SOME INVESTIGATIONS ON MULTI-COMMODITY REVERSE LOGISTICS NETWORK MODELLING

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BY

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DECLARATION

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ABSTRACT

The efficient design of a product recovery network is one of the challenging issues in the recently emerged field of reverse logistics (RL). RL process forms a part of a company's total supply chain and it includes number of recovery options viz., Remanufacturing, Recycling, Refurbishing, Reuse, and Disposal. Of late, RL is gaining more importance due to the newer and stricter environmental regulations.

One of the important means for organizations to differentiate themselves, as well as to increase profitability, in highly competitive environments, is the use of service management.

In the context mentioned, Reverse Logistics Repair Service (RLRS) can be viewed as all of the activities required to move a commodity from point of use to point of reclamation and redistribution. Such a RLRS is characterized by, uncertainty in supplies, customer requirements, value recovery, multi-party coordination and lack of flexibility. That is, RL is always tied with inherent uncertainties and the recovery options pose many challenges to the practioners and researches alike.

Reverse Logistics Networking (RLN) is "the simultaneous coordination of various Reverse Logistics activities or processes to recover the value and to dispose the returns, starting from the end users back to the manufactures". The key benefits of RLNs are improved control and asset recovery, better information and supply chain visibility – full tracking to ensure accurate information, income generation, efficient route planning – returns collections matched with outbound deliveries.

Most of the cited works in modelling deal with single product or commodity. Only a few studies have addressed the problem of flow of multi-commodities from return centers. In practical RL problems, especially in RLRS problems, dealing with more than one type of returned commodities is a norm rather than an exception.

Besides the multi-commodities nature of RLRS networks, another normal feature is the recovery of the returned commodity value in more than one stage or in other words multi-stages.

These two common, yet important features have not been taken up or analyzed in the earlier works, and there is a need to study, analyze and model such features also in RLNs. This would help the RLRS practioners in a great way.

The objectives of the present research are,

- i. **To form the framework for the multi-commodity Reverse Logistics Network**
- ii. **Formulate models for**
    - a) **Single-Level Multi-commodity Reverse Logistics Network**
    - b) **Multi -Level Multi-commodity Reverse Logistics Network**
    - c) **Single-Level Multi-commodity Reverse Logistics Network with quality variations**
    - d) **Multi-Level Multi-commodity Reverse Logistics Network with quality variations.**
- iii. **Solutions to the above models using simulation technique.**
- iv. **Applying GA to understand the effective commodity flow control.**
- v. **Energy conservation measures through vehicle routing approach.**

For the objectives mentioned above, models have been formulated in multi-commodity environment. For proper modelling of RLRS, **a new framework for multi-commodity RL Network has been formed in this current investigation.** The frame works give the step-by-step activities to be performed while operating the networks.

Single-Level Multi-commodity RL Network model, (SLMCRLN) has been addressed with objective of minimizing the overall operating cost involved in the repair service of multiple commodities, which flow into the service facility randomly. Through simulation studies, the quantity of flow of commodities to the service facilities for effective operation has been identified. For a known supply of commodities from the disposer market, i.e., the yearly returns of multi-commodities, the model helps in arriving at the efficient way of handling the return flows.

Multi -level multi-commodity Reverse Logistics Network, (MLMCRLN) model addressed the practical aspects of network that deals with variety of returns which require services at multiple levels to attain some market value. The modeling has been analyzed with the twin objectives of achieving maximum profit and customer satisfaction.

In order to handle the different quality levels of the returns (which may require different repair services), in multi-commodity environment, a new method in the RL context is proposed to consider the inherent quality variations in the returned products through a random variation approach. This method provides a basis for assessing the status of the commodities in the reverse flow and to take a decision on the repair service activities that can be made available. This treatment considers the differential cost structures for the repair service process as they logically dependent on the status of the commodity.

It is found that the proposed approach(s) reduced or eliminates some of the inaccuracies involved in arriving at the characterization of the networks, which would lead to the design, and evaluation of the networks, which is closer to the reality in both levels.

The solutions to the above said models are obtained by simulation approach, with the application of real data of a manufacturer repair service facility. The simulation results helps,

i. In taking a decision on how the reverse flow of the commodities can be handled by channelizing them suitably either to the first or the second repair service facility.

ii. To understand the problem of reverse flow of defective commodities to the repair service facilities.

iii. In planning for number of repair service facilities at the given capacities to reap maximum profit from the facilitators’ perspective.

iv. Gives an opportunity to increase the customer satisfaction.

Optimization of the settings for the flow of multiple commodities to the existing repair service facilities has also been done using Genetic Algorithm approach and the results are compared with the simulated results. The results show that the proposed algorithm is a simpler one and the optimal solution for different settings of commodity flows could be obtained in lesser computational time compared to the conventional simulation approach.

To account for the energy usage by the transportation of multi-commodities into repair service facilities, a mathematical model has been built to arrive at characterization of vehicle routing in the Multi-Commodity RL Network. The model resulted optimal routes through optimization. The minimization of the distance travelled by the truck fleet reduced the energy consumption by the trucks. This work is an attempt towards addressing the mentioned issue by way of introducing the concept of energy conservation in RL network with ever increasing reverse flows.

