.

- The uncertainty in materials recovered, that is related to the condition of return items
- The need for a reverse supply chain network for the existing process. and
- The difficulty of material matching restrictions.

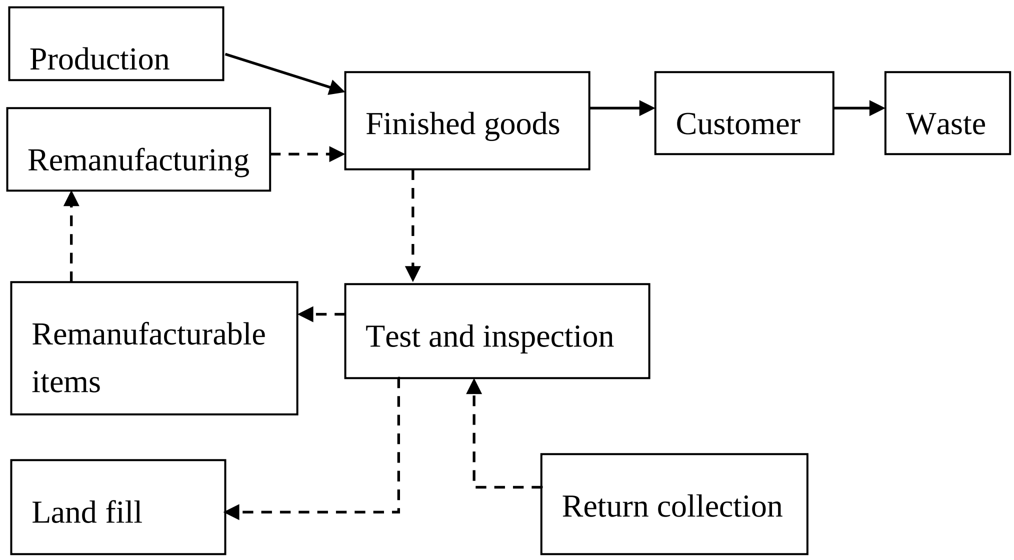


Figure 1.6: Remanufacturing cycle

An additional problem arising from a remanufacturing environment is that to manufacture a product the production path is uncertain, since depends of the returned materials and parts.

Remanufacturing offers tremendous untapped opportunities for businesses, consumers, work forces and the society as a whole. The most prominent beneficiaries of a successful and well managed remanufacturing process are given below.

- Business enterprises

  Reduction in capital investment expenditure; and

  Remarketing of the remanufactured products as a business strategy can increase profit.

- Consumers

  Lower prices in the order of 30-40 percent less than similar new products; and

More choice for discounted products in good condition

- The workforce

  A broader skill set and higher work satisfaction by engaging in remanufacturing.

- Society

  Remanufacturing helps in reduction in the energy consumption. Remanufacturing requires only about 15 percent of the energy used to make the product from scratch;

  Reduction in greenhouse gas emissions; and it helps in reduction in raw materials consumption for production of goods.

The importance of remanufacturing is evident from the above studies. Thus, developing a model that addresses the proper handling of this process is very valuable to original equipment manufacturers

1.5.5 Disassembly operations

Disassembly has a special identity which is not a part of forward logistics. This includes the activities related to inverse process of manufacturing. Experts working in the field of RSC relate it to remanufacturing. Several issues find its importance of discussion in this area. The first issue is whether to disassembly or not as there remains an ambiguity in quality of the returned items. There always remains a probability of getting a part of good quality for remanufacturing depending on the cause of return.

The next foremost important issue is related to the level of disassembly. There always remains a probability that some of the assemblies of the disassembled product may not work properly. If the company decides to disassemble it further then up to what level of disassembly is profitable to the company is difficult to decide.

In addition to the above problems another problem arises from upgrading or downgrading state of the product during its useful life. These changes are reflected in the return items due to repair, upgrading or downgrading, which adds to the uncertainty of the quality state of the assemblies when the product is disassembled. In general the products are not designed to support a disassembly process which leads to the risk of damaging the product during the disassembly operation. To minimize the risk of damage in the disassembly process at the end of life (EOL) of the product, companies are emphasizing now a days in Design for Disassembly processes.

1.5.6 Reverse distribution

As the conditions of the returned products are different from the new ones, it needs specific attention in the area the reverse distribution. For example, the new products should be easily palletized, which in turn allows companies to plan better for the capacity of the vehicles. It should be taken care that the returned products should correspond to a few or only one unit of a product and very well packaged, therefore the planning and establishment of the reverse distribution networks is more complex.

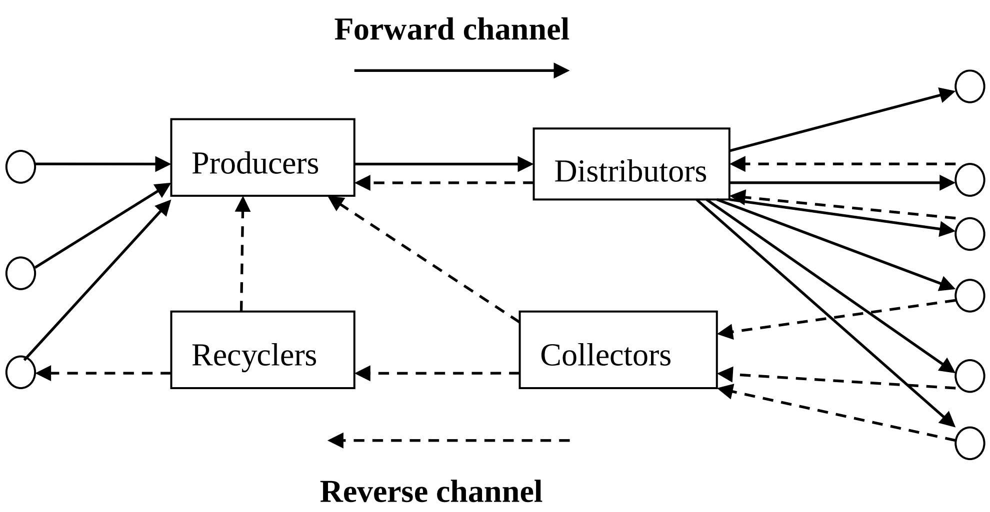


Figure 1.7: Framework of reverse distribution

Further complicacy lies in the ambiguity in number of products returned with definite lead time. Companies use to take back the return items in a reduced time frame after EOL. Apart from this, the frequency of return without prior approval of the manufacturer is much more. In some cases even without communication, the returns are sent by the retailor to the manufacturer making the issue complex. As one can observe, there are several reasons to develop new models for the improvement of the reverse supply chain operations.

1.6 Product recovery in reverse supply chain

The product recovery options in reverse supply chain involve collection of used products and components, reprocessing, and redistribution. The main difference between the options is in the reprocessing techniques. Where, Repair, refurbishing, and remanufacturing are involved in the up gradation of the used products in quality and/or technology with a difference with respect to the degree of up gradation(repair involves the least, and remanufacturing the largest),the cannibalization and recycling are involved in using parts ,components and materials of the used products.

1.6.1 Repair

Repair involves in returning the used products to "working order" with a decrease in quality. Product repair involves the repairing and/or replacement of broken parts, not affecting the remaining parts. Product repair usually requires only limited product disassembly and reassembly. Repair can be done at the customer’s location or at authorized manufacturing centers controlled by the manufacturer. It is to be noted that, large number of durable products manufacturers like IBM, DEC, and Philips are engaged in product repair.

1.6.2 Refurbishing

Refurbishing involves the disassembling of the used products into modules and inspecting, fixing or replacing all critical modules. The idea of refurbishing is to bring used products up to specified quality which is usually less rigorous than those for new products. Seldom it is found that, refurbishing is combined with technology upgrading by replacing the obsolete parts. The military and commercial aircraft can be cited as examples of products that are refurbished. The quality and service-life of refurbishing products are improved significantly. In this case the remaining service life of the refurbishing products is generally less than the new one.

1.6.3 Remanufacturing

The purpose of remanufacturing is to bring used products up to quality standards as close as the new products. The used products are completely disassembled followed by extensive inspection. Parts and modules that are worn-out and/or obsolete, are replaced with new ones. Remanufacturing can be combined with technological upgrading. A used machine tool can often be upgraded to "as new" quality and technology for 50-60% of the cost of a new one. High-value components such as engines, starter motors, and alternators have been remanufactured by BMW for a number of years. The remanufactured parts are subjected to rigorous quality check to achieve the standard of BMW exchange part.

Exchange Parts are then resold, with the same quality and warranty, at a price 30-50% cheaper than new parts.

1.6.4 Cannibalization

Out of product recovery options, in repair, refurbishing and remanufacturing a large proportion of used products are being reused. But in cannibalization, only a small proportion of used products is being reused. The aim of cannibalization is to recover a limited set of reusable parts from used products or components which are reused in repair, refurbishing, or remanufacturing of other products and components. Cannibalized parts are subjected to quality control which depends on the process in which they will be reused. The cannibalized Parts for remanufacturing have to fulfill stricter quality standards than parts for refurbishing or repair. The process of cannibalization involves selective disassembly of used products and inspection of potentially reusable parts. The remaining parts and modules are not used in cannibalization. For example, Aurora, a U.S. company, is mainly engaged in cannibalizing IC chips. In the process, the company takes out the parts they want from a computer followed by tests, straightens, redips, polishes, and the chips are sold. Sales have grown from zero to more than $40 million between 1988 and 1993.

1.6.5 Recycling

To retain the identity and functionality of used products and their components as much as possible, the previous product recovery options are mainly used. But in recycling, the identity and functionality of products and components is lost. The main purpose of recycling is to reuse materials from used products and components as raw materials. These materials can be reused in production of original parts if the quality of materials is high, or else in production of other parts or can be a input to other industries. The process of recycling begins when used products and components are disassembled into parts. These parts are separated into distinct material categories. These separated materials are subsequently reused in the production of new parts. Recycling is currently being applied to a number of used products. For example, virtually all metals in discarded cars (on average 75% of the weight of a car) are being recycled in Western countries like Germany, the UK, and the United States.

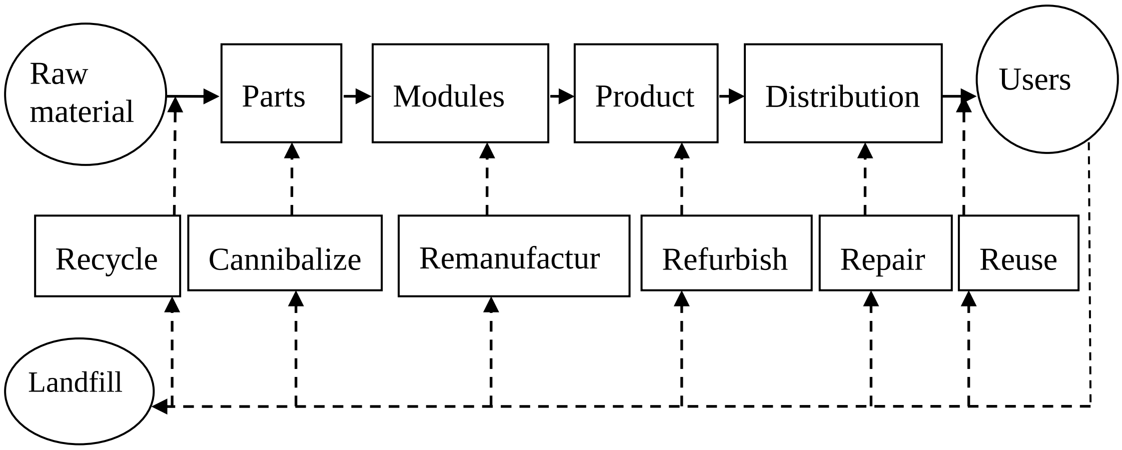


Figure 1.8: Product recovery in reverse supply chain.

1.7 Examples of Reverse Supply Chains across industries:

1.7.1 Computer/Electronics industry

The computer and electronics industry is known for short product lifecycles. A big market has emerged for used PCs — both in developing and developed countries. According to Gartner, 37 million secondary PCs were refurbished and exported to emerging markets in 2008.In emerging countries; approximately 15 million secondary PCs had to be discarded in 2007. Gartner estimates that by 2012, emerging countries will need to dispose of a total of 30 million secondary PCs annually. The need and opportunities for reuse of obsolete products cannot be over emphasized. Building to order is an effective way to minimize the return chain, as it allows manufacturers to postpone final transformation of the product until the end of the channel and configure the exact computer that the customer wants. The inventory holding period decreases sharply with this approach. This is in sharp contrast with the rest of this industry, which typically will have 30 to 60 days of inventory pre-sold into the channel. Manufacturers/retailers that sell directly to the customer and build to order have significantly lower return rates than the rest of the industry. Statistics indicate that return rates for these companies are around 5%, about half of what the rest of the industry experiences. In the words of one executive interviewed, “We send out a million computers. Pretty soon, most of them come back.” The build-to-order model, combined with direct sales, eliminates this problem. Manufacturers also contract with remanufacturing specialists to develop solutions to this problem. These specialists work with manufacturers to evaluate the root cause of returns, excess and obsolete machines, and develop methods to control cost and return rates. These companies test, recondition, repair, repack and then resell the machines. The functions of service center, warranty repair and other servicing are often outsourced to a third party that specializes in this business. These programs have led to lower returns.

1.7.2 Automotive industry

The automobile industry is one of the largest industries in the world and deals with the most expensive of consumer goods. Therefore, it is not surprising that reverse supply chains is an important subject for this industry. The three primary areas in which reverse supply chains plays a significant role are:

- Salvage of parts and materials from end-of-life vehicles.
- Remanufacturing of used parts.
- Stock-balancing returns of new parts from dealers.

The big three automakers in the U.S. have joined together to form the Vehicle Recycling Development Center (VRDC) in order to increase the recyclability of cars. At VRDC, the focus is on learning to build vehicles that can be disassembled more easily. The center is investigating one of the newest trends in engineering, Design for Disassembly (DFD). With DFD, product disassembly is made easier by reducing the number of parts, rationalizing the materials and snap-fitting components instead of using chemical bonds or screws. Unlike other environmental initiatives for manufacturing, DFD offers the possibility of many unintended positive effects, such as remanufacturing. The automobile industry may be the industry with the longest history of making use of old products. According to the Auto Parts Remanufacturers Association (APRA), the market for remanufactured auto parts is estimated at $34 billion, annually. The APRA also estimates there are 12,000 remanufacturing firms (including large-scale companies) involved in the auto parts industry. One particular company remanufactures more than four million alternators, starters and water pumps every year. Out of all the starters and alternators sold for replacement, 90% to 95% are remanufactured. The closed loop supply chain is now finding its importance in automobile sectors. Auto companies encourage their customers to bring their car to the dealers for replacement of old part with the remanufactured one. The dealer in turn sends back the old defective part to the automaker for remanufacturing. This makes the automaker to supply a stable supply of parts which is remanufactured. The estimated cost of reverse supply chains in the Indian auto and auto components industry is around 0.5% to 1% of total sales. The reverse supply chains segment has been growing at the same rate for both the auto and auto components industries during the same period.

1.7.3 Challenges

Always there remains a challenge across the manufacturing value chain for managing the reverse supply chains process. Some of these are interdependent while some are distinct. Some important points pertinent to this are given below.

- Meeting consumer needs: Customers always want the best price and completely flexible and hassle- free returns policies. This is particularly difficult to maintain in the framework of RSC.
- Volume management: Retail returns are generally high and additional to it, the total returns across the high-tech service industry are showing an upward trend. Especially during peak seasons, most of these returns are time-sensitive to process and restock for resale. If this issue is not managed properly the very objective of the RSC would end of with a loss.
- Management of costs: Expense management can represent up to 7% to 8% of the cost of goods. The process is labour intensive with very little automation.
- Data management: Always it is important to have an accurate data, but it is very difficult to obtain and manage relevant information. An organization should understand the data source, know how to analyse it and should use sub-contracting to the third-party experts if possible.
- Disposition of product: Disposition of product is sometimes over looked in the process of product recovery in RSC. Knowing the best location to handle, destroy, salvage and even where to donate products is critical. So is the ability to handle a supplier return, whether it is defective or working with overstock balancing.
- Regulatory compliance: Organizations require complete understanding of waste management laws, regulations and processes, including the company's corporate social responsibility.
- Partnership throughout the product lifecycle: The key factor is to have the right partner throughout the product lifecycle. Creating a strong and cohesive supplier agreement, jointly determining the best approach, cost sharing and having a positive relationship will help improve the bottom line for everyone.

1.8 Objective of research

With a greater importance and implementation of green law constraints, Consumer awareness has led to the need for safe return of products from the field of use. As a consequence, logistics planning has started considering both forward and return flows of products, parts, subassemblies, scrap and containers. It seems that an entirely new range of goods has emerged at what was once considered the end of the supply chain (forward).There are a number of variables available affecting the reverse supply chain, some of these is interdependent among each other.

The study of previous literatures and that of demand in industries provide ample indication that; there need to be an integrated study of forward supply chain management with reverse supply chain management. This would not only open an opportunity in helping the green supply chain but also can improve the profit level of the organization. Under this content the objective of my present research work are:

- To balance the supply chain with remanufacturing
- To compare the sensitivity of price difference with amounts of product for both the industries.
- To estimate the demand rate of new product and remanufactured product.
- Under the consideration of the case, to estimate the return rate and unit buying cost of end-of-use products from customer.
- To estimate the amount of returned product and the amount of waste product.

1.9 Methodology

Up till now many RSC models have been proposed by different researchers at different time and considering different business/manufacturing conditions. The present work envisages a generalized but optimized model which can be advantageously used for product manufacturing scenario that may use return goods and maintains business sustainability. The model has also the essence of green environment in the sense that it makes use of components from old and rejected goods which might have the potential of creating unnecessary waste inventory. The cost of the products manufactured through this route and the life expectancy as well as customer satisfaction are some of the important parameters for deciding/implementing such a model.

The proposed work shall use a remanufacturing model along with direct manu8facturing one for enhancing productivity and sustainable production. The core of the work involves development of mathematical models considering the practical constraints in order to make it more realistic. The work aims at optimizing the process variables through both deterministic as well as probabilistic approaches.

1.10 Organization of thesis

- The first chapter provides a brief description of the different dimensions of reverse supply chain, its relationship with forward supply chain and the outline theories pertaining to the RSC. Additionally this chapter describes the different reasons of return and the various options available to deal with the return items to extract value from it. Finally the chapter ends with some examples of industries using the RSC.
- The second chapter provides a review of literatures on RSC that have been prescribed by different authors from time to time. The underlying importance of this chapter is that it gives an idea on the limitations and future development on the work done by the authors in the field of RSC till now.
- The third chapter is a discussion on the different models available on RSC with special reference to Remanufacturing. This chapter helps in finding out the gaps existing in the RSC in the present scenario and is intended to fulfil the gaps and put forth objectives to minimize those gaps with the help of the remaining chapters.
- Chapter four is the first step in conceptualizing the deterministic Reverse Supply Models. The models proposed in this chapter are supposed to be the building blocks in forming a strong RSC structure. Although a lot of assumptions are intentionally made to make this model deterministic, still these models have its own identity in satisfying the needs of RSC. Two models are being discussed here.

    a. Modelling the Reverse Supply Chain with remanufacturing and

    b. Modelling the Reverse Supply Chain Inventory.

    The first one is the model of a plant dealing with the demand leakage due to the price variations. The lower price of the remanufactured product is assumed to trigger demand leakage from the new products to remanufactured products. This model tries to find out the amount of new product supply to the market, the amount of remanufactured products supply to the market, the amount of products returned from the market and the amount of waste. The second one is a deterministic model of inventory where a plant deals with both direct manufacturing and remanufacturing. The quantities of both direct manufacturing and remanufacturing quantities are optimized considering the minimum cost criteria.

- Although the previous chapter deals with the deterministic RSC models still it becomes difficult to deal with a situation where there is a fluctuation of demand in the market, which is a common phenomenon. Therefore it becomes inevitable to use the probabilistic approach for shorting out it. Chapter five deals with two probabilistic models of inventory where the uncertainty due to fluctuation of demand is taken care of by using the safety stock.

    a. A probabilistic approach for Reverse Supply Chain model for remanufacturing and

    b. A modified reverse supply chain with remanufacturing for sustainable product cycle

  The calculation of the safety stock is done on the basis of service level approach.

- Chapter six deals with the testing of the actual out come and desired out come by using adaptive-network-based fuzzy inference system (ANFIS).For this one of the models from chapter four has been considered.
- Chapter seven is exclusively designed for the results and discussions. The out puts from the chapter four, five and six is analysed by using graphs and results are compared followed by a brief discussion on the nature and variation of the input and output variables.
- The last chapter is the concluding part of the work. Occlusions are drawn based on the chapter seven and proposed models are prescribed with their advantages and limitations. The scopes for the future development of the proposed models are also described considering the type of industry and nature of the output.

1.11 Summary

This particular chapter is dedicated towards the collection and sharing of information, technical knowhow of operation of reverse supply chain and discusses the different dimensions of reverse supply chain along with forward supply chain. The basic motive behind this chapter is to make the readers know about the fundamentals of reverse supply chain.

The chapter starts with explaining the supply chain (forward) along with its different field of application like Production, inventory, location, transportation and information. It also tries to describe the cycle view and process views of supply chain(forward).The importance of reverse supply chain is described along with the different types of product returns that plays a vital role in managing the reverse supply chain.

A discussion on forward supply chain vs. reverse supply chain based on different areas of application is one of the major factors which draws a clear operational boundary between the two.

Going through the discussions on the different product recovery options at different conditions of returns, the readers can make themselves aware of the best recovery options to be adopted in practicing the reverse supply chain. Finally the chapter concludes with some examples of industries adopting reverse supply chain with its challenges.

Chapter 2

LITERATURE SURVEY

2.1 Overview

The present work surveys the different dimensions in the field of reverse supply chain. Managing the return flows, those appear in different forms of reuse of returned products and raw materials. The issues related to the optimization and utilization of return flow has acquired momentum in industrial production. Therefore there is total shift of attention towards the management of reverse supply chain during the past decades. Many authors have proposed different models considering different parameters affecting the logistics environment. In spite of this voluminous work, not a single model is able to solve all the issues related to reverse supply chain. Therefore it becomes extremely important to review the pros and corns of the issues relevant to reverse Supply chain. In this chapter, the reverse supply chain field is subdivided into some important areas namely Supply chain, Reverse supply chain, Risk analysis in RSC, Reverse distribution, Integration of forward and reverse distribution, Inventory control in RSC , SCM with remanufacturing and application of adaptive network based fuzzy inference system in RSC. Each field is reviewed and discussion and analysis is done on the reuse effort, the proposed mathematical models and the areas for future work. Care has been taken on the discussion on differences and/or similarities with the relevant classical forward supply chain method.

Reverse supply chain management is a very useful tool in the present industrial scenario. Many studies in the last decade describe the reverse supply chain management with remanufacturing. There have been a lot of research work and experimental inference for the generation of suitable and correct design of remanufacturing which is reflected through large number of literatures. The preliminary study of the subject necessitates a general review of the work carried out by various researchers. The relevant literatures are reviewed and the models of remanufacturing and systems of implementing those models in industry are discussed in the following sections.

2.2 Some important literatures related to the present work

There have been enormous research works in and around the focus area of the present piece of work. While following the literatures through various sources, the author could find some pertinent works that have been in the core of the area of the present research. Table 2.1 presents some of the important work carried out on supply chain management with remanufacturing.

Table 2.1 presents some of the important work carried out on supply chain management with remanufacturing.

Table 2-1: Some of the important work on Reverse supply chain management.

Sl.	Authors	Year	Topic	Remarks
1.	Michael Zhang and Peter C. Bell	2007	The effect of market segmentation with demand leakage between market segments on a firm's price and inventory decisions,	The demand leakage from high price to low price products is considered and customer's buy down behavior is considered considering demand leakage as a function of segment of price difference. the structure of optimal inventory and pricing policy is characterized
2.	Sergio Rubio and Albert Corominas	2008	Optimal manufacturing–remanufacturing policies in a lean production environment	This study analyses a production-management model that considers the possibility of implementing a reverse-logistics system for remanufacturing end-of-life products in a lean production environment .Decision variables including manufacturing and remanufacturing capacities and return rates and use rates for end-of-life products are identified and optimal policies are determined
3.	Shen Lian Chung, Hui Ming Wee and Po Chung Yang	2008	Optimal policy for a closed-loop supply chain inventory system with remanufacturing	A multi-echelon inventory system with remanufacturing capability is proposed. a closed-loop supply chain inventory model is developed and the joint profits of the supplier, the manufacturer, the third-party recycle dealer and the retailer under contractual design are maximized.

4.	Johan Ostlin, Erik Sundin and Mats Bjorkman	2009	Product life-cycle implications for remanufacturing strategies	The information on future market needs of remanufactured products is matched to information on the magnitude of return flows. Factors such as the mean product lifetime, rate of technical innovation, and failure rate of components are considered. Product life-cycle perspective is used to foresee the supply and demand situations
5.	Robert Pellerin, Javad Sadr, Ali Gharbi and Roland Malhame	2009	A production rate control policy for stochastic repair and remanufacturing systems	Remanufacturing operations for planned demand are executed at different rates, referring to different component replacement and repair strategies. A multi-level control problem along with a suboptimal control policy is proposed. The proposed control policy is described by inventory thresholds triggering the use of different execution modes which can lead to significant cost reduction.
6.	Erik Sundin and Bert Bras	2005	Making functional sales environmentally and economically beneficial through product remanufacturing	This paper argues the benefits for products to be used for functional sales should be remanufactured. To achieve an efficient remanufacturing process, the products aimed for remanufacturing should be adapted for the process as much as possible. Ease of access, ease of handling, ease of separation and wear resistance are the areas the product designers should focus on
7.	Yong Hui Oh and Hark Hwang	2006	Deterministic Inventory Model For Recycling System	Inventory policies and procedures for determining the optimal policy parameters for a recycling inventory system is presented
8.	Koh S.G., Hwang H., Sohn K.I. and Ko C.S.	2002	An Optimal Ordering and recovery policy for reusable items	optimal values of lot size R and Q are calculated for a recoverable process
9.	Mabini,M.C.,Pintelon, L.M. and Gelders,L.F.	1992	EOQ Type Formulation for Controlling repairable inventories	Economic purchase and repair quantities that would meet the needs of the organization is determined for a repair item inventory.
10.	Richter, K.	1996	The EOQ repair and waste disposal model with variable setup numbers	In a two shop case, lot sizes of newly manufactured products and repairable products is determined in order to meet the constant demand rate

11.	Richter, K.	1996	The extended EOQ repair and waste disposal model.	Different behavior of minimum cost, setup numbers, collection intervals and total lot sizes is studied and calculated in a two shop case.
12.	Teuner, R.H., and Vlachos,D.	2002	On necessity of a disposal option for returned items that can be remanufactured	hybrid production system with manufacturing and remanufacturing is analyzed
13.	Therry, M. C., Salomon, M., van Numen, J. A. E. E., and Van	1995	strategic issues in product recovery management	PRM opportunities and threats at different levels of return is analyzed
14.	Dobos, I ,and Richter, K	2004	An extended production/recycling model with stationary demand and return rates	By minimizing the inventory holding costs it was shown that one of the pure strategies (to produce or to recycle all products) is optimal
15.	Teunter. R , van der Laan. E	2002	On the non-optimality of the average cost approach for inventory models with remanufacturing	DCF inventory model with disposal and remanufacturing is studied,
16.	Richter.K and Sombrutzki M	2000	Remanufacturing planning for the reverse Wagner/Whitin models	Wagner/Whitin model for production planning and inventory control has been studied in a reverse fashion.
17.	Chung.S.L,Wee.H.M, andYang.P.C	2008	Optimal policy for a closed-loop supply chain inventory system with remanufacturing	An inventory system with traditional forward-oriented material flow as well as a reverse material flow supply chain is analyzed. A multi-echelon inventory system with remanufacturing capability is proposed. A closed-loop supply chain inventory model and maximize the joint profits of the supplier, the manufacturer, the third-party recycle dealer and the retailer under contractual design is developed.
18.	B. Mahadevan, David F. Pyke and Moritz Fleischmann	2002	Periodic review, push inventory policies for remanufacturing	Remanufacturing facility that receives a stream of returned products according to a Poisson process is studied. The performance of the system as a function of return rates, backorder costs and manufacturing and remanufacturing lead times is studied and an approximate lower and upper bounds on the optimal solution is investigated

19.	Martijn Thierry, Marcsalomon, Jo Van Nunen and Luk Van Wassenhove	1995	Strategic issues in product recovery management	The emphasis is given on the product recovery management. The objective of product recovery management is to recover as much of the economic (and ecological) value as reasonably possible, thereby reducing the ultimate waste quantity.
20.	Danny I. Cho and Mahmut Parlar	1991	A Survey of Maintenance Models for Multi-Unit Systems	This paper surveys the literature related to optimal maintenance and replacement models for multi-unit systems. The literature is divided into five topical categories: machine interference/ repair models, group/ block/ cannibalization/ opportunistic models, inventory/ maintenance models, other maintenance/ replacement models, and inspection/ maintenance models. This paper also provides the reader with a quick guide to a variety of classification schemes.

2.3 Supply chain management

Chen and Paulraj [24] observed that firms are linked in a networked supply chain because of rising international cooperation, vertical disintegration, along with a focus on core activities. This viewpoint leads to the challenge of designing and managing a network of interdependent relationships developed and fostered through strategic collaboration. They also observed that no research has been directed towards a systematic development of SCM tools although research interests in supply chain management are increasing. The authors identified and consolidated various supply chain initiatives and factors to develop key SCM constructs conducive to advancing the field. To this end, they analyzed over 400 articles and synthesized the large, fragmented body of work dispersed across many disciplines. The result of their study is a set of reliable, valid, and one-dimensional measurements that can be subsequently used in different contexts to refine or extend conceptualization and measurements or to test various theoretical models, paving the way for theory building in SCM.

Suhong Li, et al [25**]** opined that competition has shifted from the organizations to supply chains. They conceptualized, developed, and validated six dimensions of SCM practices (strategic supplier partnership, customer relationship, information sharing, information quality, internal lean practices, and postponement). Data for the study were collected from 196 organizations and the measurement scales were tested and validated using structural equation modeling. This study provided a parsimonious measurement instrument to assess the performance of the overall supply chain.

Kaynak and Hartley [26] argued that as competition moves beyond a single firm into the supply chain, researchers are beginning to explore quality management (QM) in a supply chain context. The literature suggests that supply chain management (SCM) consists of internal practices, which are contained within a firm, and external practices, which cross organizational boundaries integrating a firm with its customers and suppliers. Supplier quality management and customer focus are two QM practices that are also clearly in the domain of SCM. They investigated how these two supply chain management-related quality practices lead to improve performance and examine the practices that precede and mediate those relationships. They replicated and extended the relationships among the QM practices and their effects on firm performance suggested in using survey data gathered from firms operating in the U.S. The inclusion of customer focus and supplier quality management in the QM model supports the importance of internal and external integration for quality performance. Implications of the results for researchers and practitioners are discussed.

Foster Jr. [27] defined that supply chain quality management (SCQM) to operationalize and understand the effect of increased emphasis on supply chain management on the practice of quality management. He reviewed current research in quality management and identified common themes found in the literature. Key quality management content variables identified are customer focus, quality practices, supplier relations, leadership, HR practices, business results, and safety. He used these variables to propose areas for future research in the field of supply chain quality management.

Robinson and Malhotra [28] focused on supply chain management (SCM) concepts in recent years; its interlinking with the quality management perspective is often limited and tangential in nature. While the importance of quality management is universally recognized, academic researchers need a more focused approach in evaluating quality management issues within the internal and external supply chain contexts. Consequently they defined the concept of supply chain quality management (SCQM), and evaluated its relevance in academic and industrial practice by comprehensively reviewing prior quality and SCM literature in major journals and inductively identifying the themes that emerge within it. They took a more critical look at those published studies that specifically lie at the interface of quality and external SCM, and argued that quality practices must advance from traditional firm centric and product-based mindsets to an inter-organizational supply chain orientation involving customers, suppliers, and other partners. They also showed that SCQM across inter-organizational supply chains has received scant research attention, even though that perspective is sorely needed in delivering value to customers in often globally scattered supply chains. A case study of a firm that is a first-tier supplier in an offshoot of automotive supply chain is presented to better illustrate the SCQM themes and their treatment in industrial practice. Based on the present research, the case study, and experience of working with firms in the domain of quality management and the ISO 9001 certification processes, they proposed a Quality-SCM framework that can be used to place prior work in perspective, as well as identify three specific opportunities for future SCQM research.

Adriana [29] extended tourism developments and signals of the negative effects on destinations have put sustainability at the core of the business agenda. However, the fragmented structure of the tourism sector remains a key challenge for achieving consensus and developing coherent sustainable tourism strategies. Although supply chain strategies seem logically suitable for the interconnected nature of the tourism industry, there is limited discussion in tourism research about their adoption. This article explored the adoption of environmental supply chain management (ESCM) by eight large tour operators. The results of the investigations show that in the absence of regulatory pressures and cost saving benefits, the adoption of ESCM is triggered by public pressures and its implementation is limited by organizational factors and strategic myopia.

Chow,et al [30] used an empirical survey of middle-line managers in the US and Taiwan to study the association of supply chain management components and organizational performance. Through structural equation modeling, critical components of supply chain management are found to have considerable effects on organizational performance. The findings of the study are summarized as follows:

- Supply chain competencies have positive effects on organizational performance in both the US and Taiwan. Supply chain competencies are developed around quality and service, operations and distribution, and design effectiveness. The goal of supply chain competencies is to satisfy customer requirements.

- Supply chain practices, which are made up of supply chain features, integration, and customer services, have direct impact on organizational performance in Taiwan, but they have only indirect impact in the US.
- Supply chain practices and competencies are significantly associated in both the US and Taiwan. However, supply chain concerns and practices are associated in the case of the USA only.

These results help middle-line managers in both the US and Taiwan to know which components and practices of supply chain management to focus on to improve organizational performance. They also showed some of the similarities between the two regions and note differences that may be situation-dependent. However, what is measured here is the perception of middle-line managers. The actual practices may be different from these perceptions.

Seuring and Muller [31] found that academic and corporate interest in sustainable supply chain management has risen considerably in recent years. This can be seen by the number of papers published and in particular by journal special issues. To establish the field further, the purpose of this paper is twofold. First, it offered a literature review on sustainable supply chain management taking 191 papers published from 1994 to 2007 into account.

Second, it offered a conceptual framework to summarize the research in this field comprising three parts. As starting point related triggers are identified. This allows putting forward two distinct strategies:

- Supplier management for risks and performance, and
- Supply chain management for sustainable products. It is evident that research is still dominated by green/environmental issues.

Carlsson and Reonnqvist [32] used the concept of supply chain management and optimization is of increasing importance in the forest industry. The overall wood-flow starts with standing trees in forests and continues with harvesting, bucking, sorting, transportation to terminals, sawmills, pulp mills, paper mills and heating plants, conversion into products such as pulp, paper, lumber, and ends at different customers. Many planning problems arise along the chain and these cover different time horizons. Coordinating the wood-flow is a vital concern for many companies. They studied Seodra, one of the larger Swedish forest companies, which is involved in all stages of the wood-flow. They focused in particular on Seodra Cell AB, a company within Seodra, which is responsible for pulp production. They described the operations at Seodra Cell and the decision support tools used for supply chain planning. They described five major projects or cases which focus on improving their supply chain management and optimization. These cases included the introduction of new technologies for sales and orders, new distribution structures using terminals, and the development of integrated optimization models and methods.

Hicks et al. [33] represented the characteristics of Engineer to Order (ETO) companies are described in terms of their markets, products and the internal processes of their organization. These are set in the context of current trends in supply chain management. The business processes associated with the procurement and marketing functions and the interactions with other processes are analyzed. These are compared for a number of different types of ETO Company. The variety of work in ETO projects, the customized, complex products and the underlying uncertainties of markets all indicate that procurement and marketing need to be integrated with other processes, particularly tendering and design. These characteristics put constraints on the application of established supply chain management methods. It is argued that a strategic view of supply chain management in which procurement makes a greater contribution in the tendering and early product development activities has the potential to improve performance.

Kim [34] suggested a set of best organization structures for efficient supply chain management. They derived organization types for supply chain management according to the formalization and centralization level of an independent department responsible for supply chain management (SCM) activities, and hierarchical relationship in organizational position and operational responsibility between the SCM department and existing other functional departments. And then, they identified organizational characteristics, which have significant influences on SCM performance by investigating the difference in performance across the proposed organization types. From the results of empirical test, they found that even though too excessive formalization and centralization of the SCM department within a firm may interrupt complete SC integration and performance improvement, a certain range of control by the SCM department is inevitable to build the fundamentals of integrated supply chain management, and thus the temporary pursuit of intensive control focused organization type such as integrated line organization may be considered depending on firm characteristics and environmental change. However, the empirical results further indicate that in the long run, intermediate organization types such as Functional and Process Staff organization that the SCM department maintains an adequate level of balance and harmony with other functional departments while it controls, adjusts, and integrates various SCM activities effectively might be advisable. Yet, the study findings reveal that a more dynamic and extensive approach in reaching the best organization type for SCM performance is necessary.

Grover and Malhotra [35] studied transaction cost theory (TCT), it has received considerable attention from researchers in various disciplines of business. Unfortunately, the rich theoretical base of TCT has seen limited application in the operations and supply chain management research. They tended to change that by providing a cogent synthesis of TCT, its assumptions, constructs, and propositions. It also summarized existing empirical work in management and other disciplines that draws from the TCT perspective and examines relationships in manufacturing organizations. A measurement model of transaction costs is subsequently presented using data from 203 manufacturing firms in the OEM electronics industry. Guidelines and recommendations for researchers are then presented regarding both the uses of the theory and its measurement. It is hoped that this study will stimulate work in the important areas of inter-firm relationships that draw from this rich but underutilized theoretical lens, and thereby add another perspective to the knowledge base in related areas of the operations and supply chain management fields

Jung, et al.[36] observed in the petrochemical, chemical and pharmaceutical industries, supply chains typically consisted of multiple stages of production facilities, warehouse/distribution centers, logistical subnet works and end customers. Supply chain performance in the face of various market and technical uncertainties is usually measured by service level, that is, the expected fraction of demand that the supply chain can satisfy within a predefined allowable delivery time window. Safety stock is introduced into supply chains as an important hedge against uncertainty in order to provide customers with the promised service level. Although a higher safety stock level guarantees a higher service level, it does increase the supply chain operating cost and thus these levels must be suitably optimized.

Minner [37] reviewed inventory models with multiple supply options and discussed their contribution to supply chain management. After discussed strategic aspects of supplier competition and the role of operational flexibility in global sourcing, inventory models which use several suppliers in order to avoid or reduce the effects of shortage situations are outlined. Further, related inventory problems from the fields of reverse logistics and multi-echelon systems are presented. Finally, issued for future research and a synthesis of available supply chain management and multiple supplier inventory models are discussed.

Stlin, et al. [38**],** studied remanufacturing is an industrial process where used products are restored (remanufactured) to useful life. In comparison to manufacturing, remanufacturing has some general characteristics that complicate the supply chain and production system. For example, a company must collect the used products from the customers, and thus the timing and quality of the used products are usually unknown. Remanufacturing companies are dependent on customers to return used products (cores). Seven different types of closed-loop relationships for gathering cores for remanufacturing have been identified. The relationships identified are ownership-based, service contract, direct-order, deposit-based, credit-based, buy-back and voluntary-based relationships. By exploring these relationships, a better understanding can be gained about the management of the closed-loop supply chain and remanufacturing.

Ahire and Dreyfus [39] observed that design management and process management are two important elements of total quality management TQM implementation. They are drastically different in their targets of improvement, visibility, and techniques. They established a framework for identifying the synergistic linkages of design and process management to the operational quality outcomes during the manufacturing process internal quality. Through a study of quality practices in 418 manufacturing plants from multiple industries, they empirically demonstrated that both design and process management efforts have an equal positive impact on internal quality outcomes such as scrap, rework, defects, performance, and external quality outcomes such as complaints, warranty, litigation, market share. A detailed contingency analysis shows that the proposed model of synergies between design and process management holds true for large and small firms; for firms with different levels of TQM experience; and in different industries with varying levels of competition, logistical complexity of production, or production process characteristics. Finally, the results also suggest that organizational learning enables mature TQM firms to implement both design and process efforts more rigorously and their synergy helps these firms to attain better quality outcomes. These findings indicate that, to attain superior quality outcomes, firms need to balance their design and process management efforts and persevere with long-term implementation of these efforts. Because the study spans all of the manufacturing sectors SIC 20 through 39, these conclusions should help firms in any industry revisit their priorities in terms of the relative efforts in design management and process management.

Choi and Hartley [40] found that the US auto industry has undergone tremendous changes during the past decade. Companies have increased their level of out-sourcing and are relying more heavily on their supply chain as a source of their competitive advantage. Thus, determining which suppliers to include in the supplier chain has become a key strategic consideration. However, they compared supplier-selection practices based on a survey of companies at different levels in the auto industry. In this work the findings rebut the common thinking that indirect suppliers who are more involved in commodity purchasing emphasize initial price and de-emphasize relational considerations. They learned that selecting suppliers based on the potential for a cooperative, long-term relationship is just as important to direct and indirect suppliers as it is to the auto assemblers. They also learned that price is one of the least important selection items, regardless of position on the supply chain. Further, contrary to the existing understanding that quality and delivery are separated constructs, they formed a single construct in this study. To summarize the empirical results, no differences among the auto assemblers, direct suppliers, and indirect suppliers were found for the importance placed on consistency (quality and delivery), reliability, relationship, flexibility, price, and service. Statistically significant differences were found between the auto assemblers and indirect suppliers on the importance placed on technological capability and financial issues.

Gunasekaran and Ngai[41] studied the build-to-order supply chain management (BOSC) strategy has recently attracted the attention of both researchers and practitioners, given its successful implementation in many companies including Dell computers, Compaq, and BMW. The growing number of articles on BOSC in the literature is an indication of the importance of the strategy and of its role in improving the competitiveness of an organization. The objective of a BOSC strategy is to meet the requirements of individual customers by leveraging the advantages of outsourcing and information technology. There are not many research articles that provide an overview of BOSC, despite the fact that this strategy is being promoted as the operations paradigm of the future.

Gunasekaran and McGaughey [42] studied Supply chain management (SCM) has been a major component of competitive strategy to enhance organizational productivity and profitability. The literature on SCM that deals with strategies and technologies for effectively managing a supply chain is quite vast. In recent years, organizational performance measurement and metrics have received much attention from researchers and practitioners. The role of these measures and metrics in the success of an organization cannot be overstated because they affect strategic, tactical and operational planning and control.

Performance measurement and metrics have an important role to play in setting objectives, evaluating performance, and determining future courses of actions. Performance measurement and metrics pertaining to SCM have not received adequate attention from researchers or practitioners. They developed a framework to promote a better understanding of the importance of SCM performance measurement and metrics. Using the current literature and the results of an empirical study of selected British companies, they developed the framework presented herein, with a hope that it would stimulate more interest in this important area.

Bhagwat and Sharma [43**]** developed a balanced scorecard for supply chain management (SCM) that measures and evaluates day-to-day business operations from following four perspectives: finance, customer, internal business process, and learning and growth. Balanced scorecard has been developed based on extensive review of literature on SCM performance measures, supported by three case studies, each illustrating ways in which BSC was developed and applied in small and medium sized enterprises (SMEs) in India. They suggested that a balanced SCM scorecard can be the foundation for a strategic SCM system provided that certain development guidelines are properly followed, appropriate metrics are evaluated, and key implementation obstacles are overcome. The balanced scorecard developed in this paper provides a useful guidance for the practical managers in evaluation and measuring of SCM in a balanced way and proposes a balanced performance measurement system to map and analyze supply chains. While suggesting balanced scorecard, different SCM performance metrics have been reviewed and distributed into four perspectives. This helps managers to evaluate SCM performance in a much-balanced way from all angles of business.

2.4 Reverse supply chain

The increasing growth in consumer waste in recent years has become an environmental issue. Product recovery is therefore practiced in different ways to safe guard the environment and makes more profit. The Product recovery aims to minimize the amount of waste sent to landfill sites by recovering materials and parts from old or outdated products by means of repair, recycle, refurbish, remanufacture and cannibalize, Product recovery includes collection, disassembly, cleaning, sorting, repairing, reconditioning, reassembling and testing Gupta and Taleb [44]. In support to this, Brennan et al. [45] has opined the establishment of disassembly plants with the concept of product designs to facilitate disassembly enabling manufacturers to carry out item segregation. The relevant issues associated with item segregation like the operations and production planning and control

Product recovery and reuse of products and materials is not a new experience. Waste paper recycling, metal scrap brokers, and deposit systems for soft drink bottles are all examples that are in practice for a long time. These cases find recovery of the used products is economically more attractive than disposal. In the recent past an increasing attention has shifted towards ‘reuse’ because of the growth of environmental concerns. Recovering parts for reuse, repair, recycle, refurbish, remanufacture and cannibalize are the examples of reverse logistics having an attractive business opportunity and emphasizing sustainability. “By ignoring the efficient return and refurbishment or disposal of product, many companies miss out a significant return on investment”, Andel [46]. Effective management of reverse flow can result in direct benefits, including improved customer satisfaction, decreased inventory levels, and reductions in Distribution and storage costs .The idea of reuse with waste reduction has triggered the economy of the developing countries. Paper recycling rate in 2010 in Europe is 68.9% which when compared to the recycling rate of 46.6% in the year 1995 shows a definite inclination towards reuse. The recycling rate of glass has reached even more like 67.42% in Europe in 2009.The total reuse and recycling rate of end of life vehicles arising in the member state and treated within or outside the member state for France has increased from 79.6% in 2006 to 79.9% in 2008. Dutch industry generated 16.6 million tons of industrial waste in 2009,out of which 15 million tons, that is 90.36% are recycled and the remaining are dumped or incinerated.(CBS 2010).

As compared to this Dutch industry generated 20.2 million tons of industrial waste in 2002, 3% less than in 2001 and 83% of this waste was recycled (CBS 2003). The facts presented above leads to the conformation that the reuse opportunities are investigated more and more which gives rise to a new channel of flow from the user back to the sphere of producers. The management of this material flow opposite to the conventional supply chain flow is the concern of the recently emerged field of 'reverse logistics' (Stock, 1992)[47]; (Kopicki et al., 1993)[48].The review of this paper is limited towards the different models and analysis of the same in different spheres of reverse supply chain. Reverse supply chain includes the logistics activities all the way from end of life products to the products again usable in a market. Analysis of the term reverse in reverse supply chain reveals the fact about the flow and distribution of the items (used) in the reverse direction from the end user to the manufacturer. Thus the flow is affected by the frenzied market scenario which is full of risk, thus comes the risk management aspect. The flow is affected by the distribution channel. An optimized and well-judged distribution channel can only be able to overcome the problems in getting back the items collected from the end user to the producer, thus the distribution channel. The next step in the reverse logistics is to transform the returned materials to useful products so the inventory control aspect is included. All these activities is strongly controlled by the production planning and control tool. These are the domains which forms the frame work of this chapter. The layout of the remaining chapter is as given below. The section 2 is basically dedicated to the discussion on the considered field. Sections 2.5 to 2.9 are committed to the discussion and review on risk management, Distribution channel, inventory control and remanufacturing respectively. Care has been taken for presenting a short discussion of each reference to provide the relevant readers with a broad overview of the topics investigated so far. In this context, the author hopes to have mentioned the most relevant references. Last but not least, Section 2.11 and 2.12 states some general conclusions that will make the readers aware of the overall impact and benefits of practicing reverse supply chain. With an intention to create an idea among the scholars not yet familiar with the issues of reverse supply chain, it is recommended to the readers to carefully collect an overview on the major issues relating to reverse supply chain.

2.5 Risk analysis in reverse supply chain

There are a number of reasons responsible to determine the Returns policies. A well-structured overview of types of returns policies and reasons for their use is provided by Padmanabhan and Png[49]. Chu [50] has cited two reasons for ordering to satisfy the demand. One reason is, when demand is high it allows a manufacturer to credibly signal demand information to the distributor, inducing him to order enough product. Another reason is to reduce the distributor’s overage cost, inducing him to order more. Hence a much needed return policy is required to avoid the distributor to order less than in the integrated channel since his margin is smaller than the integrated channel. According to Pasternack[51] if returns parameters are properly chosen it can induce the distributor to order an optimal amount for the channel. The distributor and manufacturer can agree upon a pair that is Pareto optimal within this set of parameters, a large number of papers with similar approach as Pasternack [51] adopted for single-product returns policies. The basic approach is to find a returns policy structure with a number of parameters like wholesale price, returns price, return allowance, etc and then finding sets of these parameter values to induce the distributor to make order decisions that optimize the integrated channel. Finally one of the sets is selected so that both parties have larger expected profit. Many supply contracts are mathematically equivalent to returns policies were discussed by Lariviere,[52]. A good number of papers using this approach under various policies and models including Kandel[53], Emmons and Gilbert [54], Donohue [55], Taylor [56],Tsay[57] and Brown and Lee [58] are available. A different approach considering the issue of risk is put forth by Webster and Weng[59]. They have evaluated the returns policies that increase the retailer's expected profit while ensuring the manufacturer's worst case profit will always be at least as large. Ferguson et al. [60] examine a situation in which consumers may return the products to the retailer with no functional or cosmetic defect. A rebate mechanism is developed by them to attract the retailer to increase her effort to reduce the number of false returns. By considering the single-product case, they show that the rebate mechanism is Pareto optimal. Focusing on the relationship between performance of companies in terms of managing product returns and customer loyalty, Ramanathan [61] studied in the context of the business-to-consumer (B2C) segment of electronic commerce,. The analysis presented mainly contributes to the literature by providing a risk perspective to existing studies. They have analyzed the relationship between performance of companies in handling product returns and firm performance. Their analysis considers only ease of returns/ refunds as the indicator.