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NOMENCLATURE

dc_{ij}	Unit disposal cost of commodity “i” at facility “j”,
P_{ik}^{u}	Unit penalty cost for not satisfied demand of reuse market “k” (Rs),
P_{ik}^{w}	Unit penalty cost for not collecting the returns from the disposer Market “k” (Rs),
μ	Average repair service rate,
B_i	Bit Length,
$B_{ij}(q)$	Boolean indicating whether facility “j” for commodity “i” is installed at capacity level *q (*value = 1*)* or not *(*value = 0*)*,
c	Number of servers in the repair service facility,
C_{ij}	Flow of commodity “i” to the repair service facility “j”,
$C_{ij}(q)$	Total no of commodities repair serviced at facility “j” at installed capacity “q” (level I),
C_{ijk}	Commodity “i” flows from repair service facility “j” at level I to reuse market “k”,
C_{ijr}	Commodity “i” flow from facility at level I to level II,
C_{ikj}	Commodity “i” flow from disposer market to repair service facility,
$C_{ir}(q)$	Total no of commodity repair serviced at facility “r” at installed capacity “q” (level II),
C_{irk}	Commodity “i” flows from repair service facility “r” at level II to reuse market “k”,
Com.	Commodity
dc_{ij}	Disposal Cost of commodity “i” flows from repair service facility “j” (Rs.),
D_{ik}	Yearly Demand of commodity “i” at reuse market “k”,
Dij	Yearly demand of commodity “i” at repair service facility “j”,
$E(N)_{ij}$	Expected number of commodities in the facility (Level I) (Nos.),
$E(N)_{ir}$	Expected number of commodities in the facility (Level II) (Nos.),
$E(Q)_{ij}$	Expected waiting time of the individual commodity in the queue,
$F_{ij}(q)$	Fixed cost to open a facility “j” at capacity level “q” for commodity “i”,

$F_{ir}(q)$	Fixed cost to open a facility “r” at level II with capacity “q” for commodity “i”,
FL	Forward Logistics,
GA	Genetic Algorithm,
H_{ij}	Unit holding cost per year at facility “j” (level I),
H_{ir}	Unit holding cost per year at facility “r” (level II),
Hrs	Hours,
I	Index: Number of commodities i; (i=1,2,3…..I max),
i	Number of customers (vehicle routing),
J	Index: Number of repair service facilities j; j=1,2,3…..n),
j	Repair Service Facility,
K	Number of customer locations k; k=1,2,3…..n),
Km	Kilometer,
KWh	Kilo Watt hour,
L1	Level 1,
L2	Level 2,
$M_{ij}(q)$	Maximum capacity level (q) service facility “j”,
Min	Minutes,
M_{k1} & M_{k2}	Disposer Markets,
M_{k3} & M_{k4}	Reuse Markets,
M_{ij} (q)	Maximum capacity level (q),
MLMCF	Multi Level Multi Commodity Flow,
MLSCF	Multi Level Single Commodity Flow,
N	Number of customers or truck Stops,
Nos	Numbers,
P_{ik}	Selling price of the commodity “i” flows from “j” at level I to reuse market “k”,
q	Capacity of the repair service facility,
Q	Capacity of the vehicle (in terns of Nos.),
r	Repair service facility at level II,
REV	Revenue,
R_i	Resolution,
R_{ik}	Represents the yearly returns from disposer customer “k”,

$R_{ij}(q)$	Unit repair service cost of commodity “i” flow at facility “j” operating at capacity “q” (at level I),
R_{ik}	Yearly returns from disposer customer “k”,
$R_{ir}(q)$	Unit repair service cost of commodity “i” flow at facility “r” operating at capacity “q” (at level II),
RL	Reverse Logistics,
RLRS	Reverse Logistics Repair Service,
Rs	Indian National Rupees (INR),
RSRL	Repair Service Reverse Logistics,
RVM	Randomized Variation Method,
SLMCF	Single Level Multi Commodities Flow,
SLSCF	Single Level Single Commodity Flow,
t	Average repair service time (Sec),
T	Set of customers (in vehicle routing),
T_{ijr}	Unit transportation cost between the facilities at level I and level II,
T_{ikj}	Unit transportation cost between disposer market and repair service facility “j”,
u_{ik}	Fraction of demand not satisfied at reuse market “k” for commodity “i”,
w_{ik}	Fraction of returns not collected from the disposer market “k”,
X	variable factor in Genetic Algorithm,
Y	fixed factor in Genetic Algorithm,
yr	Yearly returns (Nos.),
yr_{ik}	Yearly returns of commodity “i” from disposer market “k”,
λ	Average arrival rate ,
ρ	Effective utilization level.

CHAPTER 1
INTRODUCTION

1.1 Introduction to Reverse Logistics

Reverse Logistics (RL) is an important issue in the context of Supply Chain Management. It has been attracting, of late, the attention of industrialists and academicians, because of its potential for significant value addition. The basic concept behind RL is "the process of planning, implementing, and controlling the efficient and cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin, for the purpose of recapturing value or proper disposal" **(Rogers and Lembke, 1999)**. In RL, the origin and destination of flow of materials and information are reversed when compared to the usual forward logistics.

Though the idea of RL has been in the vogue for long, the naming is difficult to trace with exactness. Systematically related with recycling, terms like Reverse Channels or Reverse flow started emerging in the scientific literature of the seventies **(Guiltinan and Nwokoye, 1974)**. During eighties, movements of reverse flows inspired different definitions, as against the traditional flows, in supply chain. **Lambert et al. (1981)** put it as the process that goes the wrong way on a one-way street because the great majority of product shipments flow in one direction.

In the early nineties a formal definition of RL was put together by the **Council of Logistics Management.** It states the term, Reverse Logistics, is often used to refer to the role of logistics in recycling, waste disposal, and management of hazardous materials; a broader perspective includes all issues relating to logistics activities to be carried out in source reduction, recycling, substitution, reuse of materials and disposal". **Pohlen and Farris, (1992)** defined RL, as "...the movement of goods from a consumer towards a producer in a channel of distribution, and brought out the dominant characteristics of direction in a distribution channel. **Carter and Ellram, (1998)** kept the concept linked to environmental purposes, as "the process whereby companies can become environmentally efficient through recycling, reusing, and reducing the amount of materials used".

Dowlatshali, (2000) defined RL as “a process in which a manufacturer systematically accepts previously shipped products or parts from the point of consumption for possible recycling, remanufacturing or disposal”. **Guide et al. (2000)** defined RL as “the task of recovering discarded products: it may include packaging and shipping materials and back hawling them to a central collection point for either recycling or remanufacturing”.

Lourenco and Soto, (2002) put RL as “a new concept that deals with the management of the products in the reverse way i.e., it is the process of managing all the flow of returned products and information from the point of consumption to the origin”. **Chouinard et al. (2005)** put RL “as the activities referred to the recovery and processing of unused products and to the redistribution of reusable materials”**.**

Another important aspect of RL, which is missed by most of the definitions, is related to repair service. This aspect of RL can conveniently be used to differentiate an organization from others in this highly competitive market environment. This can otherwise be called as service management, i.e. those activities and interactions that follow a product's sale. The existence, effectiveness, and efficiency of service management activities, such as repair services, heavily depend on the effective RL operations. This approach paves the way for increased profitability of the business activities.

In the context mentioned, Reverse Logistics Repair Service (RSRL) can be viewed as all of the activities required to move a commodity from the point of use to the point of reclamation and redistribution. RSRL has the unique characteristics of uncertainty in supplies, customer requirements, an value recovery. Multi-party coordination and lack of flexibility are other dominant characteristics.

A close and careful attention towards the RL definitions results in few important elements and these contribute to different possibilities of RL processes **(Juan Pablo Soto, 2002)**. They are what RL is, the inputs, tasks or activities, outputs or consequences, and the starting and ending point of RL processes. Table 1.1 shows the different possibilities of RL processes.

The first point to be considered, is the way in which the authors define **what RL is?** Some authors define RL as a task or a set of logistics management skills and activities, but most of them defined it as a **process**. A process is more general in its concept and incorporates tasks and activities to reach a specific objective.

Table 1.1 Reverse Logistics Possibilities

(Source: Lourenco and Soto, 2002)

What is?	Inputs	Activities	Output	From	To
Process • Task • Skills and Activities	• Discarded products. • Used products. • Products or parts previously shipped. • Packages and from hazardous and non-hazardous waste. • Information • Raw materials • In process inventory • Finished goods • Related Information	• Planning, Implementing Controlling an efficient and cost effective flow. • Collection •Transportation • Storage • Processing • Acceptation • Recovering • Packaging • Shipping • Reducing • Managing • Disposing • Disassembly • Inventories • Production	• Products Again reusable • Recycling • Re-Manufacturing • Disposal • Reducing • Managing • Recapturing value	•Point of Consumption	•Manufacturer •Central Collection Point. •Point of origin.

The second one is about **the inputs** that the RL process uses to perform its activities. Almost all of the authors agree that the inputs are basically used products, discarded products or parts previously shipped, hazardous and non-hazardous waste from the products, information, raw materials, in process inventory, and finished goods. These inputs identify the scope of the RL process. Some authors limit the input to only waste or recycled products, but others allow a wider concept where information, raw materials, inventories and goods are managed through the RL system

Third element to be considered is the **task or activities** involved in the RL process. In other words, after the inputs are introduced in reverse flow, what is happening? The tasks/activities are similar to the activities performed in the forward logistics, with some additional activities. An important point to be sited here is the inherent uncertainty (frequency of the RL activities, the quality, quantity and timing of the products returned) involved in RL activities.

To summarize, the RL tasks or activities involve,

- Planning, implementing and controlling an efficient and cost effective flow of products and
- Collection, transportation, recovery, storage, process, acceptance, reduction, management, disposal, and shipment of products.

These activities are the same activities, which are performed in Forward Logistics. But, how they are performed in Forward and Reverse logistics differ totally.

The fourth point to be considered is the **outputs or consequences** of the RL process. The authors argue that, the objectives of RL consist of reusing, recycling, remanufacturing, disposal, reducing, and recapturing the value of the “inputs”.

The last two elements to be considered are the starting and ending point of the RL process. All authors converge in the point that RL process starts from the point of consumption, which include distributors, retailers and consumers, and ends (destination) with the manufacturer or, a central collection point or, the point of origin of the new product.