An analytical model for the use of e-marketplace in a supply chain is provided by Choi,T.M. et al[62]. They have considered a two-echelon supply chain with a single manufacturer who supplies a single item to a distributor and the manufacturer with a buyback policy. Under the returns policy, the distributor can return any unsold product to the manufacturer for a partial re-fund after the selling season is over.

2.6 Reverse distribution

Reverse distribution is the compilation and transportation of used products and packages for different reasons. Reverse distribution can be executed through the original forward channel, through a separate reverse channel, or through combinations of the forward and the reverse channel. Guiltinan and Nwokoye[63] provided one of the first analyses of reverse distribution networks according to the actors involved. Pohlen and Farris [64] claim that, the reverse channel depending on individual channel members' functions and ability to perform recycling or remanufacturing tasks may take several different forms. A major issue in reverse distribution systems is the question if and how forward and reverse channels should be integrated. In order to set up an efficient reverse distribution channel, decisions have to be made with respect to:

- The actors in the reverse distribution channel.

The actors may be members of the forward channel (e.g. traditional manufacturers, retailers, and logistics service providers) or specialized parties (e.g. secondary material dealers and material recovery facilities). This distinction sets important constraints on the potential integration of forward and reverse distribution.

- The functions have to be carried out in the reverse distribution channel.

The possible functions in the reverse distribution channel are: collection, testing, sorting, transportation, and processing. For finding out suitable locations for these functions, a distribution network is to be designed. One important issue is the location of sorting and testing within the network. Timely testing might save transportation of useless returns. On the other hand, sophisticated testing might involve expensive equipment which can only be afforded at a few locations. Decentralized testing is therefore typically restricted to a rather rough, preliminary check. Sorting of a return stream into different reusable fractions (e.g. in household waste collection) might be less expensive at an early stage close to collection.

However, subsequent handling costs may increase and transportation capacity utilization may decrease for early splitting into distinct streams. Customer ability (and willingness) to partly carry out the sorting function is another aspect to be considered Jahre, [65].

- The relation between the forward and the reverse distribution channel.

Recycling can often be described as an open-loop system, i.e. the products do not return to the original producer but will be used in other industries. Possibilities for integration of forward and reverse distribution are scant as the actors differ in both channels. Remanufacturing and reuse often lead to closed-loop systems: the product or packaging returns to the original producer. Reverse distribution may either take place through the original network directly, using traditional middlemen or through specialized logistical providers. Even if the same actors are involved, integration of forward and reverse distribution may be difficult at the routing level since collection and delivery may require different handling.

Fig. 1.7 shows a framework for reverse distribution combining the forward flow from producer to user, and the reverse flow from user to producer. Within this framework, Operational Research methods have been applied to study reverse flow networks. The focus has mainly been on network design issues. We describe models for the separate reverse flow problem in Section 3.1. Models partly using the original forward network for the reverse distribution are described in Section 3.2.

- Separate modelling of reverse flow

Several authors have proposed modifications of traditional facility location models, Mirchandani and Francis, [66] for the design of reverse distribution networks. One special characteristic to be taken into account is the convergent structure of the network from many sources to few demand points, Ginter and Starling, [67].Such 'many-to-few' problems have also been studied in the hazardous waste disposal literature. Batta and Chiu[68], has considered the problem of determining optimal paths for routing an undesirable vehicle on a network embedded on an Euclidean plane. His work involves in finding out a path that minimizes the weighted sum of lengths over which this vehicle is within a threshold distance lambda of population centers. Erkut [69] did use the decision support systems that provide sound directions for transportation of hazardous materials. By contrast, traditional location models typically consider a divergent network structure from few sources to many demand points.

Another peculiarity of reverse distribution networks is their high degree of uncertainty in supply both in terms of quantity and quality of used products returned by the consumers. Both are important determinants for a suitable network structure since, e.g., high quality products may justify higher transportation costs (and thus a more centralized network structure), whereas extensive transportation of low value products is uneconomical. Moreover, end-markets for recovered products may not be well known, exposing network planning in this context to even more uncertainty.

2.7 Integration of forward and reverse distribution

At present, there are very few models treating forward and reverse distribution simultaneously. As discussed below, these models consider location of joint facilities for both networks. To the authors' knowledge there are no models dealing with combined routing. We note that in industrial practice rather simple approaches are taken to integrate forward and reverse distribution (e.g. of reusable soft drink bottles). In the network design part, an additional cost component representing collection and return handling is added to the transportation costs. Routings are planned completely forward flow driven; empty bottles are collected along with the delivery tours. Closer investigations whether these simple approaches are adequate have not been reported until now.

Del Castillo and Cochran [70] study production and distribution planning for products delivered in reusable containers. Their model includes transportation of empty containers back to the plants. Availability of empty containers is modeled as a resource constraint for the production of the original product. The model is applied to a case study of a soft-drink company using returnable bottles.

2.8 Inventory control in reverse supply chain

The inventory control is one of the important areas in the field of reverse supply chain. Many researchers had done a lot of work on this and developed different models to fit into the RSC. The two basic models are deterministic and probabilistic models are to be discussed here.

2.8.1 Deterministic models

Imre Dobos [71] has reformulated and solved the model of Schardy. He has also shown that for a smaller recovery rate it gives a better solution if the procurement batch number is greater than one and on the basis of model of Schardy he has obtained a more effective solution for higher return rate. Zhang Qiushuang [72] et al have investigated Richter’s remanufacturing model with limited inventory where they used a polynomial algorithm computing the limited serviceable productions inventory problem and return productions inventory problem. From this analysis they have concluded that the polynomial algorithm could not solve the problem of serviceable inventory and returns inventory at the same time efficiently.

Silver investigated [73] and presents a tutorial overview of inventory management that includes a categorization, by number of dimensions of inventory problems & associated models. He concludes that continuing gap between theory and practice, followed by a number of suggested research topics will help bridge the gap Hesham K. Alfares[74] has presented a model of an inventory system with stock-dependent demand, in which the holding cost is a step function of storage time. Two types of holding cost variation in terms of storage time have been considered: retroactive increase, and incremental increase. Simple optimization algorithms have been developed, and numerical examples have been solved. From the analysis he concluded that both the optimal order quantity and the cycle time decrease when the holding cost increases.

Chung et al.[75] have analyzed an inventory system with forward-oriented material flow as well as reverse material flow supply chain. They have also developed a closed loop supply chain inventory model which maximizes the profits of the supplier and the manufacturer. From the above analysis an optimal production and replenishment policy was formulated to maximize the joint profit. Mahadevan et al.[76] have focused on product recovery and in particular on production control and inventory management. They have studied a remanufacturing facility that receives a stream of returned products according to a Poisson process. They have also analyzed the performance of the system as a function of return rates, backorder costs and manufacturing and remanufacturing lead times. From the above analysis, they observed a convexity in the objective function in the decision variable and some unusual behaviour such as costs decreasing when lead times increase. Verstrepen et al.[77] investigated on a reverse logistics survey of shippers and logistics service providers in Flanders, one of the leading logistics regions in Europe. They offers an exploratory analysis of reverse logistics practices for products and packaging materials and company performance that will offer objective arguments to overcome resistance to implementing reverse logistics processes in the extended company by creating awareness on reverse logistics and by encouraging academic research in this field.

Imre Dobos and Knut Richter[78] have investigated production-recycling system & categorized the system in to two segments or models. The 1^{st} model examines the EOQ-related costs & minimizes the relevant cost whereas the 2^{nd} model generalizes the 1^{st} model with the introduction of cost function with linear waste disposal. Finally they have concluded that by minimizing the inventory holding cost one of the pure strategies (to produce or to recycle) will be optimal. Though these pure strategies are technologically not feasible, this kind of generalization of this basic model could be the introduction of an upper bound on the buyback rate which is strongly smaller than one.

Teunter and Vlachos [79] have studied single item hybrid production system with manufacturing and remanufacturing assuming remanufacturing is profitable & more demands than returns. They have investigated for a variety of cases with different demand, return, manufacturing, and remanufacturing characteristics & cost reduction for returned item using simulation. Based on their numerical results they have concluded that in general it is not necessary to include a disposal option returned items for which remanufacturing is almost expensive as manufacturing plus disposal.

Oh Y.H, and Hwang H [80] considered a recycling system where the supplier receives a fixed portion of recyclable material from customers. Like used cans and crashed bottles, recyclable materials become raw materials of new ones. In order to meet the demand, he also purchases additional raw material from outside. He did find out the optimal solution by considering/comparing the total cost of (P*, 1) and (1, O*) where (p*, O*) is the “P” production set-up and “O” orders. Two cases like (P, 1) and (1, O) are discussed. The total costs of these two models are calculated. The order quantity, production setup and the production lot is optimized based on minimization of the total cost.

Koh et al. [81] obtained the Economic order quantity for newly produced products and the optimal inventory level of recoverable items to start the recovery process simultaneously in a joint EOQ and EPQ model. According to the relationship with the parameters, a numerical model is proposed. Then a solution procedure is established to find out the optimal control parameters.

Mabini, et al. [82] described economic purchase and repair quantities that would meet the needs of the organization is determined for a repair item inventory. it is shown that the cost function is convex and that the constraints form a convex set. Hence, a unique solution exists for the problem, irrespective of the parameters. He has proposed the use of nonlinear program optimizer such as GINO.

Knut Richter [83] modeled a situation where some share of the used products is collected and later repaired; the other products are disposed outside according to some waste disposal rate. In the present paper this model is extended to the case of variable setup numbers n and m for production and repair within some collection time interval. First, for a fixed waste disposal rate the cost optimal setup numbers and the minimum cost are determined. Secondly, the minimum cost is analyzed as a function of this rate and it is shown to be convex for small and medium waste disposal rates and to be concave for large rates.

Knut Richter [84] studied an EOQ model in which the stationary demand can be satisfied by newly made products and by repaired used products. This model assumes that the used products are collected and later repaired at some rate and the other products might be disposed outside according to some waste disposal rate. This model extends previous studies to the case of variable setup numbers n and m for production and repair within some variable collection time interval.

Therry et al. [85] discussed the PRM opportunities and threats at different levels of return and analyzed it. In his paper he has discussed the product recovery management that encompasses the management of used and redundant products, components and materials that comes under the responsibility of a manufacturing plant. The objective is to recover the economic as well as the ecological value as much as possible. This work is being supported by different case studies from Copy magic, BMW and IBM etc. Teunter and vander Laan [86] provided a DCF inventory model with disposal and remanufacturing as while analyzing average cost (AC) inventory models, it is common use to add the discount rate times the capital tied up in a product, to the out-of-pocket holding cost rate. This way, capital costs are (roughly) included. In this paper he showed that such a method may not always be appropriate for reverse logistics inventory models with both remanufacturing and disposal of returned products.

Richter and Sombrutzki [87] in his paper has discussed the reverse Wagner/Whitin’s dynamic production planning and inventory control model and some of its extensions. The Wagner/Whitin model is studied in the reverse manner with focus on recycling strategies in production and marketing systems. Chung et al [88] analyzed an inventory system with traditional forward-oriented material flow as well as a reverse material flow supply chain. In the reverse material flow, the used products are returned, remanufactured and shipped to the retailer for resale. A multi-echelon inventory system with remanufacturing capability is proposed. We then develop a closed-loop supply chain inventory model and maximize the joint profits of the supplier, the manufacturer, the third-party recycle dealer and the retailer under contractual design. The analytical results of this study show a significant increase in the joint profit when the integrated policy is adopted.

2.8.2 Stochastic models in reverse supply chain

a) Periodic review models:

Like the conventional forward supply chain, this category of models typically focuses on proving the structure of the optimal policy rather than finding optimal parameter values. For example, Simpson [89] provides the optimal policy structure for an inventory model with product returns. Here the product demands and returns can be stochastically dependent within the same period only. A joint probability function is used to find out the demand and returns which can differ from period to period. A trade-off between material savings due to reuse of old products and additional inventory carrying costs is carried out. This in turn proves optimality of a three parameter policy to control order, recovery, and disposal, not considering the fixed costs and lead times.

The previous model is extended by Inderfurth [90] with non-zero (re)manufacturing and procurement lead times. Other assumptions are same as Simpson's model. According to Inderfurth, there is a simple optimal control policy structure as long as the lead-times for manufacturing and remanufacturing differ at most one period. According to him, the difference between the two lead times is the decisive factor for the complexity of the system. Buchanan and Abad [91] considered a system with partial returns. Each period, a fixed fraction of products is lost while a stochastic fraction is returned. The authors establish an optimal policy for the case that the time until return is exponentially distributed. Toktay et al. [92] study ordering policies for a business case of single-use Kodak's cameras. The model is as follows. After using the camera, customers take it to a shop/ laboratory to develop the film. The laboratories return the used cameras to Kodak (but sometimes they go to the so-called jobbers). Kodak dismantles the used cameras and reuses the flash circuit board of every camera in the manufacturing of new ones. A closed queuing network model is applied to decide on periodic ordering decisions. Custom demand is treated as a Homogeneous Poisson Process (HPP) from which a known percentage is returned. The time the cameras are with respectively the customer and the lab are modeled by a queuing system with two infinite servers with general processing times. These two servers together model the time until the camera returns to Kodak. Main objective here is to find an ordering policy that minimizes the overall expected procurement, inventory holding, and lost sales cost. Unique characteristics of the system associated with return flows of used cameras are the uncertainty and unobservability. Another important feature of this paper is the identification of the information's value according to different scenarios. Kiesm¨uller and Van der Laan [93] developed a periodic review inventory model where product returns depend on the demand process. Both the demand and the return streams follow a Poisson distribution. All returns depend on previous demands through a constant time until return, and two probabilities: the return probability (when demand occurs, it is assumed to be known whether, or not, an item returns) and the probability that a returned item is in a sufficiently good condition to be remanufactured. The authors compare this model with the situation of independent demands and returns. The outcome supports that it is worth using information about the dependency structure between demands and returns. This work shows that if the dependency between demands and returns of products is neglected then it may lead to bad performance with respect to total average relevant costs. In addition to it, his work helps to find out the minimal recovery probability for which reuse is profitable. Two newsboy models with returns have been respectively proposed by Vlachos and Dekker [94] and Mostard et al. [95]. The first paper is based on the assumption that, E-commerce or mail sales catalogues suffers higher return rates as compared to traditional products. So for decision making, various options considered as strategic decisions are studied to handle the return flow. The optimal order quantities are obtained by solving the models developed for individual options. Decision making guidelines are presented to choose between the return options and some properties of the optimal solution In the second, each item that is sold has a constant probability of being returned and once returned it has a constant probability of being recovered. Returned items can be re-sold more than once. This work focuses on commercial returns from catalogue/internet mail order retailer selling style goods. The author opines that, if there is sufficient demand. Returned products arriving before the end of the selling season can be resold. Because of non-availability of much historical information the analysis is done on the distribution-free newsboy problem with returns, with a known mean and variance of demand .Based on this a closed form expression for the distribution-free order quantity is derived and compared with optimal order quantity when demand is normal, lognormal or uniform. Both articles investigate the optimal order quantity for the single period. These models are inspired by the order size decision that mail-order-companies and e-tailers face every season.

b) Continuous review models

Heyman[96] analyzed different disposal policies for a single-item inventory system with returns. He uses a model where demands are independent and returns are generally distributed quantities. Outside procurement and Remanufacturing are instantaneous, resulting in perfect service and only one inventory to be considered. He derives an explicit expression for the optimal disposal level for the case of Poisson distributed demands and returns. He also proved optimality of the one parameter policy in this case. An explicit expression for the optimal disposal policy is given when the processes are Poisson. Also Muckstadt and Isaac [97] investigated the control of a single item inventory system with independent demands and returns following a Poisson Process. The authors derive some approximations. More recently, Van der Laan et al.[98] deal with policies in the context of two inventory facilities, one of new products and the other of remanufactured items. Here the analysis is done on an (s, Q) inventory model where the used products can be remanufactured to as good as new one. This work shows that disposal is essential as the inventory level may rise due to variability in the return flow. An approximation is developed for cost evaluation and optimization with much less numerical effort.

The model is based on unit demand and unit returns with independent Poisson processes. The analysis of Fleischmann et al. [99] is based on the review of case studies on logistics network design for product recovery in different industries. The general characteristics of product recovery networks are identified and compared with that of the traditional one. Hence, a classification scheme for different types of recovery networks is derived. He has shown that the major distinction between product recovery networks and traditional production-distribution networks is the ambiguity of supply both in quantity and quality. This paper appears to be the first step towards a comprehensive analysis of logistics networks in a product recovery background. Yuan and Cheung [100] discuss an (s, S) inventory system with returns and analyze the impact of partial returns on rental systems. This work presents a new continuous review (s, S) inventory system with returns in the retail and rental businesses. The performance is considered to be a function of demand rate, return time, return rate and replenishment frequency. An algorithm is proposed to search for the optimal replenishment parameters based on Markovian approach and essential operating characteristics of the system is derived. This work provides some valuable insights towards the impact of partial returns.

Bayindir et al. [101] employed a queuing model to investigate a hybrid (re)manufacturing system when the return ratio is a decision variable. He investigated the cost reducing benefits of remanufacturing related to inventory. A model is presented to deal with the inventory-related decisions and remanufacturing decisions simultaneously. It is shown through computational study that the coexistence of direct manufacturing and remanufacturing does not provide any cost benefits if expected lifetime of the product is long or the remanufacturing requires high value added and/or long lead time operations .The authors conclude that the remanufacturing facility is more or less used depending on whether the production capacity is finite or not. Although the above does not constitute an exhaustive review of the literature on inventory models with returns, it serves to identify the common assumptions of these models. Table 6.1 summarizes the main assumptions of the demand and return processes, and of the dependency structure between these two processes. More information on inventory models with returns can be found in Van der Laan [102].The main Purpose here is to evaluate the performance of the average costs criterion compared to the preferred net present value criterion. Where he claimed that, for the well-known EOQ model, the average cost models give near optimal solutions under certain conditions. With the right choice of the holding cost parameters, the performance of Average cost approach fluctuates. A theoretical basis is provided for choosing the parameters through the analysis of a deterministic model.

The bulk of the literature, especially when uncertainty is modeled, assumes the following: 1) the demand is a homogeneous (compound) Poisson process; 2) the return process is also a homogeneous (compound) Poisson process, and 3) the two processes are independent. These choices have to do with the tractability of the Poisson distribution. This is also the main reason behind the independence assumption. In fact, less restrictive assumptions complicate the analysis significantly. Besides, as the review of the literature shows, in order to pursue an exact analysis or to give explicit expressions for optimal policies one has to make these common assumptions. The independence assumption has also been motivated by the scarcity of individual data on product returns, see Fleischmann et al., [103]. This motivates empirical analysis of real data

2.9 Supply chain management with remanufacturing

Zhang and Bell [104] addressed the simultaneous determination of price and inventory replenishment in a newsvendor setting when the firm faces demand from two or more market segments in which the firm can set different prices. They allowed for demand leakage from higher-priced segments to lower-priced segments and assume that unsatisfied demand can be backlogged. They examined the case where the demands occur concurrently without priority and are met from a single inventory. They considered customer's buy-down behaviour explicitly by modeling demand leakage as a function of segment price differentiation, and characterized the structure of optimal inventory and pricing policies (as opposed to models that use EOQ approaches). Decision variables were identified (including manufacturing and remanufacturing capacities and return rates and use rates for end-of-life products) and optimal policies were determined. Moreover, the structure of these optimal policies was analyzed. The conclusion drawn was that, in many realistic scenarios, mixed policies (that is, with return rates and use rates strictly between 0 and 1) could be optimal. This conclusion was contrary to results published in earlier studies, which were based on more restrictive assumptions.

Jung and Hwang [105] considered the case of remanufacturing in a reverse logistics chain with one remanufacturer and one original equipment manufacturer (OEM).This case is appropriate with Toner cartridge industry dealing with remanufacturing under the “take-back requirement”, The OEM sells new products and takes the responsibility by paying corresponding penalties if the take-back quota for the end-of-use products is breached. Through the development of mathematical models with the objective of profit maximization, he studied the optimal pricing policies of OEM and remanufacturer under two cases, competition and cooperation. The repeated game model and a search procedure are used to solve these cases. To analyze the interactions between the two a sensitivity analysis was conducted.

Pellerin et al. [106] in their work, considered the importance of planned demand at the end of the expected life of each individual piece of equipment and unplanned demand triggered by a major equipment failure in the control of a manufacturing system. This type of manufacturing system is difficult to control because of the variable nature of the remanufacturing process. a multi-level control problem is formulated and a suboptimal control policy is proposed. The proposed control policy is described by inventory thresholds triggering the use of different execution modes. Based on parameter optimization of analytical cost expressions, control policy parameters are Determined. The author presented a numerical example based on a real case. This analysis demonstrates the significant reduction in the total average cost by using the proposed control approach as compared to current practices

The work of Sundin and Bras [107] was based on the fact that, when the functional sales contracts are used in connection with product remanufacturing, it has both economic and environmental benefits. The author here provides a clarification on these benefits and provides an argument for why products to be used for functional sales should be remanufactured. The products aimed for remanufacturing should be adapted for the process as much as possible to achieve an efficient remanufacturing process. The cleaning and repairing steps are most critical in the remanufacturing process is clear from the analyses of remanufacturing facilities for household appliances and automotive parts. The author opine that the product designers should focus on giving the products the properties like, ease of access, ease of handling, ease of separation and wear resistance to facilitate these two steps.

Subramoniam et al. [108] in their work paper addressed the gap between reverse logistics and the strategic decisions in particular to automotive industry. The author has done a vivid study on customer demand(s), product design and development, cost-benefit analysis of remanufacturing, core (i.e., used product) supply management, remanufacturing competencies and skills, product life cycle strategies, remanufacturing and reverse logistics network design, relationships among key stakeholders, impact of emerging economies, regulations, and environmental considerations. The literature findings along with their experience in working with automotive remanufacturing products were used as inputs to guide the formulation of seven major propositions for the strategic factors in decision making within remanufacturing. The propositions were then tested through a case study. He has identified the factors like OE (original equipment) customer requirements. The author is in opinion that this particular work can provide a foundation for further research for companies dealing with Original Equipment Sales, Service, as well as Independent Aftermarket business in the automotive sectors**.** The case study reconfirmed many of the factors like product life cycle, regulations, etc.

Kim et al. [109] proposed a general framework for a remanufacturing environment and a mathematical model that maximizes the total cost savings by optimally deciding the quantity of parts to be processed at each remanufacturing facilities, the number of purchased parts from subcontractor. This particular work is applicable to the remanufacturing process of reusable parts in reverse logistics, where the manufacturer has two alternatives for supplying parts: either ordering the required parts to external suppliers or overhauling returned products and bringing them back to ‘as new’ conditions. This model is newly introduced and developed in the reverse logistics literatures. Through a set of experimental data reflecting practical business situation and sensitivity analyses conducted on various parameters to gain insight into the proposed model. This model seems extremely good.

Franke et al. [110] developed a generic remanufacturing plan for mobile phones for successful remanufacturing of mobile phones that must meet the challenges of continuously falling prices for new phone models, short life cycles, disassembly of unfriendly designs and prohibiting transport, labor and machining costs in high-wage countries. A linear optimization model is introduced, for the planning of remanufacturing capacities and production programs, To support the planner in the periodic adaptation of an existing remanufacturing facility under quickly changing product, process, and market constraints, discrete-event simulation is applied. Uncertainties regarding quantity and conditions of mobile phones, reliability of capacities, processing times, and demand are considered for the model development. The simulation model is generated by an algorithm using results from the linear optimization approach to cope up with the mobile phone remanufacturing sectors.

Schneeweiss[111],in his work gave a systematic overview as to the specific contribution each single science is providing in the areas like applied mathematics, operations research, economics and artificial intelligence. In supply chain, the identification of different classes of distributed decision making problems in such areas is of great importance. Particularly indicating possible synergies, it points to those distributed decision-making problems that prove to be of major relevance for supply chain management.

2.10 The Adaptive Network Based Fuzzy Inference System in RSC

Wei and Zhao[112] have explored the decisions of reverse channel in a fuzzy Reverse supply chain. Manufacturer produces new products by using original components or by remanufacturing used products and wholesales the new products to the retailer who then sells them to the consumers. The used products are collected by the manufacturer or the retailer or a third party. They have investigated the collection modes on the decision of manufacturer, the retailer, and the third party, and on their own profits in the expected value model. The firm’s optimal strategies are obtained by using game theory and fuzzy theory.

Amin and Zhang [113] have investigated a closed loop supply chain which includes multiple plants, collection centers, demand markets, and products. A mixed-integer linear programming model is proposed that minimizes the total cost. Additionally they have investigated the impact of demand and return uncertainties on the network configuration by stochastic programming (scenario-based). They have shown that, the model can handle demand and return uncertainties, simultaneously based on computational results.

Kannan [114] proposed a structured model for evaluating and selecting the best third party reverse logistics provider (3PRLP) under fuzzy environment for the battery industry. In his work, the multi-criteria decision-making tools such as analytic hierarchy process (AHP) and fuzzy analytic hierarchy process (FAHP) are adopted to solve the problem of selection of 3PRLP. This provides a useful decision model for practicing managers and researchers in this field. The various relationships and information processing required for the management involved in the selection of a reverse logistics provider under fuzzy environment are also discussed. A separate logistics system is developed in order to inspect and maintain the collected returned products in the downstream management, because of the complexity of collecting the returned products from the customer end to the manufacturer end in the supply chain management,.

Maity et.al, [115] presented an optimal control recycling production inventory system in fuzzy environment. Recycling or disposal is done on used items which are bought back from the customers. Recycled products can be used for the new products which are sold again. Here, the rate of production, recycling and disposal are assumed to be function of time and considered as control variables. The demand inversely depends on the selling price. The selling price is serviceable stock dependent. The holding costs (for serviceable and non-serviceable items) are fuzzy variables. the expected values of fuzzy variable is defined and the system is transferred to the fuzzy expected value model. In this paper, an optimal control approach is proposed to optimize the production, recycling and disposal strategy to maximize the expected value of total profit.

Efendigil et al. [116] focused on the in time right decisions depending on demand information to enhance the commercial competitive advantage in a constantly fluctuating business environment. Their work developed a comparative forecasting methodology pertaining to uncertain customer demands in a multi-level supply chain structure through neural techniques. This work proposed a new forecasting mechanism modeled by artificial intelligence approaches including the comparison of both artificial neural networks and adaptive network-based fuzzy inference system techniques to manage the fuzzy demand with incomplete information. Using real-world data from a company, the effectiveness of the proposed approach to the demand forecasting issue is demonstrated.

Efendigil and Onut [117] proposed a methodology for supply chain integration from customers to suppliers through warehouses, retailers, and plants via both adaptive network based fuzzy inference system and artificial neural networks approaches. The methodology presented provides this integration by finding the requested supplier capacities using the demand and order lead time information across the whole supply chain in an uncertain environment. By comparing the obtained results with the traditional statistical techniques, the sensitivity analysis is made. Applicability of the proposed methodology is checked with a company serving in durable consumer goods industry that produces consumer electronics.

2.11 The Gaps that exist in the previous research

Before finding the best possible remanufacturing, the generation of supply chain management with remanufacturing is important. The above mentioned literatures have been reviewed on supply chain management with remanufacturing based on returned product, reducing waste product etc. various old and recent methodologies have been studied to represent the remanufacturing based on Reverse supply chain management. The studied literatures give a comprehensive idea about the current trend of work in the subject. The survey of literatures made in this chapter indicates that a lot of research remains to be done for improvement for the currently available techniques.

The issue of simplicity and adaptability of the model with more application oriented is to be prioritized. More emphasis should be given to the models of reverse supply chain with remanufacturing. The design for disassembly should be given importance for smoothing the application of reverse supply chain.

2.12 Problem statement

The studied literatures give a comprehensive idea about the current trend of work in the subject. The survey of literatures made in this chapter indicates that a lot of research remains to be done for improvement for the currently available techniques. In this context it is needless to say that, remanufacturing is among the most advanced and environmentally friendly production processes in use. By using recovered materials in the production process, the remanufacturing business model depends less on labour cost containment, thus providing workers the possibility of greater job security and prosperity. Remanufacturing is the process of disassembly and recovery at the module level and, eventually, at the component level. It requires the repair or replacement of worn out or obsolete components and modules. The remanufactured products are assumed to be as good as the new ones in terms of features, quality and worth. Therefore the objective of the present work is to deal with the different models of remanufacturing either new or existing for adding new features to it and making it simple and more user oriented. The aim is to make these models usable to achieve maximum advantages by reutilization of resources integrating the upstream and downstream chains.

2.13 Summary

The study of literatures is conducted in the present chapter is specifically intended to know the trend in the field of RSC and hence find out the possible modification and/or development in the current scenario. For this purpose the relevant literatures are studied based on forward supply chain, RSC, Risk analysis in RSC, reverse distribution, Integration of Forward and reverse distribution, Inventory control ,SCM with remanufacturing and application of adaptive network based fuzzy inference system in RSC. This voluminous work ends up with a conclusion favouring the remanufacturing as the key area for improvement. The problem statement is set accordingly and in the subsequent chapters the discussion shall be limited to remanufacturing part of the RSC.

Chapter 3

AN OVERVIEW OF SUPPLY CHAINS WITH REMANUFACTURING

3.1 Overview

Remanufacturing ("Reman") transforms end-of-life material into same-as-new components and products typically used in industrial, medical, on-road, heavy engineering and other applications. Access to end-of-life goods is core component of the remanufacturing business model. Remanufacturing can help keep such goods out of landfills and return them into the stream of commerce in original working condition several times during the course of their extended lives. Each time the product, or component, returns to the in an "as new" condition. Remanufactured products enjoy similar warranties and meet the same specifications and quality standards as products that are manufactured entirely from new materials, yet often cost substantially less than brand new goods. Remanufactured products are not used or reused products. The physical characteristics, the appearance and the performance of remanufactured products are in all respects identical to and undistinguishable from those of products manufactured entirely from virgin new parts or components. Remanufacturing is among the most advanced and environmentally friendly production processes in use. Remanufacturing saves energy, reduces the production of greenhouse gases, and recycles the vast majority of materials used in the original manufacturing process. By using recovered materials in the production process, the remanufacturing business model depends less on labor cost containment, thus providing workers the possibility of greater job security and prosperity. The consumer, environmental and labor benefits of remanufacturing may stimulate companies to adopt remanufacturing as an adjunct strategy for market support and expansion. Remanufacturing is the process of disassembly and recovery at the module level and, eventually, at the component level. It requires the repair or replacement of worn out or obsolete components and modules. Parts subject to degradation affecting the performance or the expected life of the whole are replaced.

3.2 Benefits of remanufacturing

The one of the advantages of using remanufactured products is that they are cost-efficient and economical to use. In fact, remanufactured products cost less than new OEM (Original Equipment Manufacturer) products. Above all, the price difference can be around 50% or even more. So, a person can save a great deal of money by using remanufactured products. Even though remanufactured products are cheap but the product quality does not suffer as the manufacturers guarantee the product quality. Ending up in landfills can be another benefit of using remanufactured products. According to estimates, every year around millions of products end up in landfills, causing pollution problems. Remanufactured products are not biodegradable and these products they will remain intact for a very long time. Recycling of products can help in sorting out this problem and hence helps in retaining the ecological balance of the environment. Nowadays, the usage of remanufactured product helps in creating more opportunity in business world. Today, the demand of used products has been constantly increasing, giving new potential enterprises to show their worth in this fast changing world. This new business activity has generated new chances to create jobs for young people, hence helps in smooth functioning of the economy. When people have jobs, they have income and purchasing power. Thus the overall effect of this is definitely good for the economy as a whole. Thus, remanufactured products are of great importance and save the money.

3.3 Available models of supply chain with remanufacturing method

In the past several supply chain models have been developed by various researchers considering different conditions of supply demand ratio, process parameters and key parameters as per the requirement of the business. Some of the well-known models are described in the following sections to understand the philosophy and to build new models for product manufacturing scenarios with remanufacturing concept.

3.3.1 General framework of remanufacturing

The general form of remanufacturing system in the Fig.3.1, [80] shows that a given demand can be satisfied either from returned items those are remanufactured to as good as new ones (remanufacturing process) or from new items produced (production process).

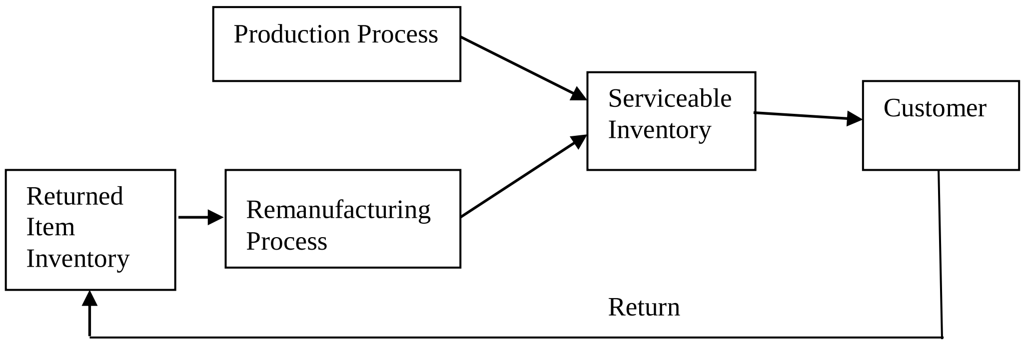


Figure 3.1: Framework of Remanufacturing System.

Remanufacturing differs from other recovery processes in its completeness; remanufactured machine should match the same customer expectation as new one. Through a series of industrial processes in a factory environment, a discarded product is completely disassembled. Useable parts are cleaned, refurbished, and put into inventory. Then the product is reassembled from the old parts (and where necessary, new parts) to produce a unit fully equivalent and sometimes superior in performance and expected lifetime to the original new product".

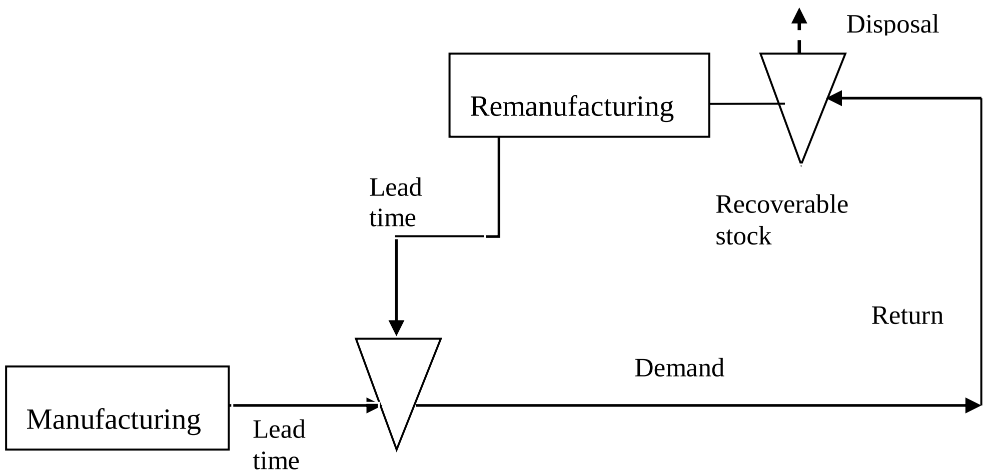


Figure 3.2: The material flow in a simple manufacturing /remanufacturing system

Tang and Grubbstrom [118] studied a manufacturing/remanufacturing system with stochastic lead times and a constant demand. The approach is based on previous research in which models are developed to describe an inventory system with stochastic lead times. They first adopted the method to manufacturing/ remanufacturing situations, where there are essentially two supply sources for replenishing serviceable inventory (Fig.3.2). Then a solution procedure is provided when a cycle ordering policy is used. Secondly, they investigated the possibility to use a dual sourcing ordering policy in which each order is split between a manufacturing and a remanufacturing process. They have provided solution procedures and optimization conditions to determine control parameters in different cases, such as planned lead time and planning interval after developing the inventory and stock out functions for different ordering policies. The final part compares the two ordering policies and illustrates how the lead-time patterns influence the economic outcome.

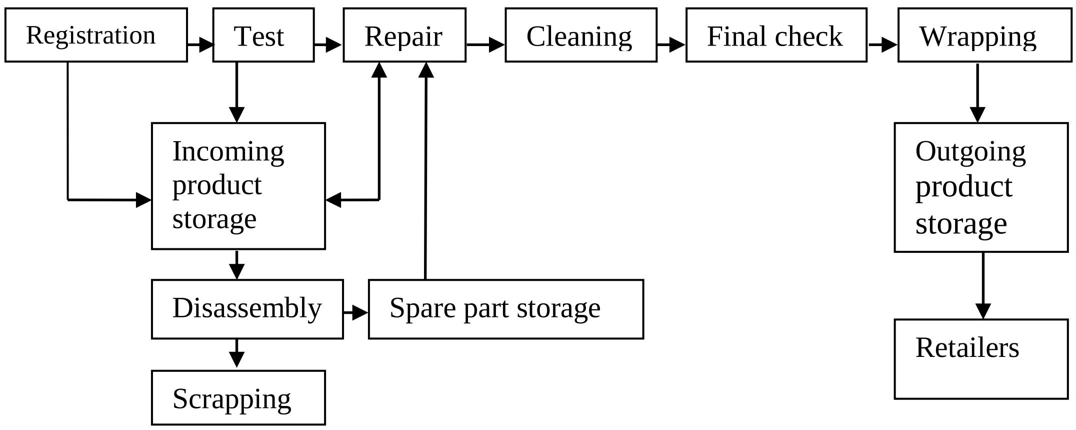


Figure 3.3: The remanufacturing process showing the main material flows at the Electrolux remanufacturing facility.

When it is not possible to repair a product on site, it is delivered to industry, via the service centers, by trucks. Upon arrival, the products are unwrapped and registered in a computer system. At this point, a decision is made whether the products are to be remanufactured or used for spare parts. The products that undergo remanufacturing are tested to find out what type of damage they have received. After testing, the products proceed either to repair or to the product spare part storage. Depending on type of product and error, the time needed for repair varies from short to long (5-30 min). If spare parts are needed, they can either be taken from the products at the spare part storage or ordered from the facility; this means that the products may wait for several days or even a few weeks for the right spare parts to arrive. When the products are repaired, they are cleaned and high-voltage tested. Finally, the products are wrapped in plastic and put into storage, ready for transport to retailers for resale. The Electrolux remanufacturing process is illustrated in Fig. 3.3. Sudin [119], analyzed technical and economic aspects of a specific remanufacturing process at Electrolux AB in Motala, Sweden. All the remanufacturing steps are analyzed and thoroughly examined in order to find out where to put the most effort to make the remanufacturing process more efficient. The technical analysis showed that the cleaning step is the root cause of the bottleneck in the remanufacturing process. Suggestions are given in this article to make the cleaning more efficient with economical calculation show which activities hold the largest cost shares. He found out two remanufacturing activities stand for the most costs, which were the storing of products and administration of the entire process.

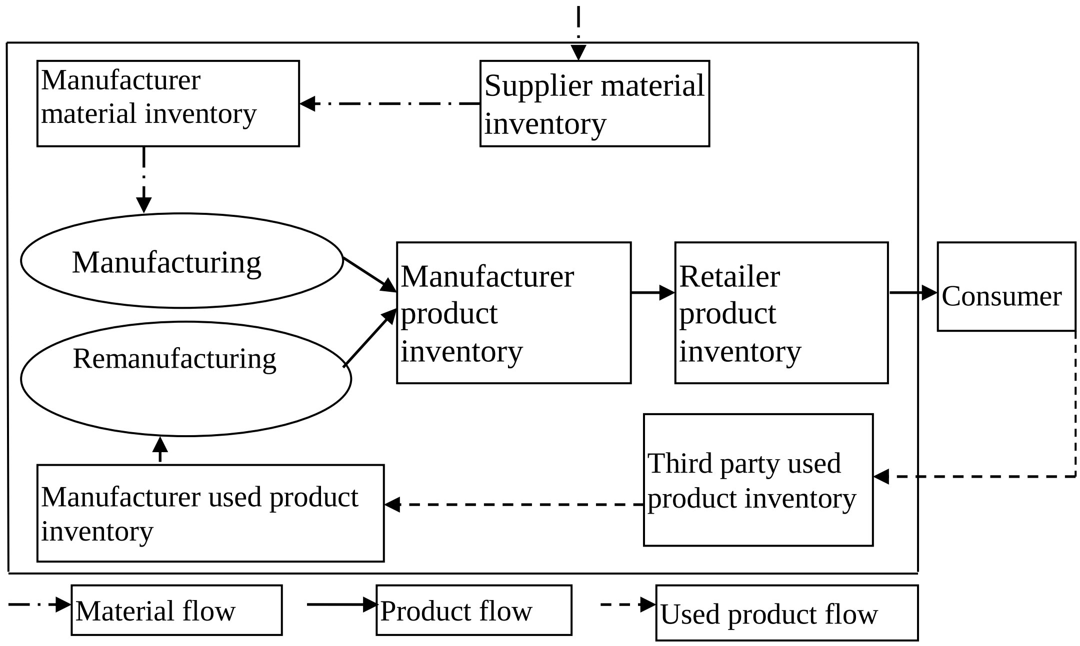


Figure 3.4 : The integrated closed-loop supply chain inventory system.

The model shown in figure 3.4 is a closed-loop supply chain inventory system discussed by Chung et al.[75]. In addition to traditional forward material flows, the model examines used products returned to a reconditioning facility where they are stored, remanufactured then shipped back to retailers for retail sale. Figure 3.4 illustrates the proposed process. The proposed optimal policy for a multi-echelon inventory system with remanufacturing is developed by integrating the concerns of the supplier, the manufacturer, the retailer and the third-party recycle dealer. An example of the closed-loop supply chain with a remanufacturing system illustrates the system.

The solutions are obtained for both decentralized and integrated centralized decision making. The findings of this model demonstrated that the proposed integrated centralized decision making approach can substantially improve the efficiency of the system.

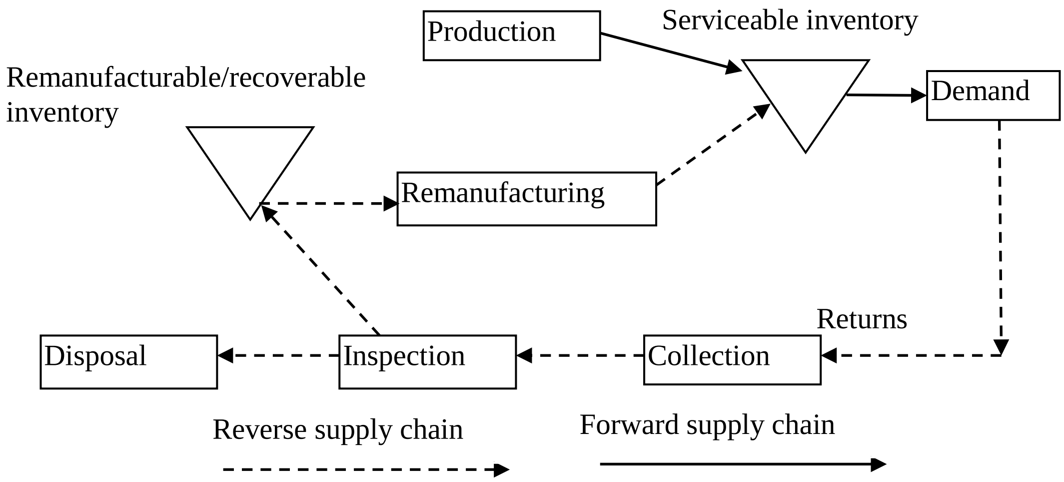


Figure 3.5: Single product remanufacturing system within the context of Closed Loop Supply Chain

The above model is based on a single product remanufacturing system within the context of Closed Loop Supply Chain [120]. Several operations like production, collection and inspection of used products, remanufacturing and disposal are used in the model. The focus is on the return of products from customers/products users at the EOL. The returns like product recalls and B2B commercial returns are excluded in the study. Figure 3.5 shows the remanufacturing process considered for the model. The forward supply chain involves production of new products to fulfil the demand of the customers. After product use, returns are collected, inspected and either stored as remanufacturable/recoverable inventory or disposed of depending on whether the quality of returns is suitable for remanufacturing according to the company's quality standard policy. The serviceable inventory comprises of new or remanufactured products which are as good as new. Production and manufacturing are important components of any remanufacturing system. Equally important to the process is analysis and decision making regarding inventory, operational and marketing activities.

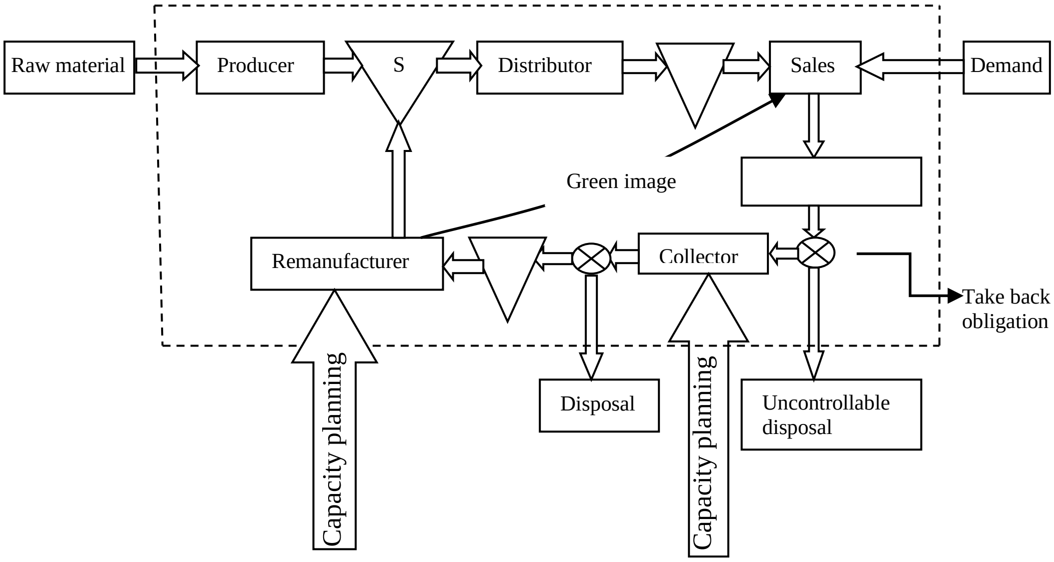


Figure 3.6: Single product closed-loop supply chain.

This model by Valchos et al.[94],focuses on a single product closed-loop supply chain. The model includes the operations like supply, production, distribution, use, collection (and inspection), remanufacturing and disposal. Fig. 3.6 presents the system under study. The forward supply chain includes two echelons (producer and distributor). In the reverse channel, we assume that the only reuse activity is remanufacturing. Remanufacturing brings the product back into an "as good as new" condition by carrying out the necessary disassembly, overhaul and replacement operations [6]. Specifically, the finished products are first transferred to the distributor and then sold to satisfy demand. The product sales at the end of their life-cycle turn into used products, which are either uncontrollably disposed or collected for reuse. The collected products after inspection are either rejected and controllably disposed or accepted and transferred for remanufacturing. The loop "closes" with the remanufacturing operation in two ways. First, through the flow of "as good as new" products to the serviceable inventory (SI in Fig. 3.6) and second through the impact on sales via the "green image". Raw materials input, total demand and legislation acts (take-back obligation) shape the external environment of the system.