Different authors use different terms, reverse flow logistics, reverse distribution, RL, reverse supply chain, closed loop supply chain systems and supply loops to describe the same activity, or parts of it. The key element in all definitions and discussions of RL is the movement of logistics materials (that includes both products as well as packaging materials) from one location to another after its intended utility is fully or partly consumed.

1.1.1 Difference between Forward Logistics and Reverse Logistics

RL sometimes also called as “logistics backward’, because in RL, the flow of goods is just opposite to the flow in the conventional supply chain. Whereas the forward flow of goods runs from the manufacturer, distributors, retailer o the consumer, RL deals with all the flows of goods and information that are necessary to collect used products from the users/customers and bring them to places where they can be reused, remanufactured, recycled and redistributed or disposed of properly. Figure 1.1 shows the flow of goods in the forward Logistics (FL) and RL.

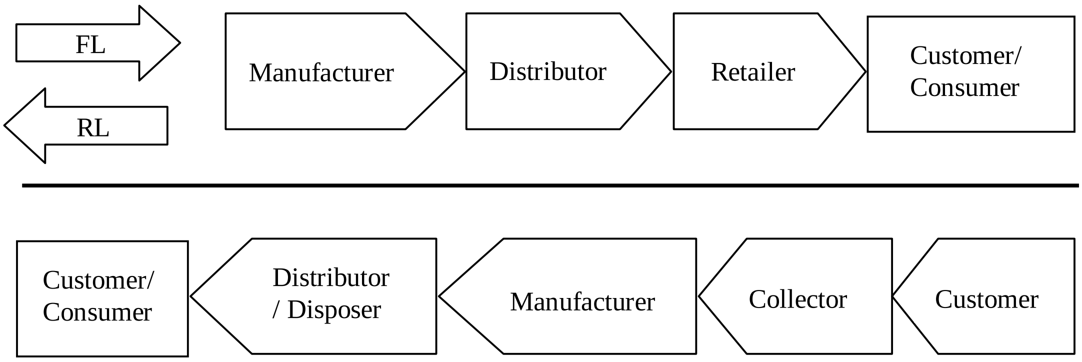

Figure 1.1 Flow of goods in Forward and Reverse Logistics

The relation between various processes involved in Forward Logistics and RL are manifold. Suppliers and manufacturers can use Recycled materials as secondary materials and/or it can be used as a substitute for new products by the retailers and customers. The material, which has no secondary use or money value, can be disposed off. Table 1.2 illustrates the comparison between Forward and Reverse Logistics.

From the comparison, it is obvious that RL process is more difficult to practice. Some of the difficulties are prediction of time, quality and quantity of returns, information on the destination and disposition of the returns, cost structure (pricing) for the recovery process, inventory, complicated life cycle issues, speed of the recovery, etc. Hence, the management of all the processes involved during the recovery of the returns need more expertise or good management techniques.

Table1.2 Comparison between Forward and Reverse Logistics (http://www.rlec.org)

Forward Logistics	Reverse Logistics
• Forecasting relatively Straightforward	• Forecasting more difficult
• One to many distribution points	• Many to one distribution points
• Product quality uniform	• Product quality not uniform
• Product packaging uniform	• Product packaging often damaged
• Destination options clear	• Destination not clear
• Disposition options clear	• Disposition not clear
• Pricing relatively uniform	• Pricing dependent on many factors
• Importance of speed recognized	• Speed often not considered a priority
• Forward distribution costs easily visible	• Reveres costs less directly visible
• Inventory management	• Inventory management not consistent
• Product life cycle manageable	• Product life cycle issues more complex
• Negotiation between parties straightforward	• Negotiation complicated by several factors
• Marketing methods well known	• Marketing complicated by several factors
• Visibility of process more transparent	• Visibility of process less transparent

1.2 Importance of Reverse Logistics

In today’s highly competitive economy, high quality and customer service are the tickets to the game. It makes an organization to differentiate itself from its competitors. In this regard, RL could be one of the significant differentiators that organizations could rely upon.

As environmental regulations coming into force, nowadays, countries are insisting the manufacturer to use recycled materials to make new products. For example, In Japan, any products purchased by the government must, by law, have a specific content of recycled materials. In the United States, there are hundreds of environmental laws and regulations within individual states, as well as the federal government, which include mandates for recycling operations and responsibility for distribution/packaging.

In the European Union (EU), a directive on handling waste from electrical and electronic equipment has been issued and member states are working on national legislation to implement it. In Netherlands, (which adopted RL legislation in the year 1999) manufacturers are held responsible for collection, processing, and recycling of used products such as refrigerators, washers, freezers, TVs, and consumer electronics items and their associated packaging.

The following are the statistics to get understood about the magnitude and importance of environmental action by the corporations.

- It is estimated that RL costs account for approximately one-half of one percent of the total United States’ GDP. RL is becoming an integral component of retailers and manufacturers profitability and competitive position. **(http://www.rlec.org)**.

- The market for environmentally friendly products has grown to over $200 billion.

- AT&T Network Systems Division has saved nearly $100 million in the 19 months it has been operating a RL program for its telephone switching equipment.

The following are impact of RL in current business scenario. These justify the increased focus on RL.

- **Competitive Advantage:** Returns have the potential to be one of the greatest untapped sources for increased revenue and customer loyalty in the present competitive environment. L.L. Bean and Nordstrom's have used their liberal return policies as a powerful way to attract and retain their customers. **Return Buy Inc**.

- **Returns Contain a Wealth of Information on Products and Merchandising:** Returns offer an immense amount of information about consumers and products that few retailers and merchants capture. For example, returns can provide information about the original merchandising, actual product performance, ease of use, product defects and consumer expectations.

- **Taking Full-Advantage of New Returns Technology is the Key:** New technologies and service providers have emerged to address the increasing demand for better solutions in return management.

- **Return Rates are higher than ever:** Return rates are high and climbing, especially for online businesses which are experiencing increased return rates as a result of trial and impulse Internet purchasing. Calls and traffic to customer service also increases as online buyers, in particular, expect fast credits and refunds.

- **Retailers ultimately assign the cost of Returning Items to Vendors:** Retailers in many industries simply return products to vendors.

- **The Traditional liquidation of Returns Channels are slow, inefficient and costly:** Recovering value from returns is a difficult task through the traditional liquidation channels. Although these channels are widely used, they lack ease and efficiency, and the end result for merchants is the recovery of a mere 10 to 20 percent of cost. Products lose value at every step to final disposition.

- **Returns: Not Just a Necessary Cost of Doing Business:** Returns have traditionally been considered just a necessary cost of business. However, the costs associated with returns are far from trivial when all of the hard and soft costs are calculated to determine true business impact.

- **Environmental concerns:** Environmentally motivated restrictions are forcing firms to take back some of the materials associated with their products. Also, many producers are required by law to take back their products at the end of their useful lifetime **(Ashish Daga, 2005)**.

1.2.1 Application Areas

Effective management of RL will no doubt improve customer service levels, support companies' environmental strategies, meet developing legislative requirements and has the potential to positively impact profitability and competitive positioning. The following are the list of industries in which RL plays an important role,

- Consumer goods industry: To fulfill the commitments of after sale service – buy back guarantee and repair service work to recover the value of the used goods.

- Automobile industries: To fulfill the commitments of after sale service and buy back guarantee.

- Heavy industries: To collect and reuse the waste.

- Pharmaceutical industries: To collect the expired formulations and drugs for environment friendly disposal.

- Beverage industries: To collect, reuse the empty bottles e.g. Coca Cola & Pepsi.

- Publication houses: To take back the unsold volumes for reuse.

Examples

- Helping smooth the repair process for the user, Teknet enables the user to log on and obtain a Return Material Authorisation, which is a unique number attached to each returned product, cutting out the need to phone through and book a repair. The system is also capable of arranging automatic collection of the faulty equipment from the client's site by linking automatically into the Fedex system. Teknet then sends an image of the airway bill to the client's screen, ready for printing out. The system also offers tracking of the repair and full data on the client's repairs history and accounts.

- During 2005, Dell increased the amount of material recovered from consumers by 72 percent over the previous year, beating a company goal for an increase of 50 percent. Dell attained this through, 1) Dell recycling (recycled consumer computer products); 2) ARS (computer products recovered from businesses, governments, schools, and universities); 3) donation (computer products donated to U.S. charities through Dell recycling); and 4) recycling events (computer products dropped off at recycling events sponsored or supported by Dell).

- A subcontractor for NASA utilizes remanufactured machine tools to produce complex spherical components for spacecraft. Remanufacturing was chosen over purchasing new equipment to generate cost savings.

- Hewlett-Packard uses remanufactured parts as service parts. They are able to receive failed parts and assemblies, remanufacture and refurbish those items, and then use them as their primary materials throughout their service network. They can reuse a valuable asset and reduce the costs associated with servicing computers and other complex machinery.

1.3 Trends in Reverse Logistics Implementation

This section provides overall status/ideas about the trends and practices used in the RL context and its implementation. The materials available in literature regarding RL process can be grouped as,

- Re-distribution/Re-sale/Re-use
- Remanufacturing, and
- Recycling

and the same are discussed below in proper perspective.

1.3.1 Re-distribution/Re-sale/Re-use

Re-distribution refers to "one type of logistics approach used to re-introduce a product into a marketplace and transfer it to the customer". This entails storage, sales and transportation. Efficient marketing of re-usable products requires clear and concise communication between interested parties and mechanisms to facilitate matching offers with requests. Re-use refers to cases where returned products have such a good quality that they can be reused almost immediately in the same or an alternative market. This happens for re-usable bottles, containers and most leased or rented equipment. It may also happen for surplus goods, e.g. spare parts, which are left over after discarding the original equipment.

Kroon and Vrijens, (1995) discussed the design of a logistics system for reusable transportation packaging. **Castillo and Cochran, (1996)** presented a study of production planning, product distribution and collection of re-usable containers and they applied it to re-usable bottles at a soft drink company.

Fleischmann et al. (2002) gave a systematic approach to analyze the inventory in the reuse process to determine the optimal values of the control parameters for ordering new items. **Guide et al. (2003)** gave a contingency approach to explore the factors that impact production planning and control for closed-loop supply chains that incorporate product recovery with reuse.

Mostard and Teunter, (2006) analyzed the resalable returns with a newsboy problem and they developed a procedure to estimate the variance of demand. **Jeung Ko and Evans, (2007)** presented the design of a dynamic integrated distribution network to account for the integrated aspect of optimizing the forward and return network simultaneously.