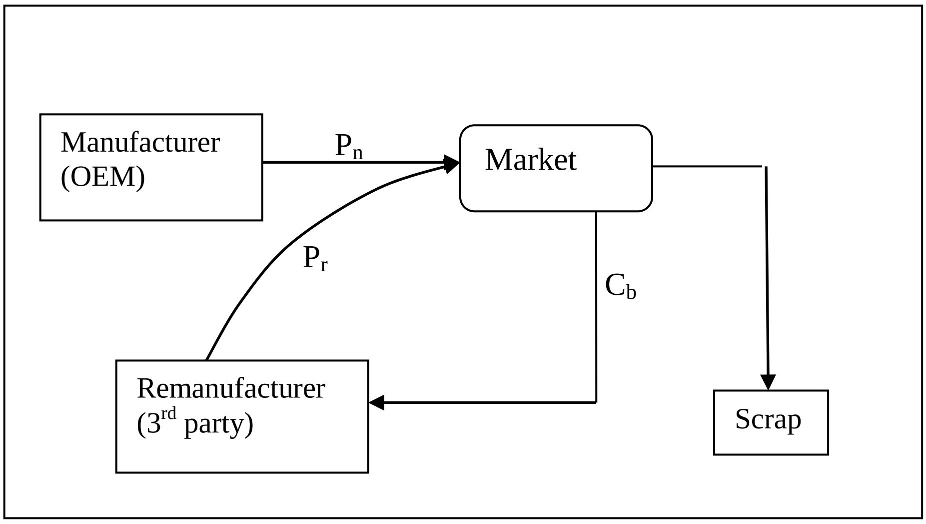


Figure 3.7: Remanufacturing system with take-back requirement.

Jung and Hwang [105], presented a remanufacturing model with take-back requirement. Products are sold at the price p_n for an OEM under the take-back requirement. The OEM takes the responsibility of paying corresponding penalties if the take-back quota for the end of use products is breached. At the end of life time of products, they are collected by a remanufacturer at the unit cost of $c_{b.}$ The remanufactured products are released to the market with the unit price of p_r. In this model the pricing policies of the OEM and the remanufacturer under two cases is being emphasized, competition and cooperation. Where in competition, each party tries to maximize its own profit, in the case of cooperation; two parties cooperate to maximize the sum of each profit (fig 3.7).

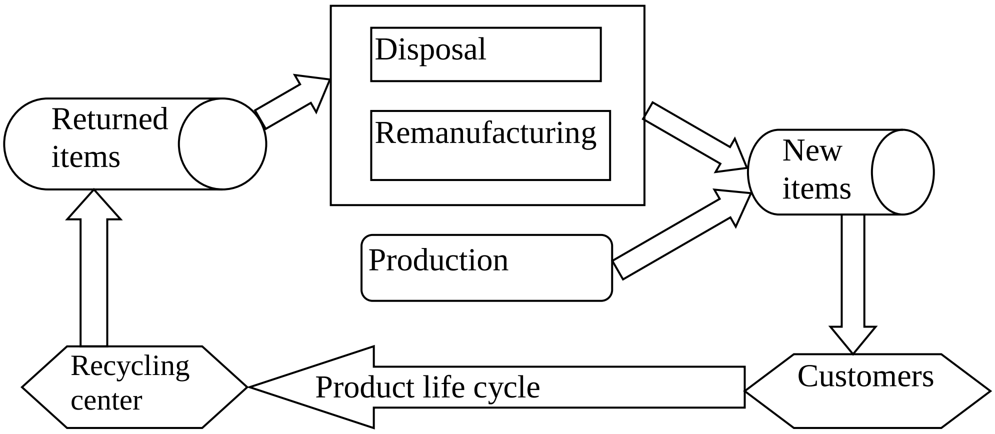


Figure 3.8: Closed-loop supply chain with production, disposal and remanufacturing

The figure 3.8 shows a general mathematical model of CDLP with production, disposal and remanufacturing options [121]. Here factory produces a certain kind of product, of which demands are deterministic but time-varying during a finite planning horizon and should be satisfied without backlogging, that is shortages are not allowed. In this model, the factory is held responsible for processing used products returned from customers. The amount of the returned products is regarded deterministic over the planning horizon. There are two options available for these returned products: remanufacturing and disposal. Remanufactured products can be sold as new ones with the same quality commitment. So there is no difference between the remanufactured products and newly produced products. Both of them are called serviceable products. The cost of disposal can be either positive or negative. The negative disposal cost means some useful material can be recycled from the returned production. In this model, there is no clear segregation between recycling from disposal. Disposal refers to all the returned products processing operation without generating serviceable products. Moreover, the capacities of production, disposal and remanufacturing are limited.

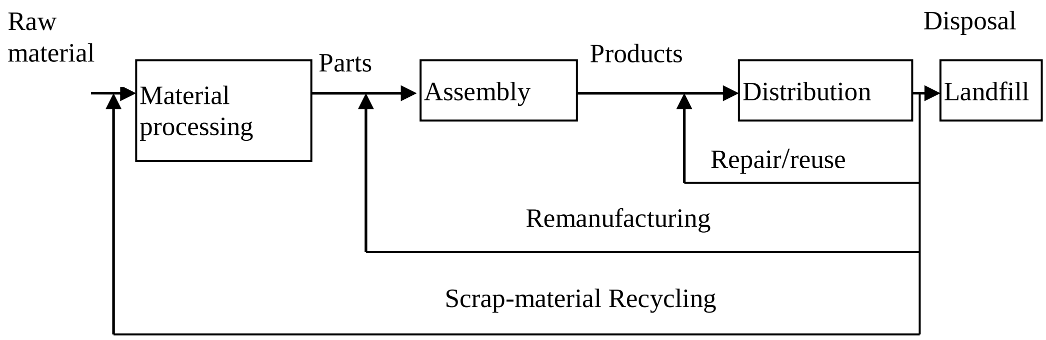


Figure 3.9: Product life cycle

To enforcing design for manufacturing, Mabee and Boomer[122] have put forth a structured approach based on cross functional teams filling out a series of design charts. The authors state that, these results can be used to identify the opportunities for remanufacturing enhancement, set goals and measure progress. To support this they have presented a case study illustrating charts demonstrating their sensitivity to product modification. They have shown the importance of design requirement at every stage of life cycle (fig 3.9) emphasizing on remanufacturing that will reduce the cost by using less materials, tools, parts and penalties imposed by the government agencies.

Kim et al.[108] discussed the remanufacturing process of reusable parts in reverse logistics .The manufacturer has two alternatives for supplying parts

- Ordering the required parts to external suppliers
- Overhauling returned products and bringing those back to 'as new' conditions.

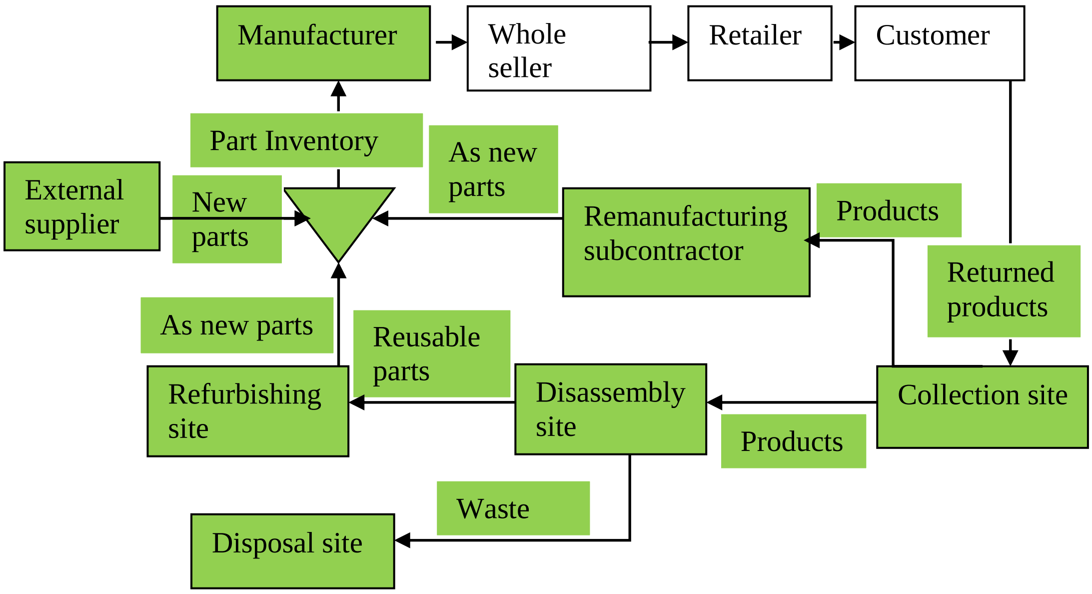


Figure 3.10: Conceptual frame work for remanufacturing system.

They propose a general framework for this remanufacturing environment and developed a mathematical model to maximize the total cost savings by optimally deciding the quantity of parts to be processed at each remanufacturing facilities as well as the number of purchased parts from subcontractor. The remanufacturing model is conceptualized into a framework as shown in the shade region of the fig 3.10.The model is newly introduced and developed in the reverse logistics literatures. The validation of this model lies through a set of experimental data reflecting practical business situation and sensitivity analyses conducted on various parameters to gain insight into the proposed model.

3.4 Summary

In this chapter, the goal of the supply chain management with remanufacturing is discussed in the light of various existing models of supply chain management with remanufacturing. The remanufacturing is useful in industry as it saves about 85% of the energy that would otherwise have been used in producing a new product.

Each model studied is different in approach and modeled differently based on the restriction imposed either on percent return or cost of conversion or cost of disposal etc.

Chapter 4

MODELING RSC WITH REMANUFACTURING FOR QUANTITATIVE ANALYSIS

4.1 Overview

Technology is becoming pervasive across all facets of our lives today. Technology innovation leading to development of new products and enhancement of features in existing products is happening at a faster pace than ever. It is becoming difficult for the customers to keep up with deluge of new technology. This trend has resulted in gross increase in use of new materials and decreased customers' interest in relatively older products. This in turn results in the deteriorating conditions of the environment due to the reduction of non-renewable resources and steady increase in the land fill of waste. Time has come to think in a different direction to consider recovery alternatives such as reuse, repair, recycle, refurbish, remanufacture and cannibalize, rather than discarding of the products after end of life. The present work deals with the remanufacturing to facilitate and support the recovery process minimizing the degrading condition of the environment. In this context it is needless to say that, remanufacturing is among the most advanced and environmentally friendly production processes in use. By using recovered materials in the production process, the remanufacturing business model depends less on labour cost containment, thus providing workers the possibility of greater job security and prosperity. Remanufacturing is the process of disassembly and recovery at the module level and, eventually, at the component level. It requires the repair or replacement of worn out or obsolete components and modules. The remanufactured products are assumed to be as good as the new ones in terms of features, quality and worth. Therefore it has become important now to deal with the different models of remanufacturing either new or existing for adding new features to it and making it simple and more user oriented. The aim is to make these models usable to achieve maximum advantages by reutilization of resources integrating the upstream and downstream chains.

4.2 Modeling the reverse supply chain with remanufacturing

An industry sells products at the price of new product under the 'take back requirement' and once the life time of products ends, they are collected by a remanufacturer at the unit buy back cost c_b. Figure 4.1 shows the model of supply chain management with remanufacturing. The remanufactured products are released to the market with the price of remanufactured product. In this model, focus areas are;

I. the demand rate of new product,

II. demand of remanufactured product,

III. the amount of product supply to the market Q_s,

IV. the amount returned product Q_r and

V. the amount of waste product Q_w,

There might be two situations which may arise during the process. The situations are discussed under the two cases.

- Case-1: When the demand rate of the remanufactured product is more than the return rate of the new product after end of use, that is $D_2 > D_1$ $D_1\alpha(c_b)$
- Case-2: When the demand rate of the remanufactured product is less than or equals to the return rate of the new product after end of use, that is $D_2 \leq D_1\alpha(c_b)$

. Mathematical models are developed for calculating the above need under the considered situations. The response of the system to the changes in process parameters are examined through numerical experiments. This model deals with remanufacturing in a reverse supply chain. After manufacturing the new product, it goes to holding inventory which is categorized into three parts like manufacturing holding inventory, Remanufacturing holding inventory, Inventory of used product.

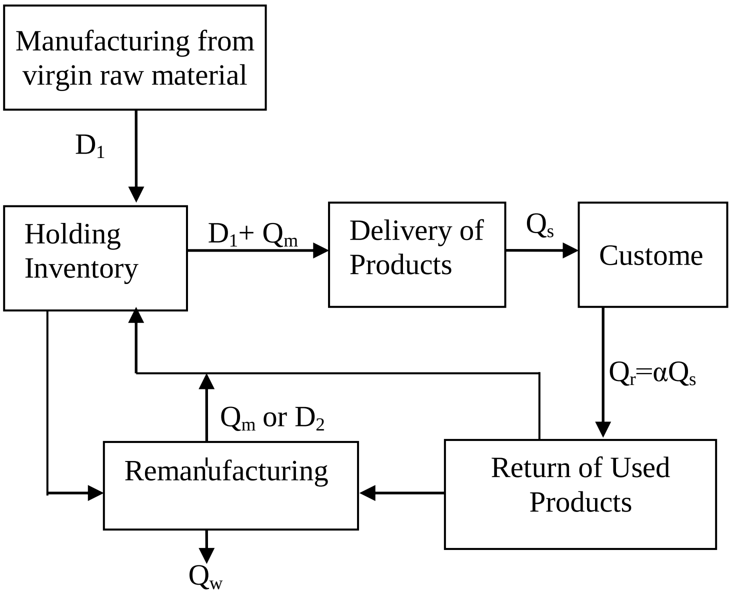


Figure 4.1: Model of supply chain with remanufacturing

Notations

D_1 = Demand rate of new product [unit/time]

D_2 = Demand rate of remanufactured product [unit/time]

c_1 = unit manufacturing cost for new product [Rs/unit]

c_2 = unit remanufacturing cost for remanufactured product [Rs/unit]

$\alpha\,(c_b)$= return rate of end-of-use products where $\alpha(c_b) = \frac{c_b}{s}$

p_1 = unit price of new product [Rs/unit]

p_2 = unit price of remanufactured product [Rs/unit]

Q_s = the number of units of new product supply to the market [units]

Q_m = the number of units of remanufactured product [units]

Q_r = the number of units of return for end-of use products [units]

Q_w = the number of units of waste product [units]

a_1 = the maximum units of sales of new product [units]

a_2 = the maximum units of sales of remanufactured product [units]

b_1 = the price sensitive to the customer for new product [Rs/unit]

b_2 = the price sensitive to the customer of remanufactured product [Rs/unit]

γ = Units of demand leakage per price difference [units/Rs]

c_b = unit buy back cost for taking back of the end-of-use products from customers [Rs/unit]

s = scaling factor [Rs/unit] = $c_1 - c_2$

The present model is based on various conditions during manufacturing and subsequent use of the product by the consumer and the buyback policy after end of use of the product. In order to avoid the complicacies in the model which may arise during the real situations during manufacturing and marketing, the following assumptions are made.

- Demand rate is dependent on the price of the product
- The cost parameters are known and constant
- No shortages are allowed
- The unit buy back cost includes the remanufacturing cost; hence no additional cost is needed after take back.
- Production rate of OEM and remanufacturer is large enough to meet the demand.
- There is no penalty cost as the manufacturer takes back the obligatory take back quota.

4.2.1 Mathematical formulation

It is a common practice that, if there is a price difference among products segments, more customers are willing to migrate to low priced segments as the price difference increases. Zhang and Bell (2007) modeled the demand leakage as a linear function of the difference between the prices. In this study, the lower price of the remanufactured product is assumed to trigger demand leakage from the new products to remanufactured products. Considering D_1 as the price dependent demand functions for the new product and D_2as the price dependent demand functions for the remanufactured product, the modeling procedure may proceed as follows

Let Q_S = f (D_x, ξ) be the demand function continuously over the interval $[p_1, p_2]$, where D_x is the demand for some quantity 'x' and ξ is an additive error sensitive to price difference between new product and the remanufactured product.

Considering a linear demand curve with additive error (ξ)

$$Q_s = D_x + \xi \tag{4.1}$$

From the actual linear demand curve

$Q = a - bp$, where ‘a’ and ‘b’ are variables and p is the price per unit.

From equation (4.1) we have,

$Q_s = D_x + \xi$

$\Rightarrow D_x = Q_s - \xi$

$\Rightarrow D_x = a - bp - \xi$

Here the demand is given by a simple homoscedastic regression model, with the variables ‘a’ and ‘b’, the quantity demanded x, the unit price P and the additive error ξ. The above equation implies a demand with an expected value which decreases linearly with unit price.

For demand rate of new product, $p_1 > p_2$

$D_x = a - bp - \xi$,

With $\xi = \gamma(p_1 - p_2)$, where γ is the sensitivity to price difference, we get

$D_1 D_1 = a_1 - b_1 p_1 - \gamma(p_1 - p_2)$

Now considering the demand rate of remanufactured product, $p_2 > p_1$

$D_x = a - bp - \xi$

$\xi = \gamma(p_2 - p_1)$

$D_2 = a_2 - b_2 p_2 - \gamma(p_2 - p_1)$

$\Rightarrow D_2 = a_2 - b_2 p_2 + \gamma(p_1 - p_2)$

With reference to the figure 4.1, the mathematical formulation for finding the solutions to the model of supply chain management with remanufacturing can be made as follows.

The number of units of new product supply to the market can take as the summation of the number of units of new products and remanufacturing products produced with unit time

$$\Rightarrow Q_s = D_1 + D_2 \tag{4.2}$$

Equating the demand rate of remanufactured product to the amount of remanufacturing products with unit time,

$$Q_m = D_2 \tag{4.3}$$

Considering the return rate of the end of life products to be 'α', the number of units of return for end of use product and number of units of product supply to the market are related as given below.

$$Q_r = \alpha Q_s \tag{4.4}$$

Considering the waste (amount of returned products that cannot be remanufactured)

$$Q_r = Q_m + Q_w \tag{4.5}$$

$$D_1 = a_1 - b_1 p_1 - \gamma (p_1 - p_2) \tag{4.6}$$

$$D_2 = a_2 - b_2 p_2 + \gamma (p_1 - p_2) \tag{4.7}$$

Now considering a profit of 30% on the new product and 60% on the remanufactured product as a common practice,

$$p_1 = 1.3c_1 \tag{4.8}$$

$$p_2 = 1.6c_2 \tag{4.9}$$

Referring to the work done by Hwang and Jung [82], profit function of the remanufacturer can be set under two cases as explained herewith. The minimum and maximum values of $C_{b\,min}$ and $C_{b\,max}$ can be calculated with the optimization of the profit function for the remanufacturer .Instead of dealing with the extreme values of C_b, the average value is taken care of to find and compare the results for a wide range of variables. Two cases are considered for the study purpose and the relevant equations for both the cases are given below.

Case 1: When the demand rate of the remanufactured product is more than the return rate of the new product after end of use, that is $D_2 > D_1$ $D_1\alpha(c_b)$

$$c_{b\,min} = \frac{p_2 - c_2}{2} \tag{4.10}$$

Case 2: When the demand rate of the remanufactured product is less than or equals to the return rate of the new product after end of use, that is $D_2 \leq D_1\alpha(c_b)$

$$c_{b\,min} = \frac{s\{a_2 - b_2 p_2 + \gamma(p_1 - p_2)\}}{a_1 - b_1 p_1 - \gamma(p_1 - p_2)} \tag{4.11}$$

$$c_{b\,max} = c_1 - c_2 \text{ (For both the cases)} \tag{4.12}$$

An example of cartridge manufacturing industry for checking the model of supply chain management with remanufacturing is considered. The numerical data is taken from the industry.

4.2.2 Numerical experiment for a cartridge manufacturing industry

In order to check the model, a study on its sensitivity i.e. its degree of response to the external changes is carried out. An experiment is conducted numerically to assess the sensitivity. Relevant data were collected from a cartridge manufacturing company to carry out this numerical experiment.

$a_1 = 6000\,\text{Units}$

$a_2 = 3000\,\text{Units}$

$b_1 = 1.10\,\text{Unit/Rs}$

$b_2 = 1\,\text{Unit/Rs}$

$p_1 = \text{Rs}1000/\text{unit}$

$p_2 = \text{Rs}700/\text{unit}$

$\gamma = 0.2$ unit/Rs

Calculations:

From the equation (4.8)

$$c_1 = \frac{p_1}{1.3} \Rightarrow c_1 = \frac{1000}{1.3} \Rightarrow c_1 = \text{Rs}769.29/\text{unit}$$

From the equation (4.9)

$$c_2 = \frac{p_2}{1.6} \Rightarrow c_2 = \frac{700}{1.6} \Rightarrow c_2 = \text{Rs } 437.5/\text{unit} \quad c_2$$

$s = c_1 - c_2 =$ Rs 331.73 /unit

To calculate the demand rate of new product, from the equation (4.6)

$D_1 = a_1 - b_1 p_1 - \gamma (p_1 - p_2)$

Putting all the given value in this equation

$$D_1 = 6000 - 1.1 \times 1000 - 0.2(1000 - 700)$$

$$\Rightarrow D_1 = 6000 - 1100 - 60$$

$$\Rightarrow D_1 = 4840\,\text{units}$$

To calculate the demand rate of remanufactured product, from the equation (4.7)

$D_2 = a_2 - b_2 p_2 + \gamma (p_1 - p_2)$

Putting all the given value in this equation

$$D_2 = 3000 - 1 \times 700 + 0.2(1000 - 700)$$

$$\Rightarrow D_2 = 3000 - 700 + 60$$

$\Rightarrow D_2 = 2360$ units

To estimate the amount of new product supply to the market, from the equation (4.2)

$Q_s = D_1 + D_2$

$Q_s = 4840 + 2360$

$\Rightarrow Q_s = 7200$ units

Let us consider the following cases.

Case 1: $D_2 \rangle D_1 \alpha(c_b)$

Step 1: To estimate the minimum unit buy back cost of the end-of use products from customers

From the equation (4.10)

$$c_{b\,min} = \frac{p_2 - c_2}{2} \Rightarrow c_{b\,min} = \frac{700 - 437.5}{2}$$

$\Rightarrow c_{b\,min} = \text{Rs}\,131.25/\text{ unit}$

The maximum unit buy back cost, from the equation (4.12)

$c_{b\,max} = c_1 - c_2 \Rightarrow c_{b\,max} = 769.23 - 437.5$

$\Rightarrow c_{b\,max} = \text{Rs}\,331.73\,/\text{unit}$

The averages of the unit buy back cost

$$c_{b\,avg} = \frac{c_{b\,max} + c_{b\,min}}{2}$$

$$\Rightarrow c_{b\,avg} = \frac{331.73 + 131.25}{2} \Rightarrow c_{b\,avg} = \text{Rs}\,231.49/\text{unit}$$

Step 2: To estimate return rate of end-of use products

$$\alpha = \frac{c_{b\,avg}}{s}$$

$$\Rightarrow \alpha = \frac{231.49}{331.73}$$

$\Rightarrow \alpha = 0.6978 = 69.78\,\%$

Step 3: To estimate the amount of return end-of use products, from the equation (4.4)

$Q_r = \alpha Q_s$

Q_r=5024

Step 4: To estimate the amount of waste products after returned, from the equation (4.5)

$Q_r = Q_m + Q_w$

Q_w=2664

Case 2: $D_2 \leq D_1 \alpha(c_b)$

Step 1: To estimate the minimum unit buy back cost of the end-of use products from customers

From the equation (4.11)

$$c_{b\,min} = \frac{s\{a_2 - b_2 p_2 + \gamma(p_1 - p_2)\}}{a_1 - b_1 p_1 - \gamma(p_1 - p_2)}$$

$$\Rightarrow c_{b\,min} = \frac{331.73\{3000 - 1 \times 700 + 0.2(1000 - 700)\}}{6000 - 1.1 \times 1000 - 0.2(1000 - 700)}$$

$$\Rightarrow c_{b\,min} = \frac{331.73\{3000 - 700 + 0.2 \times 300\}}{6000 - 1100 - 0.2 \times 300}$$

$$\Rightarrow c_{b\,min} = \frac{331.73 \times 2360}{4840}$$

$$\Rightarrow c_{b\,min} = \text{Rs}\, 161.75/\text{ unit}$$

The maximum unit buy back cost, from the equation (4.12)

$$c_{b\,max} = c_1 - c_2$$

$$\Rightarrow c_{b\,max} = 769.23 - 437.5$$

$$\Rightarrow c_{b\,max} = \text{Rs}\, 331.73/\text{unit}$$

The averages of the unit buy back cost,

$$c_{b\,avg} = \frac{c_{b\,max} + c_{b\,min}}{2}$$

$$\Rightarrow c_{b\,avg} = \frac{331.73 + 161.75}{2}$$

$$\Rightarrow c_{b\,avg} = \text{Rs}\, 246.74/\text{unit}$$

Step 2: To estimate return rate of end-of use products

$$\alpha = \frac{c_{b\,avg}}{s}$$

$$\Rightarrow \alpha = \frac{246.74}{331.73}$$

$$\Rightarrow \alpha = 0.7438 = 74.38\,\%$$

Step 3: To estimate the amount of return end-of use products, from the equation (4.4)

$$Q_r = \alpha\, Q_s$$

$$\Rightarrow Q_r = 0.7438 \times 7200$$

$$\Rightarrow Q_r = 5355.36 \approx 5355\,\text{units}$$

Step 4: To estimate the amount of waste products after returned, from the equation (4.5)

$$Q_r = Q_m + Q_w$$

$$\Rightarrow Q_w = Q_r - Q_m$$

$$\Rightarrow Q_w = 5355.36 - 2360$$

$$\Rightarrow Q_w = 2995.36\,\text{units} \approx 2995\,\text{units}$$

A second example of tire manufacturing industry for checking the model of supply chain management with remanufacturing is considered. The numerical data are taken from the industry.

4.2.3 Numerical experiment for tire manufacturing industry

For sensitivity study, a remanufacturing system with following parameter values is considered.

$a_1 = 15000\,\text{units}$

$a_2 = 7000\,\text{units}$

$b_1 = 1.4\,\text{units/Rs}$

$b_2 = 1.2\text{units/Rs}$

$p_1 = \text{Rs}\,1500/\text{unit}$

$p_2 = \text{Rs}\,1050/\text{unit}$

$\gamma = 0.4\,\text{unit/Rs}$

From the equation (4.8)

$$c_1 = \frac{p_1}{1.3} \Rightarrow c_1 = \frac{1500}{1.3} \Rightarrow c_1 = \text{Rs}1153.85/\text{unit}$$

From the equation (4.9)

$$c_2 = \frac{p_2}{1.6} \Rightarrow c_2 = \frac{1050}{1.6} \Rightarrow c_2 = \text{Rs } 656.25/\text{unit } c_2$$

$s = c_1 - c_2 =$ Rs 497.6 /unit

Equation (4.6) may be used to calculate the demand rate of the new product.

$D_1 = a_1 - b_1 p_1 - \gamma (p_1 - p_2)$

Putting all the given value in this equation

$$D_1 = 15000 - 1.4 \times 1500 - 0.4(1500 - 1050)$$

$$\Rightarrow D_1 = 15000 - 2100 - 180$$

$$\Rightarrow D_1 = 12720 \text{ units}$$

Equation (4.7) may be used to calculate the demand rate of the remanufactured product.

$D_2 = a_2 - b_2 p_2 + \gamma (p_1 - p_2)$

Putting all the given value in this equation

$$D_2 = 7000 - 1.2 \times 1050 + 0.4(1500 - 1050)$$

$$\Rightarrow D_2 = 7000 - 1260 + 180$$

$$\Rightarrow D_2 = 5920 \text{ units}$$

Equation (4.2) may be used to estimate the amount of new product supply to the market.

$Q_s = D_1 + D_2$

$Q_s = 18640$

Now, **Case -1**: $D_2 \rangle D_1 \alpha(c_b)$

Step 1: To estimate the minimum unit buy back cost of the end-of use products from customers

From the equation (4.10)

$$c_{b\,min} = \frac{p_2 - c_2}{2} \Rightarrow c_{b\,min} = \frac{1050 - 656.25}{2}$$

$$\Rightarrow c_{b\,min} = \text{Rs}\,196.87/\ \text{unit}$$

The maximum unit buy back cost, from the equation (4.12)

$$c_{b\,max} = c_1 - c_2 \Rightarrow c_{b\,max} = 1153.85 - 656.25$$

$$\Rightarrow c_{b\,max} = \text{Rs}497.6\ /\text{unit}$$

The averages of the unit buy back cost

$$c_{b\,avg} = \frac{c_{b\,max} + c_{b\,min}}{2}$$

$$\Rightarrow c_{b\,avg} = \frac{497.6 + 196.87}{2} \Rightarrow c_{b\,avg} = \text{Rs}347.24/\ \text{unit}$$

Step 2: To estimate return rate of end-of use products

$$\alpha = \frac{c_{b\,avg}}{s}$$

$$\Rightarrow \alpha = \frac{347.24}{497.59}$$

$$\Rightarrow \alpha = 0.6978 = 69.78\,\%$$

Step 3: To estimate the amount of return end-of use products, from the equation (4.4)

$$Q_r = \alpha\, Q_s$$

$$\Rightarrow Q_r = 0.6978 \times 18640$$

$$\Rightarrow Q_r \approx 13007\ \text{units}$$

Step 4: To estimate the amount of waste products after returned, from the equation (4.5)

$$Q_r = Q_m + Q_w$$

$$Q_w = 7087$$

Case 2: $D_2 \le D_1\alpha(c_b)$

Step 1: To estimate the minimum unit buy back cost of the end-of use products from customers

From the equation (4.11)

$$c_{b\,min} = \frac{s\{a_2 - b_2p_2 + \gamma(p_1 - p_2)\}}{a_1 - b_1p_1 - \gamma(p_1 - p_2)}$$

$$\Rightarrow c_{b\,min} = \frac{497.6\{7000 - 1.2 \times 1050 + 0.4(1500 - 1050)\}}{15000 - 1.4 \times 1500 - 0.4(1500 - 1050)}$$

$$\Rightarrow c_{b\,min} = \frac{497.6\{7000 - 1260 + 180\}}{15000 - 2100 - 180}$$

$$\Rightarrow c_{b\,min} = \frac{497.6 \times 5920}{12720}$$

$$\Rightarrow c_{b\,min} = \text{Rs } 231.58/\text{ unit}$$

The maximum unit buy back cost, from the equation (4.12)

$$c_{b\,max} = c_1 - c_2$$

$$\Rightarrow c_{b\,max} = 1153.85 - 656.25$$

$$\Rightarrow c_{b\,max} = \text{Rs } 497.6/\text{unit}$$

The averages of the unit buy back cost,

$$c_{b\,avg} = \frac{c_{b\,max} + c_{b\,min}}{2}$$

$$\Rightarrow c_{b\,avg} = \frac{497.6 + 231.58}{2} \Rightarrow c_{b\,avg} = \text{Rs } 364.59/\text{ unit}$$

Step 2: To estimate return rate of end-of use products

$$\alpha = \frac{c_{b\,avg}}{s}$$

$$\Rightarrow \alpha = \frac{364.59}{497.6}$$

$$\Rightarrow \alpha = 0.7327 = 73.27\,\%$$

Step 3: To estimate the amount of return end-of use products, from the equation (4.4)

$$Q_r = \alpha\, Q_s$$

$\Rightarrow Q_r = 0.7327 \times 18640$
$\Rightarrow Q_r \approx 13657 \text{ units}$

Step 4: To estimate the amount of waste products after return, from the equation (4.5)

$Q_r = Q_m + Q_w$
$Q_w = 7737$

4.3 Modeling the reverse supply chain inventory

The present work deals with a model applicable to reverse supply-chain in which the stationary demand can be fulfilled by remanufactured products and newly purchased product. The model is based on the assumption that the returned items from the customers can be remanufactured at a fixed rate. The remanufactured products are as good as the new ones. This work deals with the calculation of economic order quantity for the newly procured items as well as the economic quantity of the remanufactured products simultaneously. To do so, a model is proposed and analyzed depending on the relationship between different parameters.

The objective of this work is to follow only the remanufacturing process of product recovery for the reverse supply chain. The intention is to optimize the level of products both from direct manufacturing and the remanufacturing. A general reverse supply chain with remanufacturing is shown in Fig-4.2. The solid lines show the forward supply chain and the dotted lines show the reverse supply chain. It is to be noted that the output of both direct manufacturing and remanufacturing adds to the finished product inventory. The other recovery processes like reuse, repair, refurbish and cannibalization are not being included for this model. In the fig.4.2 there are some percentage of products finds no use and discarded as waste or land fill. The remanufacturable items once collected form an inventory of remanufacturable inventory is subjected to remanufacturing process to get the finished products .These finished products are assumed to be as good as the products from direct manufacturing.

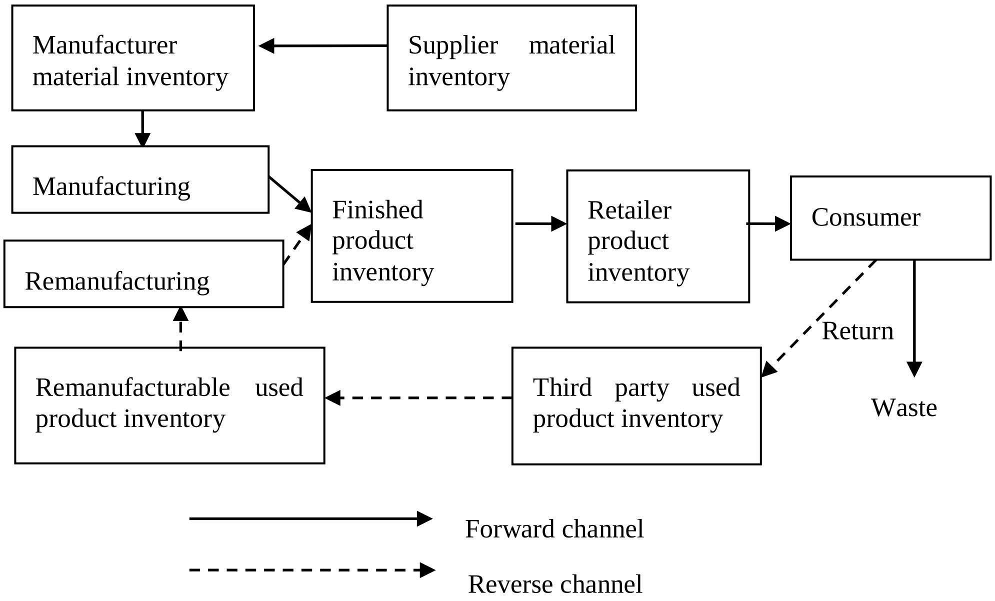


Figure 4.2: General reverse supply chain model with remanufacturing.

4.4 Proposed reverse supply chain model with remanufacturing

Based on the generalized model of reverse supply chain, the proposed model is shown in Fig-4.3, which deals with only the remanufacturing aspect of reverse supply chain. It is assumed that the remanufactured products are as good as new ones and can supplement the demand for the new products. There are two cycles operating at the same time. The first cycle comprising of the products produced or procured at a fixed rate "p", which is consumed at a fixed rate "d". The production or the procurement continues till t_1^1 after which there is only consumption till the stock level comes down to zero. The next part of this cycle is the stock of remanufactured products it receives from the second cycle. The rate of consumption of the remanufactured products (which is as good as the new ones) is also same as that of the newly produced/procured products "d". This part of the cycle continues for a time period of "t_2" till the remanufactured stock level decreases to zero. The second cycle deals with the remanufactured products. Products are collected back from the end users and subjected to remanufacturing. The remanufacturing process continues at a fixed rate "K^1" up to a time period of "t", which is the cycle time. It attains a level q^1 after which all the remanufactured products are shifted to the first cycle and the level of remanufactured products in the second cycle comes down to zero. This initiated the start of another remanufacturing cycle. As this model is based on deterministic approach, the parameters like p, d, and k^1 are assumed to be constant. The holding costs are taken as the percentages of cost per unit. As the remanufactured products are as good as new ones, so the holding cost for the newly available products and the remanufactured products are assumed to be the same.

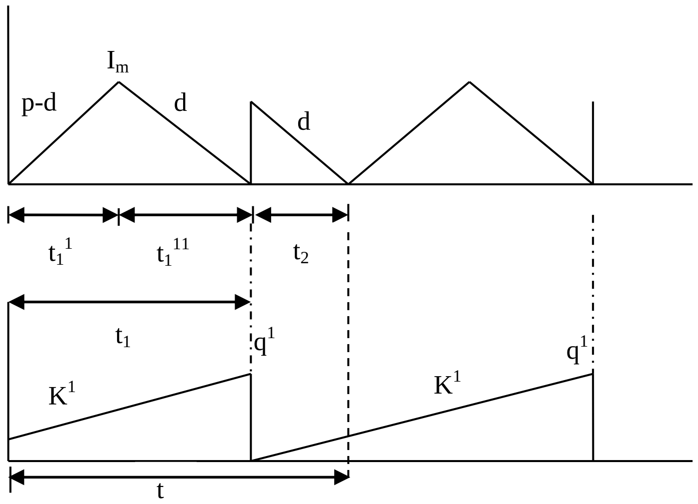


Figure 4.3: Proposed supply chain model with remanufacturing

Regarding the set up cost, the set up cost for the remanufacturing process is assumed to be smaller than the set up cost for the newly produced products. The production or the procurement cost for the new products is more than the consumption rate, that is ($p > d$). This model aims at finding out the optimum level of the newly produced or procured products as well as the optimum level of the remanufactured products**.**

4.4.1 Methodology

The methodology includes the calculation of the total cost considering the both cycles using the assumed parameters and applying partial differential method to optimize the total cost from this model tries to find out the optimum level of newly produced or procured products and optimum level of remanufactured products.

Nomenclature

d: Number of items required per unit time(demand rate).

p: Number of items produced per unit time(production rate)

C_1: Cost of holding inventory per item per unit time

$C_{2:}$ Setup cost per production run for remanufacturing

C_3: Cost of setting up a production from raw materials q: Number of items manufactured per run= d^*t_1

$q^{1:}$ Number of items remanufactured per run

t_1: Time Interval for the production run from raw materials

t_1^1: Time during which the stock is building up at a constant rate (p-d) unit per unit time

t_1^{11}: Time during which there is no production and inventory is decreasing at a constant demand rate "d" per unit time

I_m: Max level of inventory at the end of "t_1^1" which is expected to be consumed during "t_1^{11}".

t_2: Time during which the remanufactured items are consumed.

K^1: Remanufacturing rate.

Considering the model presented in figure 4.3, the maximum level of direct manufacturing and other parameters can be computed as follows.

$$I_m = (P - d) \times t_1^1 \Rightarrow t_1^1 = \frac{I_m}{(P - d)} \tag{4.13}$$

Total quantity produced during time t_1^1 is q and quantity consumed during the same period is d* $t_1^{1.}$ Remaining quantity at the end of t_1^1 is I_m. Therefore,

I_m = q- d×t_1^1

$$= q - d \times \left[\frac{I_m}{(P - d)} \right] \Rightarrow I_m = \left(\frac{p - d}{p} \right) \times q \tag{4.14}$$

Holding cost per production run i.e. for time period t_1

$$= \frac{1}{2} \times I_m \times t_1 \times C_1 \tag{4.15}$$

Setup cost per production run = C_3

The total cost for the production of finished goods from raw materials

$$= \frac{1}{2} \times I_m \times t_1 \times C_1 + C_3 \tag{4.16}$$

So, the average total cost per unit time for production of finished goods from raw materials

$$= \frac{\left(\frac{1}{2} \times I_m \times t_1 \times C_1 + C_3 \right)}{t_1} = \frac{1}{2} \times I_m \times C_1 + \frac{C_3}{t}$$

$$=\frac{1}{2}\times\left(\frac{p-d}{p}\right)\times q\times C_1+\frac{C_3\times d}{q} \qquad (4.17)$$

If a production run is made at interval t_2, a quantity $q=d\times t_2$ must be produced. Since the stock in small time dt_2 is $d\times t_2\times dt_2$, the stock in time period t_2 will be:

$$\int_0^{t_2} d\times t_2 dt_2=\frac{1}{2}\times d(t_2)^2=\frac{1}{2}\times q^1\times t_2$$

Hence, the holding cost per production run $=\frac{1}{2}\times C_1\times q^1\times t_2$ (4.18)

Setup cost per production run $=C_3$

The total cost for the remanufactured items used

$$=\frac{1}{2}\times C_1\times q^1\times t_2+C_3 \qquad (4.19)$$

Hence, the average total cost per unit time for the remanufactured items

$$=\frac{\left[\frac{1}{2}\times C_1\times q^1\times t_2+C_3\right]}{t_2}$$

$$=\frac{1}{2}\times C_1\times q^1+\frac{C_3}{t_2}$$

$$=\frac{1}{2}\times C_1\times q^1+\frac{C_3\times d}{q^1} \qquad (4.20)$$

Stock of items subjected to remanufacturing in time t

$$=\int_0^t k^1 t dt=\frac{1}{2}\times k^1\times t^2=\frac{1}{2}\times q^1\times t$$

So the holding cost $=\frac{1}{2}\times q^1\times t\times C_1$

Setup cost per production run for remanufacturing = C_2

Now the total cost for the remanufacturing per unit time,

$$= \frac{\left[\frac{1}{2} \times q^1 \times t \times C_1 + C_2\right]}{t} = \frac{1}{2} \times q^1 \times C_1 + \frac{C_2}{t}$$

$$= \frac{1}{2} \times q^1 \times C_1 + \frac{C_2 \times K^1}{q^1} \tag{4.21}$$

Total cost per unit time, T, can be computed as ; Eq (4.17)+Eq (4.20)+Eq (4.21)

$$= \frac{1}{2} \times \left(\frac{p - d}{p}\right) \times q \times C_1 + \frac{C_3 \times d}{q} + \frac{1}{2} \times C_1 \times q^1 + \frac{C_3 \times d}{q^1} + \frac{1}{2} \times q^1 \times C_1 + \frac{C_2 \times K^1}{q^1}$$

$$= \frac{1}{2} \times \left(\frac{p - d}{p}\right) \times q \times C_1 + \frac{C_3 \times d}{q} + C_1 \times q^1 + \frac{C_3 \times d}{q^1} + \frac{C_2 \times K^1}{q^1} \tag{4.22}$$

The minimum value of the total cost (T) can be mathematically determined as follows.

$$\frac{\partial T}{\partial q} = 0, \text{and } \frac{\partial T}{\partial q^1} = 0$$

$$\frac{\partial T}{\partial q} = 0 \Rightarrow \frac{1}{2} \times \frac{(p - d)}{p} \times C_1 - \frac{C_3 d}{q^2} = 0 \Rightarrow q = \sqrt{\frac{2pdC_3}{(p - d)C_1}} \tag{4.23}$$

$$\frac{\partial T}{\partial q^1} = 0 \Rightarrow q^1 = \sqrt{\frac{C_3 d + C_2 K^1}{C_1}} \tag{4.24}$$

4.4.2 Implementation of the outcome

The above discussed model can be a substitute to the existing model where,

- The demand rate is uniform
- Production rate is finite and
- Shortages are allowed.

An example problem is worked out to explain the model

Example problem:

A company has a demand of 12000 units /year for an item and it can produce 2000 such items per month. The cost of one set up is Rs.400 and the holding cost/unit/year is 0.5.It is to find out the total cost per year, assuming the cost of 1 unit as Rs.4.The shortage cost of one unit is Rs.20 per year.

As per the statement of the problem,

P= 2000*12=24000 units/year

d=12000/year

C_1=Rs0.5/unit/year

C_3=Rs300/set up

S=shortage cost =Rs 20/year

Solving this problem with shortages allowed:

The total cost:

$$= 12000 \times 4 + \sqrt{2 \times C_1 \times C_3 \times d} \times \sqrt{\frac{S}{C_1 + S}} \times \sqrt{\frac{p - d}{p}}$$

$$= 48000 + \sqrt{2 \times 0.5 \times 300 \times 12000} \times \sqrt{\frac{S}{C_1 + S}} \times \sqrt{\frac{p - d}{p}}$$

$$= 48000 + 1314.5 \times \sqrt{\frac{20}{20 + 0.5}} \times \sqrt{\frac{24000 - 12000}{24000}}$$

$$= \text{Rs } 49325.18/\text{year}$$

Now solving the problem with the proposed model with remanufacturing,

$$q = \sqrt{\frac{2pdC_3}{(p - d)C_1}}$$

$$\text{and } q^1 = \sqrt{\frac{C_3 d + C_2 K^1}{C_1}},$$

In order to arrive at a solution to this problem two more parameters viz. C_2 and K^1 need to be considered, where C_2 is the set up cost for the remanufacturing (The parameter C_2which is much less than the direct manufacturing set up cost can be taken as Rs 200/set up). The second parameter K^1 may be assumed to be 30% of the demand rate which is a standard practice. Putting these values in the equation 4.23 and 4.24and solving these we can have, q =5367 units and q^1 = 2939.388 units.

Therefore to satisfy a demand of 12000 units per year,we have to produce on an average of 7753.55 no of units from direct manufacturing and 4246.45 no of units from remanufacturing. As the cost of the remanufacturing is much less as compared to direct manufacturing we can assume the cost of remanufactured products to be Rs 2 per unit.

Hence the total cost using remanufacturing can be calculated by adding the equation 4.22 to the cost of purchase for the direct manufacturing and remanufacturing. Hence the total cost,

$$= (7753.55 \times 4) + (4246.45 \times 2)$$
$$+ \frac{1}{2} \times \left(\frac{p - d}{p} \right) \times q \times C_1$$
$$+ \frac{C_3 \times d}{q} + C_1 \times q^1 + \frac{C_3 \times d}{q^1} + \frac{C_2 \times K^1}{q^1}$$
$$= \text{Rs } 43788.13$$

Therefore the total savings = Rs 49325.18 - Rs 43788.13= Rs 5537.05.This is clear from the above calculation that the model with remanufacturing involves in the less total cost. Hence it will be economically advantageous to use this model for competitive product manufacturing.

4.5 Summary

This chapter deals with two novel deterministic models for supply chain with remanufacturing. The first model deals with the concept of demand leakage where the lower price of the remanufacturing items triggers the shift of demand from products from direct manufacturing to remanufacturing. The demand for both direct manufacturing and remanufacturing is calculated on the basis of the work done by Zhang and Bell (2007). Two example problems from pertinent industry one from tire manufacturing and one from cartridge manufacturing industry is considered for analysis. The amount of direct manufacturing quantity, remanufacturing quantity, the rate of return are calculated with different values of γ (sensitivity to price difference). The second proposed model is a deterministic one which deals with the remanufacturing as well as direct manufacturing. Two cycles are considered, one dealing with only remanufacturing process and the second cycle using the direct manufacturing as well as the products from the remanufacturing cycle to satisfy the constant market demand. An example problem is considered for this model with relevant data to check its feasibility.

Chapter 5

PROBABILISTIC MODELING OF RSC WITH REMANUFACTURING

5.1 Overview

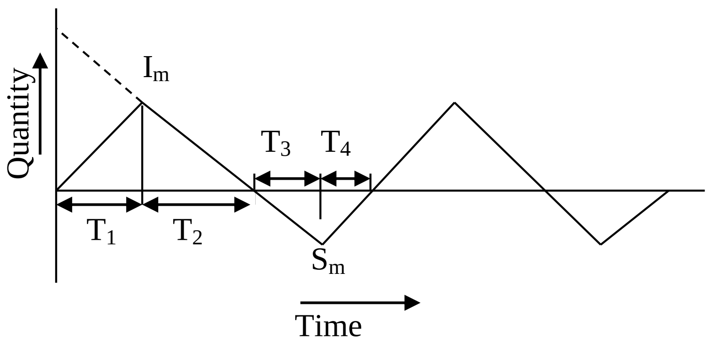
It is needless to say that, inventory control is one of the fundamental activities in the field of reverse supply chain dealing with remanufacturing. In this context a number of models have been developed to find the optimal order quantity for an integrated manufacturing and remanufacturing system with an intention to optimize the cost. The modeling of reverse supply chain with remanufacturing becomes more critical with the fluctuation in demand for the product in the market which results in stock out. The consequences are customer dissatisfaction, lost sales and more predominantly the loss of goodwill in the market. However these situations are hard to study and predict due to the fact that these situations are very uncertain. It is difficult to formulate a deterministic mathematical model to estimate the quantity of inventory for the process. If an appropriate corrective action is not taken, this situation may continue to arise time and again. These situations as evident from the characteristics, may give rise to either a stock out situation or an over stocking situation. While the latter is not detrimental to meet the demand of the customer, the former has the possibility of losing them during the period of exist or at a later time due to loss of goodwill. The researchers are therefore forced to think in this direction by using a probabilistic model for stock out. The probabilistic model can also predict the safety stock levels by integrating stock out probability with demand uncertainty. Along with the normal inventory, in this particular chapter care has been taken to use the concept of safety stock which is determined with a specified service level.

5.2 A probabilistic approach for RSC model for remanufacturing

The objective of the present work is to provide an approachable model which in future may replace the existing model with demand rate uniform, production rate finite with shortages allowed. This particular study is directed towards stabilizing the diversified opinions in the field of returned item inventory. In most of the cases, models are deterministic and a particular use of returned item inventory (like either remanufacturing or recycling) was discussed. The approach here is different from the models discussed earlier. Returned item inventory is being used as a substitute to stock out conditions. The primary concern is environmental benefits where use of return items will decrease the depletion rate of resources. Successful implementation of the method can reduce the inventory cost of finished goods. This model helps in reduction of the raw material supplies thereby minimizing the risk associated with the environment.

5.2.1 The conventional inventory model

Considering a manufacturing scenario, the conventional model of inventory shown (in figure-5.1) has a finite production rate. In this model, it is assumed that the inventory is zero at the beginning. The finished product inventory increases at a constant rate (K-R) for time T_1 until it reaches a level I_m. There is no replenishment during timeT_2t_2. Inventory decreases (as it is shipped out or used internally) at a constant rate R tillit becomes zero. Shortage starts filling up at a constant rate R during time T_3(as there is no manufacturing) until this backlog reaches a level S_{max}. At the beginning of time T_4, manufacturing starts and backlog is filled at a constant rate K-R till the backlog becomes zero at the end of period T_4. This completes the cycle.



Costs:

- Holding cost
- Procurement cost
- Shortage cost

Other considerations:

- Demand rate
- Consumption rate
- Cycle time

Figure 5.1 A model with uniform demand rate, finite production rate and shortages allowed

5.2.2 The model formulation for optimal manufacturing

This model is formulated by using the following variables:

q = Manufactured quantity during the cycle

K = rate of production (units/year).

R = rate of consumption (units/year).

C_1= Holding cost during the time interval T (Rs/unit/year).

C_2= Shortage cost during time interval T (Rs/unit/year).

C_3= Setup cost per setup.

T_1= Time for which there is production/procurement as well as consumption till the stock level increases to I_m.

T_2=Time for which there is only consumption and the stock level comes down to zero.

T_3=Time for which there is no production but due to customer order, the number of units for back ordering increases to S_m.

T_3=Time for which the production/procurement starts again realizing the back orders till the stock level comes back to zero completing one cycle.

The total time is given by;

$T= T_1 + T_2 + T_3 + T_4$

The total cost per unit time can be computed as follows,

$$\text{Total cost} = C = \frac{\frac{1}{2}C_1 \times I_m \times (T_1 + T_2) + \frac{1}{2}C_2 \times S \times (T_3 + T_4) + C_3}{T_1 + T_2 + T_3 + T_4} \qquad (5.1)$$

$$\text{It can be shown that, } I_m = q\left(1 - \frac{R}{K}\right) - S \qquad (5.2)$$

$$T_1 + T_2 = \frac{I_m}{K - R} + \frac{I_m}{R}$$

$$\Rightarrow T_1 + T_2 = I_m\left(\frac{1}{K - R} + \frac{1}{R}\right)$$

$$\Rightarrow T_1 + T_2 = \left\{ q\left(1 - \frac{R}{K}\right) - S \right\} \left(\frac{1}{K-R} + \frac{1}{R} \right) \tag{5.3}$$

It may also be derived that,

$$T_3 + T_4 = \frac{S}{K-R} + \frac{S}{R} \Rightarrow T_3 + T_4 = S\left(\frac{1}{K-R} + \frac{1}{R} \right) \tag{5.4}$$

$$\text{Hence, } T_1 + T_2 + T_3 + T_4 = \frac{q}{R} \tag{5.5}$$

Now substituting $(T_1 + T_2), (T_3 + T_4), T_1 + T_2 + T_3 + T_4$ and I_m in the equation (5.2) for total cost and using $\frac{\partial C}{\partial q} = 0$, we get;

$$q_{optimal} = \sqrt{2C_3 \times \frac{C_1 + C_3}{C_1 \times C_2}} \times \sqrt{\frac{K \times R}{K-R}} \tag{5.6}$$

However, this model is bound to have stock outs which may lead to disturbance in the committed delivery schedule and hence customer dissatisfaction. Further, the model uses virgin raw materials for production which calls for more investment on acquiring the materials as well as its processing requirements.

5.2.3 The proposed model

This model as shown in Figure-5.2can be a substitute for the inventory models where stock outs are allowed. The stock out part for the existing model is replaced by the products from remanufacturing. The total cycle time is taken as‘t’. There are two cycles operating at the same time (one is remanufacturing cycle which is shown at the bottom and the second one is the direct manufacturing with remanufactured items which is shown on the top).

In the remanufacturing cycle the products having potential to be remanufactured are collected back at a rate f.d, where f is the fraction of return and d is the demand rate. The value of ‘f’ may vary between 0 and 1 whereas that of‘d’ depends on the market demand. The rate of remanufacturing needs to be decided in such a manner that it reaches the maximum level ‘S’ at the end of the cycle time ‘t’. The whole lot of remanufactured products is transferred to the direct manufacturing cycle at this point of time for satisfying the market demand. An inventory level of the remanufactured products becomes zero, the next remanufacturing cycle begins.

In the proposed model the cycle of direct manufacturing is supplemented with remanufactured items. During the time 't_1' all the remanufactured products are consumed and the finished product inventory comes down to zero. At the beginning of time 't_2', direct manufacturing starts with a rate 'p' and at the same time the market demands are satisfied with a rate'd'. The inventory level of finished products rises at a rate (p-d) and attains a value 'I_m' at the end of period 't_2'. At the beginning of the period 't_3' the direct manufacturing is stopped and market demand is satisfied from the stock of inventory of finished products. At the end of the period 't_3' the stock level comes down to zero. By this time, the stock of finished products in the remanufactured cycle is carried over to the cycle of direct manufacturing with remanufactured items and process continues.

The silver line on the proposed model is that, the disadvantages associated in the conventional model (where stock outs are allowed) are completely eliminated. As the model uses remanufacturing of recovered products, there is a decrease in the total cost and there will be an increase in the productivity. Since returned items are remanufactured to fill out for raw material inventories, there is a substantial environmental benefit as it controls the depletion rate of resources to a great magnitude. Additionally, the possibility of loss of goodwill from the customers resulting from stock outs is completely eliminated in the proposed model. The primary concern is environmental benefits where the use of return items will decrease the depletion rate of resources. Successfully implementing the method can reduce the cost of finished goods. This helps in reduction of the raw material supplies.

5.2.4 The model variables for the proposed model

The following are the variables used for the model:

D = annual demand for the item

d = the demand rate/consumption rate for the item

p = the rate of production/procurement of the finished product in direct manufacturing

f = fraction of the demand rate that is used for remanufacturing

C_1 = holding cost for the finished goods in direct manufacturing as well as in remanufacturing

C_2 = holding cost for the goods in remanufacturing cycle

C_0 = Order cost/set up cost for direct manufacturing

C_0^1 = Order cost/set up cost for remanufacturing.

I_m = Maximum level of the finished products in direct manufacturing

S = Maximum level of the finished products in remanufacturing

t = Cycle time

t_1 = time in which remanufactured products are consumed

t_2 = time during which inventory buildup takes place in direct manufacturing

t_3 = time in which inventory level for direct manufacturing comes to zero.

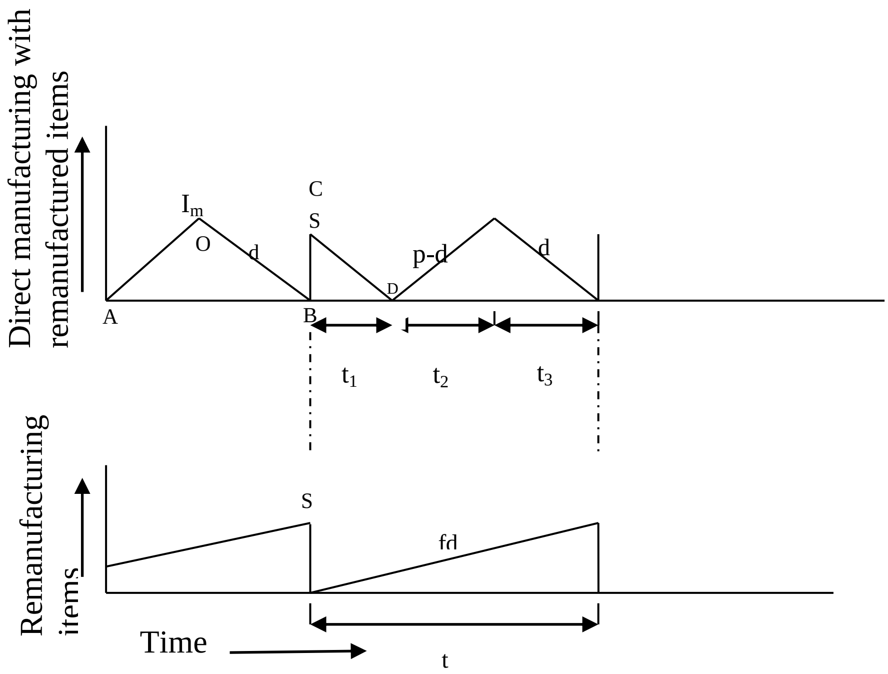


Figure 5.2 The proposed model with remanufacturing.

The model, on mathematical analysis, gives out the following parameters.

a) Holding cost for finished goods inventory $= C_1 \times (\text{Area OAB}) + C_1 \times (\text{Area BCD})$

$$= C_1 \times \frac{1}{2} St_1 + C_1 \times \frac{1}{2} I_m \times (t_1 + t_2) = \frac{C_1 St_1}{2} + \frac{C_1 I_m (t_1 + t_2)}{2}$$

$$\Rightarrow \text{Holding cost for finished goods inventory } = \left[\frac{C_1 St_1}{2} + \frac{C_1 I_m (t_1 + t_2)}{2} \right] \qquad (5.7)$$

b) Holding cost for remanufactured goods inventory $= \frac{1}{2} \times fdt^2 \times C_2$ (5.8)

c) Number of set ups $= \frac{D}{(I_m + S)}$ (5.9)

$\Rightarrow$ Set up cost for finished goods inventory $= C_0 \times \frac{D}{(I_m + S)}$ (5.10)

d) Set up cost for remanufactured goods inventory $= C_0^1 \times \frac{D}{(I_m + S)}$ (5.11)

Therefore the annual total cost of inventory,

$$(TC) = \left[\frac{C_1 St_1}{2} + \frac{C_1 I_m (t_1 + t_2)}{2}\right] + \frac{1}{2} \times fdt^2 \times C_2 + C_0 \times \frac{D}{(I_m + S)} + C_0^1 \times \frac{D}{(I_m + S)} \quad (5.12)$$

From figure 5.2, the following parameters can be derived

$$S = dt_1 \quad (5.13)$$

$$S = fdt \Rightarrow t = \frac{S}{fd} \quad (5.14)$$

From equation (5.13) and (5.14),

$$f.t = t_1 \quad (5.15)$$

$$t_2 = \frac{I_m}{(p - d)} \quad (5.16)$$

and $I_m = dt_3$ (5.17)

From equation (5.16) and (5.17),

$$dt_3 = (p - d)t_2 \Rightarrow d(t_2 + t_3) = pt_2 \quad (5.18)$$

Hence,

$$(t_2 + t_3) = \frac{p}{d} \times t_2 \quad (5.19)$$

Substituting these values in the equation (5.12) for total cost, one can have

$$TC = \frac{C_1 sft}{2} + \frac{C_1 I_m p t_2}{2d} + \frac{C_2 fdt^2}{2} + C_0 \times \frac{D}{(I_m + S)} + C_0^1 \times \frac{D}{(I_m + S)}$$

$$\Rightarrow TC = \frac{C_1 S^2}{2d} + \frac{C_1 p}{2d(p-d)} \times I_m{}^2 + \frac{C_2 S^2}{2fd} + \frac{D}{(I_m + S)}\left(C_0 + C_0^1\right)$$

$$\Rightarrow TC = \frac{S^2}{d}\left(\frac{C_1}{2} + \frac{C_2}{2f}\right) + \frac{C_1 p}{2d(p-d)} \times I_m{}^2 + \frac{D}{(I_m + S)}\left(C_0 + C_0^1\right) \tag{5.20}$$

Equation (5.20) clearly shows that the total cost is a function of C_1, S, d, p, I_m, C_2, f, D, C_0 and C_0^1. Out of these C_1, d, p, C_2, f, D, C_0 and C_0^1 are constants and are assumed to be known. The values of S and I_m can be found by minimizing the total cost function. Therefore using,

$\frac{\partial TC}{\partial I_m} = 0$ and $\frac{\partial TC}{\partial S} = 0$, We can get the maximum levels of finished products through direct manufacturing (I_m) and that through the remanufacturing (S).

Considering, $\frac{\partial TC}{\partial I_m} = 0$, we have $\frac{2 I_m C_1 p}{2d(p-d)} - \frac{D\left(C_0 + C_0{}^1\right)}{(I_m + S)^2} = 0$

$$\Rightarrow \frac{2 I_m C_1 p}{2d(p-d)} = \frac{D\left(C_0 + C_0{}^1\right)}{(I_m + S)^2} \tag{5.21}$$

Now using $\frac{\partial TC}{\partial S} = 0$, we can have $\frac{2S}{d}\left(\frac{C_1}{2} + \frac{C_2}{2f}\right) - \frac{D\left(C_0 + C_0{}^1\right)}{(I_m + S)^2} = 0$

$$\Rightarrow \frac{2S}{d}\left(\frac{C_1}{2} + \frac{C_2}{2f}\right) = \frac{D\left(C_0 + C_0{}^1\right)}{(I_m + S)^2} \tag{5.22}$$

Using equation (5.21) and (5.22)

$$\frac{2 I_m C_1 p}{2d(p-d)} = \frac{2S}{d}\left(\frac{C_1}{2} + \frac{C_2}{2f}\right)$$

$$\Rightarrow I_m = \frac{2S(p-d)}{C_1 p}\left(\frac{C_1}{2} + \frac{C_2}{2f}\right) \tag{5.23}$$

Substituting the value of I_m from equation (5.23) in equation (5.22), we get

$$\frac{2S}{d}\left(\frac{C_1}{2}+\frac{C_2}{2f}\right)=\frac{D\left(C_0+C_0^{\ 1}\right)}{\left[\frac{2S(p-d)}{C_1p}\left(\frac{C_1}{2}+\frac{C_2}{2f}\right)+S\right]^2}$$

Simplifying the above equation it can be found that,

$$S=\left[\frac{D\left(C_0+C_0^{\ 1}\right)\times 4C_1^2p^2f^3d}{\left[2(p-d)(C_1f+C_2)+2C_1pf\right]^2\times\left(C_1f+C_2\right)}\right]^{\frac{1}{3}} \tag{5.24}$$

One can use the equations5.23 and 5.24 for determining the values of I_m and S respectively.

Use of safety stock to avoid the stock out due to change in the demand

It is of great importance to consider the stock out condition in the direct manufacturing part of the cycle due to the variation of the demand rate. The model considering the safety stock is shown in figure 5.3. It is shown as a dotted line, indicating higher demand in the triangle AOB. Because of the higher demand the zero stock condition will occur at X instead of B (refer figure 5.3). Therefore the need of a safety stock is essential to cope up with this kind of situation.

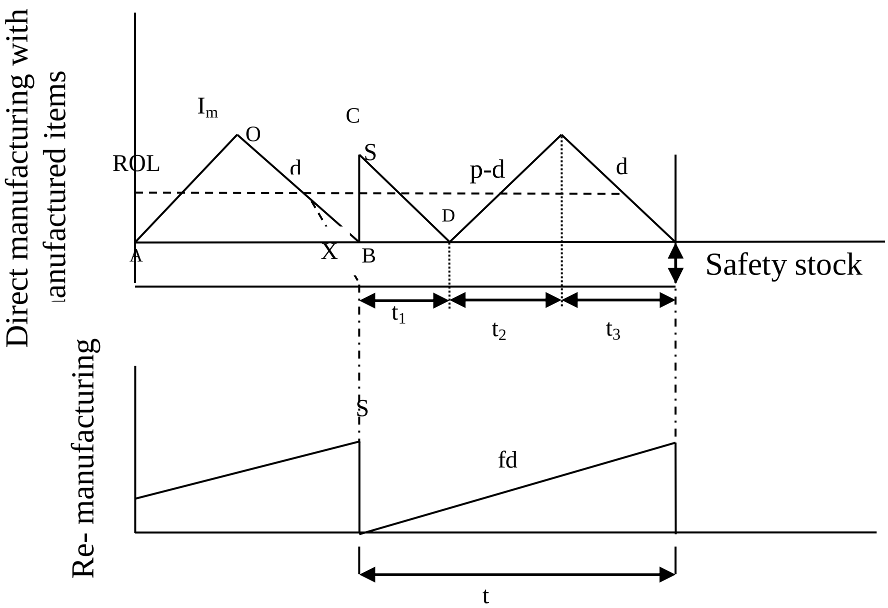


Figure 5.3 The inventory model considering safety stock.

The safety stock can be calculated by using the concept of service level. The service level is set to a very high value (more than 90%) which means that out of 100 times one face such situation he shall be able to supply the items from the stock at least 90 times.

The safety stocks can be determined as;

Safety Stock = z σ_L

Where, Z = number of standard deviations for a specified service level, which can be directly used from the normal distribution table(for example service level 95% means that ,Z=1.65), and σ_L = the standard deviation during the lead time period.

σ_L can be calculated as the square root of the sum of the variances for each day during the lead time period.

$\sigma_L = \sqrt{\sum_{i=1}^{L} \left(\sigma_{d_i}\right)^2}$, Where d_i is the standard deviation for each day during the lead time period.

It is to be remembered here that, the total cost has two components. The first one is the variable component of the total cost that is related to the figure-5.2 and the second one is the fixed component of the total cost that is related to the safety stock shown in Figure-5.3.

Example problem

Considering the pertinent data available from a firm, the following values are taken for consideration.

The annual demand for the product (D):24000 units.

The set up cost (C_0) per set up for direct manufacturing: Rs.100.

The set up cost (C_0^1) per set up for remanufacturing: Rs.60.

The holding cost for the finished goods in direct manufacturing with remanufactured items (C_1): Rs.10 per unit per year.

The holding cost for the goods in remanufacturing cycle: Rs.6 per unit per year.

The fraction return for remanufacturing (f): Within the range of 0.1 to 0.9.

Using these values in the equation (5.23) and equation (5.24) with a range of values for fraction return of used goods for remanufacturing the associated values of 'I_m'

and ‘S’ can be calculated and using the values of ‘I_m’ and ‘S’ along with the given values in equation (5.20), the total costs is computed as shown in Table-4.1.

Table 5-1: The values of S, I_m and total cost with variation of fraction returned.

f	**S**	**I_m**	**TC**
0.1	176	615	7288
0.2	277	555	6923
0.3	344	517	6684
0.4	393	491	6515
0.5	429	472	6388
0.6	457	458	6290
0.7	480	447	6211
0.8	500	437	6147
0.9	516	430	6093

5.3 A modified RSC with remanufacturing for sustainable product cycle

This paper deals with a new model, in which the stationary demand for a product can be fulfilled by remanufactured products along with newly procured product leading to minimum consumption of virgin raw materials. The remanufactured products are assumed to be as good as new ones and the returned items from the customers can be remanufactured at a fixed rate. The model helps in maintaining the goodwill of the customers by not allowing frequent stock outs by providing safety stock. A model is proposed and analyzed depending on the relationship between different parameters. An interpretive modeling based approach has been employed to model the reverse logistics variables typically found in reverse supply chains. A methodology is used for the calculation of optimum level for the newly manufactured items and the optimum level of the returned items for remanufacturing simultaneously. The major objective is to minimize the waste and gain the competitive advantage of cost of conversion. Moreover the company can sustain in the same line of business for a longer period of time.

5.3.1 Model description

As shown in the figure -5.4, there are two cycles acting simultaneously. The first one is the remanufacturing cycle and the second one is serviceable cycle comprising of products both from direct manufacturing and remanufacturing. The remanufacturing starts after a certain amount of collection (R).The remanufactured goods are assumed to be as good as new and can be a perfect substitute for the direct manufactured products. As there are certain uncertainties in the collection rate of the returned items for remanufacturing therefore a safety stock of finished goods/serviceable is proposed that provides a cushion during the fluctuation of the return collection rate.

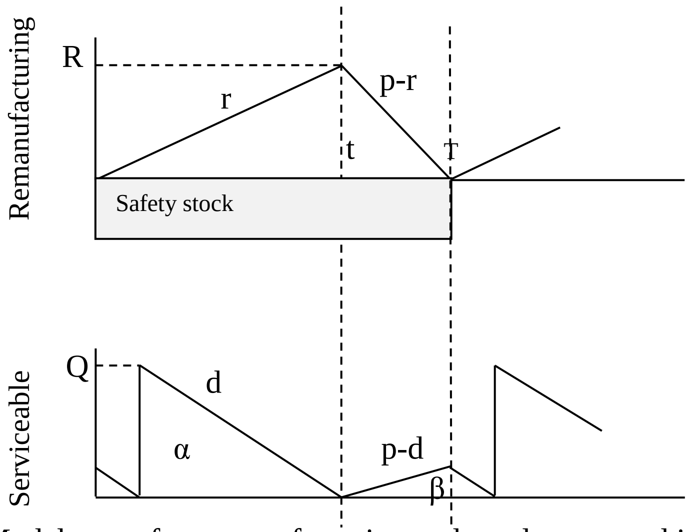


Figure 5.4 Model setup for remanufacturing and newly procured items to satisfy the market demand.

The mathematical calculation deals with the optimal value of the quantity ‘Q’ for direct manufacturing, the optimal value ‘R’, to start remanufacturing and the buffer stock.

5.3.2 Model parameters

The following are the various process parameters used in the present model.

r : the number of returned items collected from the customers in unit time (units/time)

p : the capacity of the remanufacturing process (units/time)

d : the demand of finished products/serviceable(units/time)

Cs : the set up cost for the remanufacturing process (Rs/setup)

C_0 : the ordering cost for new items (Rs/order)

C_{h1}: the inventory holding cost for the returned items for remanufacturing (Rs/unit/time)

C_{h2} : the inventory holding cost for the newly manufactured items (Rs/unit/time)

T : Cycle time.

t : Time after which remanufacturing initiates.

The model is intended to analyze the behaviour and find an optimal value for the following process variables.

a) R : the inventory level for remanufactured items,
b) Q : the order quantity for the newly procured items, and
c) S: the amount of safety stock to take care of the fluctuation of the collection rate for returned items for remanufacturing.

While formulating the model the following assumptions are made:

i. The average demand is ‘d’.
ii. Returned products are collected for remanufacturing with an average rate ‘r’.
iii. The remanufacturing capacity is ‘p’.
iv. The cost parameters are known and remain constant.
v. Purchase and remanufacturing lead times are constant.
vi. Remanufacturing rate is greater than the collection rate.
vii. Demand rate is greater than the collection rate.

5.3.3 Mathematical formulation

The cost of remanufactured items comprises of the setup cost and the inventory holding cost.

Hence, the total cost for remanufacturing cycle $= C_s + \frac{C_{h1}}{2} RT$ (5.25)

The cost of serviceable items comprises of order cost, inventory holding cost considering the triangles α and β.

Order cost = C_0 (5.26)

Holding cost for triangle α in Figure-5.4 = $\frac{dC_{h2}}{2}\left\{t - \frac{p-d}{d}(T-t)\right\}^2$ (5.27)

Holding cost for the triangle β in Figure 5.4= $\frac{p(p-d)C_{h2}}{2d}(T-t)^2$ (5.28)

It can also be shown that T = $\frac{pR}{r(p-r)}$ (5.29)

and t = $\frac{R}{r}$ (5.30)

Using equation (5.25) - (5.30) we can have the total cost,

$$TC = \frac{r(p-r)(C_s + C_0)}{pR} + \frac{C_{h1}}{2}R + \frac{C_{h2}}{2d(p-r)}\left\{r(p-d) + \frac{p(d-r)^2}{r}\right\}R \quad (5.31)$$

Since equation (5.31) is a convex function of R we can have the optimal value of R by differentiating the total cost (TC) with respect to R and then equating it to zero.

Hence, the optimal value of R can be written as

$$R = \sqrt{\frac{r(p-r)(C_s + C_0)}{pA_1}} \quad (5.32)$$

$$\text{where } A_1 = \frac{C_{h1}}{2} + \frac{C_{h2}}{2d(p-r)}\left\{\frac{p(d-r)^2}{r} + r(p-d)\right\}$$

The value of Q can be calculated by using the equation,

$$Q = \frac{p(d-r)}{r(p-r)}R \quad (5.33)$$

The safety stock

Since uncertainty lies in the remanufacturing cycle due to fluctuation of the collection rate, it is preferred to consider the additional stock of newly produced items in stock which will be adequate to satisfy the demand of the serviceable items when there is a decrease in the value of ‘r’. Further it is also assumed that the collection of the returned items continues throughout the cycle, hence the safety stock calculation should be made for the entire cycle time and it can be taken as;

Safety Stock = $Z\sigma_T$

Here, Z = number of standard deviations for a specified service level, which can be directly used from the normal distribution table. (For example service level 98% means that, Z=2.05).

And σ_T = the standard deviation of the collection rate of items for remanufacturing for the total time period. The value of σ_T can be determined by the square root of the sum of the variances for each unit time during the total cycle time period.

$$\sigma_T = \sqrt{\sum_{i=1}^{T}\left(\sigma_{d_i}\right)^2} \tag{5.34}$$

Here d_i ,is the standard deviation for each unit time during the total time period.

It is to be remembered here that, while calculating the total cost there will be two components. The first one is the fixed component for the safety stock which has to be maintained constant throughout the cycle and the second one is as calculated by using equation (5.31).

An example problem

In order to validate the model, a sample problem with the following data is considered.

r = 100 units /month,

p = 300 units /month,

d = 200 units/month,

C_0 =Rs10/order for new items

C_s =Rs20/setup for remanufacturing process

C_{h1} = Rs1/remanufacturable unit /month, and

C_{h2} = Rs2/serviceable unit/month.

The standard deviation of collection rate for returned items for remanufacturing for each day is 5 units.

The service level to be maintained is 95%.

The purchase cost for new items = Rs8 per unit and

The purchase cost for the collection of returned items for remanufacturing =Rs 4 per unit.

Using equation (5.32), equation (5.33) and equation (5.29) respectively, one can have the value of $R \cong 37$ units; Q =55 units and T = 0.555 months =16.65 days $\cong$ 17 days (say).

Safety stock =

$$Z\sigma_T = 1.65 \times \sqrt{\sum_{i=1}^{T} \left(\sigma_{d_i}\right)^2} = 1.65 \times \sqrt{\sum_{i=1}^{17} (5)^2} = 1.65 \times \sqrt{17 \times 25} = 1.65 \times 20.61 \cong 34$$

Hence, the total cost per cycle;

TC = Total cost of inventory without safety stock as calculated by equation (5.31) + the cost of safety stock + the cost of purchase of new items + the cost of purchase of returned items for remanufacturing.

Now TC inventory without safety stock = Rs109.55,

Cost of safety stock = 34×8 = Rs272,

Cost of purchase of new items without safety stock =

55×8 = Rs440, and

Cost of purchase of returned items = r×T×20=Rs222

The total cost =109.55+272+440+222 = Rs1043.55 say Rs1044

5.4 Summary

This chapter has taken care of the uncertainty arising due to the fluctuation of demand of the product in the market and collection rate of return items for remanufacturing in addition to the concept of remanufacturing. The first model deals with avoidance of stock out by using safety stock is a substitute to an already existing model where the shortages are allowed and the second model is a proposed model where the use of safety stock is justified because of uncertainties in the collection rate of return items for remanufacturing. Using the model parameters, both the models deal with optimization of model variables on the basis of minimization of total cost. Separate example problems for both the models are considered and the optimized variables are calculated using the derived relationships, which help in finding out the optimum total cost. In both the models care has been taken to set the safety stock on the basis of the service level approach.

Chapter 6

PREDICTION OF MODEL VARIABLES USING ANFIS

6.1 Overview

Agile supply chain ASC [123] considers both alertness and RSC in a simultaneous way. This led to introduction of an idea of creating ASCs for industries and organizations. Alertness in Reverse supply chain is the ability of reverse supply chain as a whole and its members rapidly align the network and its operation to dynamics and turbulent requirements of the customers [124]. It has been identified that ASC requires various distinguishing capabilities to respond changing environments. In this regard four elements are relevant.

1. Responsiveness, which is the ability to identify changes and respond to them quickly, reactively or proactively and also to recover from them.
2. Competency, which is the ability to efficiently and effectively realize enterprise objectives.
3. Flexibility, which is the ability to implement different process and apply different facilities to achieve the same goal.
4. Quickness which is the ability to complete an activity as quickly as possible.

Researchers have suggested frameworks based on other characteristics of Reverse supply chain alertness. The research works can be classified in three main categories: a) Conceptual model, b) Empirical and c) Experts' judgments. Many researchers have provided conceptual over views, different reference and mature models of RSC alertness. Collaborative relationship, Process integration Information integration and Customer/ marketing sensitivity are required to manage the RSC in an effective way. Existing approaches have not considered the impact of these factors in measuring alertness in Reverse supply chains. Moreover, it has also worth to be mentioned that the scales used to aggregate the alertness capabilities have main limitations as follow. Existing procedures do not consider about ambiguity and multi possibility associated with mapping of individual judgment to a number. The subjective judgment, selection and preference of evaluators have a significant influence on these methods. Due to the qualitative and ambiguous attributes linked to alertness measurement, most measures are described subjectively using linguistic terms and cannot be handled effectively using conventional assessment approaches. Concept of Artificial neural nets (ANNs) was designed as a simplified model of the biological neurons. In an attempt to capture "intelligence," it was theorized that since the human brain was constructed of a number of similarly constructed neural cells, a simulation constructed using these neural models should have similar capabilities. Using the mathematical model, a "neural network" can be designed by putting a number of these mathematical "neurons" together in various configurations. On the other hand ANNs are, as their name indicates, computational networks which attempt to simulate, in a gross manner, the networks of nerve cell (neurons) of the biological (human or animal) central nervous system. This simulation is a gross cell-by-cell (neuron-by-neuron, element-by-element) simulation. It borrows from the neuro- physiological knowledge of biological neurons and of networks of such biological neurons. It thus differs from conventional (digital or analog) computing machines that serve to replace, enhance or speed-up human brain computation without regard to organization of the computing elements and of their networking. Still, we emphasize that the simulation afforded by neural networks is very gross. There exists a wide variety of application and several structures for ANNs in literature of engineering and management science.

6.2 Concepts of fuzzy

The human understanding of most physical processes is based largely on imprecise human reasoning. This imprecision (when compared to the precise quantities required by computers) is a form of information that can be quite useful to humans. The ability to embed such reasoning in hitherto intractable and complex problems is the criterion by which the efficacy of fuzzy logic is judged. Undoubtedly this ability cannot solve problems that require precision and accuracy. But not many human problems require such precision- problems such as parking a car, backing up a trailer, navigating a car among others on a freeway, washing clothes, controlling traffic at intersections, judging beauty contestants and a preliminary understanding of a complex system [125]. However, the gradual evolution of the expression of uncertainty using probability theory was challenged, first in 1937 by Max Black, with his studies in vagueness, then with the introduction of fuzzy sets by Lotfi Zadeh in 1965. Zadeh's work had a profound influence on the thinking about uncertainty because it challenged not only probability theory as the sole representation for uncertainty, but the very foundations upon which probability theory was based: classical binary (two-valued) logic [125]. Fuzzy logic provides an effective means of dealing with problems involving imprecise and vague phenomena. Fuzzy concepts enable assessors to use linguistic terms to assess indicators in natural language expressions and each linguistic term can be associated with a membership function. Furthermore, fuzzy logic has found significant applications in management sciences. Lack of an efficient measuring tool for alertness of Reverse supply chain system made us to develop a procedure with aforementioned functionality. The imprecise nature of attributes for associated concepts persuade us to apply fuzzy concepts and aggregate this powerful tool with ANNs concepts in favour of gaining ANFIS as an efficient tool for development and surveying of our novel procedure. Due to our best knowledge this combination has never been reported in literature before.

6.3 Proposed model for measurement of RSC alertness

The neuro-fuzzy system attempts to model the uncertainty in the factor assessments, accounting for their qualitative nature. A combination of classic stochastic simulations and fuzzy logic operations on the ANN inputs as a supplement to artificial neural network is employed. ANFIS utilizes ANN's learning mechanisms to draw rules from input and output data pairs. The system possesses the function of adaptive learning as well as the function of fuzzy information describing and processing, and judgment and decision making. ANFIS is different from ANN in that ANN uses the connection weights to describe a system while ANFIS uses fuzzy language rules from fuzzy inference to describe a system.

The ANFIS approach adopts Gaussian functions (or other membership functions) for fuzzy sets, linear functions for the rule outputs, and Sugeno's inference mechanism [126]. The parameters of the network are the mean and standard deviation of the membership functions (antecedent parameters) and the coefficients of the output linear functions as well (consequent parameters). The ANFIS learning algorithm is then used to obtain these parameters. This learning algorithm is a hybrid algorithm consisting of the gradient descent and the least-squares estimate.

Using this hybrid algorithm, the rule parameters are recursively updated until an acceptable level of error is reached. Each iteration includes two passes, forward and backward. In the forward pass, the antecedent parameters are fixed and the consequent parameters are obtained using the linear least-squares estimation. In the backward pass, the consequent parameters are fixed and the error signals propagate backward as well as the antecedent parameters are updated by the gradient descent method. An ANFIS architecture is equivalent to a two-input first-order Sugeno fuzzy model with nine rules, where each input is assumed to have three associated membership functions [127].

6.4 Designing ANFIS architecture

Fuzzy set theory is a perfect mean for modelling uncertainty and imprecision arising from mental phenomena. These are neither random nor stochastic. In the field of artificial intelligence (machine intelligence) there are various ways to represent knowledge. Perhaps the most common way to represent human knowledge is to form it into natural language expressions of the type: IF antecedent, THEN consequence. The form in expression is commonly referred to as the IF-THEN rule-based form. This form generally is referred to as deductive form. It typically expresses an inference such that if we know a fact (premise, hypothesis, antecedent), then we can infer another fact called a conclusion. As this form of knowledge expresses human empirical and heuristic knowledge in our own language of communication which is characterized as shallow knowledge, is quite in the context of linguistics terms. FISs are one of the most applied and popular systems developed for fuzzy reasoning which use fuzzy logic for modelling uncertainty. Fuzzy reasoning, also known as approximate reasoning, is an inference procedure that derives conclusions from a set of fuzzy if-then rules and known facts. The FIS is a popular computing framework based on the concepts of fuzzy set theory, fuzzy if-then rules and fuzzy reasoning. It has been applied successfully in a wide range of science and engineering such as control, function approximation, signal processing, simulation, data clustering and data mining and decision support systems. In literature, we can find some other names such as fuzzy rule based system, fuzzy expert system, fuzzy model, fuzzy associative memory, fuzzy logic controller and simply (and ambiguously) fuzzy system. There is several inference techniques developed for fuzzy rule based systems in the literature. Mamdani FIS is the first inference methodology, in which inputs and outputs are represented by fuzzy relational equations in canonical rule-based form. In Sugeno FIS, output of the fuzzy rule is characterized by a crisp function.

6.4.1 Architecture of ANFIS

The ANFIS can perform the mapping relation between the input and output data through a learning algorithm to optimize the parameters of a given FIS. The ANFIS architecture consists of fuzzy layer, product layer, normalized layer, de-fuzzy layer, and summation layer. A typical architecture of ANFIS is shown in Fig. 1, in which a circle indicates a fixed node, whereas a square indicates an adjustable node. For example, we consider two inputs x, y and one output z in the FIS. The ANFIS used in this paper implements a first-order Sugeno FIS. Among many fuzzy systems, the Sugeno fuzzy model is the most widely applied, because of its high interpretability and computational efficiency, and built-in optimal and adaptive techniques. For a first-order Sugeno fuzzy system, the typical rule set can be expressed as:

Rule 1: If x is $A1$ and y is $B1$, then $z1 = p1x + q1y + r1$

Rule 2: If x is $A2$ and y is $B2$, then $z2 = p2x + q2y + r2$

Where *A*i and *B*i are the fuzzy sets in the antecedent, and *p*i, *q*i, and *r*i are the parameters that are assigned during the training procedure. As in Fig. 1, the ANFIS consists of five layers. Every ith node in the first layer is an adaptive node with a node output defined by:

$$O_i^1 = \mu_{A_i}(x), \qquad i = 1,2 \; O_i^1 = \mu_{B_{i-2}}(y), \quad i = 3,4$$

Where $\mu_{A_i}(x)$ and $\mu_{B_{i-2}}(y)$ can adopt any fuzzy membership function (MF). In this paper, the following

Gaussian MF is used:

$$gaussmf(x,c,s) = e^{-\frac{(x-c)^2}{2s^2}}$$

Where {ci , si} is the parameter set that changes the shapes of the MF. The parameters of this layer are termed the premise parameters. Every node in the second layer is a fixed node labelled Π, whose output is the product of all the incoming inputs:

$$O_i^2 = \omega_i = \mu_{A_i}(x)\mu_{B_i}(y), \qquad i = 1,2$$

Each node output represents the firing strength of a rule.

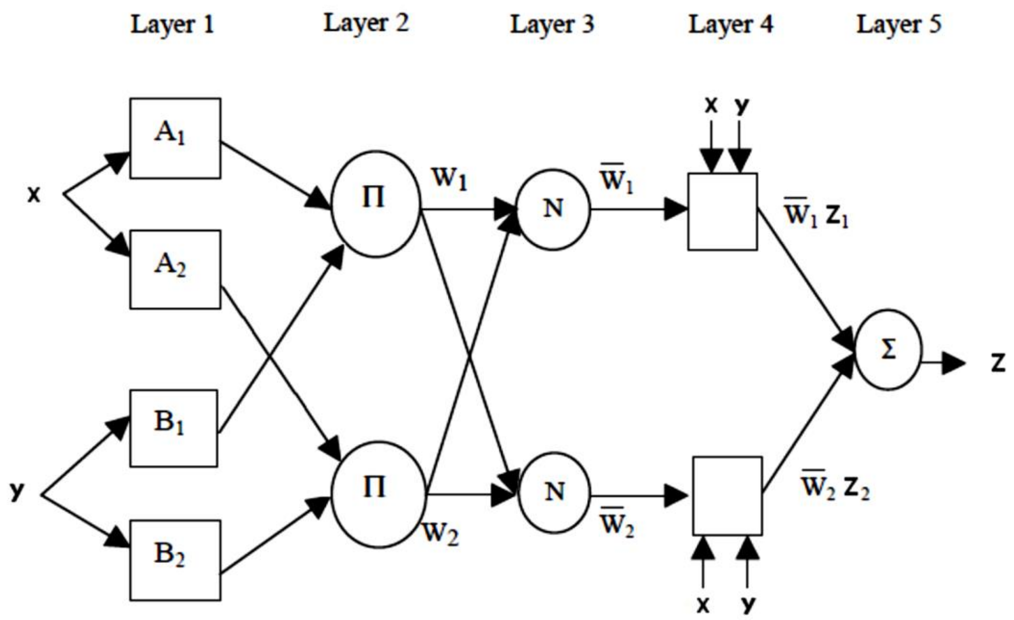


Figure 6.1: Architecture of ANFIS

Every node in the third layer is a fixed node labelled N. In this layer, the average is calculated based on weights taken from fuzzy rules:

$$O_i^1 = \overline{\omega_i} = \frac{\omega_i}{\omega_1 + \omega_2}, \quad i = 1,2$$

Where ω_i is referred to as the normalized firing strengths. Every *i*th node in the fourth layer is an adaptive node with the following node function:

$$O_i^4 = \overline{\omega_i} z_i = \overline{\omega_i}(p_i x + q_i y + r_i), \qquad i = 1,2$$

Where ω_i is the output of layer 3, and {*p*i, *q*i, *ri*} is the parameter set. The parameters of this layer are termed the consequent parameters. The single node in the fifth layer is a fixed node labelled Σ that computes the overall output as the summation of all incoming inputs:

$$O_i^4 = \sum_{i=1}^{2} \overline{\omega_i} z_i = \frac{\omega_1 z_1 + \omega_2 z_2}{\omega_1 + \omega_2}$$

6.5 Learning algorithms

It is seen from the ANFIS architecture that when the values of the premise parameters are fixed, the output of the ANFIS can be calculated as:

$$z = \frac{\omega_1}{\omega_1 + \omega_2} z_1 + \frac{\omega_2}{\omega_1 + \omega_2} z_2$$

Substituting Eq. (5) into Eq. (8) yields:

$$z = \overline{\omega_1} z_1 + \overline{\omega_2} z_2$$

Substituting the fuzzy if-then rules into Eq. (9), it becomes:

$$z = \overline{\omega_1}(p_1 x + q_1 y + r_1) + \overline{\omega_2}(p_2 x + q_2 + r_2)$$

After rearrangement, the output can be written as a linear combination of the consequent parameters:

$$z = (\overline{\omega_1} x) p_1 + (\overline{\omega_1} y) q_1 + (\overline{\omega_1}) r_1 + (\overline{\omega_2} x) p_2 + (\overline{\omega_2} y) q_2 + (\overline{\omega_2}) r_2$$

The optimal values of the consequent parameters can be found by using the Least-Square Method (LSM). When the both premise and consequent parameters are adaptive, the search space becomes larger and the convergence of training becomes slower. The hybrid learning algorithm [12], combining the LSM and the back propagation algorithm can be used to solve this problem. This algorithm converges much faster because it reduces the dimension of the search space of the back propagation algorithm. During the learning procedure, the premise and consequent parameters are tuned until the desired response of the FIS is achieved. The hybrid learning algorithm is divided into two steps: forward pass and a backward pass. In the forward pass, while the premise parameters are held fixed, the network inputs propagated forward until layer 4, where the consequent parameters are identified by the LSM. In the backward pass, the consequent parameters are held fixed while the error signals are propagated from the output end to the input end, and the standard back propagation algorithm updates the premise parameters. Figure 6.1 shows the architecture of ANFIS training. Figure 6.2 shows the structure of ANFIS model. Gaussian MFs with product inference rule are used at the fuzzification layer. Hybrid learning algorithm that combines LSM with back propagation algorithm is used to adjust the premise and consequent parameter.

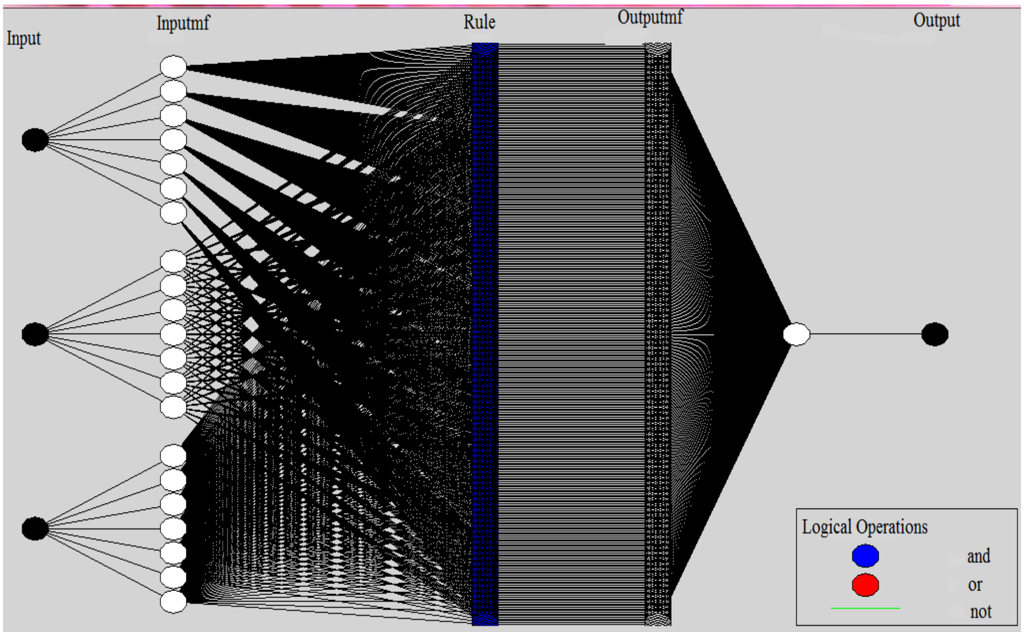


Figure 6.2: ANFIS model structure.

6.6 ANFIS simulation

Data set were generated by using the equations already derived. The Q_w, Q_r, D_2, D_1, γ, α, C_{bavg} are used as training data to train ANFIS network with Gaussian membership function with hybrid learning algorithm. A set of 1000 data sets were first generated as per the formula for the input parameters D_1, D_2 and α. These data sets were the basis for the training, evaluation and testing ANFIS. Out of the sets of 1000 data points, 700 were used as training data and 300 were used for testing the performance of ANFIS.

In the training phase, the membership functions and the weights will be adjusted such that the required minimum error is satisfied or if the number of epochs reached. At the end of training, the trained ANFIS network would have learned the input/output map and it is tested with the deduced inverse kinematics. Figure 7.35 through figure 7.88 shows the difference in joint variables analytically and the data predicted with ANFIS.

Table 6.1 gives the configuration of ANFIS. The average errors of joint variables using ANFIS are shown in table 7.19 through table 7.22. These errors are small and the ANFIS algorithm is, therefore, acceptable for obtaining the values of Q_w, Q_r, D_2, D_1, γ, α and C_{bavg}.

Table 6-1: Configuration of ANFIS.

Number of nodes	734
Number of linear parameters	343
Number of nonlinear parameters	63
Total number of parameters	406
Number of training data pairs	700
Number of checking data pairs	0
Number of fuzzy rules	343

6.7 Summary

The application, the architecture, the learning algorithm, the model structure, the simulation related to ANFIS is discussed in this chapter. The use of ANFIS seems to be appropriate in the case of uncertainty situation. The ANFIS simulation for the proposed model "Modeling the Reverse Supply Chain with Remanufacturing" is discussed and the results are shown in chapter -7 with help of figure -7.36 through 7.88 and the average testing errors are shown with the help of table –7. 19 through table –7.22. The use of Adaptive network based fuzzy inference system is justified for the said model as there lies a uncertainty in the execution of the model because of remanufacturing is done on return products.

Chapter 7

RESULTS AND DISCUSSIONS

7.1 Overview

The four models developed in this work were tested with practical data and a thorough analysis was made for each model. During the analysis, the sensitive parameters of the models were identified and their effect on the behaviour of the model under consideration was observed. This chapter contains the results and their critical analysis of the four models as presented in chapter -4 and chapter-5 viz;

- Modelling the Reverse Supply Chain with Remanufacturing.
- Modelling the Reverse Supply Chain inventory.
- A probabilistic approach for Reverse Supply Chain model for remanufacturing
- A modified reverse supply chain with remanufacturing for sustainable product Cycle

7.2 Results and discussion for “Modeling the RSC with remanufacturing”

With reference to article 4.2 of the previous chapter, the results obtained for the various values of γ are presented in these sections for both cartridge and tire manufacturing industries. In this model of supply chain management with remanufacturing, the amount of waste product for both industries is calculated by using the formula already derived. The unit buyback cost of end-of-use product from the customer, the amount of returned products and the return rate is also calculated by mathematical calculation.

7.2.1 Analysis for the cartridge manufacturing industry for case -1 with a change in γ value

Considering the parameters in article 4.2.2 for: whereD2 > D1 α (Cb) and using the equations 4.1 through 4.12, the values shown in the table 7.1 can be calculated.

Table 7-1: Change in the value of Q_m and Q_w with change in the γ value

γ	Q_m	Q_w
0.1	2330	2694.348
0.2	2360	2664.348
0.3	2390	2634.348
0.4	2420	2604.348
0.5	2450	2574.348
0.6	2480	2544.348
0.7	2510	2514.348
0.8	2540	2484.348
0.9	2570	2454.348
1	2600	2424.348
2	2900	2124.348
3	3200	1824.348
4	3500	1524.348
5	3800	1224.348
6	4100	924.3478
7	4400	624.3478
8	4700	324.3478
9	5000	24.34783

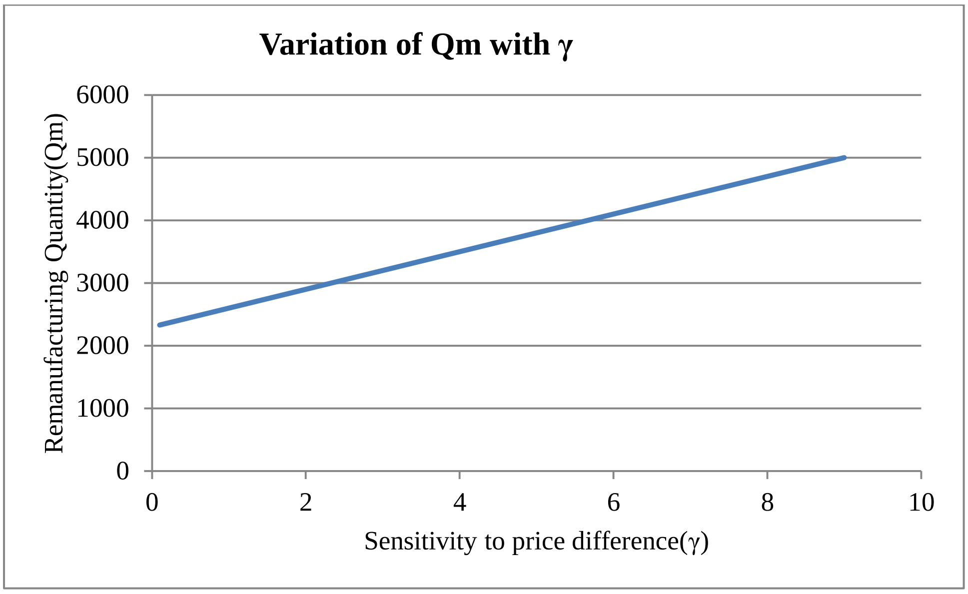


Figure 7.1: Change in the value of Q_m with corresponding change in **γ** value.