1.3.2 Remanufacturing

Remanufacturing is "a series of steps necessary to transform a used part or product into the one that is reusable as the original product or a new product". Remanufacturing is product dependent and it can be characterized by some typical activities like, cleaning, disassembly, replacement and re-assembly. Hence remanufacturing is "…an industrial process in which worn-out products are restored to like-new condition. The new product is reassembled from the old and, where necessary, new parts to produce a fully equivalent and sometimes superior in performance and expected lifetime to the original new product" **(Lund, 1983)**.

Remanufacturing is applied to complex equipment or machinery with many modules and parts. It is usually a labor-intensive activity and requires much testing. **Meijer, (1998)** discussed the remanufacturing of used scanners, printers, copiers, faxes at Canon. **Jayaraman et al. (1999)** assessed an electronic equipment collection, remanufacturing and distribution. **Krikke et al. (1999)** discussed about the remanufacturing of photocopiers with the evaluation of the costs, including effects of transportation.

Mahadevan et al. (2003) focused on the study of a remanufacturing facility that receives a stream of returned products with uncertainty in demand. They find when to release returned products to the remanufacturing line and how many new products to be manufactured. **Kiesmuller, (2003)** addressed the optimal control policy for a linear cost of a stochastic recovery system with two stocking points and different lead-times for production and remanufacturing.

Seitz, (2006) laid an in-depth case study within the remanufacturing facilities and examines the motives for product recovery in automotive remanufacturing. **Lebreton and Tuma, (2006)** presented a case study to ascertain the reasons for discrepancy and investigation of the extension of remanufacturing activities and that study implied that the retreaded truck tires have exhausted their remanufacturing potential whereas a customer-sided bottleneck hinders further development in the car tire market. **Tang et al. (2007)** examined the process lead-time in production planning and control of remanufacturing.

Langella, (2007) proposed a heuristic for demand-driven disassembly planning to deal with holding costs and external procurement of items for remanufacturing. **Subrata Mitra, (2007)** developed a pricing model to maximize the expected revenue from the recovered products and she noticed that not all the remanufactured products would be sold and different quality levels of recovered products would draw different prices in the secondary markets.

1.3.3 Recycling

Recovery of material value through recycling forms another class of closed-loop supply chains. Material recycling chains are characterized by fairly low profit margins. Commercial recycling chains concern the need for high investments for specialized recycling installations and equipment. The high investment cost and low margin combination obviously calls for high processing volumes.

Spengler et al. (1997) examined recycling networks for industrial by-products: recycling of building debris and the recycling of by products in a steel industry. **Bartels, (1998)** described the Dutch nationwide system for the recycling of batteries. **Van Burik, (1998)** described the car-recycling nation-wide scheme.

Realff et al. (1999) made a case study on carpet recycling. **Louwers et al. (1999)** discussed the set up of a carpet recycling system with a special type of carpets, of which the output is used as feedstock in the chemical industry.

Van Notten, (2000) explained the glass recycling system. **Kleineidam et al. (2000)** considered the structure of the recycling network of the paper industry. The recycling system resembles a close-loop, with used paper being collected, processed, and turned into pulp, which is raw material for the paper industry. They investigated the dynamic behavior of the chain and used it to evaluate the system.

Inderfurth, (2005) suggested that uncertainty in returns may be considered as a difficulty for recovery strategy. **Rupesh Kumar Pati et al. (2007)** studied the inter-relationship between multiple objectives of a recycled paper distribution network and he suggested that the result of the model is a viable tool and can be used to assist in making appropriate decisions.

1.4 Reverse Logistics Process Realization

Since RL has potential value, nowadays, businesses are attempting to improve the constant flow of returned goods, parts, packaging and waste back through the supply chain. Many retailers and manufacturers are recognizing the value of effective RL and identifying it as an integral and strategic part of their business due to a Supply Chain developments and hi-tech expectations of the customer.

RL network comprises of various activities. Figure 1.2 illustrates the various logistics activities that take part in the context of RL. The first activity is collection of the products to be recovered.

To design a network for collection, a company can install, several drop points for customers, integrating reverse flow of used commodities with other transportation flows or use a direct express mail system to bypass several stages of the network for fast processing. The type of design depends on different product types and needs of the customers. Retailers and distributors are often used as the points of collection.

The second activity in the network design is about the inspection of the returned commodities. Here the status of the commodities is identified, i.e., whether the commodities are serviceable or not. Then the commodities are sent for the next stage.