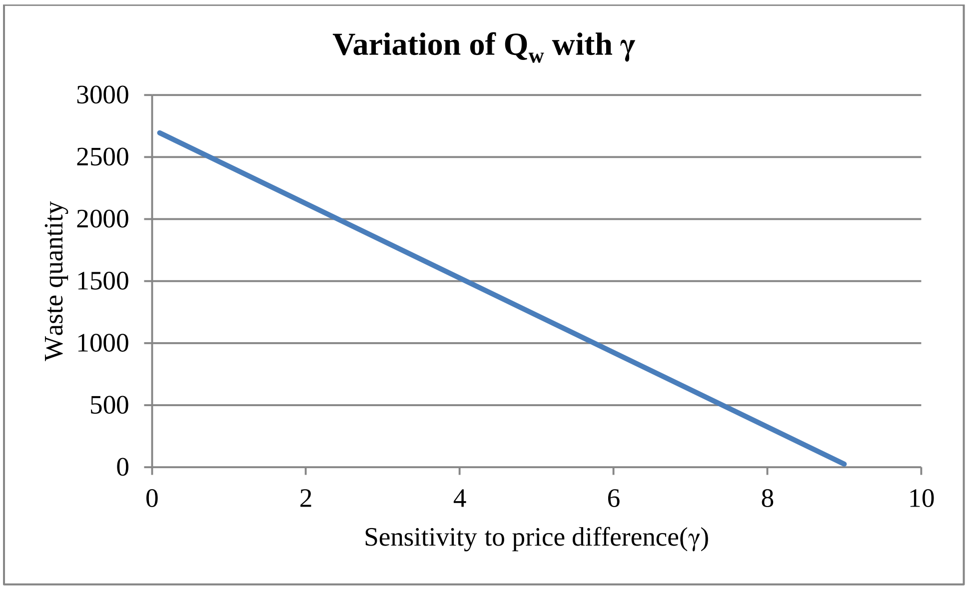


Figure 7.2: Change in the value of Q_w with corresponding change in **γ** value

7.2.2 Analysis for the cartridge manufacturing industry for case -2 with a change in γ value

Table 7-2: Effect of change in γ value on Q_m, C_{bavg}, α, Q_r and Q_w.

γ	Q_m	C_{bavg}	α	Q_r	Q_w
0.1	2330	245.2219	0.73922	5322.382	2992.382
0.2	2360	246.7419	0.743802	5355.372	2995.372
0.3	2390	248.2808	0.748441	5388.773	2998.773
0.4	2420	249.8391	0.753138	5422.594	3002.594
0.5	2450	251.417	0.757895	5456.842	3006.842
0.6	2480	253.015	0.762712	5491.525	3011.525
0.7	2510	254.6334	0.767591	5526.652	3016.652
0.8	2540	256.2727	0.772532	5562.232	3022.232
0.9	2570	257.9332	0.777538	5598.272	3028.272
1	2600	259.6154	0.782609	5634.783	3034.783
2	2900	277.7281	0.837209	6027.907	3127.907
3	3200	298.5577	0.9	6480	3280
4	3500	322.7651	0.972973	7005.405	3505.405

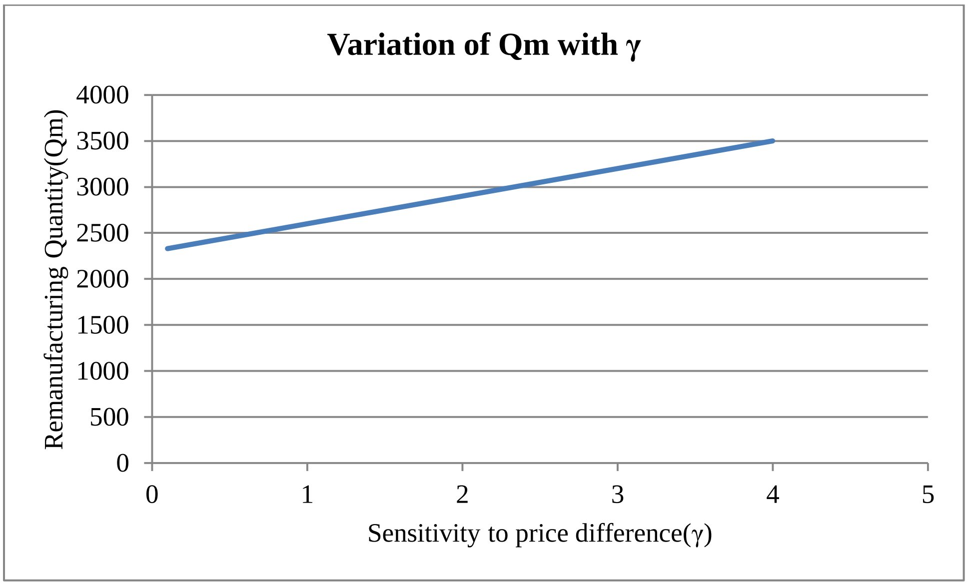


Figure 7.3: Change in the value of Q_m with corresponding change in γ value.

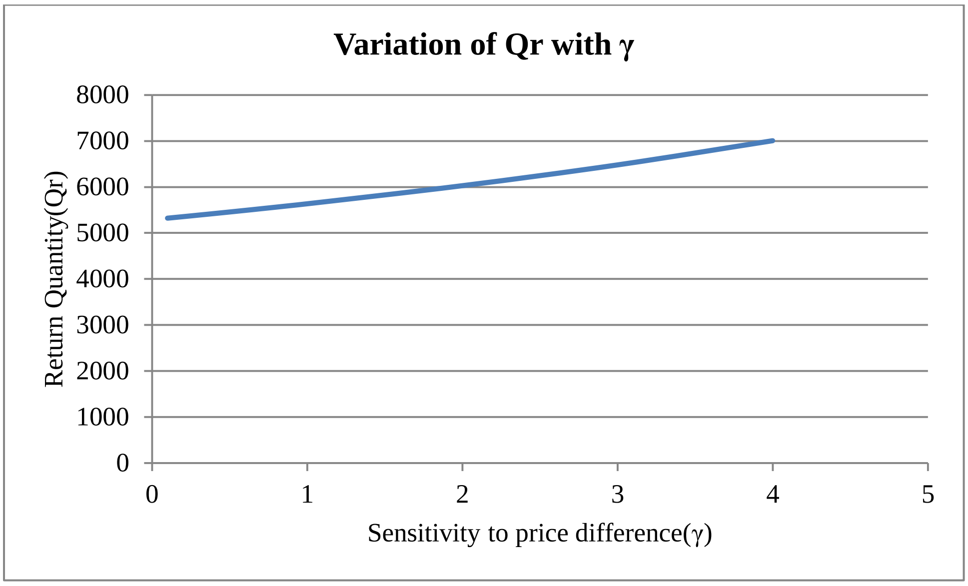


Figure 7.4: Change in the value of Q_r with corresponding change in γ value.

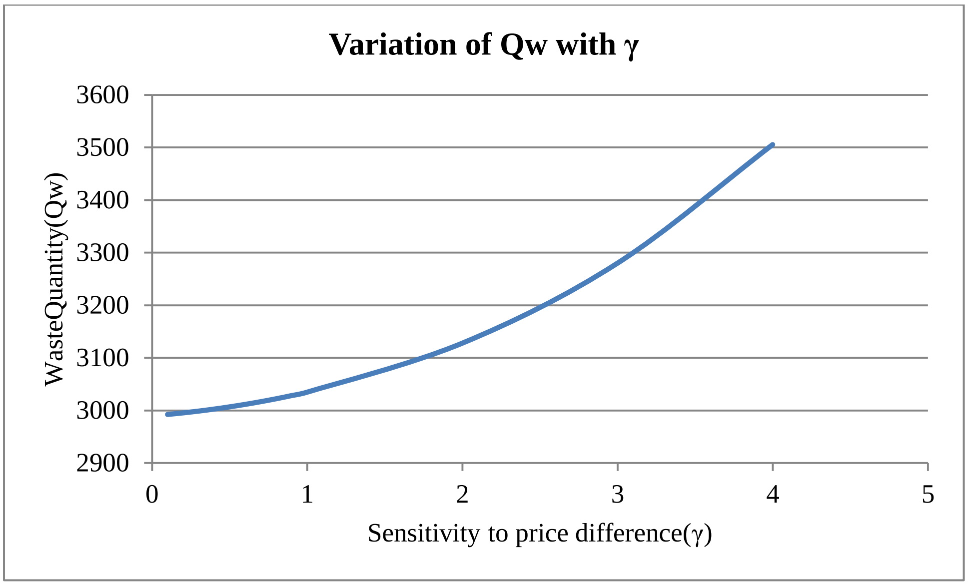


Figure 7.5:Change in the value of Q_w with corresponding change in γ value.

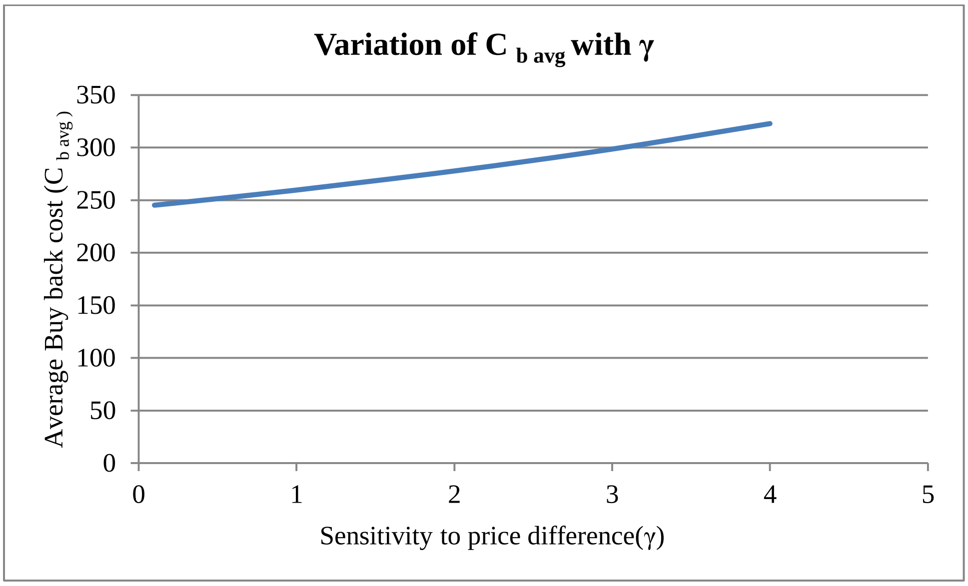


Figure 7.6: Change in the value of Q_w with corresponding change in γ value.

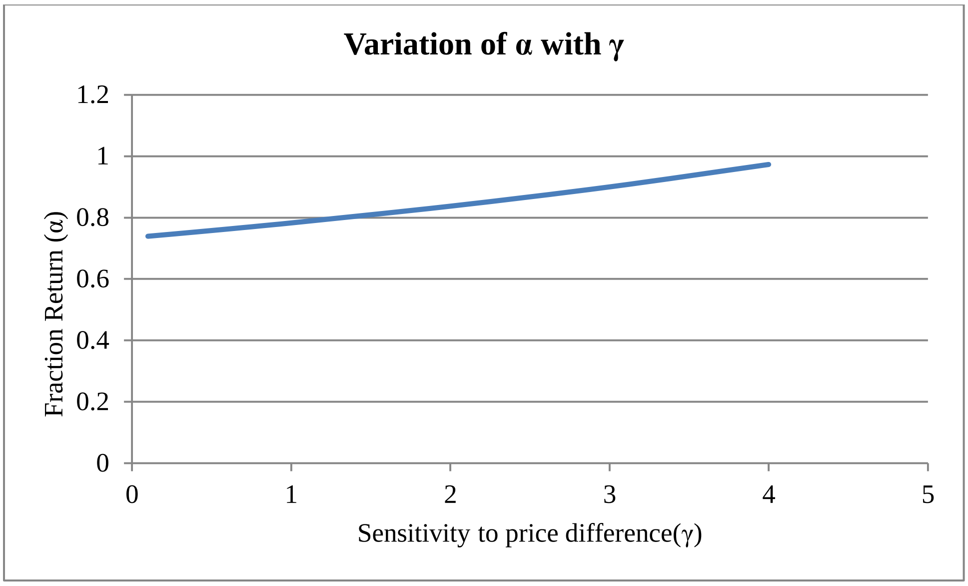


Figure 7.7: Change in the value of C_{bavg} with corresponding change in γ value.

7.2.3 Analysis for the cartridge manufacturing industry for case-2 with a change in α value

Table 7-3 : Variation of Qm and Qw with α = 0.5.

α	Qs	Qr	Qw	γ	Qm
0.5	7600	3800	1030	0.1	2770
0.5	7600	3800	960	0.2	2840
0.5	7600	3800	890	0.3	2910
0.5	7600	3800	820	0.4	2980
0.5	7600	3800	750	0.5	3050
0.5	7600	3800	680	0.6	3120
0.5	7600	3800	610	0.7	3190
0.5	7600	3800	540	0.8	3260
0.5	7600	3800	540	0.8	3260
0.5	7600	3800	470	0.9	3330

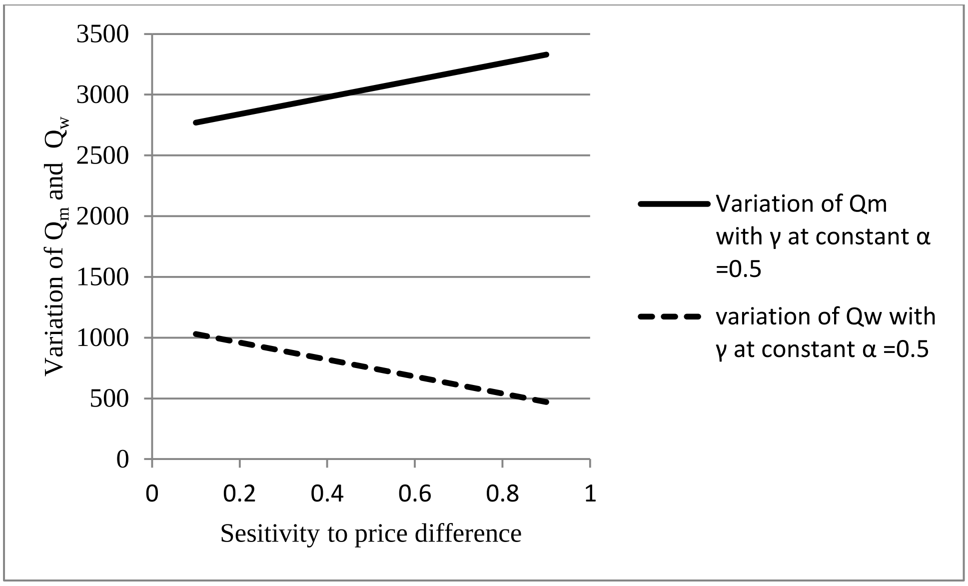


Figure 7.8 : Variation of Qm and Qw with α = 0.5.

Table 7-4 : Variation of Qm and Qw with α = 0.6.

α	γ	D2 or Qm	Qw
0.6	0.1	2770	1790
0.6	0.2	2840	1720
0.6	0.3	2910	1650
0.6	0.4	2980	1580
0.6	0.5	3050	1510
0.6	0.6	3120	1440
0.6	0.7	3190	1370
0.6	0.8	3260	1300
0.6	0.8	3260	1300
0.6	0.9	3330	1230

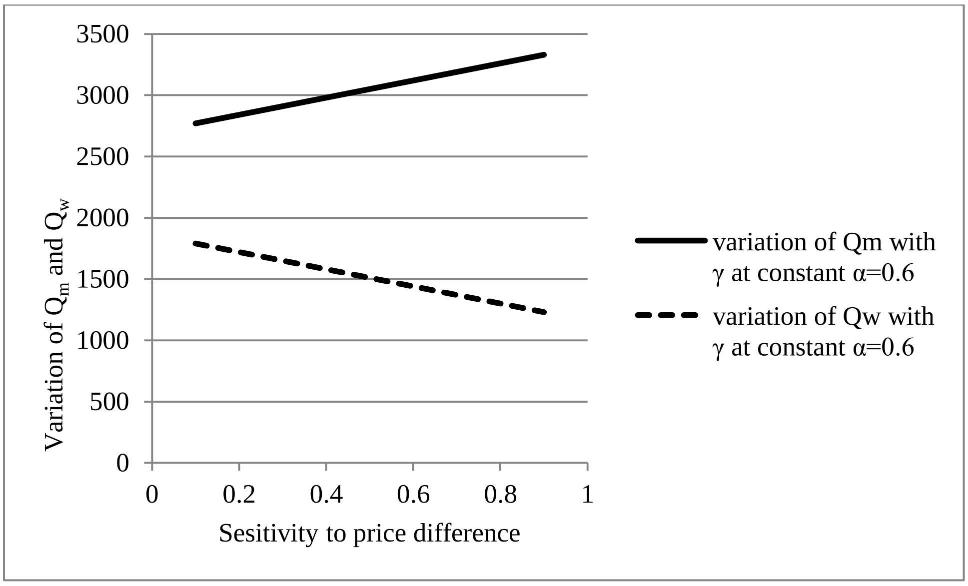


Figure 7.9 : Variation of Qm and Qw with α = 0.6.

Table 7-5 : Variation of Qm and Qw with α = 0.7.

γ	Qm	Qw	α
0.1	2770	2550	0.7
0.2	2840	2480	0.7
0.3	2910	2410	0.7
0.4	2980	2340	0.7
0.5	3050	2270	0.7
0.6	3120	2200	0.7
0.7	3190	2130	0.7
0.8	3260	2060	0.7
0.8	3260	2060	0.7
0.9	3330	1990	0.7

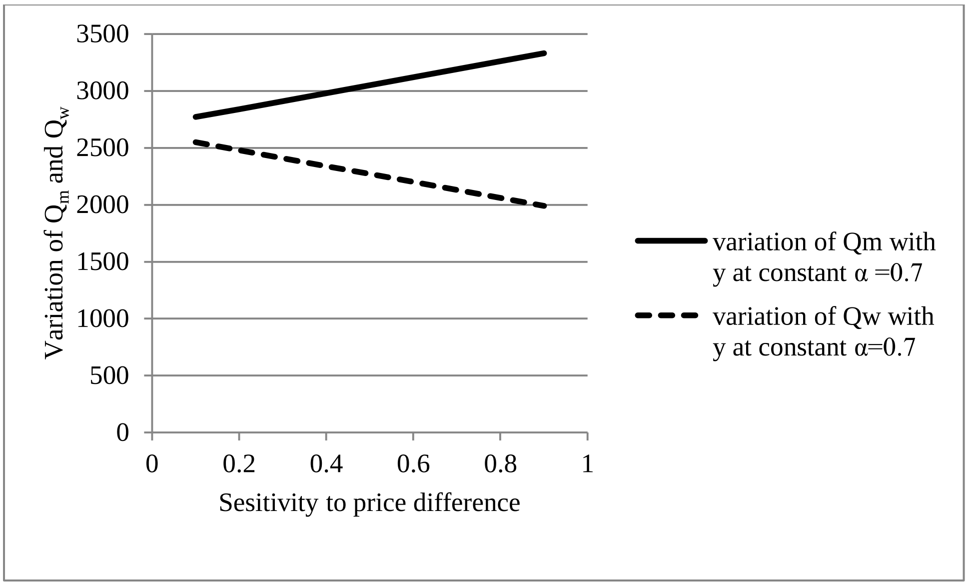


Figure 7.10 : Variation of Q_m and Q_w with α = 0.7.

Table 7-6 : Variation of Q_m and Q_w with α = 0.8.

γ	D2 or Qm	Qw	α
0.1	2770	3310	0.8
0.2	2840	3240	0.8
0.3	2910	3170	0.8
0.4	2980	3100	0.8
0.5	3050	3030	0.8
0.6	3120	2960	0.8
0.7	3190	2890	0.8
0.8	3260	2820	0.8
0.8	3260	2820	0.8
0.9	3330	2750	0.8

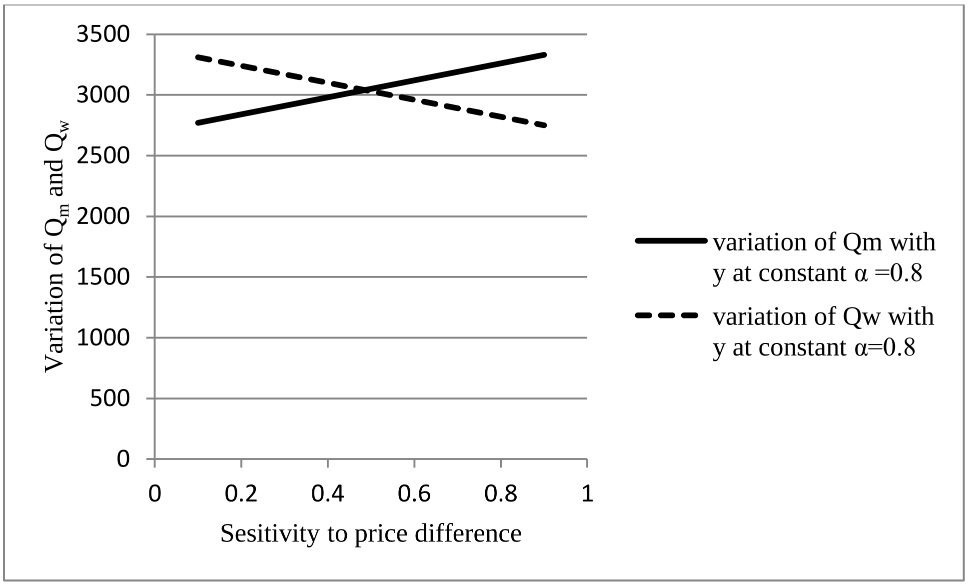


Figure 7.11 : Variation of Qm and Qw with α = 0.8.

7.2.4 Analysis for the tire manufacturing industry for case -1 with a change in γ value

Considering the parameters in article 4.2.3 for: whereD2 > D1 α (C_b) and using the equations 4.1 through 4.12, the values shown in the table 7.7 can be calculated.

Table 7-7 : Variation of model variables with change in γ value.

γ	Qm	Qw
0.1	5785	7222.478
0.2	5830	7177.478
0.3	5875	7132.478
0.4	5920	7087.478
0.5	5965	7042.478
0.6	6010	6997.478
0.7	6055	6952.478
0.8	6100	6907.478
0.8	6100	6907.478
0.9	6145	6862.478
1	6190	6817.478
2	6640	6367.478
3	7090	5917.478
4	7540	5467.478
5	7990	5017.478
6	8440	4567.478
7	8890	4117.478
8	9340	3667.478
9	9790	3217.478
10	10240	2767.478

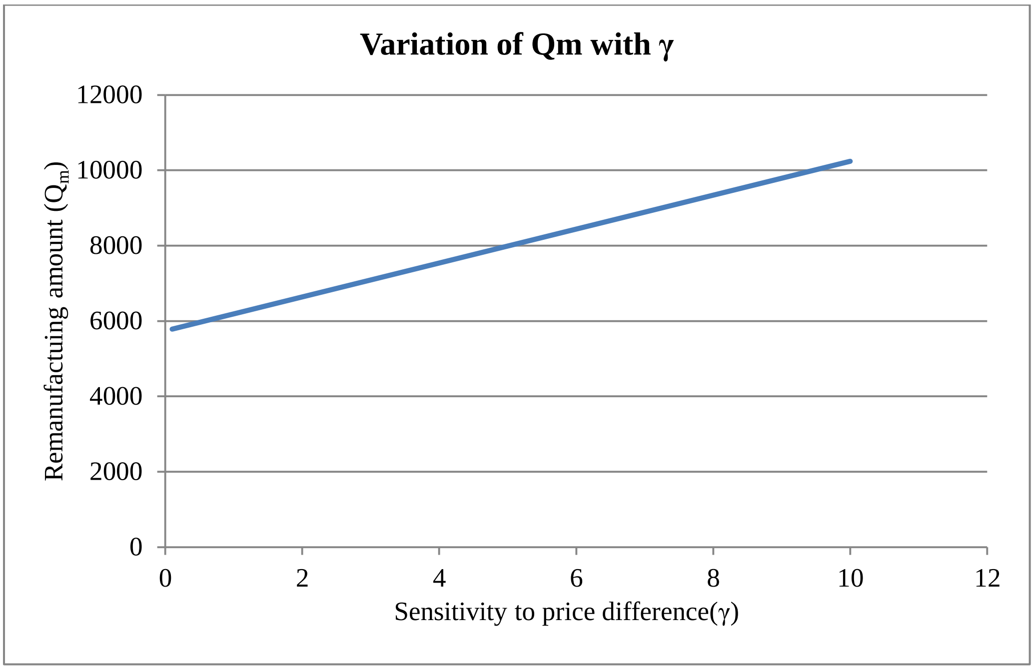


Figure 7.12 : Change in the value of Q_m with corresponding Change in the γ value

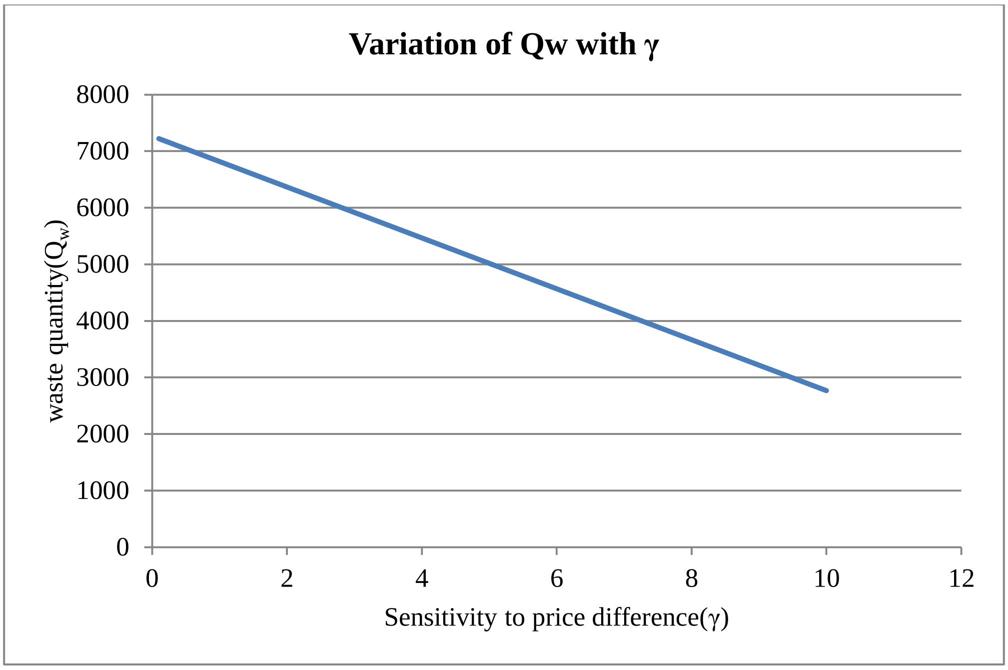


Figure 7.13 : Change in the value of Q_w with corresponding Change in the γ value.

7.2.5 Analysis for the tire manufacturing industry for Case -2 with a change in γ Value

Table 7-8 : Variation of the model variables with γ value.

γ	Qm	Cbavg	α	Qr	Qw
0.1	5785	360.7621	0.72501	13514.18	7729.181
0.2	5830	362.0294	0.727557	13561.65	7731.655
0.3	5875	363.3056	0.730121	13609.46	7734.463
0.4	5920	364.5909	0.732704	13657.61	7737.61
0.5	5965	365.8853	0.735306	13706.1	7741.099
0.6	6010	367.1889	0.737926	13754.93	7744.933
0.7	6055	368.5019	0.740564	13804.12	7749.116
0.8	6100	369.8243	0.743222	13853.65	7753.652
0.8	6100	369.8243	0.743222	13853.65	7753.652
0.9	6145	371.1562	0.745898	13903.55	7758.545
1	6190	372.4977	0.748594	13953.8	7763.799
2	6640	386.4663	0.776667	14477.07	7837.067
3	7090	401.5235	0.806926	15041.11	7951.108
4	7540	417.8015	0.83964	15650.88	8110.883
5	7990	435.455	0.875117	16312.19	8322.188
6	8440	454.6663	0.913725	17031.84	8591.843
7	8890	475.6509	0.955897	17817.93	8927.928
8	9340	498.6663	1.002151	18680.09	9340.086
9	9790	524.0222	1.053107	19629.92	9839.921
10	10240	552.0948	1.109524	20681.52	10441.52

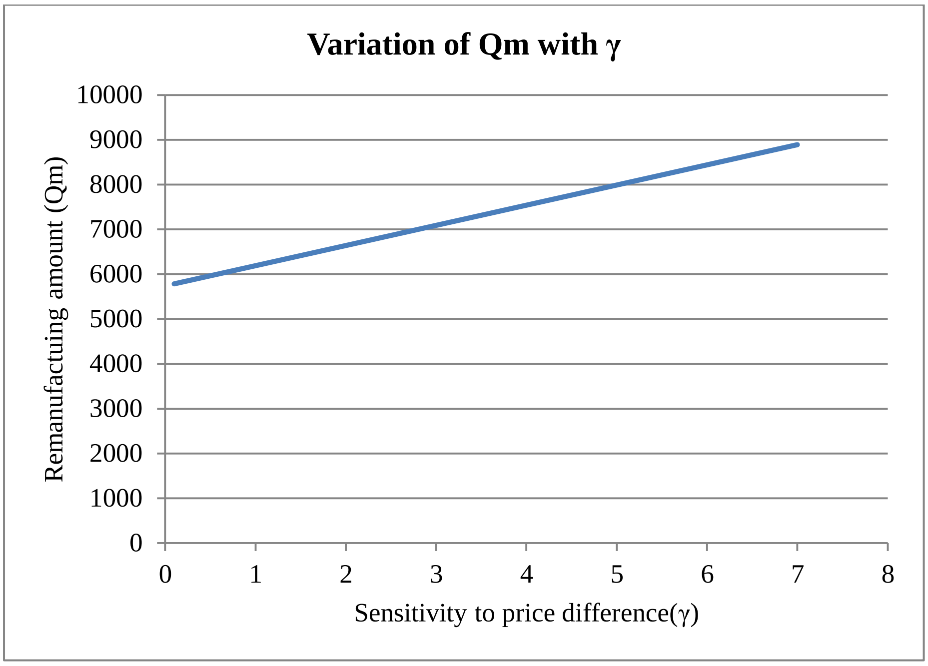


Figure 7.14 : Change in the value of Q_m with corresponding Change in the γ value.

Figure 7.15 : Change in the value of Q_r with corresponding change in γ value.

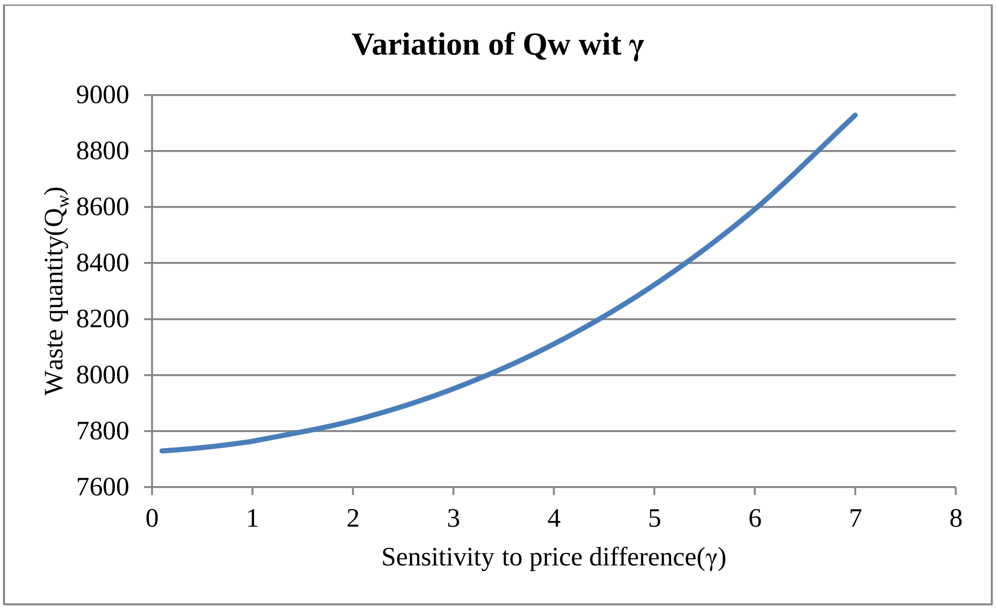


Figure 7.16 : Change in the value of Q_w with corresponding change in γ value.

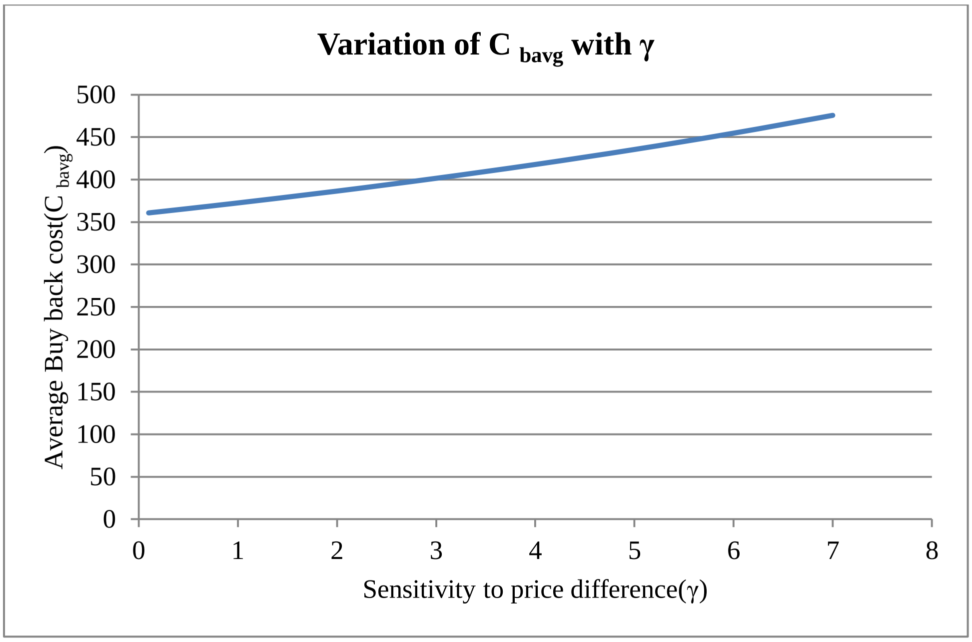


Figure 7.17 : Change in the value of C_{bavg} with corresponding change in γ value.

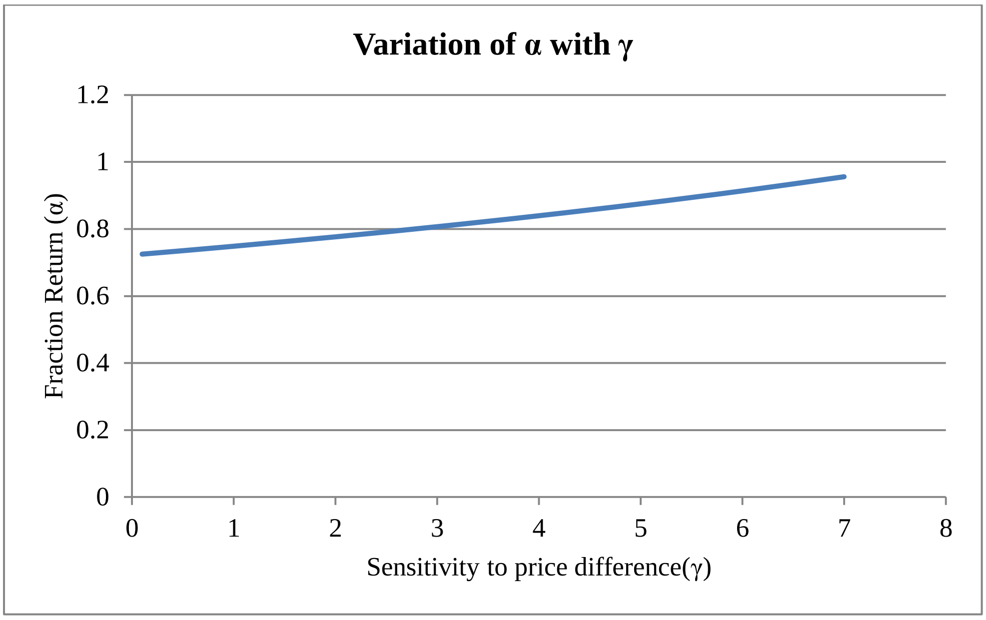


Figure 7.18 : Change in the value of α with corresponding change in γ value.

7.2.6 Analysis for the tire manufacturing industry for case -2 with a change in α value

Table 7-9 : Variation of Q_m and Q_w with $\alpha = 0.5$.

α	Qw	Qm	γ
0.5	3220	6370	0.1
0.5	3130	6460	0.2
0.5	3040	6550	0.3
0.5	2950	6640	0.4
0.5	2860	6730	0.5
0.5	2770	6820	0.6
0.5	2680	6910	0.7
0.5	2590	7000	0.8
0.5	2500	7090	0.9

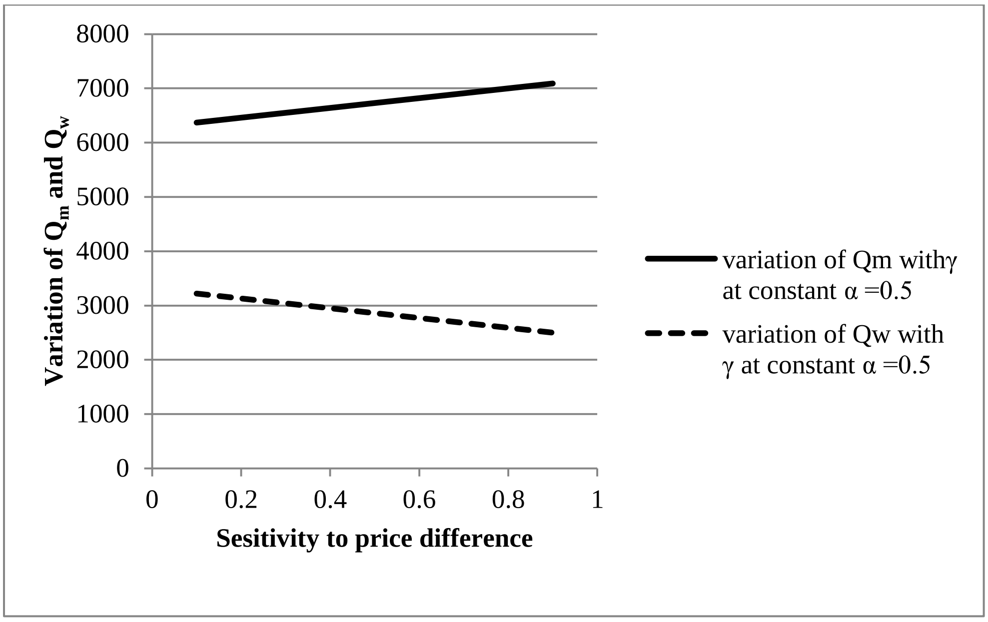


Figure 7.19 : Variation of Q_m and Q_w with α = 0.5.

Table 7-10 : Variation of Q_m and Q_w with α = 0.6.

α	Qw	Qm	γ
0.6	5138	6370	0.1
0.6	5048	6460	0.2
0.6	4958	6550	0.3
0.6	4868	6640	0.4
0.6	4778	6730	0.5
0.6	4688	6820	0.6
0.6	4598	6910	0.7
0.6	4508	7000	0.8
0.6	4418	7090	0.9

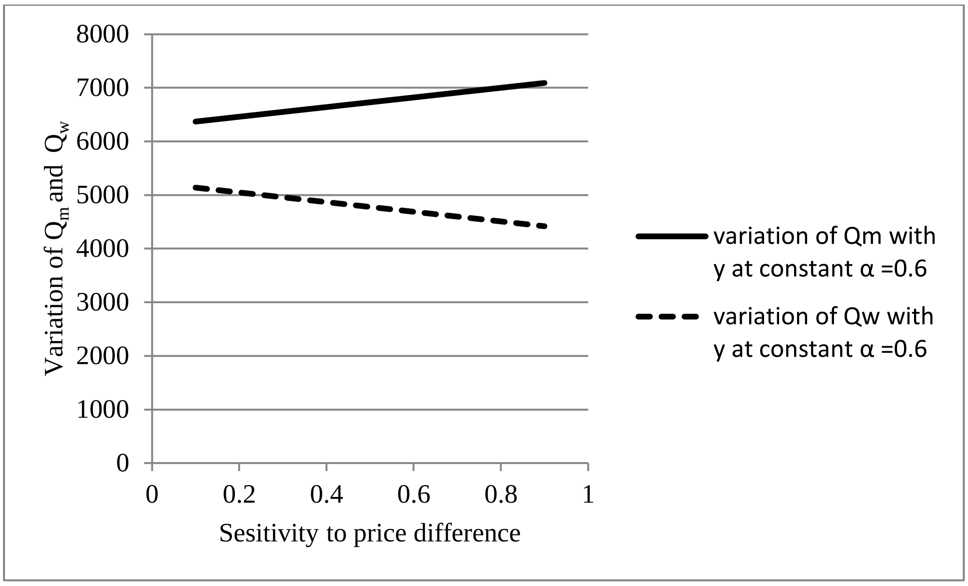


Figure 7.20 : Variation of Q_m and Q_w with α = 0.6.

Table 7-11: Variation of Q_m and Q_w with α = 0.7.

α	Qw	Qm	γ
0.7	7056	6370	0.1
0.7	6966	6460	0.2
0.7	6876	6550	0.3
0.7	6786	6640	0.4
0.7	6696	6730	0.5
0.7	6606	6820	0.6
0.7	6516	6910	0.7
0.7	6426	7000	0.8
0.7	6336	7090	0.9

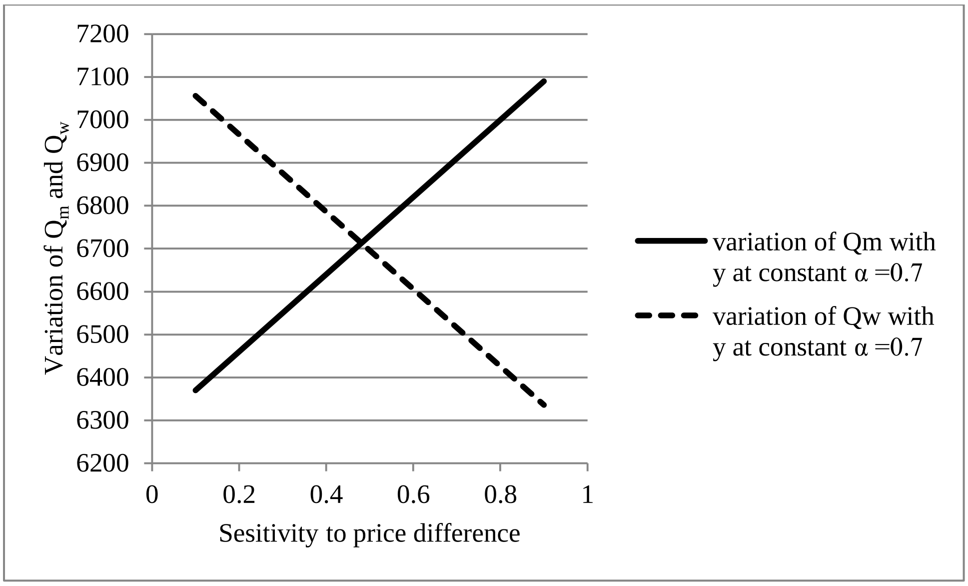


Figure 7.21 : Variation of Q_m and Q_w with α = 0.7.

Table 7-12 : Variation of Q_m and Q_w with α = 0.8.

α	Qw	Qm	γ
0.8	8974	6370	0.1
0.8	8884	6460	0.2
0.8	8794	6550	0.3
0.8	8704	6640	0.4
0.8	8614	6730	0.5
0.8	8524	6820	0.6
0.8	8434	6910	0.7
0.8	8344	7000	0.8
0.8	8254	7090	0.9

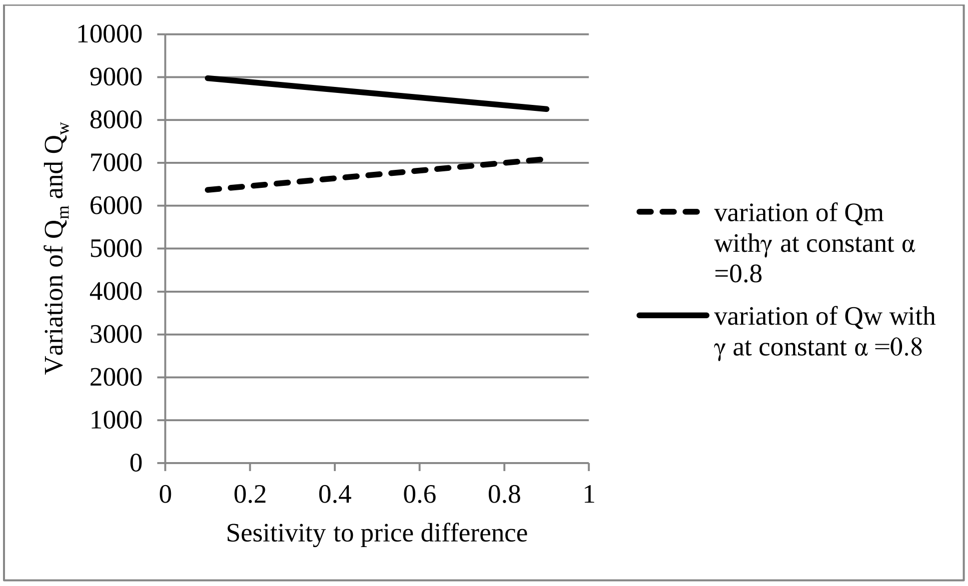


Figure 7.22 : Variation of Q_m and Q_w with α = 0.8.

7.3 Results and discussion for "Modeling the RSC Inventory"

As shown in the section 4.3.2, the model proposed in the section 4.3 is a reverse supply-chain model in which the stationary demand can be fulfilled by remanufactured products and newly purchased product. This can be a substitute to the existing model where the demand rate is uniform, production rate is finite and the shortages allowed. The total cost for one existing model is calculated and compared with that of the proposed model and the proposed model is found to be suitable from the economical point of view.

Further analysis is required to check the feasibility of the model with the change in the fraction of return. The discussion in the following sections is based on the effect of change in fraction of return on the following parameters

- Total cost
- Profit
- Direct manufactured quantity
- Remanufactured quantity
- Total number of cycles and
- Length of the operating cycle.

Table 7-13 : Variation of Total cost using Remanufacturing with fraction return.

Fraction return	TC using RM
0.1	43940.34
0.2	43861.48
0.3	43788.13
0.4	43719.75
0.5	43655.87
0.6	43596.09
0.7	43540.05
0.8	43487.44
0.9	43438
1	43391.47

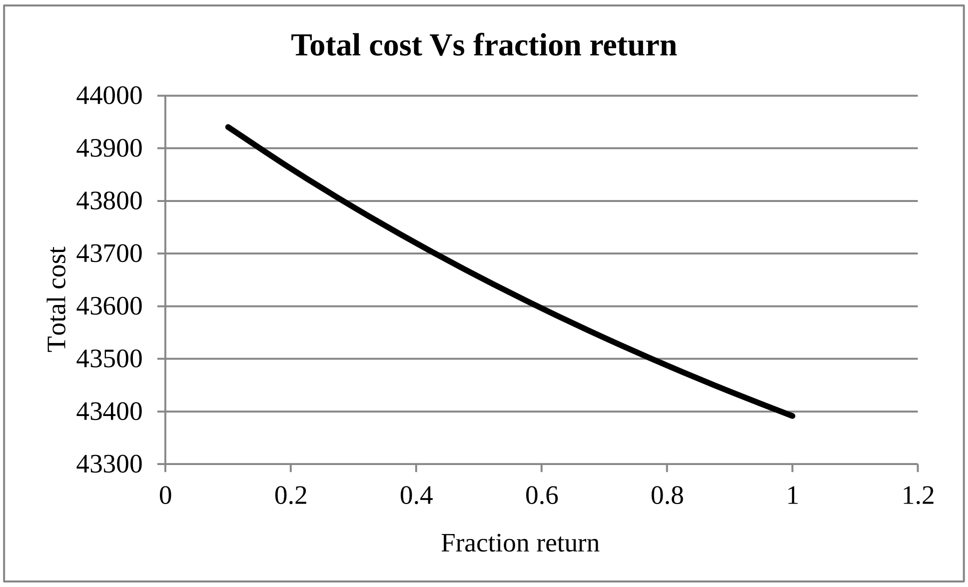


Figure 7.23: The variation of total cost with fraction return.

As seen from the figure 6.21, there is a decrease in the total cost with an increase in the fraction return. It is also evident from the graph that, the total cost with fraction is decreasing at a decreasing rate.

Table 7-14 : Variation of profit with variation in fraction return.

Fraction return	Profit
0.1	5384.837
0.2	5463.697
0.3	5537.047
0.4	5605.427
0.5	5669.307
0.6	5729.087
0.7	5785.127
0.8	5837.737
0.9	5887.177
1	5933.707

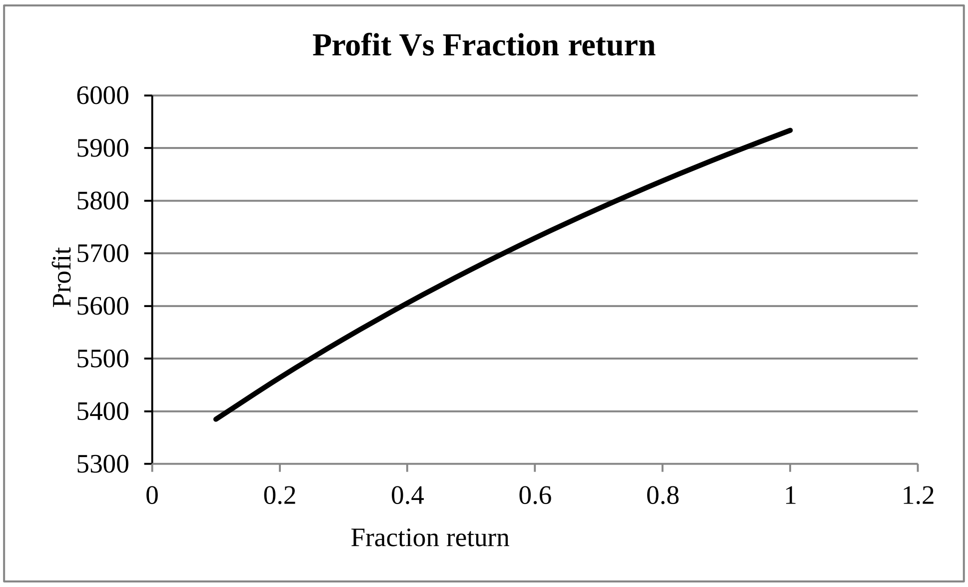


Figure 7.24 : Profit Vs Fraction return.

As seen from the figure 6.22, there is an increase in the profit margin with increase in the fraction return .The variation is not linear and it is evident from the graph that the profit is increasing at a decreasing rate.

Table 7-15 : Change in Direct manufacturing quantity, Remanufacturing quantity and Number of cycles required annually with change in fraction return.

Fraction return	Direct manufacturing quantity (annual)	Remanufacturing quantity (annual)	No. of cycles (annual)
0.1	7913.71	4086.29	1.474513
0.2	7831.634	4168.366	1.45922
0.3	7753.551	4246.449	1.444671
0.4	7679.088	4320.912	1.430797
0.5	7607.922	4392.078	1.417537
0.6	7539.773	4460.227	1.404839
0.7	7474.397	4525.603	1.392658
0.8	7411.576	4588.424	1.380953
0.9	7351.121	4648.879	1.369689
1	7292.861	4707.139	1.358834

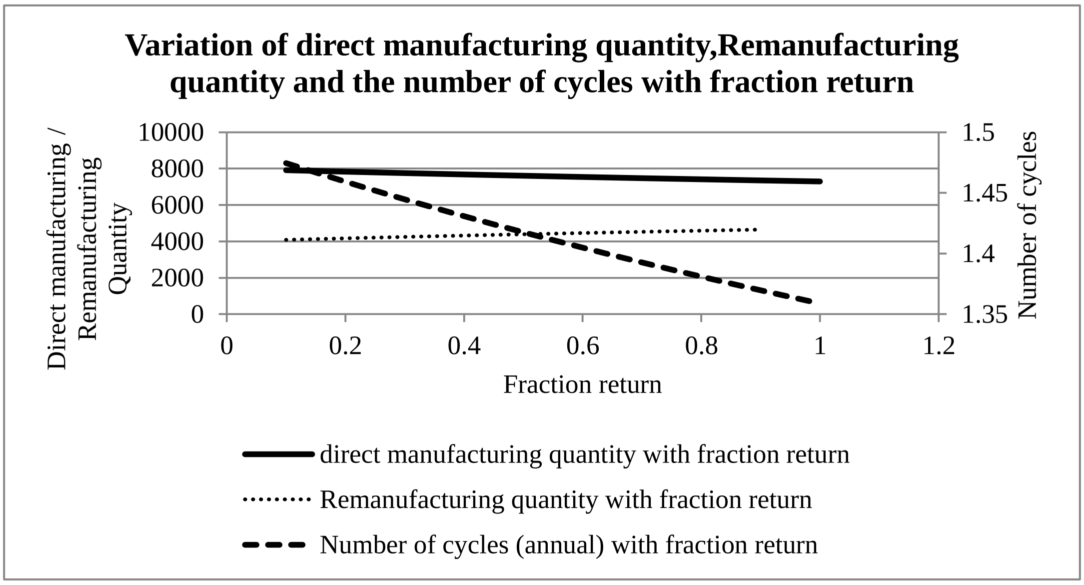


Figure 7.25: Variation of direct manufacturing quantity, Remanufacturing quantity and Number of cycles with fraction return.

The figure 6.23 above shows the variation of direct manufacturing quantity, Remanufacturing quantity and the number of cycles annually needed to satisfy the annual demand. The remanufacturing quantity is increasing and the direct manufacturing quantity is decreasing with an increase in the fraction return. The number of cycles is showing a decrease with increase in the fraction return. The cycle here means the operating cycle that comprises of the combination of direct manufacturing and remanufacturing.

Table 7-16 : Variation of length of operating cycle (in days) with variation in fraction return.

Fraction return	Length of operating cycle (in days)
0.1	244.1484
0.2	246.7071
0.3	249.1917
0.4	251.608
0.5	253.9616
0.6	256.2571
0.7	258.4985
0.8	260.6895
0.9	262.8334
1	264.933

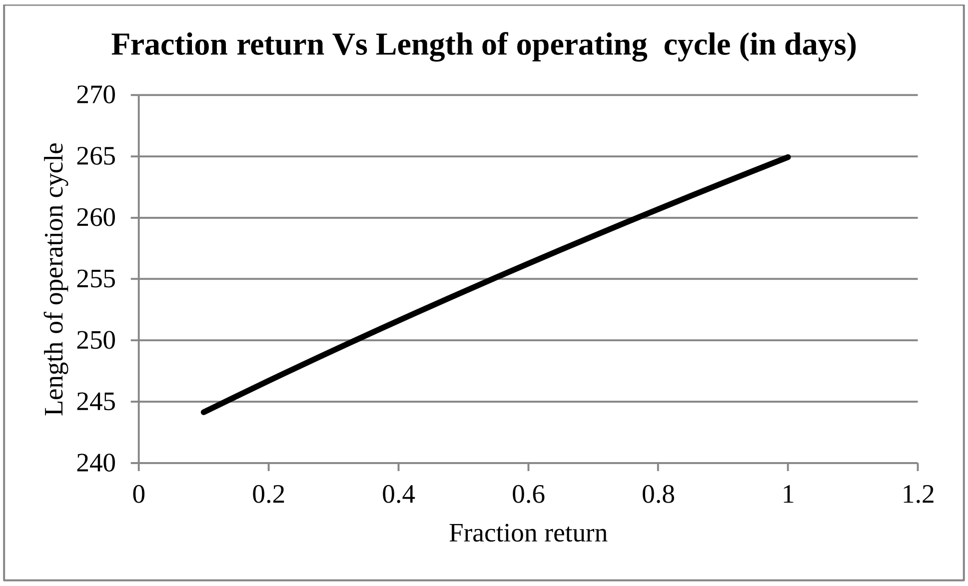


Figure 7.26: Variation of length of operating cycle with fraction return.

As seen from the figure 6.24, the length of the operating cycle is showing an increase with increase in the fraction return. However the variation is not linear and at higher values of return the increase rate of the length of operating cycle is less.

7.4 Results and analysis for "A probabilistic approach for RSC model for remanufacturing"

The results obtained from the calculations are shown in Table-1. The inter-relationship between the various parameters is shown in Figure 7.27, Figure 7.28 and Figure 7.29. Looking at the values of the total cost, it is evident that the total cost decreases with the increase in the fraction return for remanufacturing (f). Figure 7.27 shows the variation of Im and S with the fraction of demand returned for remanufacturing. The variation S with f shows that the rate of increase in S decreases with increase in the f value. The variation of Im shows that the rate of decrease in Im (ΔI_m) decreases with increase in the f value. The values of Im and S almost agree at f=0.6.

Table 7-17: The values of S, I_m and total cost with variation of fraction returned

f	S	I_m	TC
0.1	176	615	7288
0.2	277	555	6923
0.3	344	517	6684
0.4	393	491	6515
0.5	429	472	6388
0.6	457	458	6290
0.7	480	447	6211
0.8	500	437	6147
0.9	516	430	6093

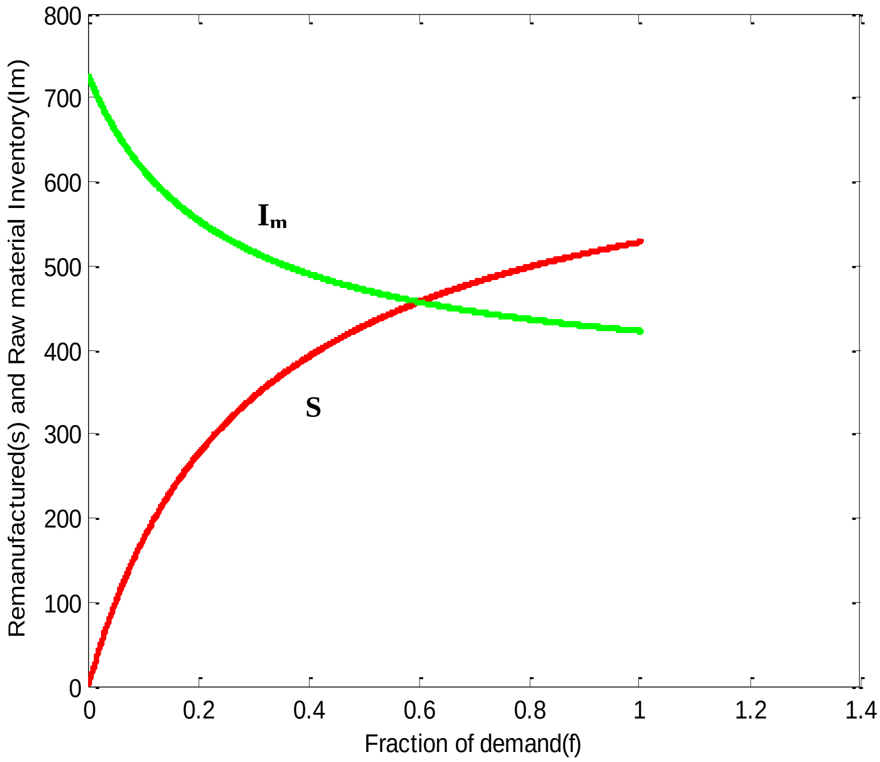


Figure 7.27: The variation of remanufactured quantity and raw material inventory with fraction of demand.

Figure 7.28 shows the variation of remanufactured quantity and the maximum level of the inventory in direct manufacturing with change in the fraction of demand return. The exponential nature of the curve shows the decrease in the values of these parameters at both the ends i.e. at the maximum values of the parameters and the minimum values of the parameters. This indicates the optimal level of the parameters that can be chosen for better return on investment and the increased productivity.

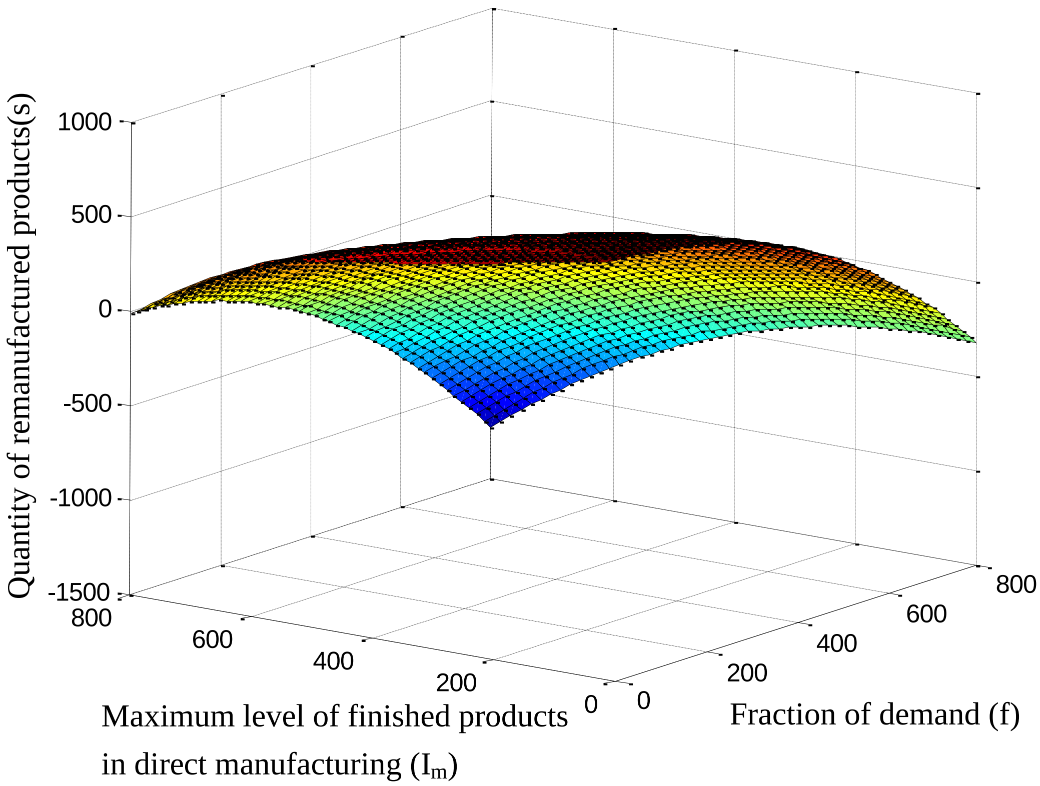


Figure 7.28: The variation of quantities for direct manufacturing and remanufacturing with change in fraction of demand return.

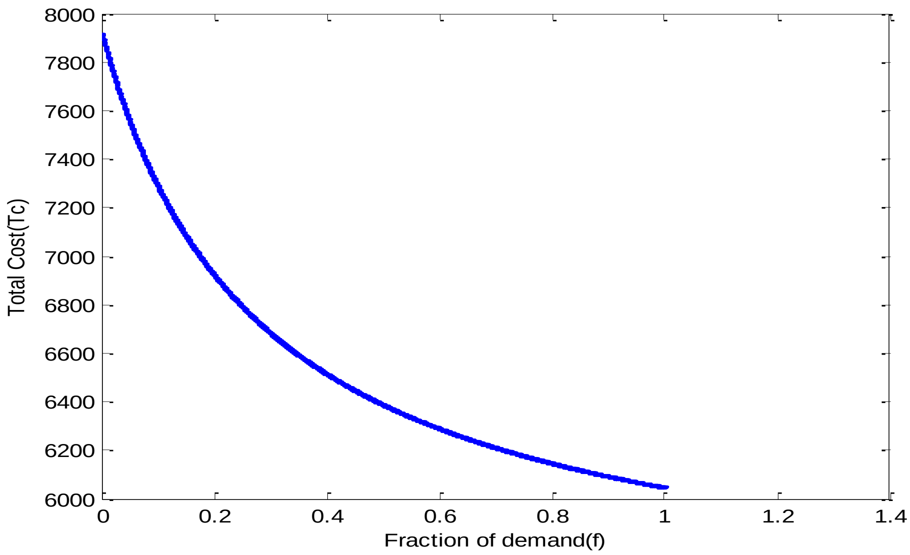


Figure 7.29 : The variation of total cost with fraction of demand.

Figure 7.28shows the variation of total cost with fraction of demand. The exponential nature of the curve shows the decrease in the total cost decreases at a decreased rate with increase in the 'f' value.

The major factor in the proposed model is the fraction return for remanufacturing. This factor varies depending on the type of industry the type of product and therefore it is very difficult to quantify. All the returned items cannot be remanufactured. Remanufacturing depends on the condition of the returned item as shown in figure 1.8. So the major limitation is 100% remanufacturing is not attainable. Therefore, one needs to set the values of Im and S depending on the type of industry and closely analyzing its return percentage for remanufacturing.

7.5 Results and analysis for "A Modified RSC with remanufacturing for sustainable product cycle"

In order to make an analysis of the model and the associated inventory system, the developed mathematical model was tried to find out the relationship of the various parameters at different situations. Accordingly the parameters were chosen and their relationships are determined. Table.5.10 presents a concise state of conditions for analyzing the behaviour of these identified parameters. The values used in the analysis are the standard values as used in typical production units. A brief interpretation of the behaviour is presented to examine the validity of the model.

Table 7-18: Process Parameters for Model Analysis.

Relationship	Constants	Variables
Co vs. R,Q	r, p, Cs, Ch1	d, Co, Ch2
Cs vs. R,Q	r, d, Co, Ch2	Cs, p, Ch1
d vs. R, Q	r	d, p, Cs, Co, Ch1, Ch2
p vs. R, Q	r, Co, Ch2	p, d, Cs, Ch1
Ch1 vs. R, Q	r, Co, Ch2	Ch1, p, Cs, d
Ch2 vs. R, Q	r, p, Cs, Ch1	Ch2, Co, d

As shown from the graphs, Fig.7.30 C_0vslot size R and Q, it is clear that the value of R is more than Q at small value of C_0. As the value of C_0 increases, R and Q agree with each other at around C0=5.5.the difference between R and Q shows an increase with higher values of C_0, where the relative increase in Q value is more.

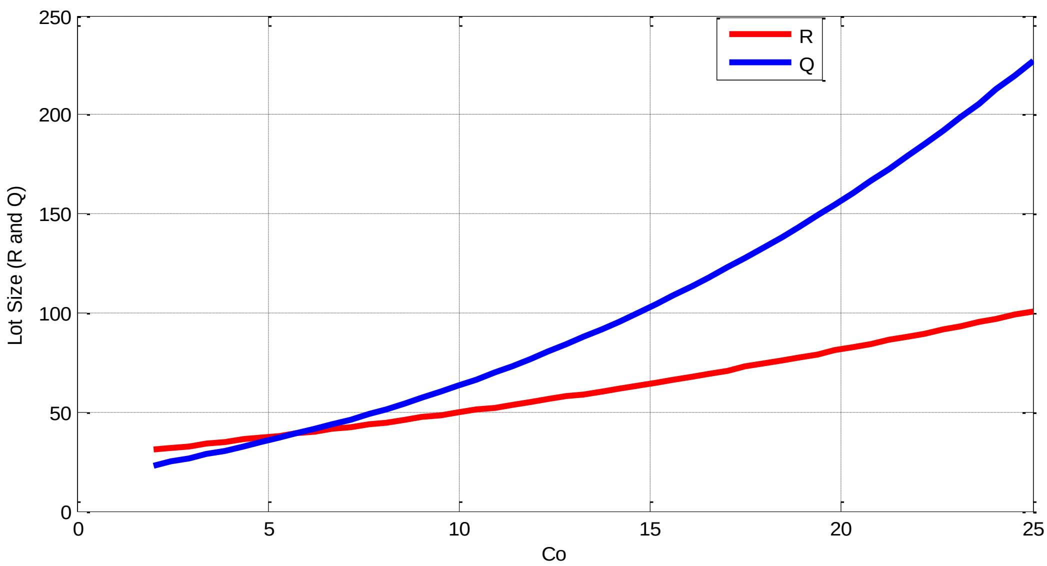


Figure 7.30: Effect of order cost (C_0) on the system.

The effect of variation of Cs (Fig. 7.31) has appreciable effect on Q which decreases rapidly in the beginning but increases at a rather slow rate after Cs reaches a value of around 20. After which it has a little effect on the difference between R and Q. Both these quantities vary almost linearly with the variation of Cs maintaining a constant difference.

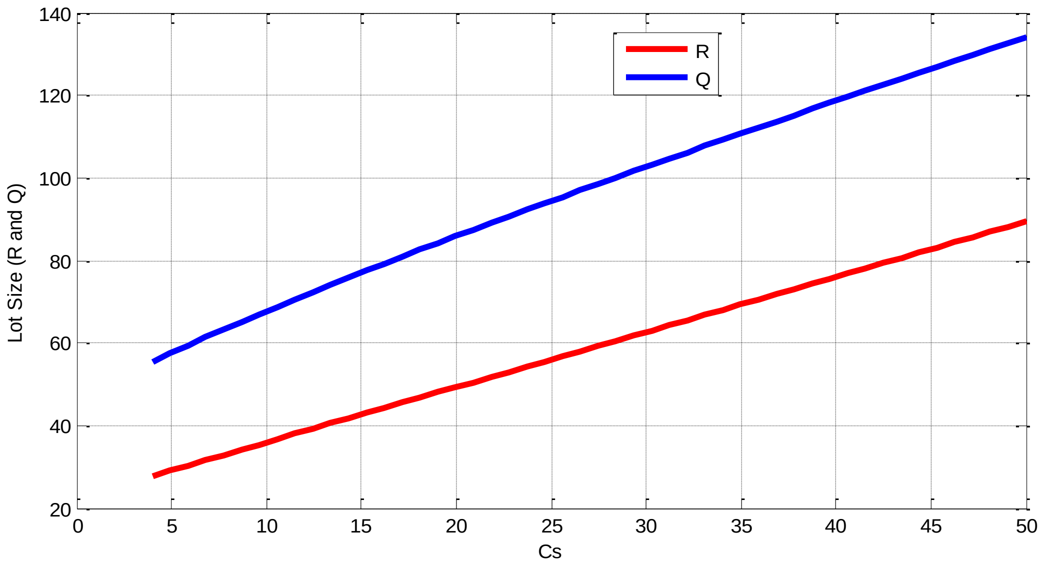


Figure 7.31: Effect of setup cost for remanufacturing (C_s) on the system.

The effect of variation of p in Fig. 7.32 shows at small values of p, the quantities R and Q are close to each other. With increase of p, the Q value increases more as compared to the value of R.

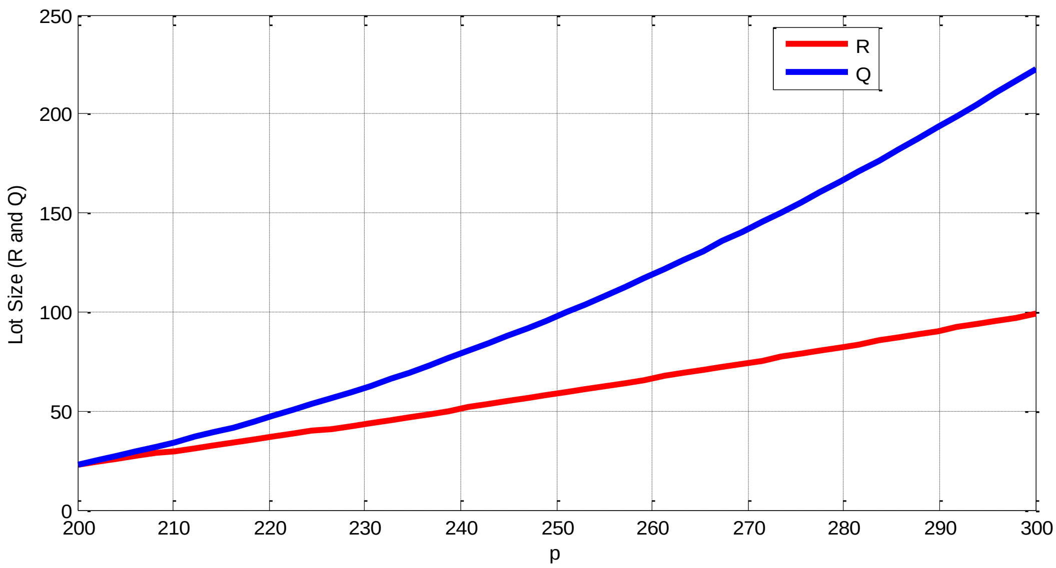


Figure 7.32: Effect of capacity of recovery process (p) on the system.

The effect of variation of d as shown in Fig. 7.33 depicts that at small values of d, the quantities R and Q are close to each other. With increase of d,the Q value increases more as compared to the value of R.

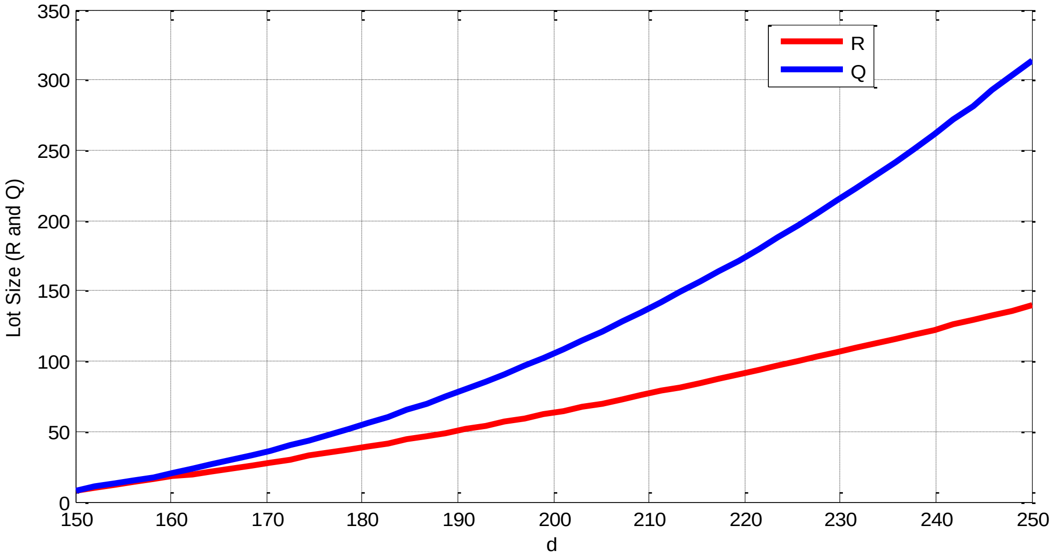


Figure 7.33: Effect of demand rate (d) on the system.

The effect of variation of C_{h1} (Fig. 7.34) shows that at small values of C_{h1}, the quantities R and Q are close to each other. With increase of C_{h1},the Q value increases more as compared to the value of R.

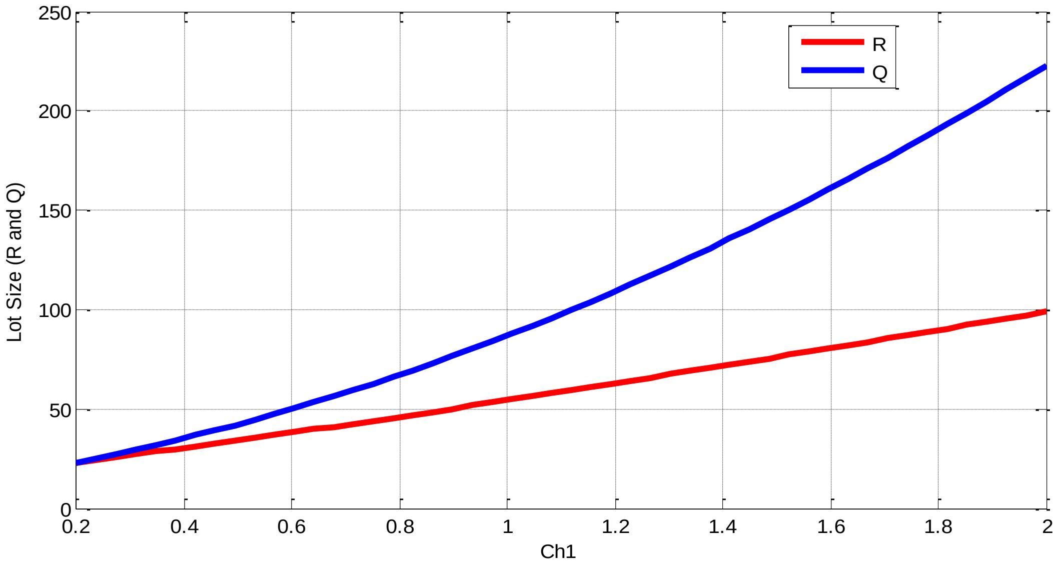


Figure 7.34: Effect of holding cost for returned items for remanufacturing (C_{h1}) on the system.

The effect of variation of C_{h2} (Fig. 7.35) shows that at small values of C_{h2}, the quantities R and Q are close to each other. Even below the value of 1,the value of R is higher than Q. With increase of C_{h2},the Q value increases more as compared to the value of R.

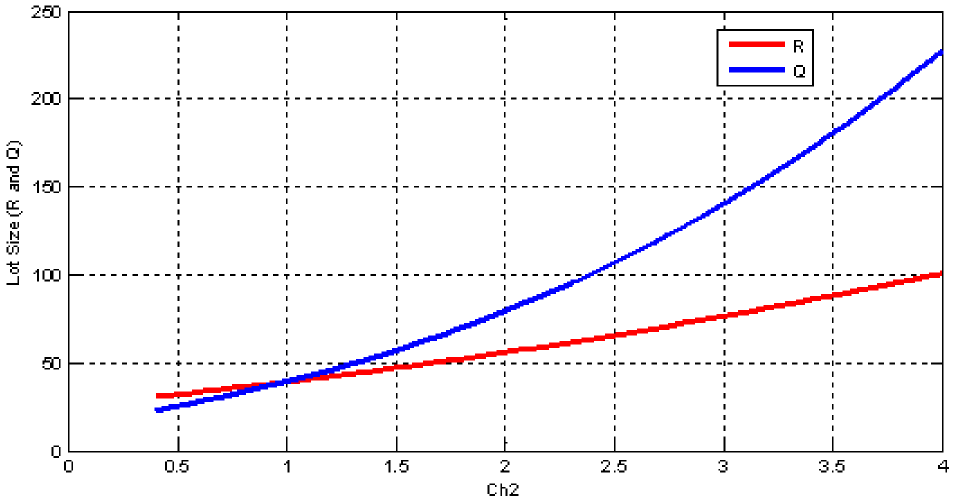


Figure 7.35: Effect of holding cost for new items (C_{h2}) on the system

From the above analysis it is clear that one have to keep the parameters C_0, p, d, C_{h1} and C_{h2} as small as possible. This will help in maintaining a balance between the R and Q with both the values remaining close to each other. The aim is to use the returned items for remanufacturing equivalently with the directly procured products.

7.6 Results and Analysis for ANFIS

7.6.1 Tire manufacturing case-1

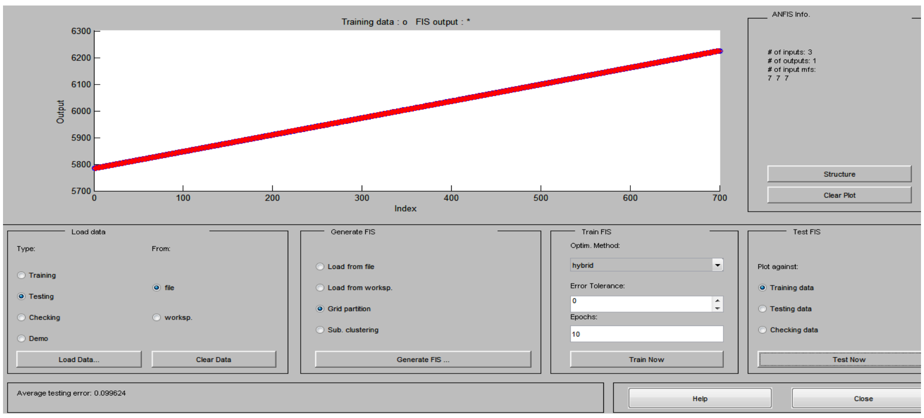


Figure 7.36: Comparison of predicted and desired value for Q_w.

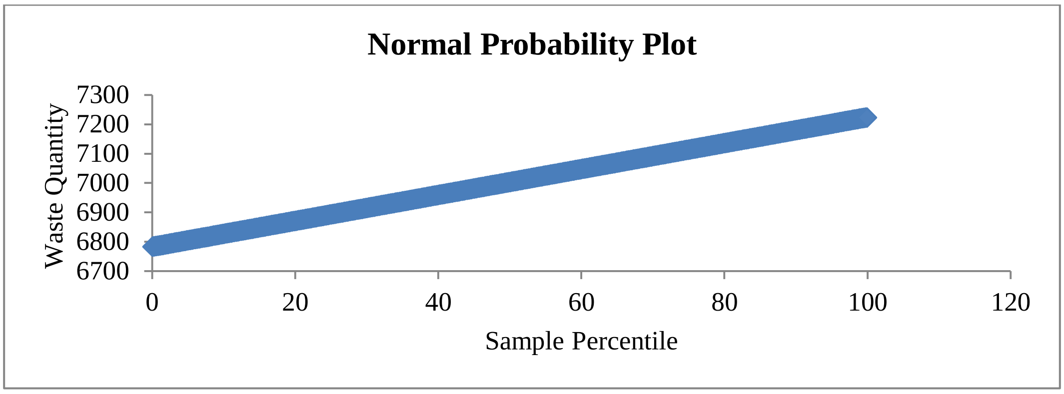


Figure 7.37: Normal probability plot for Q_w.

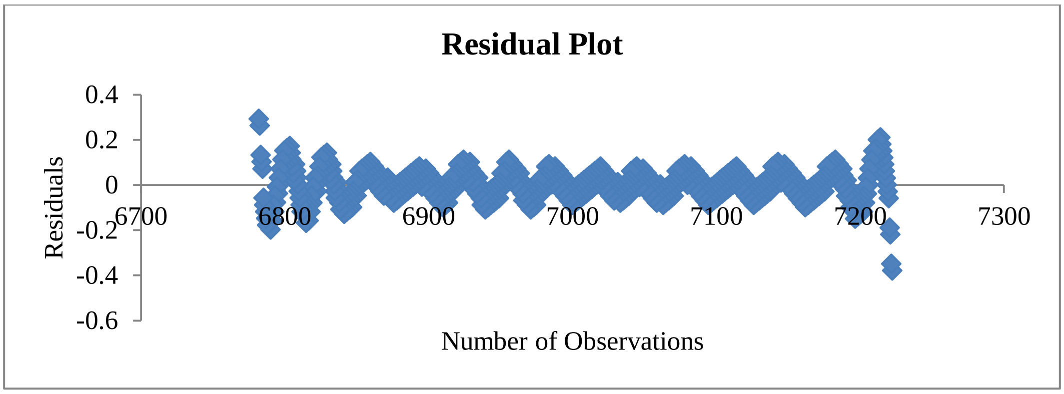


Figure 7.38: Residual plot for Q_w.

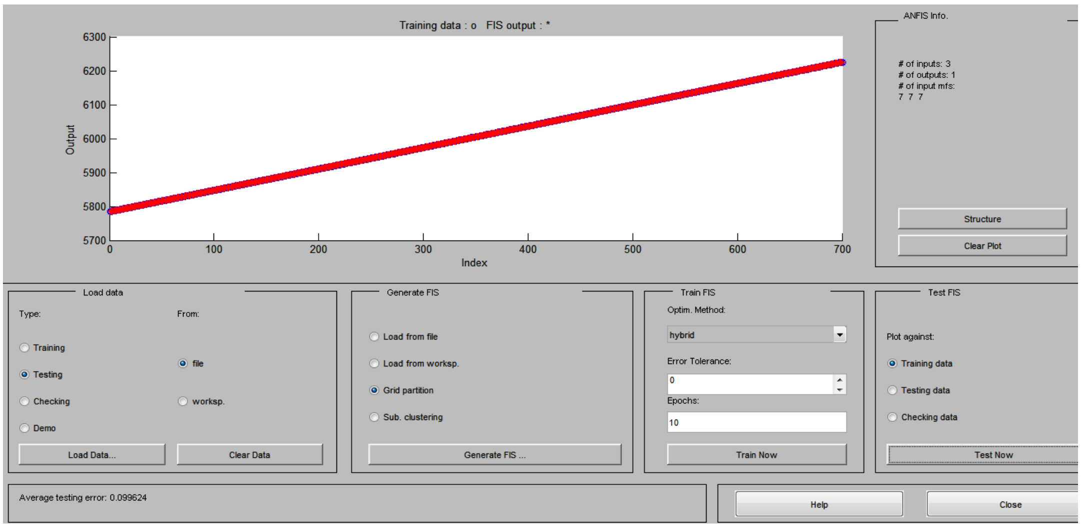


Figure 7.39: Comparison of predicted and desired values for D_2.

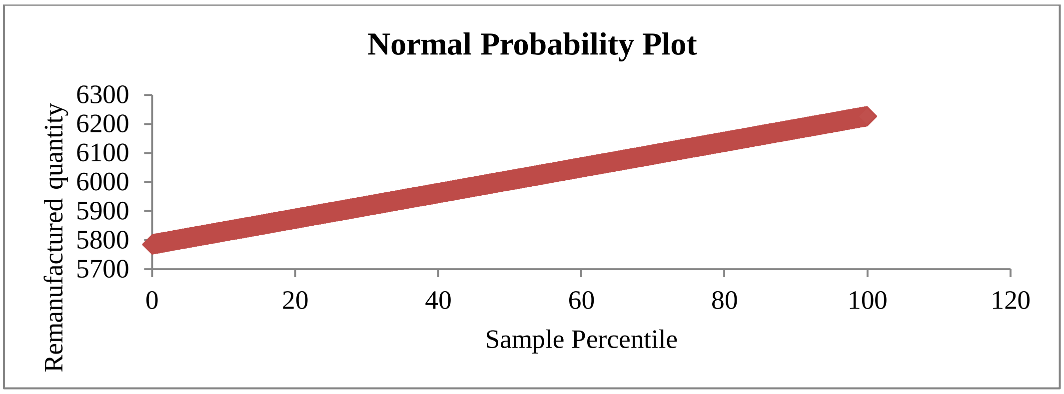


Figure.7.40: Normal probability plot for D_2.

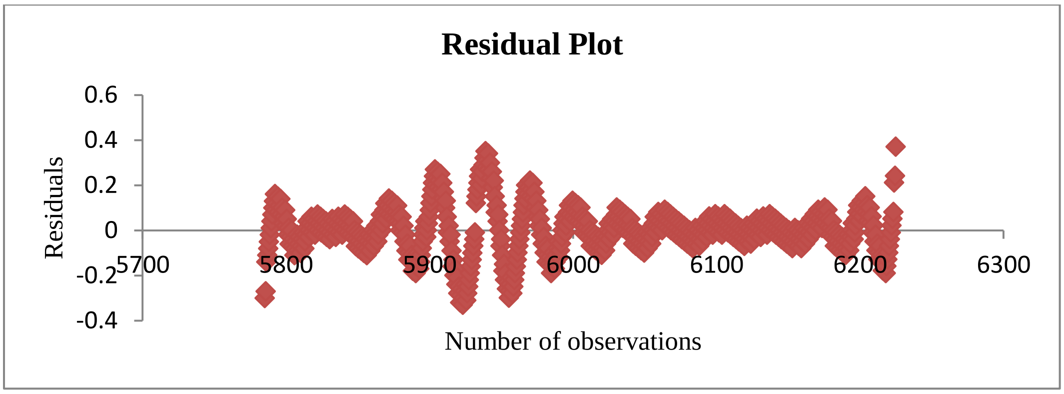


Figure 7.41: Residual plot for D_2.

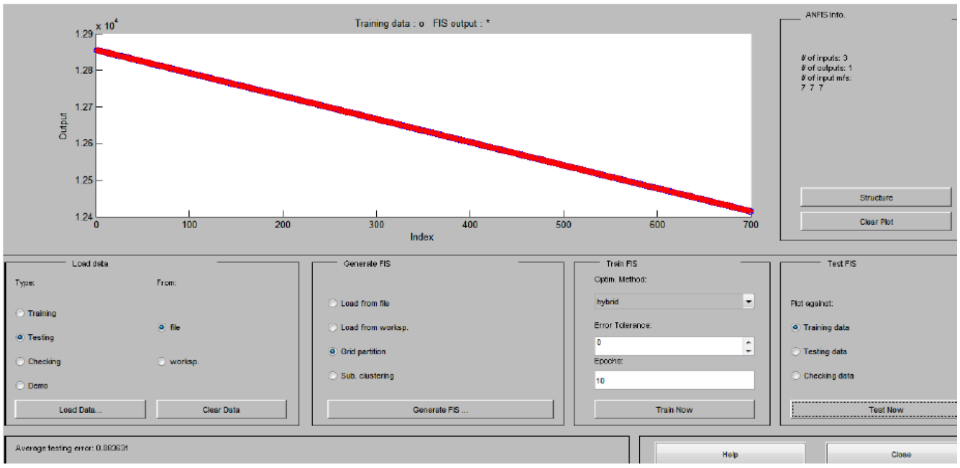


Figure7.42: Comparison of predicted and desired values for D_1.

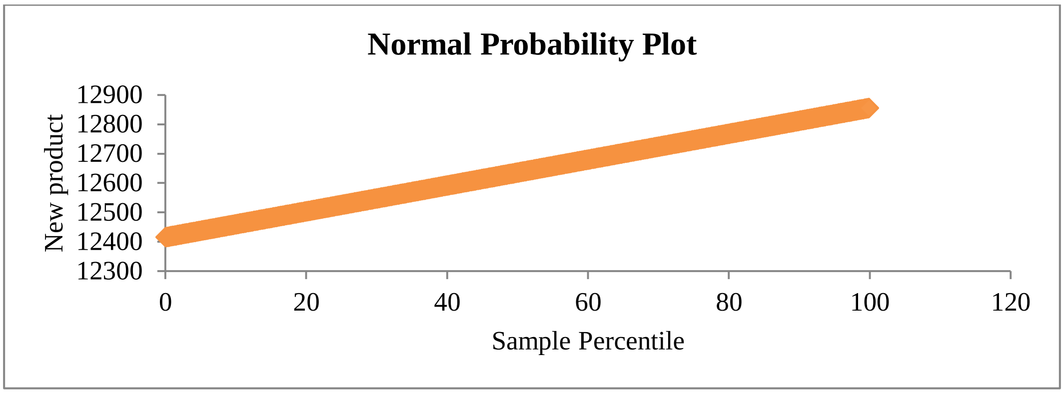


Figure 7.43: Normal probability plot for D_1.

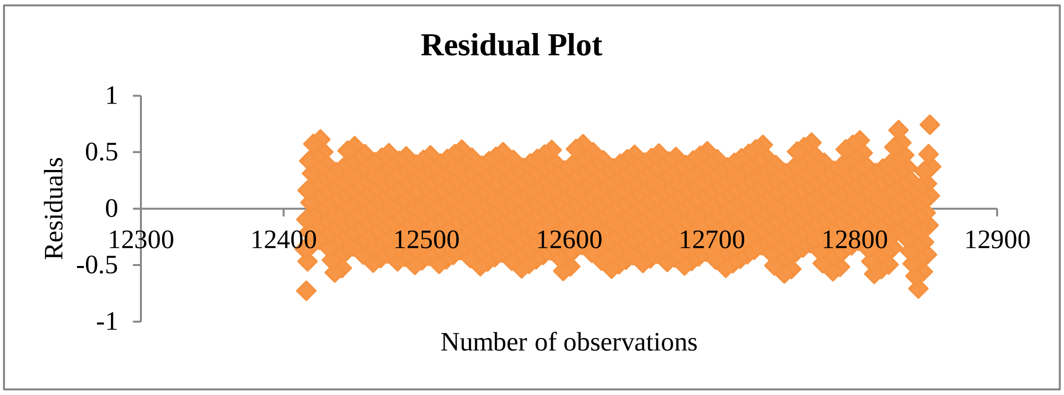


Figure 7.44: Residual plot for D_1.

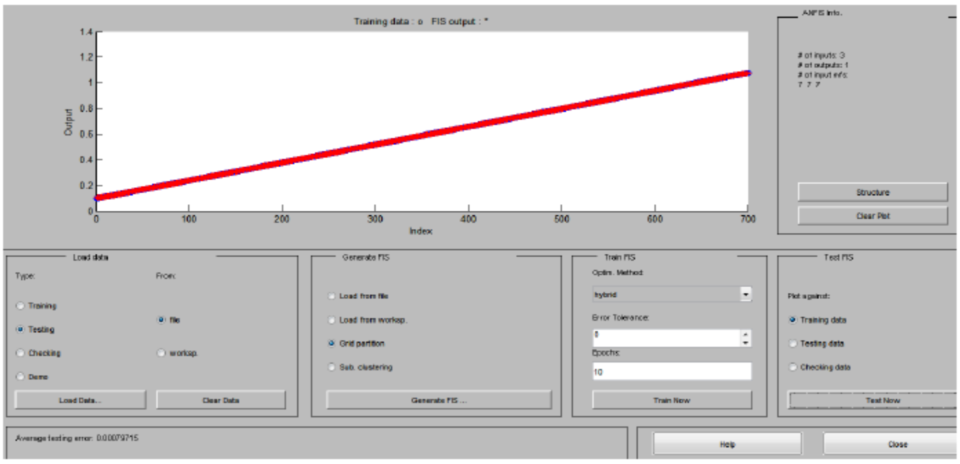


Figure 7.45: Comparison of predicted and desired values for γ.

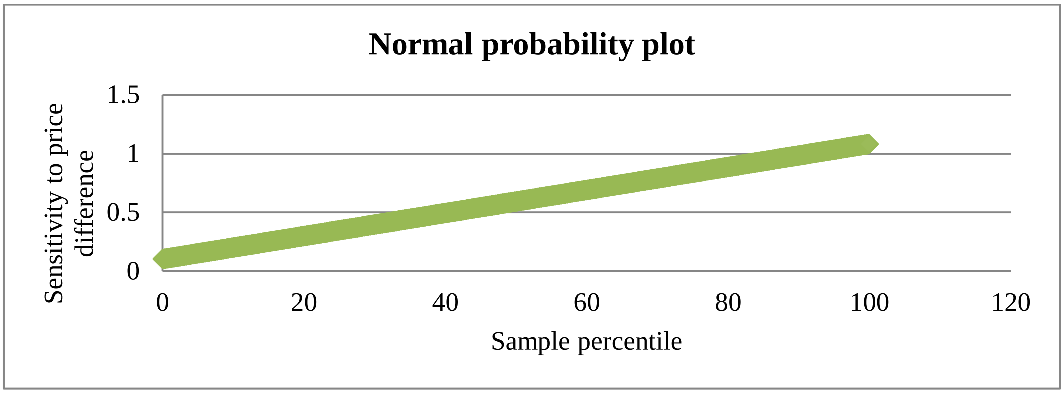


Figure 7.46: Normal probability plot for γ.

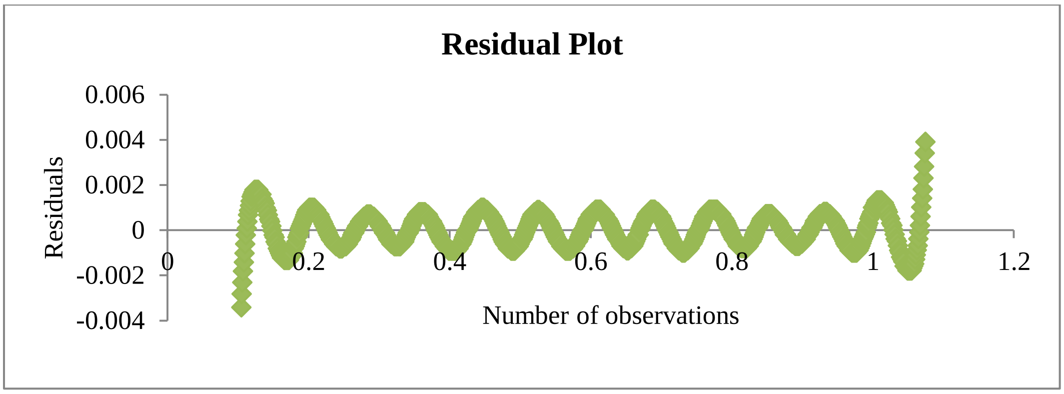


Figure 7.47: Residual plot for γ.

Table 7-19: Comparison of results for case -1 for Tire manufacturing.