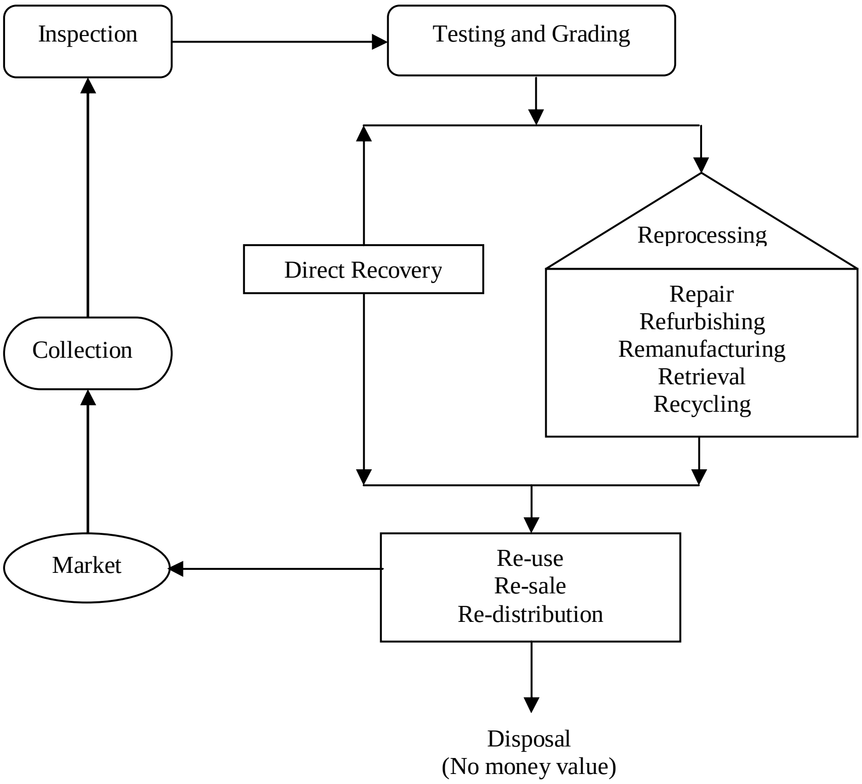

Figure 1.2 Reverse Logistics Process

The third activity in the network design is about the Testing/Grading operations. The location of the test and grade operations in the network has an important impact on the flow of goods. The individual commodities can be assigned to an appropriate recovery option and hence to a geographical destination after testing and grading. It is important to see a tradeoff between transportation and investment costs at this stage.

Testing collected commodities early in the channel may minimize total transportation distance since graded commodities can directly be sent to the corresponding recovery operation. On the other hand, expensive test equipment and the need for skilled labor act as drivers for centralizing the test and grade operations.

The fourth activity is reprocessing, and it generally requires high investments in establishing the network for RL. Reprocessing entails the transformation of a used product into a usable product **Fleischmann et al. (2001)**. Re-processing can occur at different levels: product level (repair), module level (refurbishing), component level (remanufacturing), selective part level (retrieval), material level (recycling), energy level (incineration) **(Thierry, et al. 1995; Fleischmann et al. (1997)**.

Goggin and Browne, (2000) listed various points of view on recovery or re-processing levels. Reprocessing commodities can increase productivity, because materials or components that serve as production input or spare parts can be extracted from used products, thus using inputs more productively **(Porter and Van der Linde, 1995)**.

The costs for specialized remanufacturing or recycling equipment influence the economic viability of reprocessing. If the quality of the product is "as-good-as-new," it can be fed into the market almost immediately through re-use, re-sale and re-distribution. Otherwise, it undergoes re-processing. Integration of product recovery operations with the original manufacturing process can offer economies of scale which involves sharing of locations, workforce, or even manufacturing lines.

The next and the last strategic activity, in the RL network design is the Redistribution stage. This point resembles a traditional distribution network. In particular, we find the conventional tradeoff between consolidation and responsiveness in transportation. If collection and redistribution are combined, we can achieve efficiencies in vehicle loading. Redistribution can also be done along with distribution of new commodities if integrated with forward supply chain. In RL, the sender, who may be a stakeholder in the chain, plays an important role by way of product package, dispatching and a closing link in the chain. The success of RL operations, i.e., effectiveness and profitability, depends on the network design adopted.

Resources are saved if the costs to regain the used components value are lower than the costs of purchasing. Reprocessing of used goods can add value through creating a greener corporate image. In case of component recovery, products are dismantled and the used parts can be used either in the manufacturing of the same products or different products (remanufacturing). At the material recovery stage, the materials are sorted out and are grouped together according to their quality and material nature so that they can be the input raw materials in the manufacture of different or related products.

Redistribution refers to directing reusable products to a potential market and physically moving them to future users **(Stock, 1998)**. Redistributing remanufactured or used goods can increase productivity. According to anecdotal evidence, remanufactured goods are often sold for a higher margin than original items on secondary markets. The higher margins are the result from the savings in raw materials or customers being willing to pay a premium for remanufactured products **(Stock et al. 2002)**. Disposal is required for products that cannot be reused for technical/economic reasons, e.g. excessive repair requirements / insufficient market potential.

1.5 Strategies of Reverse Logistics

Returns may come in one at a time or in random without any caution or with no or a very little accompanying information, against the forward logistics. Hence, handling returns in such a situation is complicated and the assembling technology/methodology employed for the effective management of RL is even more complicated. In order to get recuperate the potential it has, RL may have to be practiced with the consideration of the strategic variables/points.

Strategic variables should be managed for the economic viability of an organization. A goal of almost every business is to lock customers in, so that they will not move to another supplier. Hence, RL should be seen as an opportunity to build competitive advantage, cut costs, and improve customer satisfaction. An important service a manufacturer can offer to its customers is the ability to take back unsold or defective merchandise quickly, and credit the customers in a timely manner.

To make effective and efficient RL processes, a manufacturing industry should consider the following strategic points.

1. **Customer to be an interactive partner:** An organization should place the customers as a well interactive person or partner in their business.