Sl	Output	Average testing error
1	Q_w	0.060064
2	D_2	0.099624
3	D_1	0.083631
4	γ	0.00079715

The values for Q_w, D_1 , D_2 and γ are calculated by using the derived formula. One thousand number of data points are calculated in this manner out of which 700 data are taken as the training data for the ANFIS. With the help of the training data, ANFIS predicted a set of data points for all the above mentioned parameters. All the parameter values are compared based on predicted value and the desired values (calculated) as shown in figure 7.36 through 7.47.The average testing errors are shown in table 7.19.The testing errors are very less indicating the calculated values are nearly matching with the predicted values and can be accepted.

7.6.2 Tire manufacturing case-2

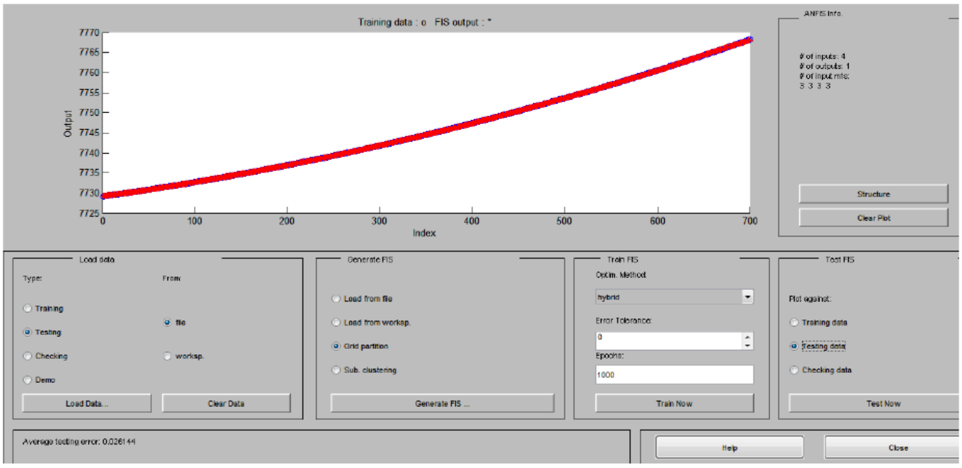


Figure 7.48: Comparison of predicted value and desired value for Q_w.

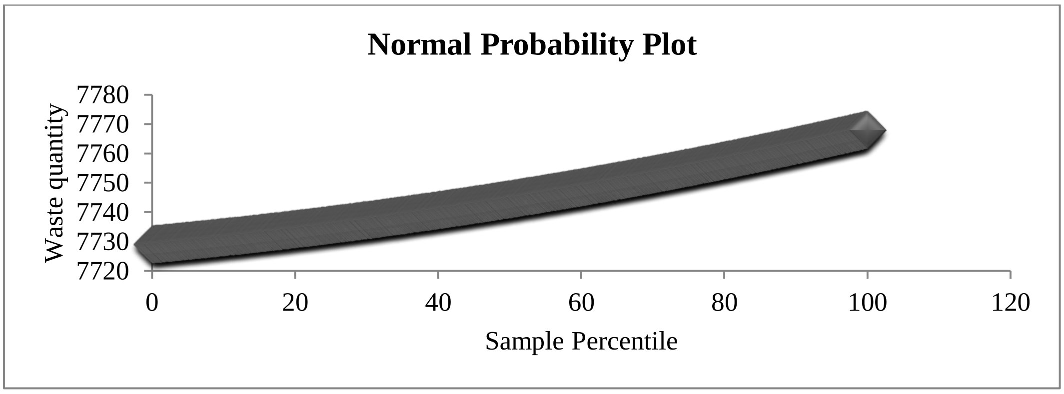


Figure 7.49: Normal probability plot for Q_w.

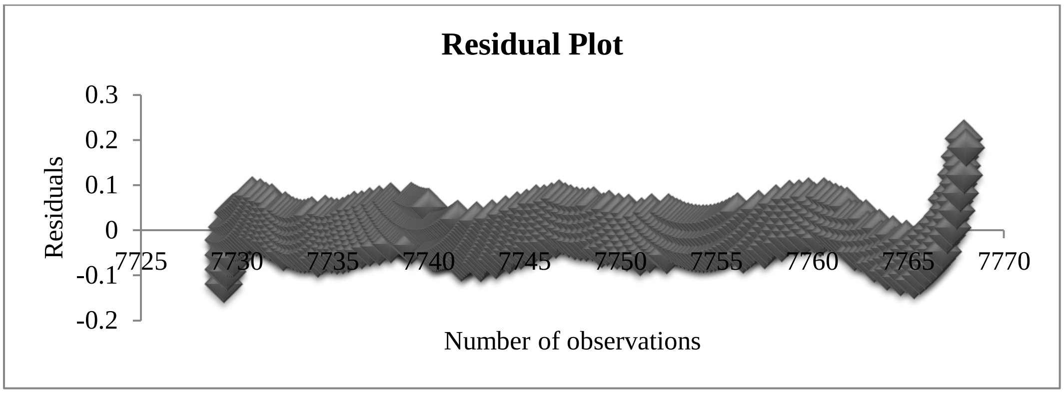


Figure 7.50: Residual plot for Q_{w}.

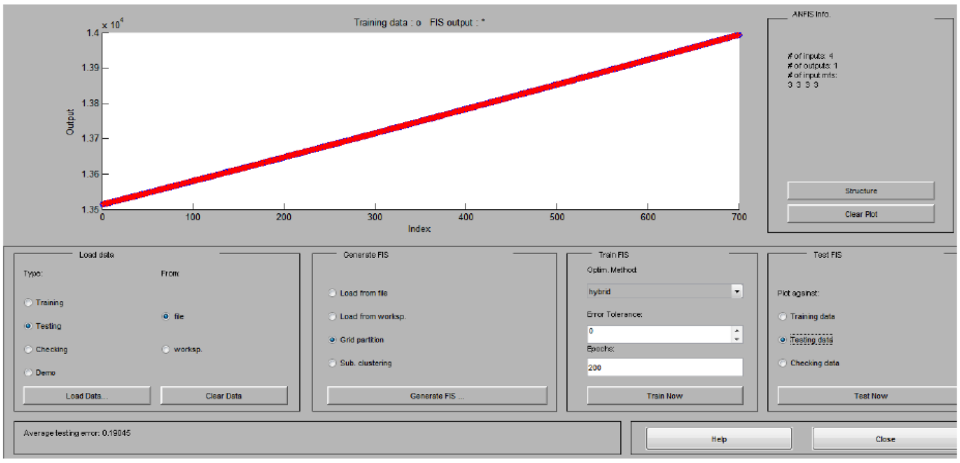


Figure 7.51: Comparison of predicted value and desired value for Qr.

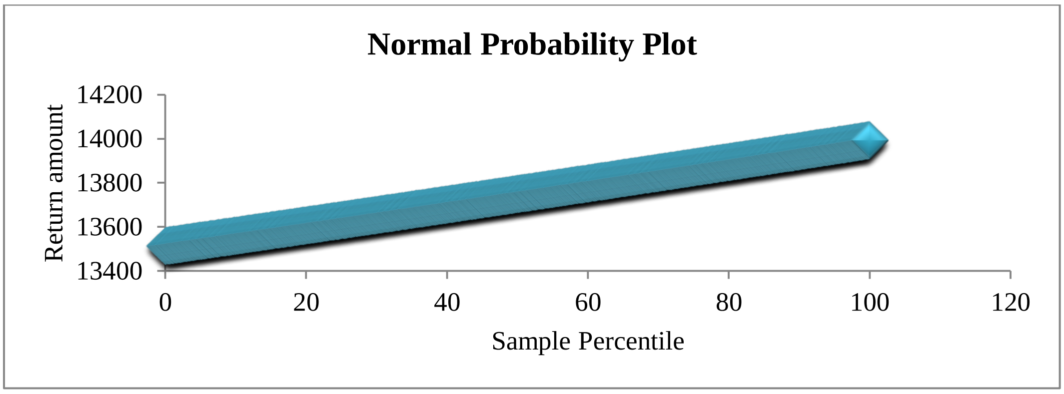


Figure 7.52: Normal probability plot for Q_{r}.

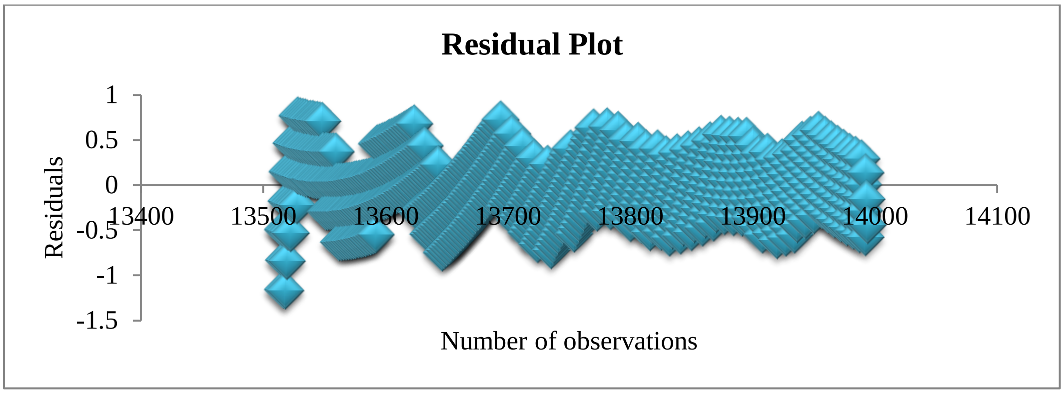


Figure 7.53: Residual plot for Q_r

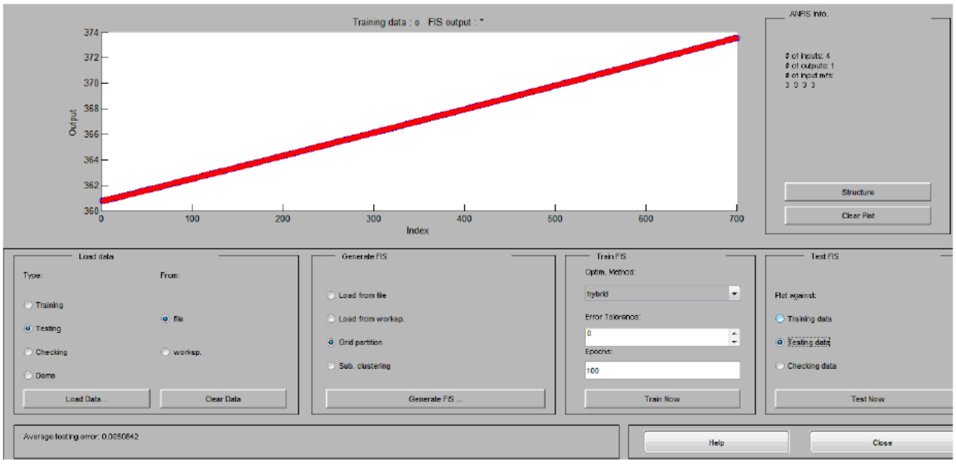


Figure 7.54: Comparison of predicted value and desired value for C_{bavg}.

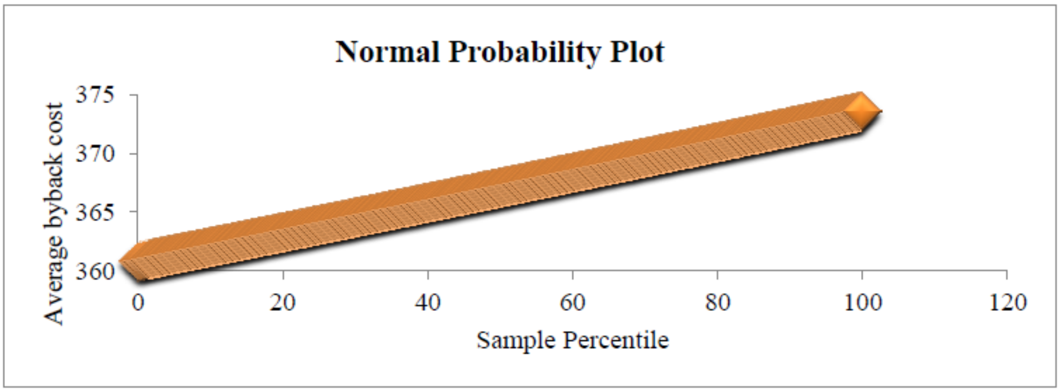


Figure 7.55: Normal probability plot for C_{bavg}.

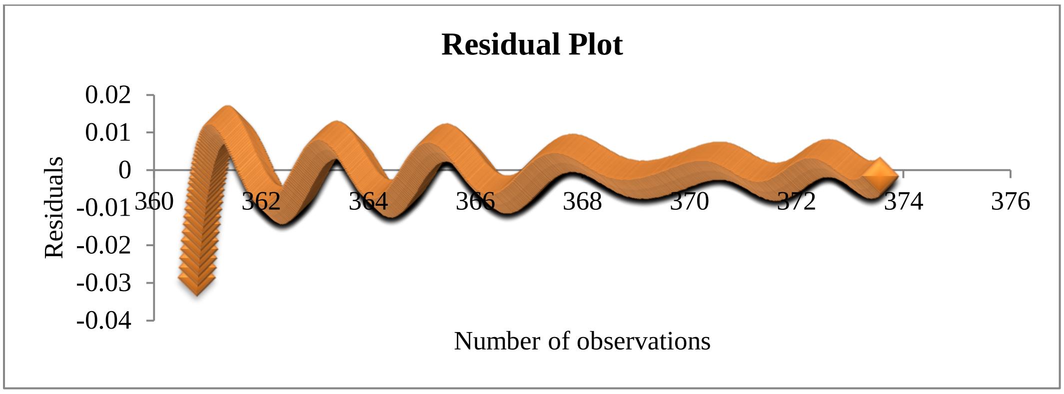


Figure 7.56: Residual plot for C_{bavg}.

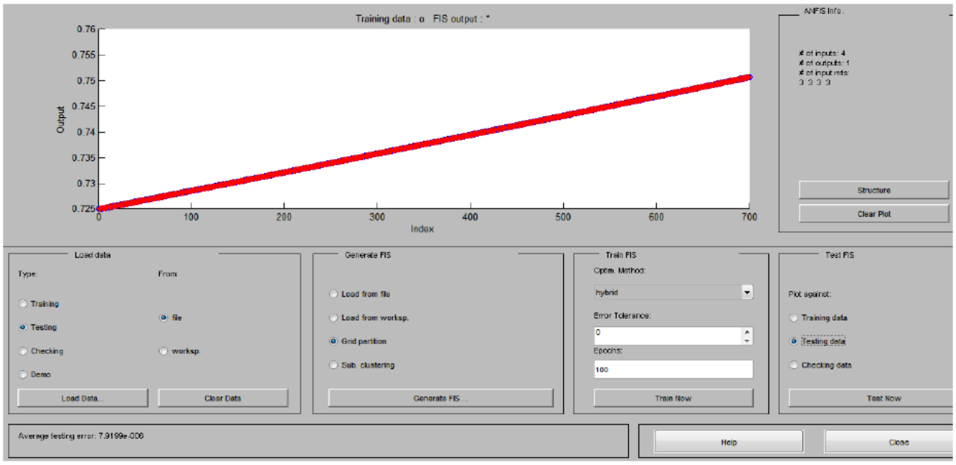


Figure 7.57: Comparison of predicted value and desired value for α.

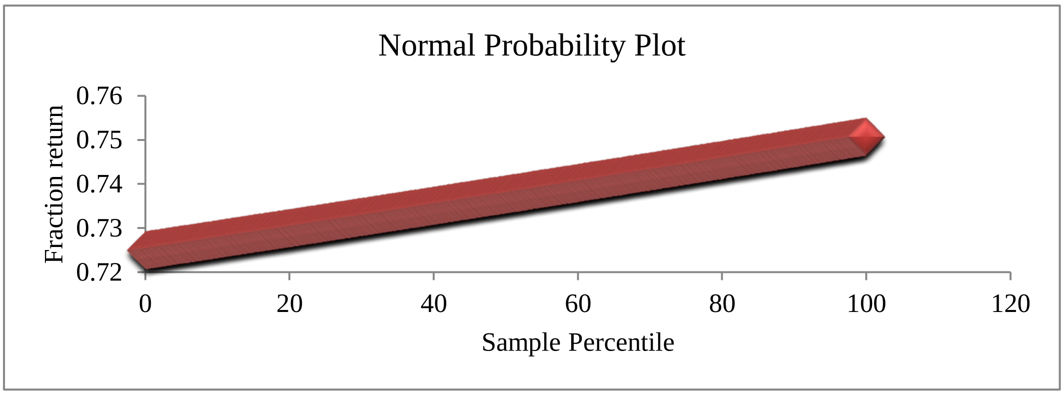


Figure 7.58: Normal probability plot for α.

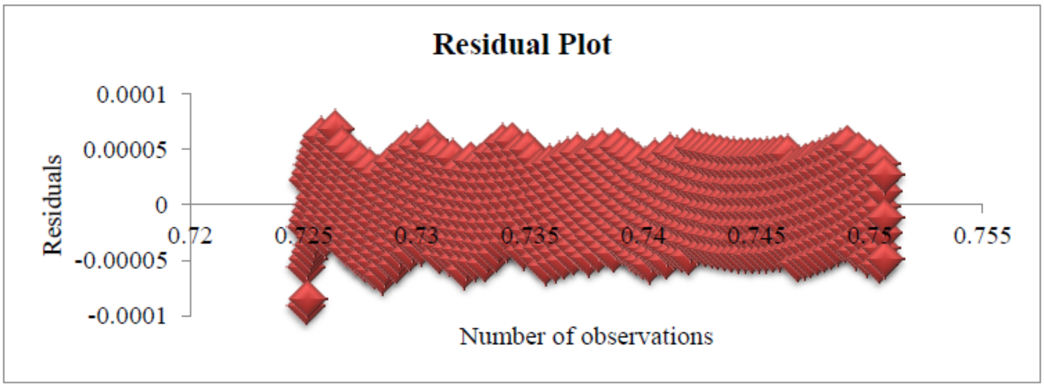


Figure: 7.59: Residual plot for α.

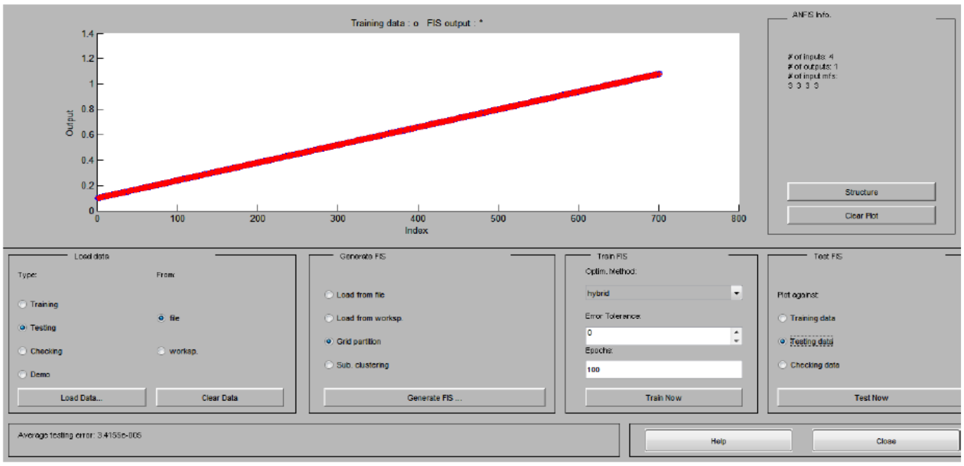


Figure 7.60: Comparison of predicted value and desired value for γ.

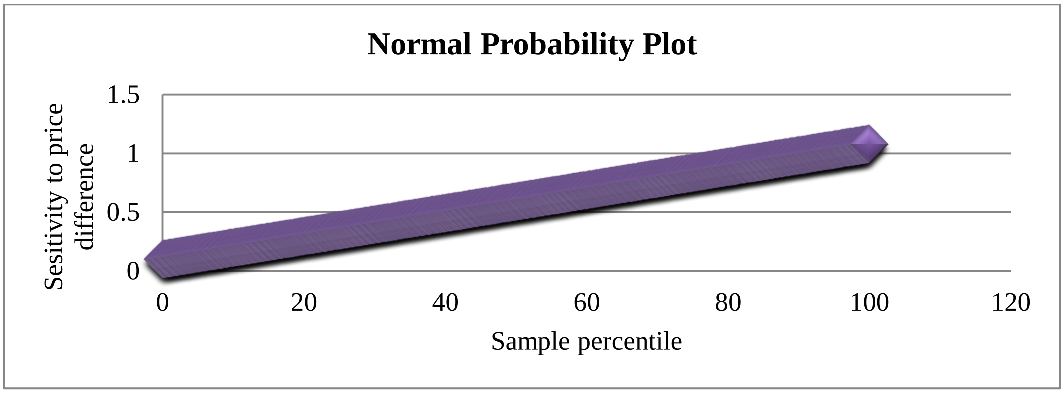


Figure 7.61: Normal probability plot for γ.

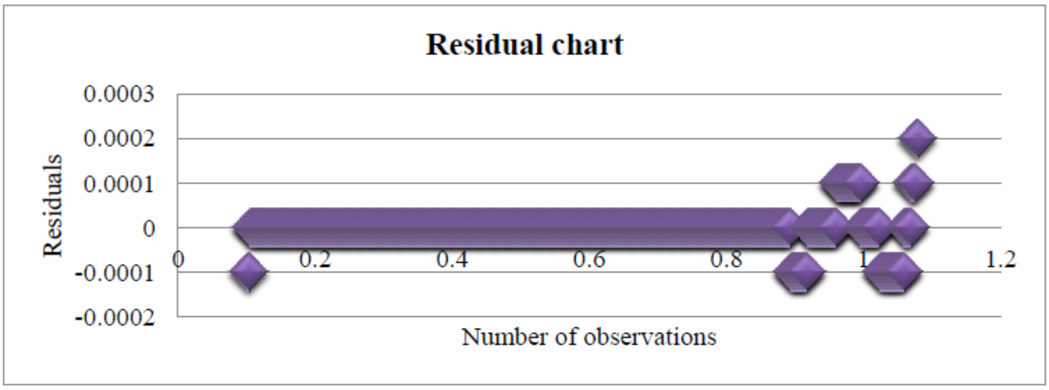


Figure 7.62: Residual plot for γ.

Table 7-20: Comparison of results for case -2 for Tire manufacturing.

Sl	Output	Average testing error
1	Q_w	0.026144
2	Q_r	0.19045
3	α	7.9199×10^{-005}
4	γ	3.4155×10^{-005}
5	C_{bavg}	0.0050842

The values for Q_r Qw, α, C_{bavg}, and γ are calculated by using the derived formula. One thousand number of data points are calculated in this manner out of which 700 data are taken as the training data for the ANFIS. With the help of the training data, ANFIS predicted a set of data points for all the above mentioned parameters. All the parameter values are compared based on the predicted values and the desired values (calculated) as shown in figure 7.48 through 7.62 with the help of testing errors, normal probability plot and residual plot. The average testing errors are shown in table 7.20.The testing errors are very less indicating the calculated values are in accordance with the predicted values and can be accepted.

7.6.3 Cartridge manufacturing case-1

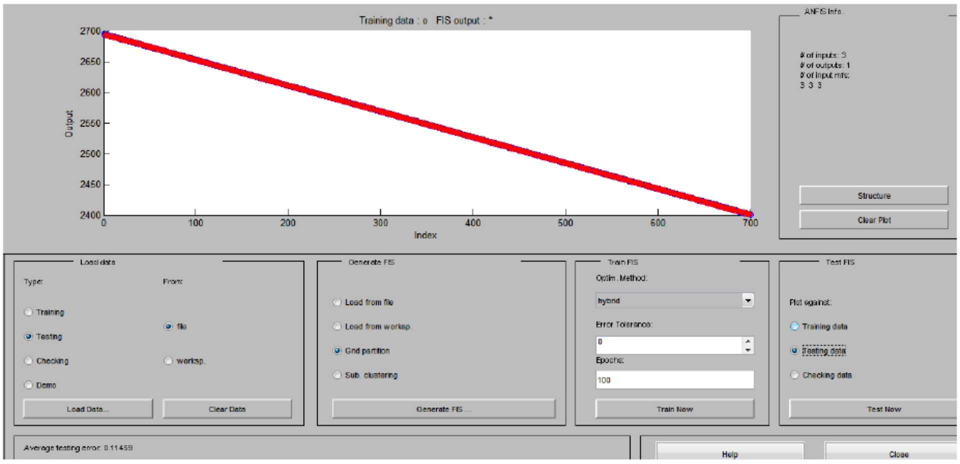


Figure 7.63: Comparison of predicted value and desired value for Q_w.

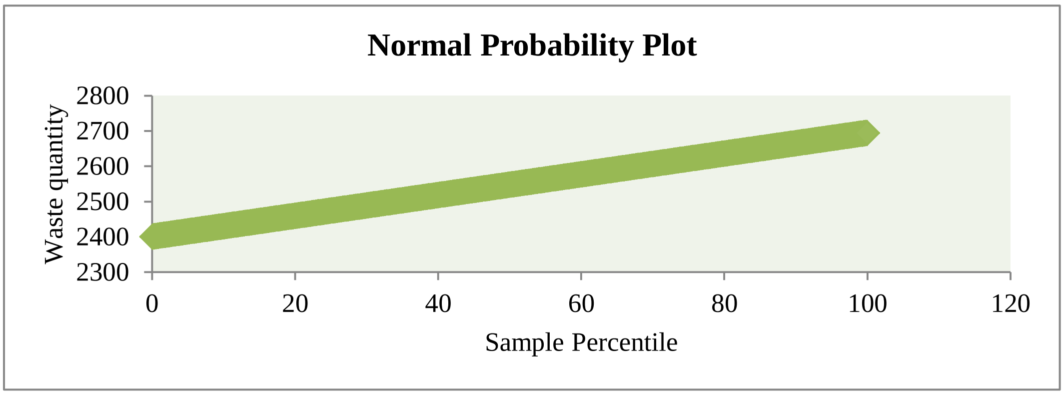


Figure 7.64: Normal probability plot for Q_w.

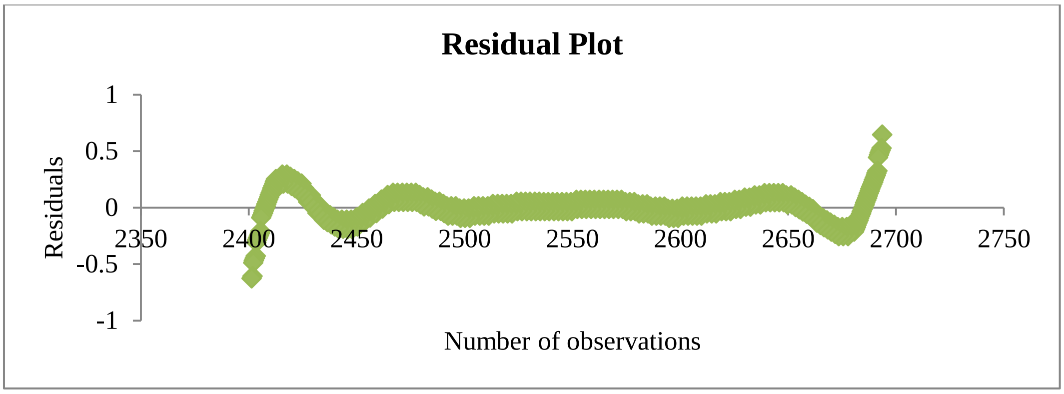


Figure 7.65: Residual plot for Q_w.

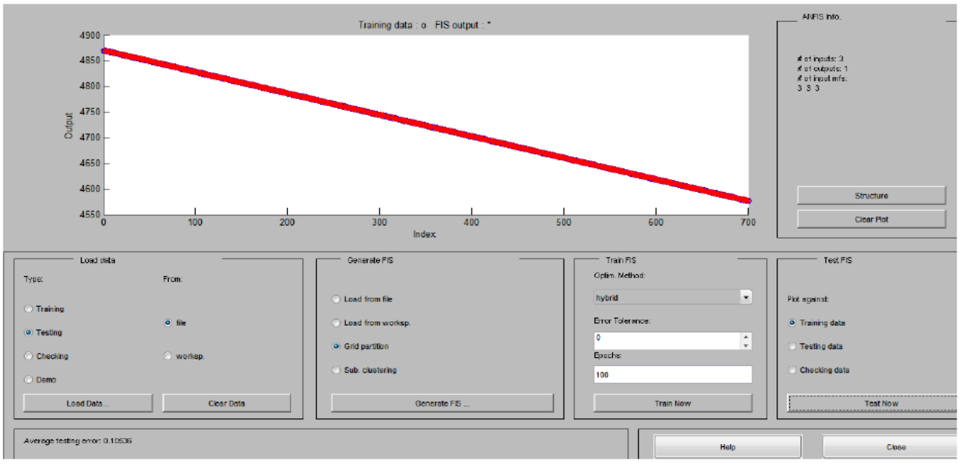


Figure 7.66: Comparison of predicted value and desired value for D_1.

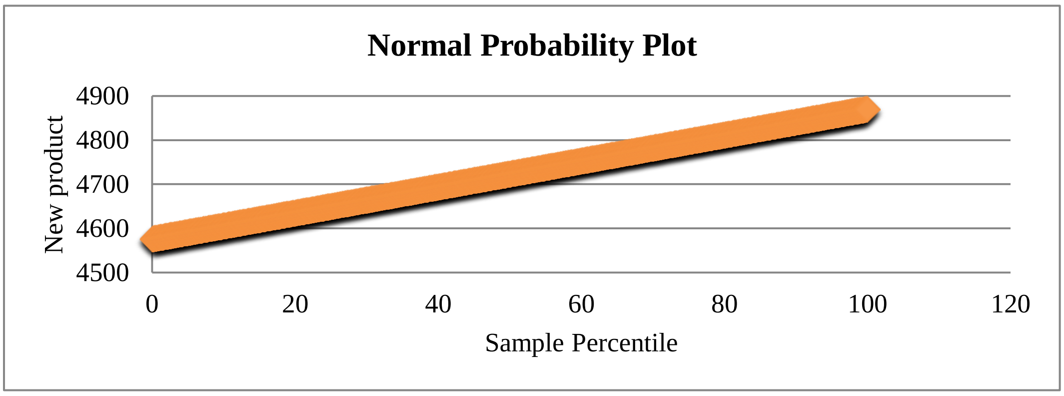


Figure 7.67: Normal probability plot for D_1.

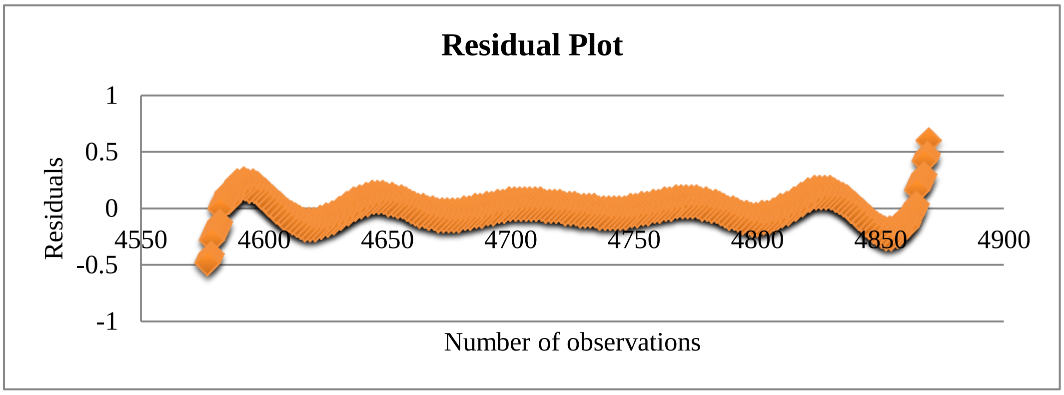


Figure 7.68: Residual plot for D_1.

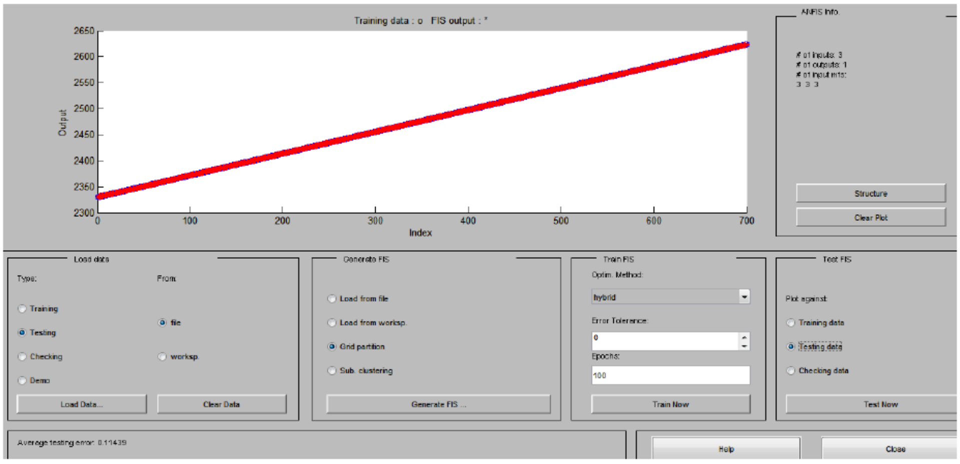


Figure 7.69: Comparison of predicted value and desired value for D_2.

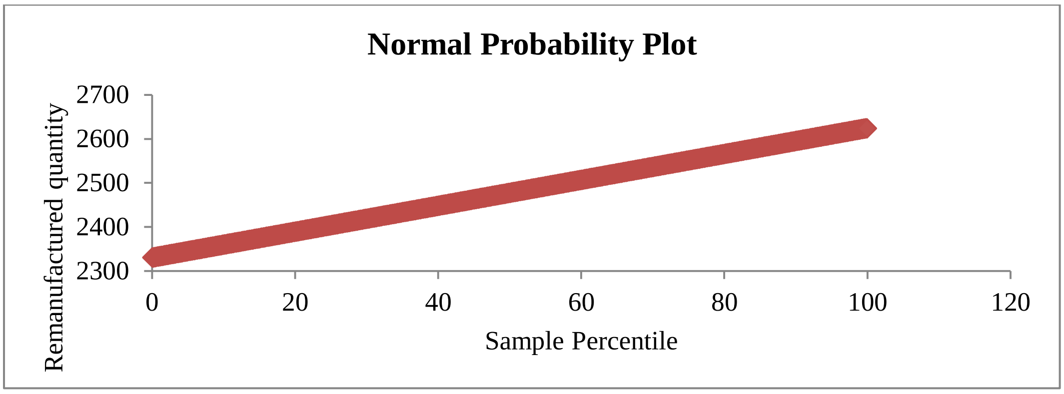


Figure 7.70: Normal probability plot for D_2.

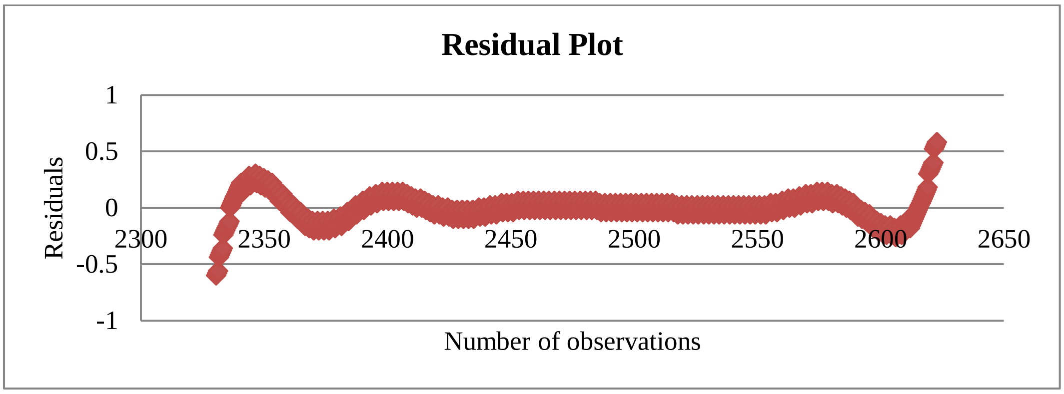


Figure 7.71: Residual plot for D_2.

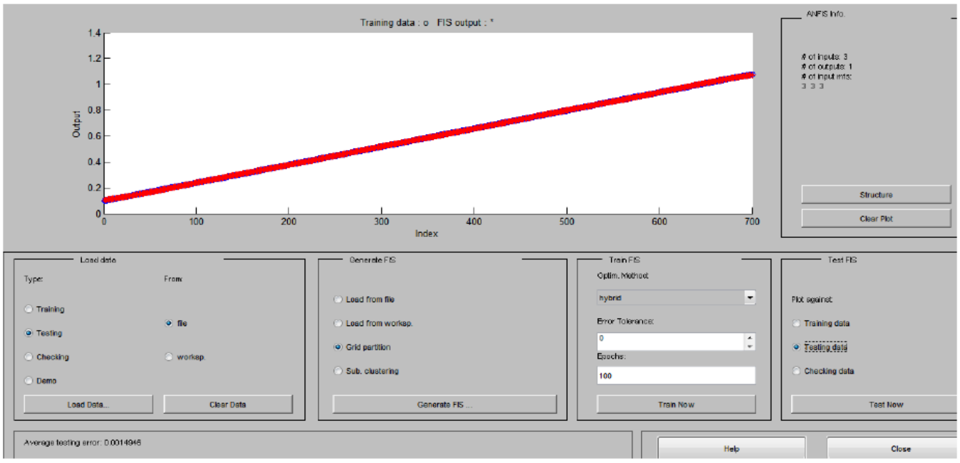


Figure 7.72: Comparison of predicted value and desired value for γ.

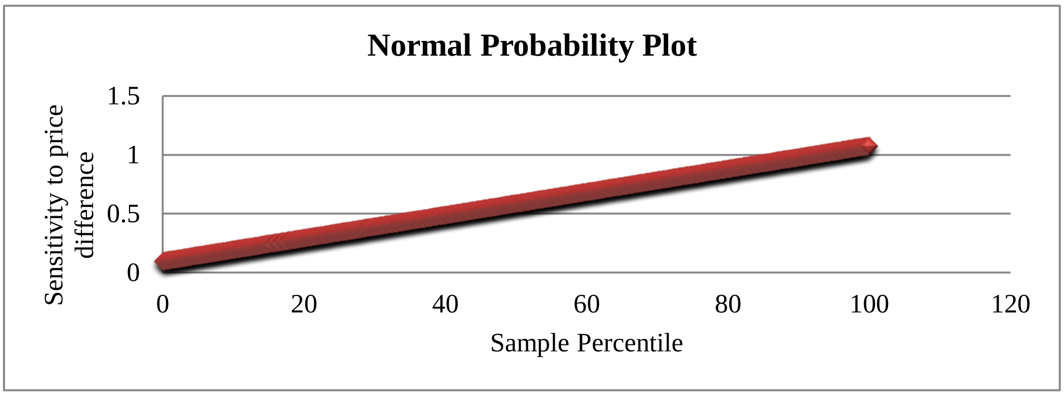


Figure 7.73: Normal probability plot for γ.

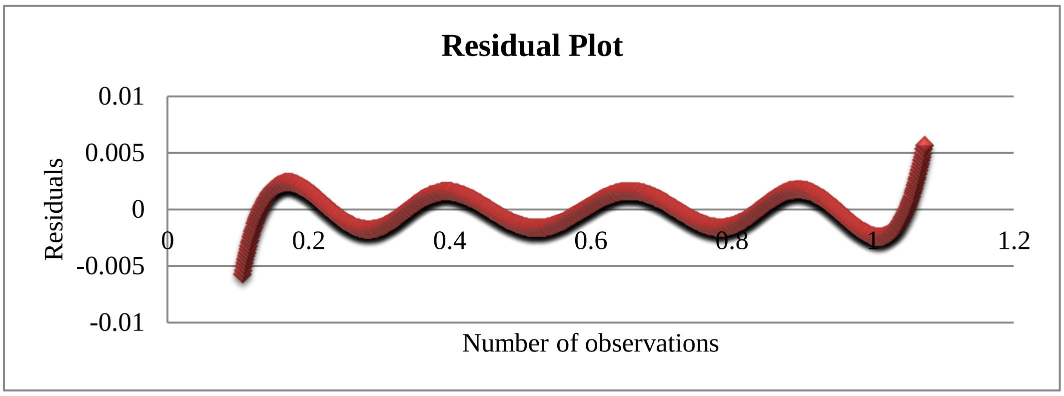


Figure 7.74: Residual plot for γ.

Table 7-21: Comparison of results for case -1 for cartridge manufacturing.

Sl	Output	Average testing error
1	Q_w	0.11459
2	D_2	0.11439
3	D_1	0.10536
4	γ	0.0014946

The values for Q_w, D_1 , D_2 and γ are calculated by using the derived formula. One thousand number of data points are calculated in this manner out of which 700 data are taken as the training data for the ANFIS. With the help of the training data, ANFIS predicted a set of data points for all the above mentioned parameters. All the parameter values are compared based on predicted value and the desired values (calculated) as shown in figure 7.63 through 7.74 with the help of testing errors, normal probability plot and residual plot. The average testing errors are shown in table 7.21.The testing errors are very less indicating the calculated values are in accordance with the predicted values and can be accepted.

7.6.4 Cartridge manufacturing case -2

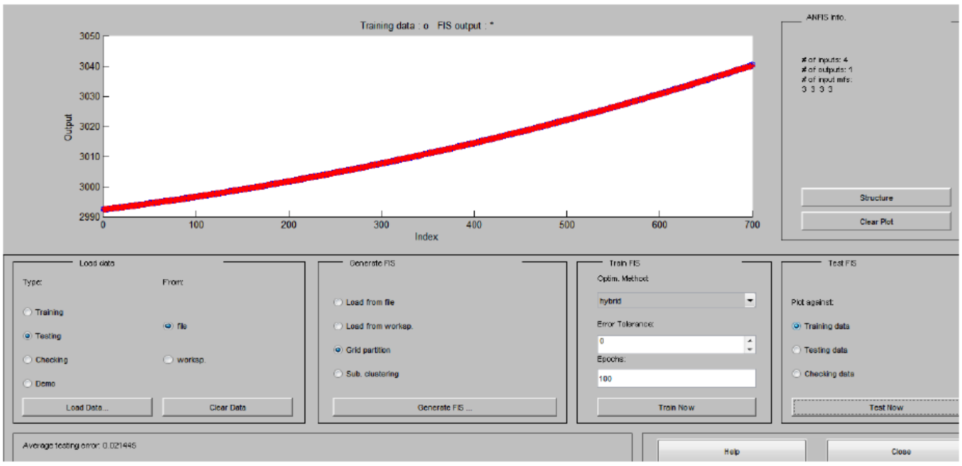


Figure 7.75: Comparison of predicted value and desired value for Qw.

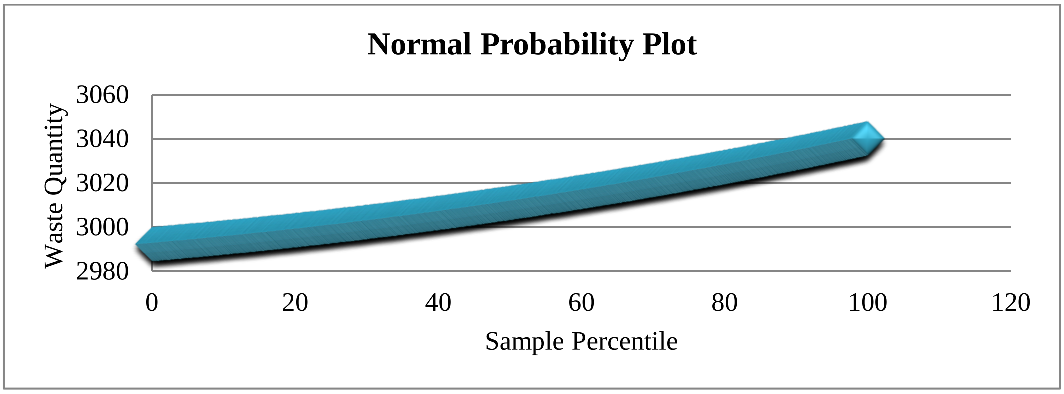


Figure 7.76: Normal probability plot for Q_w.

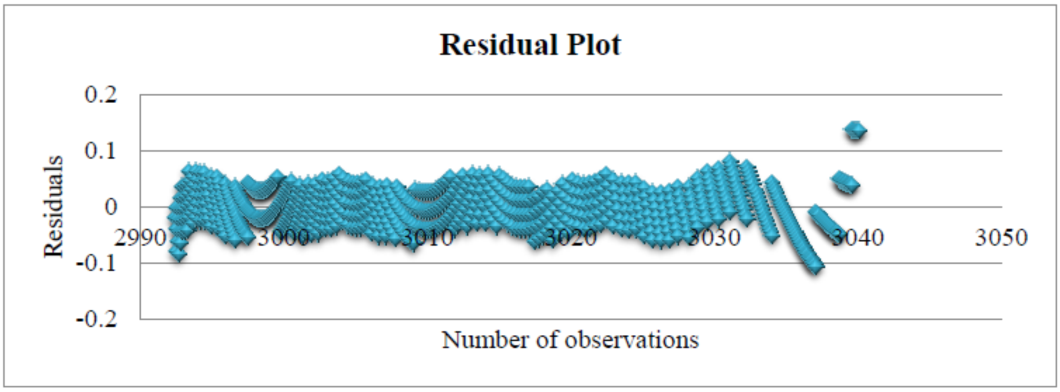


Figure 7.77: Residual plot for Q_w .

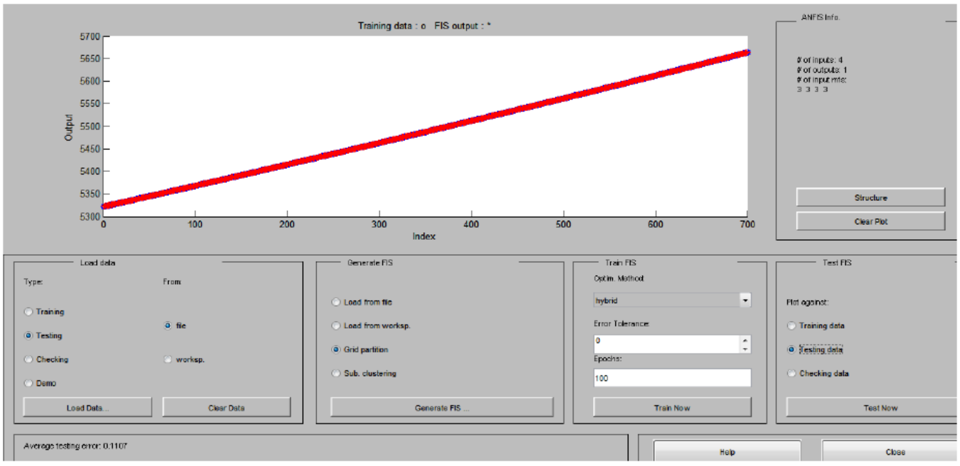


Figure 7.78: Comparison of predicted value and desired value for Q_r

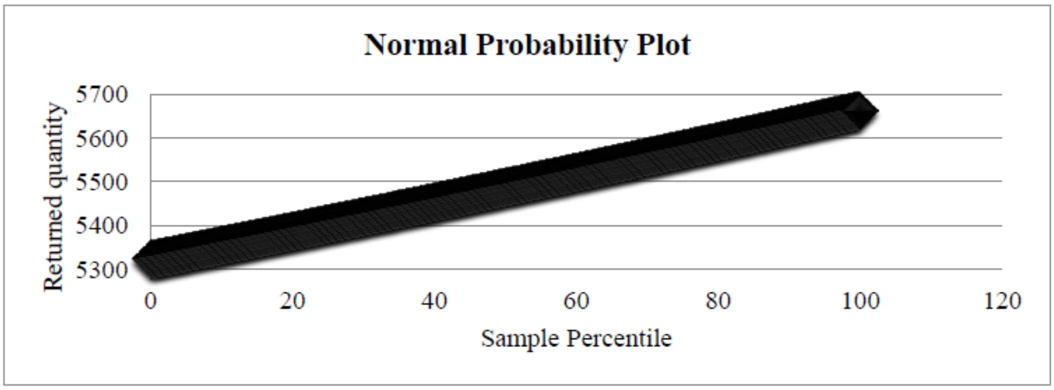


Figure 7.79: Normal probability plot for Q_r.

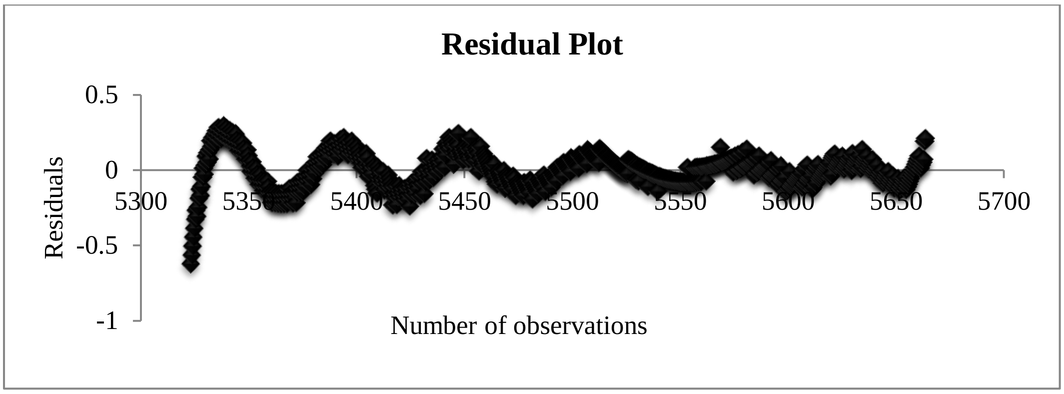


Figure 7.80 Residual plot for Q_r.

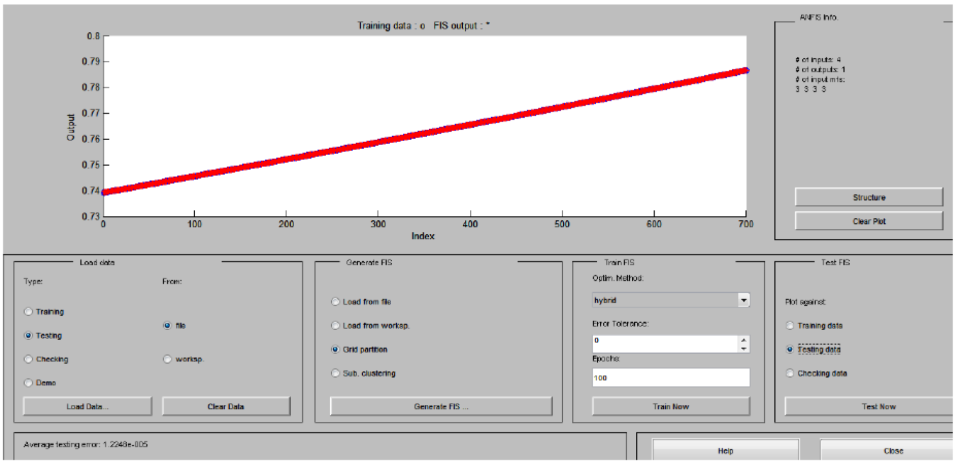


Figure 7.80: Comparison of predicted value and desired value for α.

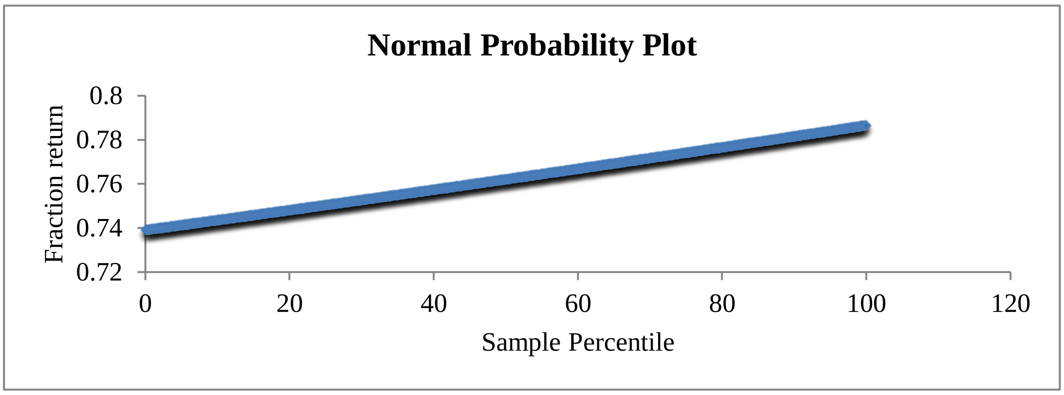


Figure 7.81: Normal probability plot for α.

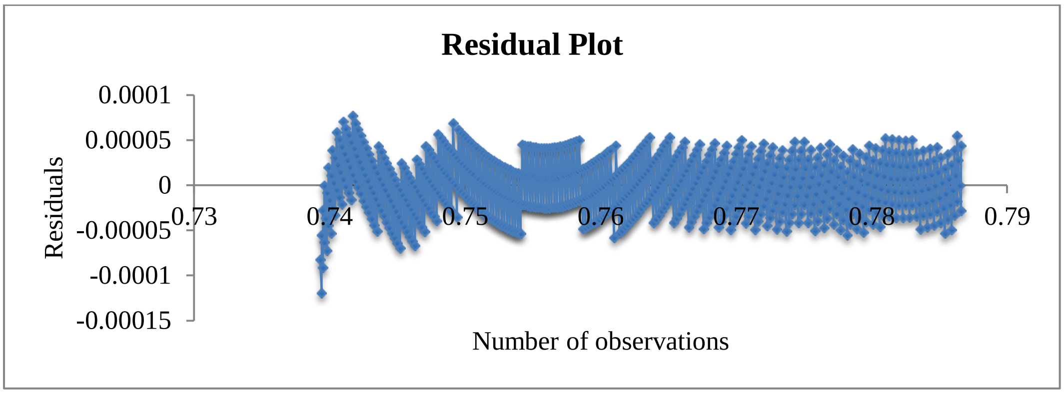


Figure 7.82: Residual plot for α.

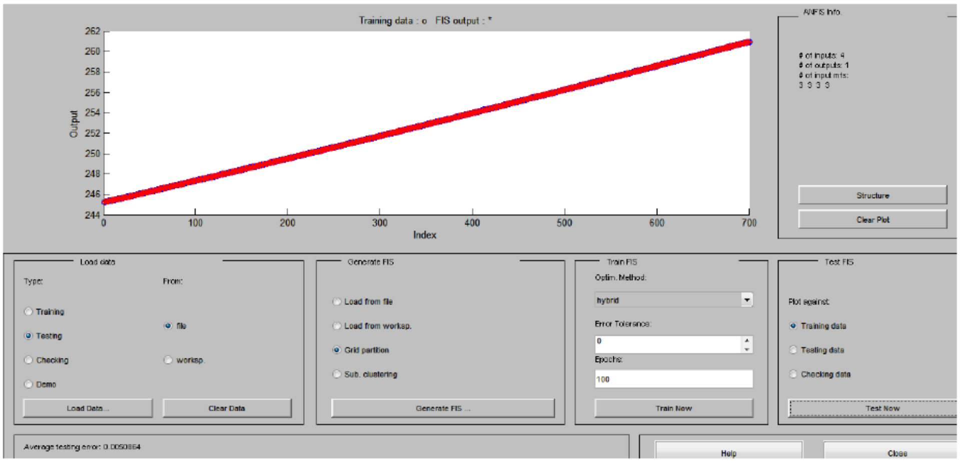


Figure 7.83: Comparison of predicted value and desired value for C_{bavg}.

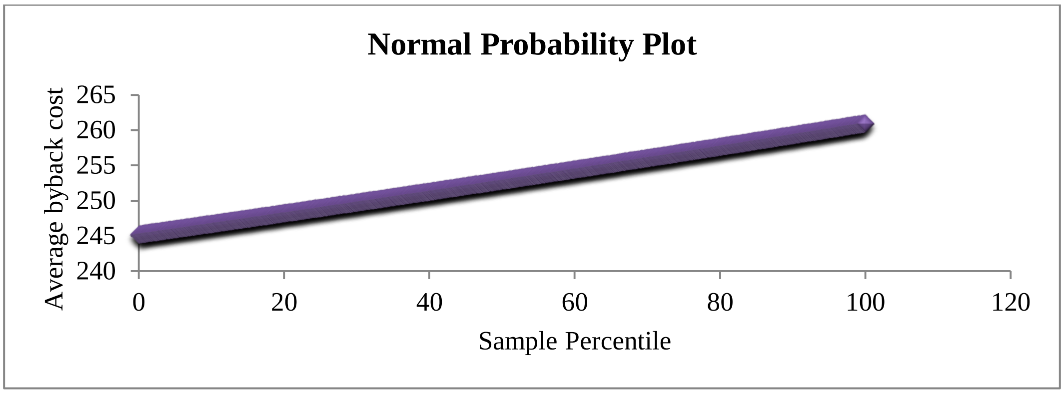


Figure 7.84: Normal probability plot for $C_{bavg.}$

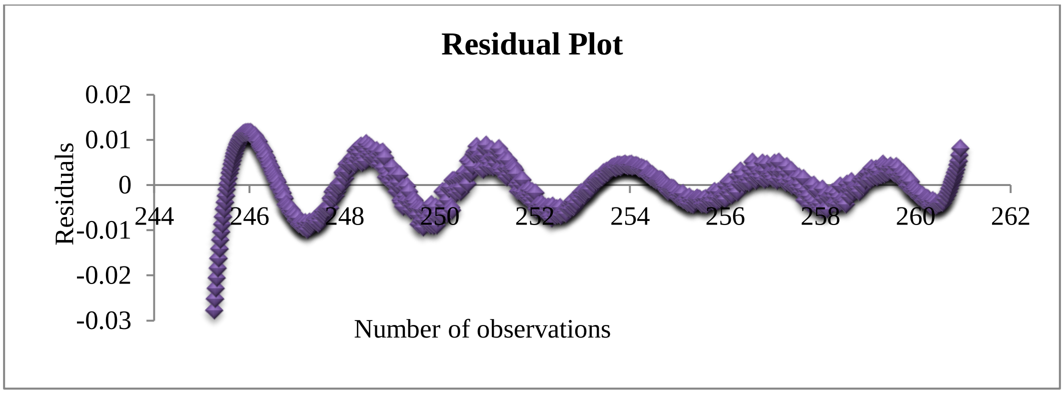


Figure 7.85: Residual plot for $C_{bavg.}$

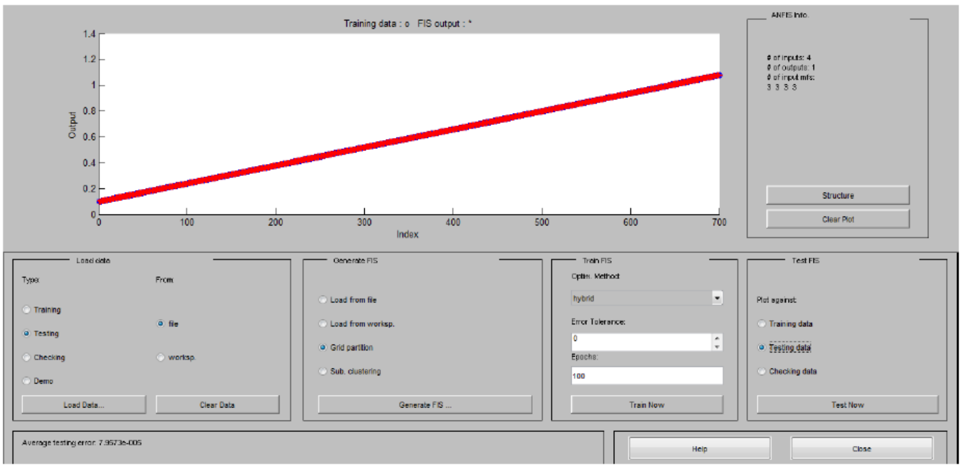


Figure 7.86: Comparison of predicted value and desired value for γ.

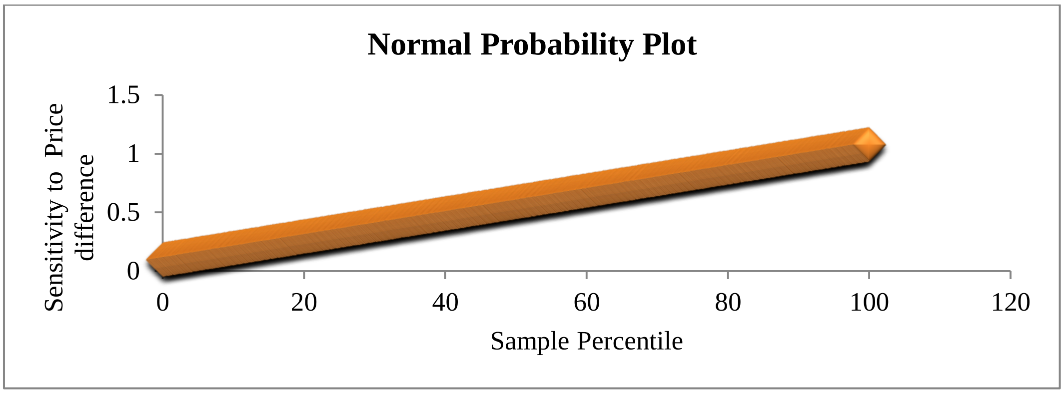


Figure 7.87: Normal probability plot for γ.

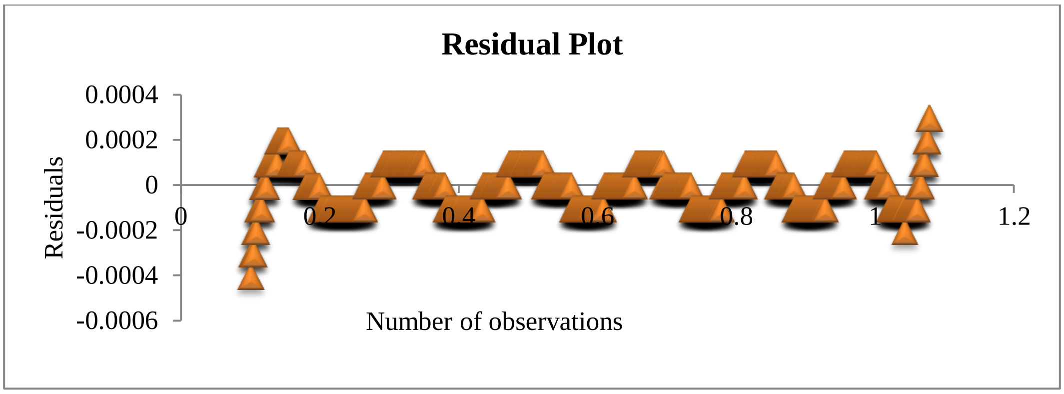


Figure 7.88: Residual plot for γ.

Table 7-22: Comparison of results for case -2 for cartridge manufacturing.

Sl	Output	Average testing error
1	Q_w	0.021445
2	Q_r	0.1107
3	α	1.2248×10^{-005}
4	γ	7.9573×10^{-005}
5	C_{bavg}	0.0050864

The values for Q_r Qw, α, C_{bavg}, and γ are calculated by using the derived formula. One thousand number of data points are calculated in this manner out of which 700 data are taken as the training data for the ANFIS. With the help of the training data, ANFIS predicted a set of data points for all the above mentioned parameters. All the parameter values are compared based on the predicted values and the desired values (calculated) as shown in figure 7.75 through 7.88 with the help of testing errors, normal probability plot and residual plot. The average testing errors are shown in table 7.22.The testing errors are very less indicating the calculated values are in accordance with the predicted values and can be accepted.

7.7 Summary

All the four proposed models for this work are tested with practical data. A through discussion is done on the results obtained. All the results are represented with the help of figures which are supported by data in tabular form. The variation of critical parameters for all the four models are discussed based on the formulae derived in chapter-4 and chapter-5.The outcomes of these results and discussions are summarized in chapter -8 in the form of conclusion which shows the effect of the change of various model variable on the proposed models.

Chapter 8

CONCLUSIONS AND SCOPE FOR FURTHER WORK

8.1 Overview

Today's organizational focus is concentrated on and around the customer satisfaction and organizational sustainability by producing new products. In this regard, much priority is given on the careful use of virgin raw materials. Technological advancement leading to product development and diversification is forcing the manufacturing organizations to use virgin raw materials to increase the product sales for growth and sustainability. On the other hand, as product sales increase, so do product returns, which in tum has initiated a change in the companies' strategy to deal effectively with the return items to get more profit out of that. Hence it has become important to make a proper blending of the forward and reverse supply chains with a view to satisfy the market demand. This in turn will reduce the pressure of using only virgin raw materials rather it helps to support the production flow line with a supplement of remanufactured products which are as good as new products. This particular research is aimed at developing and justifying different models of remanufacturing in the reverse supply chain network that integrates with the forward supply chain to satisfy the market demand. All the discussed models are based on remanufacturing as it makes the output as good as new ones. The model variables are optimized using mathematical models considering the profit maximization. Along with the deterministic models of remanufacturing, this study has additionally discussed the fluctuation of demand and probabilistic approaches have been adopted to deal with it. The results in one of the proposed deterministic models are checked with the predicted value using ANFIS. The work is summarized and concluded along with the statements on contributions made on the present research. The scope for the future work is duly suggested in the present chapter.

8.2 Conclusions

The present work is based on the development of four models of remanufacturing. All the models primarily focus on profit maximization by using the remanufacturing process. The first two of these models are deterministic in nature and next two are probabilistic in nature. These models are,

- Modelling the Reverse Supply Chain with Remanufacturing.
- Modelling the Reverse Supply Chain inventory.
- A probabilistic approach for Reverse Supply Chain model for remanufacturing
- A modified reverse supply chain with remanufacturing for sustainable product Cycle
- Additional to this, the calculated values of the first model is compared with the predicted value using ANFIS.

On analysis of the results of the first model, it is clear that for both cartridge and tire manufacturing industry when the demand rate of the remanufactured product is more than the return rate of the new product after end of use $D_2[D_2 > D_1 D_1\alpha(C_b)]$,There is an increase in the amount of the remanufactured items and decrease in the amount of waste with increase in the value of the sensitivity to price difference (γ). This gives a clear indication to maintain a high value of γ [table 7.1 and 7.7].

Considering the demand rate of the remanufactured product is less than or equals to the return rate of the new product after end of use [$D_2 \leq D_1\alpha(c_b)$],the amount of remanufactured item, returned item and the amount of waste items are increasing with the increase in the γ value for both tire and cartridge industry. The value of γ for the cartridge industry as well as tire manufacturing should be limited to 2 after which the waste quantity increases exponentially which are undesirable [table 7.2 and 7.8].

The optimum value of α (return fraction) should be 0.7 for cartridge manufacturing industry and 0.6 for the tire manufacturing industry.

From the analysis of the results of the second model, it can be concluded that the fraction return should be maintained as high as possible to get less total cost and more profit [table 7.13 and 7.14].This helps in increasing the length of operating cycle and decreases the number of cycles [table 7.15 and 7.16].The use of remanufacturing items increases with a decrease in the direct manufacturing items [table 7.15].

From the analysis of the results of the third model, from table 7.17, it can be concluded that the fraction return should be kept high to reduce the use of virgin raw materials and increase the use of remanufactured items. This helps in reducing the depletion rate of virgin raw material which is an environmental concern. Additionally this helps in reducing the total cost of the plant or the organization.

The result and analysis of the fourth model, it can be concluded that, The ordering cost for new items, the capacity of the remanufactured process, the demand of finished product, the inventory holding cost of the returned items for remanufacturing and the inventory holding cost for the newly manufactured items should be maintained at a low level to have equivalent proportion of remanufactured and newly manufactured products in the production flow line.

Checking out the results obtained from the use of ANFIS, it can be concluded that there is a very little difference between the already calculated values and the predicted value for the first model by ANFIS simulation. Therefore the calculated values can be used to predict the outcome for the first model which is already discussed.

8.3 Limitations

The proposed models are only applicable to those processes where there is a possibility of return and remanufacturing. Although the conclusions are made depending on the results obtained through various theoretical models still there remains a difference between the actual process and the theoretical outcome. The major factor in the proposed models is the fraction return for remanufacturing. This factor varies depending on the type of industry the type of product and therefore it is very difficult to quantify. Neither all the returned items can be remanufactured nor can all the items used by the customers be returned to the plant or organization. Remanufacturing depends on the condition of the returned item as shown in figure 1.8. So the major limitation is 100% remanufacturing is not attainable nor the 100% return. Therefore, one need to set the values of fraction return and intern decides the direct manufacturing quantity and remanufacturing quantity on the type of industry and closely analyzing its return percentage for remanufacturing.

8.4 Contributions

The contribution of the present work is directed towards the environmental benefits. The manufacture of durable goods is one of the major contributors to the GNP of all developed countries. It employs large amounts of human resources, raw materials and energy. The raw materials and energy in the production of durable goods have been continually depleted. Many durable products are disposed in landfills at the end of their useful lives as well. The landfill space has been decreasing and the price charged by the landfills is increasing at a faster rate. This becomes an environmental concern. Remanufacturing, as discussed earlier is one of the predominant product recovery option for the return products. With respect to quality it is considered to be as good as new ones but with a lower cost of conversion. Therefore focusing on remanufacturing option of product recovery not only decreases the depletion rate of virgin raw materials and rate of land fill but also contributes much towards the GNP. The models proposed in this work are simple and can be practically implemented to get benefits from the return items and still satisfying the market demand for sustainable production. The overall contributions with emphasis given to reduction of the use of virgin raw material, reduction of waste, and production with less through put, reduced manufacturing lead time and retaining customers' goodwill are summarized below.

- The use of virgin raw material is of immense concern mainly because of two reasons. The first one is when there is massive usage of virgin raw material because of high product demand and the second one is where there is rare availability of virgin raw materials but the demand is reasonably good. In both these cases the proposed models for remanufacturing can be applied to reduce the depletion rate of virgin raw materials leading to environmental benefit maintaining a sustainable product cycle.
- The reduction of waste can be minimized by using remanufacturing for returned items thereby reducing the cost of land fill and environmental hazards.
- Use of remanufacturing helps to make the product available for market supply with less through put because remanufacturing needs less manufacturing lead time.
- Remanufacturing processes are economically beneficial and helps in maintaining the market lead.
- It helps in retaining the customers' good will for the brand.

- Remanufacturing is helpful in avoiding the stock out condition when the supply of virgin raw material is insufficient to meet the market demand.
- Remanufacturing smoothens the task of scheduling for production planning and control by decoupling the direct manufacturing product inventory

8.5 Scope for further work

This particular work is mainly focusing on the remanufacturing aspect of product recovery options in Reverse supply chain. This should be understood that this is not the only product recovery option available for the returned items. All the products that return may not fall into remanufacturing category. Therefore it is essential to consider the other recovery options as well to get the total benefit from the returned items. Other recovery options can very well be discussed under the same concept as discussed in the present work.

REFERENCES

[1] Christopher, M., (2005), "Logistics and Supply Chain Management-Creating Value-Adding Networks," Prentice Hall/ Financial Times, ISBN: 0273681761, 9780273681762.

[2] Chopra, S., Meindl, P., Kalra, D.V.,(2010), "Supply chain Management strategy, planning and operations",4th edition,pearson,ISBN:978-81-317-3071-3,2010.

[3] Koster,R.B.M.D., Brito,M.P.D., Vendel,M.A.V.D.,(2002),"Return handling: An exploratory study with nine retailer warehouses", International Journal of Retail & Distribution Management,Vol. 30,No.8,pp. 407-421.

[4] Tsay, A.A., Nahmias, S., Agrawal, N., (1999), "Modeling supply chain contracts: A review", Tayur,S., Ganeshan, R., Magazine, M., (Eds.), Quantitative Models for Supply Chain Management, International Series in Operations Research & Management Science Kluwer, Dordrecht,Vol.17, pp. 299–336.

[5] Smith, N.C., Thomas, R.J., Quelch, J.A., (1996). "A strategic approach to manage product recalls", Harvard Business Review, 102–112.

[6] Kroon, L., Vrijens, G., (1995), "Returnable containers: An example of reverse logistics", International Journal of Physical Distribution and logistics management Vol.25, No.2, pp. 56–68.

[7] Duhaime, R., Riopel, D., Langevin, A., (2001), "Value analysis and optimization of reusable containers at Canada Post", Interfaces, Vol. 31, No.3, pp. 3-15.

[8] Andel T., (1997), "Reverse logistics: a second chance to profit whether, through refurbishment or recycling, companies are finding profits in returned products", Transportation &distribution, Vol.38, No.7, pp. 61-64.

[9] Ferguson, N., Browne, J. (2001), "Issues in end-of-life product recovery and reverse logistics", *Production Planning & Control*, Vol. 12 No.5, pp.534-47.

[10] Rogers, D.S., Tibben-Lembke,R.S., (1999), "Going Backwards: Reverse Logistics *Trends and Practices" Pittsburgh: RLEC Press, ISBN 0-9674619-0-1.*

[11] *Bendoly, E., Donohue, K., Schultz, K.L., (2006), "Behavior in operations management: Assessing recent findings and revisiting old assumptions", Journal of Operations Management, Vol. 24, No. 6, pp. 737-52.*

[12] Guiltinan, J.P., Nwokoye, N., (1974), "Reverse channel for recycling: An analysis for alternatives and public policy implications", American Marketing Association Proceedings, No.36, pp. 341-346.

[13] Ginter, P. M., & Starling, J. M. (1978). Reverse distribution channels for recycling. California Management Review, 20(3), 72-81.

[14] Lambert, D.M., Stock, J.R. (1982), "Strategic Physical Distribution Management", Irwin, Homewood, Illinois.

[15] Murphy, P., (1986), "A preliminary study of transportation and warehousing aspects of reverse distribution", Transportation Journal, Vol. 25, No.4, pp. 12–21.

[16] Murphy, P.R. & Poist, R.F. (1989). Management of logistical retro movements: an empirical analysis of literature suggestions. Journal of the Transportations research forum,Vol.29, No.4, pp. 177-184.

[17] Stock J.R., 1992, Reverse Logistics, Council of Logistics Management, Oak Brook, IL.

[18] Rogers, D. S. Tibben-Lembke,R.S.(1999).Going Backwards: Reverse Trends and Practices, Reverse Logistics Executive Council.

[19] Rogers, D. S., Tibben-Lembke, R., (2001). "An Examination of Reverse Logistics Practices." Journal of Business Logistics, Vol. 22, No.2, pp. 129-148.

[20] Fernández, I. (2003). Household waste collection: a case study. LOADO'2003. Proceedings of the Congress.

[21] Krikke, H.R. (1998). "Recovery strategies and reverse logistic network design". [S.l.]: [s.n.].

[22] Fleischmann,M.,Bloemhof-Ruwaard,J.M.,Dekker,R.,Laan,E.V.D.,A.E.E.,J., Wassenhove, L. N. V.,

(1997) “Quantative models for reverse logistics: A review”, European Journal of Operational Research,103,1-17.

[23] Guide, V. D. R., Jayaraman, V., Srivastava, R., & Benton, W. C. (2000). “Supply-chain management for recoverable manufacturing systems”. Interfaces, Vol. 30, No.3, pp. 125–**142.**

[24] Chen, I.J., Paulraj, A.,(2004), “Towards a theory of supply chain management: the constructs and measurement”, Journal of Operations Management Vol. 22, No. 2, pp. 119–150.

[25] Li, S., Rao, S.S., Ragu-Nathan, T.S., Ragu-Nathan.,(2005),“Development and validation of a measurement instrument for studying supply chain management practices”, Journal of Operations Management, vol. 23,No.6,pp 618–641.

[26] Kaynak, H., Hartley, J. L., (2008), “A replication and extension of quality management into the supply chain”, Journal of Operations Management, Vol. 26, No.4, pp 468–489.

[27] Foster Jr, S. T.,(2008),“Towards an understanding of supply chain quality management”, Journal of Operations Management, Vol. 26,No.4,pp. 461–467.

[28] Robinson, C. J., Malhotra, M. K., (2005), “Defining the concept of supply chain quality management and its relevance to academic and industrial practice”, Int. J. Production Economics, Vol. 96, No.3, pp. 315–337.

[29] Adriana, B., (2009,) “Environmental supply chain management in tourism: The case of large tour operators”, Journal of Cleaner Production, Vol. 17, No.16, pp. 1385–1392.

[30] Chow, W. S., Madu, C. N., Kuei, C.H., Lu, M. H., Lind, C., Tseng, H., (2008) , “Supply chain management in the US and Taiwan: An empirical study”, Omega, Vol. 36,No.5,pp. 665 – 679.

[31] Seuring, S., Muller, M. (2008) “From a literature review to a conceptual framework for sustainable supply chain management”, Journal of Cleaner Production, Vol. 16, No.15, pp. 1699–1710.

[32] Carlsson, D., Reonnqvist, M., (2005), “ Supply chain management in forestry—case studies at Sodra Cell AB”, European Journal of Operational Research, Vol. 163,No.3,pp. 589–616.

[33] Hicks, C., McGovern, T., Earl, C.F. (2000), "Supply chain management: A strategic issue in engineer to order manufacturing", Int. J. Production Economics, Vol. 65, No.2, pp. 179-190.

[34] Kim, S. W., (2007), "Organizational structures and the performance of supply chain management", Int. J. Production Economics, Vol. 106, No.2, pp. 323–345.

[35] Grover, V., Malhotra, M. K., (2003), "Transaction cost framework in operations and supply chain management research: theory and measurement", Journal of Operations Management, Vol. 21, No.4, pp. 457–473.

[36] Jung, J. Y., Blau, G., Pekny, J. F., Reklaitis, G. V., Eversdyk, D., (2008) , "Integrated safety stock management for multi-stage supply chains under production capacity constraints", Computers and Chemical Engineering, Vol. 32,No.11,pp. 2570–2581.

[37] Minner, S.,(2003), "Multiple-supplier inventory models in supply chain management: A review", Int. J. Production Economics, Vol. 81–82,pp. 265–279.

[38] Ostlin, J., Sundin, E., Bjorkman, M., (2008), "Importance of closed-loop supply chain relationships for product remanufacturing", Int. J. Production Economics, Vol. 115, No.2, pp. 336– 348.

[39] Ahire, S. L., Dreyfus, P., (2000), "The impact of design management and process management on quality: an empirical investigation", Journal of Operations Management, Vol. 18, No.5, pp.549–575.

[40] Choi, T. Y., Hartley, J. L., (1996), "An exploration of supplier selection practices across the supply chain", Journal of Operations Management, Vol. 14, No.4, pp. 333-343.

[41] Gunasekaran, A., Ngai, E.W.T., (2005), "Build-to-order supply chain management: a literature review and framework for development", Journal of Operations Management, Vol. 23, No.5, pp. 423–451.

[42] Gunasekaran, A., Patel, C., McGaughey, R. E., (2004), "A framework for supply chain performance measurement", Int. J. Production Economics, Vol. 87, No.3, pp. 333–347.

[43] Bhagwat, R., Sharma, M. K., (2007), “Performance measurement of supply chain management: A balanced scorecard approach”, Computers & Industrial Engineering, Vol. 53, No.1, pp. 43–62.

[44] Gupta, S. M., Taleb, K. N., (1994), “Scheduling disassembly”. International Journal of Production Research, Vol.32, No.8, pp. 1857–1866.

[45] Brennan, L., Gupta, S. M., Taleb, K. N., (1994), Operations planning issues in an assembly/disassembly environment. International Journal of Operations and Production Management, Vol.14, No.9, pp. 57–67.

[46] Andel T., (1997), “Reverse logistics: a second chance to profit whether, through refurbishment or recycling, companies are finding profits in returned products”, Transportation &distribution, Vol.38, No.7, pp. 61-64.

[47] Stock J.R., 1992, “Reverse Logistics”, Council of Logistics Management, Oak Brook, IL.

[48] Kopicki R.J., M.J. Berg, L. Legg, V. Dasappa , C. Maggioni,(1993), “Reuse and Recycling: Reverse Logistics Opportunities”, Council of Logistics Management, Oak Brook, IL.

[49] Padmanabhan, V., Png, I.P.L., (1995), “Returns policies: make money by making good”, Sloan Management Review, Vol. 37, No.1, pp.65–72.

[50] Chu, W., (1993), “Demand signaling and screening in channels of distribution”, Marketing Science, Vol. 11, No.4, pp. 327–347.

[51] Chu, W.,(1993), “Demand signaling and screening in channels of distribution”, Marketing Science, Vol. 11,No. 4,pp. 327–347.

[52] Lariviere, M.A., 1999. “Supply chain contracting and coordination with stochastic demand”, Tayur, S., Magazine, M., Ganeshan, R. (Eds.), Quantitative Models for Supply Chain Management. Kluwer Academic Publishers, Dordrecht, (Chapter 8).

[53] Kandel, E., (1996), “The right to return”, Journal of Law Economics, Vol. 39, No.1, pp. 329–355.

[54] Emmons, H., Gilbert, S.M., (1998).”The role of returns policies in pricing and inventory decisions for catalogue goods”, Management Science, Vol. 44, No.2, pp. 276–283.

[55] Donohue, K.L., (1996). “Supply contracts for fashion goods: optimizing channel profits”, University of Minnesota, Working Paper.

[56] Taylor, T.A., (2001), “Channel coordination under price protection, mid-life returns, and end-of-life returns in dynamic markets”, Management Science, Vol. 47, No. 9, pp. 1220–1234.

[57] Tsay, A.A., (1999), “The quantity flexibility contract and supplier–customer incentives”, Management Science, Vol. 45, no.10, pp.1339–1358.

[58] Brown, A.O., Lee, H.L., (1998), “The win–win nature of option based capacity reservation arrangements”. Vanderbilt University, Working Paper.

[59] Webster, S., Weng, Z.K.,(2000), “A risk-free perishable item returns policy”, Manufacturing and Service Operations Management, Vol. 2,No.1,pp. 100–106.

[60] Ferguson, M., Guide Jr., D.V., Souza, G., (2005), “Supply chain coordination for false failure returns”, Working paper, Robert Smith School of Business, University of Maryland.

[61] Ramanathan, R. (2011),"An empirical analysis on the influence of risk on relationships between handling of product returns and customer loyalty in e-commerce", International Journal of Production Economics, Vol.130, No.2, pp. 255-261.

[62] Choi, T. M., Li, D., Yan, H. (2004), “Optimal returns policy for supply chain with e-marketplace”, Int. J. Production Economics, Vol.88, pp.205-227.

[63] Guiltinan, J.P., Nwokoye, N.G. (1975), “Developing distribution channels and systems in the emerging recycling industries”, International Journal of Physical Distribution, Vol. 6, No. 1, pp. 28-38.

[64] Pohlen, T. L., Farris, M.T., (1992), “Reverse logistics in plastic recycling”, International Journal of Physical Distribution & Logistics Management, Vol. 22, No. 7, pp. 35-47.

[65] Jahre, M. (1995b), “Logistics Systems for Recycling – Efficient Collection of Household Waste”, Chalmers University of Technology, Gothenburg.

[66] Mirchandani, P.B., Francis, R.L., editors, (1989),"Discrete Location Theory", John Wiley and sons, New York.

[67] Ginter, P. M., Starling, J. M., (1978), "California Management Review", Vol. 20, No. 3, pp.72.

[68] Batta, R., Chiu, S.S., (1988), "Optimal obnoxious paths on a network: Transportation of hazardous materials". Operations Research, Vol. 36, No.1, pp.84-92.

[69] Erkut, E., (1996), "The road not taken", ORMS Today, Vol.23, No.6, pp. 22-28.

[70] Castillo, D. E., Cochran, J.K. (1996), "Optimal short horizon distribution operations in reusable container systems", Journal of the Operational Research Society, Vol.47, No.1, pp.48-60.

[71] Dobos, I., (2002), "The generalization of schardy's model: with repair", Budapest university of economics and public administration, veres palne U. 36, H-1053, Budapest, Hungary.

[72] Qiushuang, Z., Nengmin, W., (2008) "Decision for Remanufacturing of Dynamic Lot Sizing Problem with limited inventory." Proceedings of the 27th Chinese Control Conference. Pp.784-788.

[73] Silver, E. A., "INVENTORY MANAGEMENT: A TUTORIAL CANADIAN PUBLICATIONS, PRACTICAL APPLICATIONS AND SUGGESTIONS FOR FUTURE RESEARCH", Haskayne School of Business University of Calgary 2500 University Drive N.W. Calgary, Alberta, CANADA T2N 1N4.

[74] Alfares, H. K., "Inventory model with stock-level dependent demand rate and variable holding cost",(2007),International Journal of Production Economics,Vol.108,No.1-2,pp.259-265.

[75] Chung, S.L., Wee, H.M., Yang, P.C., (2008), "Optimal policy for a closed-loop supply chain inventory system with remanufacturing." Mathematical and Computer Modelling, Vol. 48, No. 5-6, pp.867-881.

[76] Mahadevan, B., Pyke, D. F., Fleischmann, M., (2003) "Periodic review, push inventory policies for remanufacturing", European journal of operational research, Vol.151, No.3, pp. 536-551.

[77] Verstrepen, S., Cruijssen, F., Brito, M. P. d., Dullaert , W., (2007), "An Exploratory Analysis of Reverse Logistics in Flanders" European Journal of Transport and Infrastructure Research, Vol. 7, No. 4, pp. 301-316

[78] Dobos, I., Richter, K., (2003), "An extended production/recycling model with stationary demand and return rates", International Journal of Production Economics, Vol. 90, No.3, pp.311–323.

[79] Teunter, R. H., Vlachos, D., (2002), "On the necessity of a disposal option for returned items that can be remanufactured", International Journal of Production Economics, Vol. 75, No.3, pp. 257-266.

[80] Oh, Y. H., Hwang H., (2006), "Deterministic inventory model for recycling system" Journal of Intelligent Manufacturing, Vol. 17, pp.423–428.

[81] Koh, S.G., Hwang, H., Sohn, K. I., Ko, C. S., (2002), "An optimal ordering and recovery policy for reusable items", Computers and Industrial Engineering, Vol.43, pp.59–73.

[82] Mabini, M. C., Pintelon, L. M., Gelders, L. F. (1992). "EOQ type formulation for controlling repairable inventories", International Journal of Production Economics, Vol.28, pp.21–33.

[83] Richter, K., (1996a). "The EOQ repair and waste disposal model with variable setup numbers", European Journal of Operational Research, Vol.95, No.2, pp. 313–324.

[84] Richter, K., (1996b), "The extended EOQ repair and waste disposal model", International Journal of Production Economics, Vol.45, pp.443–447.

[85] Therry, M. C., Salomon, M., van Numen, J. A. E. E., Van Wassenhove, L. N. (1995). "Strategic issues in product recovery management" California Management Review, Vol.37, No.2, pp. 114–135.

[86] Teunter, R., Laan, E. v. d., (2002)," On the non-optimality of the average cost approach for inventory models with remanufacturing", International Journal of Production Economics, Vol. 79, pp. 67-73.

[87] Richter, K., Sombrutzki, M., (2000), "Remanufacturing planning for the reverse Wagner/Whitin models", European Journal of Operational Research, Vol.121, pp. 304-315.

[88] Chung, S.L., Wee, H.M., Yang, P.C., (2008), "Optimal policy for a closed-loop supply chain inventory system with remanufacturing", Mathematical and Computer Modelling, Vol. 48, pp. 867–881.

[89] Simpson, V.P., (1978), "Optimum solution structure for a repairable inventory problem", Operations Research, Vol. 26, No.2, pp. 270 281.

[90] lnderfurth, K., (1996), Modeling period review control for a stochastic product recovery problem with remanufacturing and procurement lead-times", Working paper 2/96. Faculty of Economics and Management, University of Magdeburg, Germany.

[91] Buchanan, D.J., Abad, P.L., (1998), "Optimal policy for a periodic review returnable inventory system", IIE Transactions, Vol.30, No.11, pp.1049-1055.

[92] Toktay, B., Wein, L., Stefanos, Z., (2000), "Inventory management of remanufacturable products", Management Science, Vol. 46, No.11, pp.1412–1426.

[93] Kiesmuller, G. P., Laan E. A. V.,(2001), "An inventory model with dependent product demands and returns", International Journal of Production Economics, vol. 72, no. 1, pp. 73-87,

[94] Vlachos, D., Dekker, R., (2003), "Return handling options and order quantities for single period products", European Journal of Operational Research, Vol.151, No.1, pp.38-52.

[95] Mostard,J., Koster, R. d., Teunter, R.,(2005,) "The distribution-free newsboy problem with resalable returns", International Journal of Production Economics, Vol. 97, No. 3, pp. 329-342.

[96] Heyman, D.P., (1977), "Optimal disposal policies for a single-item inventory system with returns", Naval Research Logistics Quarterly, Vol. 24, No.3, pp. 385-405.

[97] Muckstadt, J.A., Isaac, M.H., (1981), "An analysis of single item inventory systems with returns", Naval Research Logistics Quarterly, Vol. 28, No.2, pp. 237-254.

[98] Laan E. A. V., Dekker, R., Salomon, M., (1996), "An (s, Q) inventory model with remanufacturing and disposal, International Journal of Production Economics, Vol.46, No.7, pp.339-350.

[99] Fleischmann, M., Krikke, H. R., Dekker, R., Flapper, S. D. P., (2000), "A characterisation of logistics networks for product recovery", Omega, Vol.28, No.6, pp. 653-666.

[100] Yuan, X. M., Cheung, K. L., (1998), "Modeling returns of merchandise in an inventory system", Operations-Research-Spektrum, Vol. 20, No. 3, pp. 147-154.

[101] Bayindir, Z.P., Erkip, N., Gullu, R., (2003), "A model to evaluate inventory costs in a remanufacturing environment", International Journal of Production Economics, Vol. 81-82, pp.597–607.

[102] Laan, E.V.D., (2003), "An NPV and AC analysis of a stochastic inventory system with joint manufacturing and remanufacturing", International Journal of Production Economics, Vol.81-82, pp.317-331.

[103] Fleischmann, M., Ruwaard, J.M.B., Dekker, R., Laan, Laan. E.V.D., Nunen, J.A.E.E.V. Wassenhove, L.N.V., (1997),"Quantitative models for reverse logistics: A review", European Journal of Operational Research, Vol.103, No.1, pp.1-17.

[104] Zhang, M., Bell, P. C., (2007), "The effect of market segmentation with demand leakage between market segments on a firm's price and inventory decisions", European Journal of Operational Research, Vol. 182, No.2, pp.738–754.

[105] Jung, K.S., Hwang, H. (2011), "Competition and cooperation in a remanufacturing system with take-back requirement", Journal of Intelligent Manufacturing, Vol.22, No.3, pp.427-433.

[106] Pellerin, R., Sadr, J., Gharbi, A., Malhame, R., (2009), "A production rate control policy for stochastic repair and remanufacturing systems", International Journal of Production Economics, Vol. 121, No.1, pp. 39–48.

[107] Sundin, E., Bras, B., (2005) "Making functional sales environmentally and economically beneficial through product remanufacturing", Journal of Cleaner Production, Vol. 13, No.9, pp. 913-925.

[108] Subramoniam, R., Huisingh, D., Chinnam, R. B., (2009), "Remanufacturing for the automotive aftermarket-strategic factors: literature review and future research needs", Journal of Cleaner Production, Vol. 17, No.13, pp. 1163–1174.

[109] Kim, K., Song, I., Kim, J., Jeong, B., (2006), “Supply planning model for remanufacturing system in reverse logistics environment”, Computers & Industrial Engineering, Vol. 51, No.2, pp. 279–287.

[110] Franke, C., Basdere, B., Ciupek, M., Seliger, S., (2006), “Remanufacturing of mobile phones—capacity, program and facility adaptation planning”, Omega, Vol. 34, No.6, pp. 562 – 570.

[111] Schneeweiss, C., (2003), “Distributed decision making in supply chain management”, International Journal of Production Economics, Vol.84, No.1, pp. 71–83.

[112] Wei, J., Zhao, J., (2012), “Reverse channel decisions for a fuzzy closed-loop supply chain” Applied mathematical Modelling, Vol. 37, pp. 1502-1513.

[113] Amin, S. H., Zhang, G., (2013), “A multi-objective facility location model for closed-loop supply chain network under uncertain demand and return”, Applied mathematical Modelling, Vol. 37, pp. 4165-4176.

[114] Kannan, G., (2009), “Fuzzy approach for selection of third party reverse logistics provider”, Asia Pacific Journal of Marketing and Logistics, Vol. 21, No. 3, pp. 397-416.

[115] Maity,A. K., Maity, K., Maity, M.,(2008), “A production–recycling–inventory system with imprecise holding costs”, Applied Mathematical Modelling, Vol. 32, pp. 2241-2253.

[116] Efendigil,T.,Onut,S., Kahraman, C., (2009), “A decision support system for demand forecasting with artificial neural networks and neuro fuzzy models: A comparative analysis”, Expert Systems with Applications, Vol. 36, pp. 6697-6707.

[117] Efendigil,T., Onut, S., (2012), “An integration methodology based on fuzzy inference systems and neural approaches for multi-stage supply-chains”, Computers & Industrial Engineering, Vol. 62,No. 2, pp. 554-569.

[118] Tang, O., Grubbstro¨m, R. W.,(2005),“Considering stochastic lead times in a manufacturing/ remanufacturing system with deterministic demands and returns”, Int. J. Production Economics, Vol. 93-94, pp.285-300.

[119] Sudin, E.,(2001), “An economical and technical analysis of a household appliance remanufacturing process”, Environmentally Conscious Design

and Inverse Manufacturing, Proceedings Eco Design 2001: Second International Symposium on Geoscience; Power, Energy, & Industry Applications, pp.536-541.

[120] Poles, R., Cheong, F.,(2009), "Inventory Control in Closed Loop Supply Chain using System Dynamics", The 27th International System Dynamics Conference,27-31July Albuquerque, New Mexico, USA.

[121] Pan, Z., Tang, J., Ou, L., (2009), "Capacitated dynamic lot sizing problems in closed-loop supply chain", European Journal of Operational Research, Vol. 198,pp. 810–821.

[122] Mabee,D.G.,Bommer,M.(1995), "Design charts for remanufacturing assessment", Journal manufacturing systems, Vol.18,No.5,

[123] Christopher, M., Towill, D. R., (2000). "Supply chain migration from lean and functional to agile and customized", International journal of Supply Chain Management, Vol. 5, No.4, pp. 206-213.

[124] Ismail, H.S., Sharif, H., (2006). "A balanced approach to building agile supply chains" International Journal of Physical Distribution and Logistics Management, Vol 36, No. 6, pp. 431-444

[125] Ross, T. J., (2004). Fuzzy Logic with Engineering Applications. SecondEdition. John Wiley and Sons Ltd. The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England.

[126] Spekman, R. E. Kamau Jr., J. W., Myhr. N. (1998), "An empirical investigation into supply chain management, A perspective on partnerships", International Journal of Physical Distribution and Logistics Management, Vol.28, No. 8, pp. 630-650.

[127] Zhang, Z., Ding, D., Rao, L., Bi, Z., (2006), An ANFIS based approach for predicting the ultimate bearing capacity of single piles. Proceedings of Foundation Analysis and Design,pp. 159-166.

CURRICULUM VITAE

National Institute of Technology
Rourkela, Odisha, India

Personal Details:

Name	**: RABINDRA NARAYAN MAHAPATRA**
Father's Name	**: Rama Narayan Mahapatra**
Date of Birth	**: 25.11.1966.**
Fields of Interest	**: Production Management, Supply chain, FMS.**

Phone : +91 9861014982**, E-mail : rnm26@rediffmail.com**

Academic Qualification:

2013	Ph.D. Dissertation submitted at NIT, Rourkela.
2003	M.E. (Mech. Engg.) from VSSUT (former UCE), Burla,
1992	B.Tech (Prod. Engg.), COE, Osmanabad, Maharastra
!983	Intermediate Science, UU, Odisha
1981	Matriculation, BSE, Odisha

Work Experience:

October 1992 to December 2005:	Lecturer	OEC, Bhubanesdwar.
December 2005 to July 2009 :	Asst. Professor	SIT,Bhubaneswar.
July 2009 to till date :	Associate Professor	ITER,Bhubaneswar

Rabindra Narayan Mahapatra

List of Publications

1. R. N. Mahapatra, B. B Biswal, R. P. Mohanty (2013), "A modified reverse supply chain with remanufacturing for sustainable product Cycle", International Journal of Supply Chain Management,Vol.2,No.2.
2. R. N. Mahapatra, B. B. Biswal, P. K. Parida, "A Modified Deterministic Model for Reverse Supply Chain in Manufacturing", Journal of Industrial Engineering , Hindawi Publishing Corporation,Vol.2013.
3. R. N. Mahapatra, B. B Biswal, R. P. Mohanty, (2012), "A modified reverse supply chain with remanufacturing for sustainable product Cycle", International conference on Best Practices In Supply Chain Management", Oct 22-23, SOAU, Bhubaneswar.
4. R. N. Mahapatra, B. B. Biswal, P. K. Parida,(2012), "A Modified Deterministic Reverse Supply Chain Model for Increasing Productivity and Market Share", International conference on Best Practices In Supply Chain Management", Oct 22-23,SOAU,Bhubaneswar.
5. R. N. Mahapatra, B. B. Biswal, "A deterministic approach for remanufacturing inventory for reverse supply chain" published in the Proceedings of the National Conference on Emerging Trend and its Application in Engineering (NCETAE-2011), December 26-28, 2011, held at Indira Gandhi Institute of Technology (IGIT), Saranga, Odisha , India.
6. R. N. Mahapatra, B. B. Biswal, (2011),"Modeling for the Optimization of Closed-loop Supply Chain with Remanufacturing", International conference on Uncertainty Management, Jan 22-24.