2. **Consistent thinking ahead of customers:** Customers always have their own liberty in making their good choices. An organization cannot able to build a wall around their customers and they will not stay always, even though the organization has good customer support.

3. **Customary thinking, ahead of the customers:** Anticipating customers needs and wants.

4. **Making Good reputation:** An organization should keep their operating strategies always strong, represented and promoted with time to time updated.

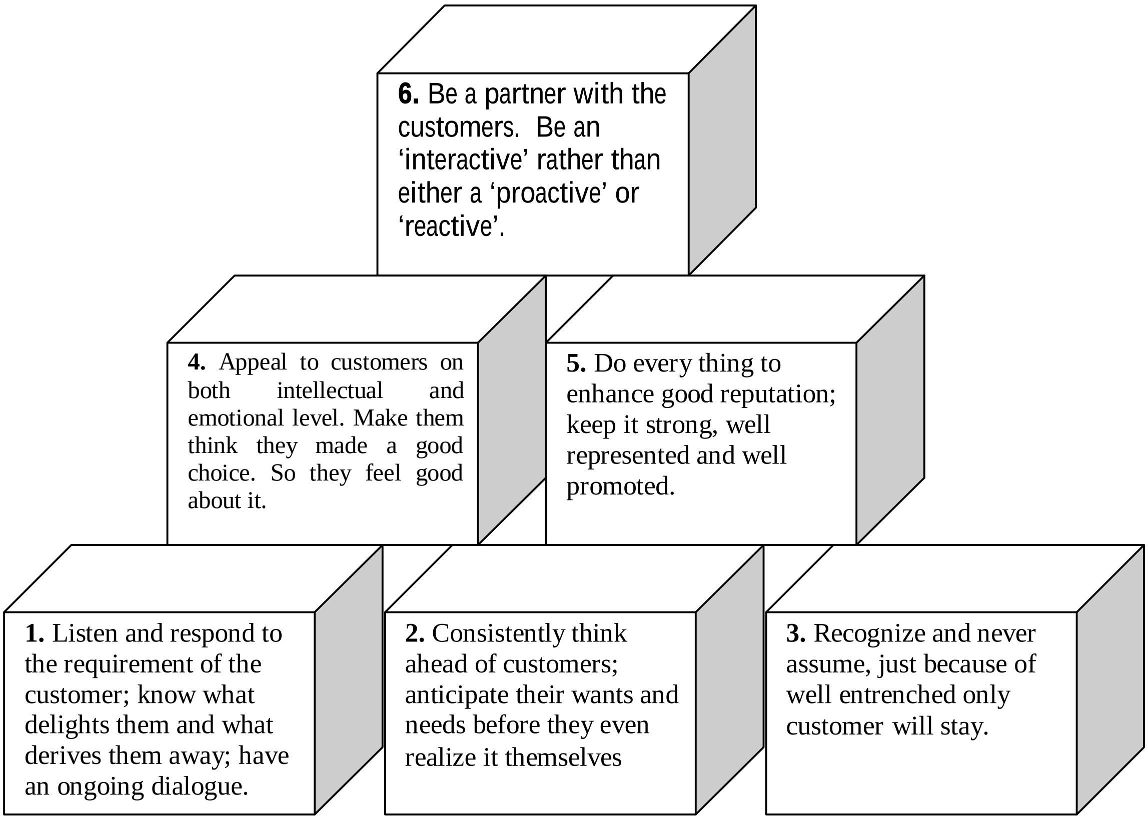

Figure 1.3 Strategies to maximize Customer Service and Competitive Performance

5. **Logical and emotional level of customers:** Customers should feel about the organizations that, they made a perfect choice for a long run.

6. **Paying attention:** Attention towards the exact requirement of the customers, based on what they actually want and what drives them away while maintaining good customer relationships.

Figure 1.3 shows stepladder for the growth of customer’s service and performance.

With the RL strategies, the customer satisfaction and competitive advantage of an organization can be improved through,

- The identification, measurement and promotion of both real and perceived value of an organization's total capabilities to their customers.
- Continually transforming the improvements in RL capabilities, into improved customer service and satisfactory ratings.
- Using RL improvement as an ongoing marketing and promotional tool and
- Keeping the position of the organization as a well ahead of the competition, by aggressive promotion of specific value and its benefits associated with RL capabilities.

To sum up, the effective implementation of RL strategies mainly depends on the manufacturer’s center of attention towards the trends of returns and giving importance to the customer’s expectations or requirements in time.

1.6 Scope of present work

One of the important means for organizations to differentiate themselves, as well as to increase profitability, in highly competitive environments, is the use of service management. Among the various service related activities, repair service stands unique. All the service related activities, especially, repair services, depend heavily on RL operations.

The demand of customers in the reverse channel unlike forward logistics, vary widely. One cannot predict the nature or conditions of the returned products/commodities. Moreover, when, where, and in what quantities the products/ commodities are returned is also not known. That is, RL is always tied with inherent uncertainties. So, the RL operations to recover the value of the returns are complex in nature and they pose many challenges to the practioners and researches alike.

RSRL consists of different stages, starting from collection of the returns, transport, inspection to assess the condition and decide on recovery options (value addition), product delivery, or and disposal.

During the collection stage, the returns from disposer markets, i.e. customers' locations, are collected and brought to the repair service facilities (second stage) where the recovery of the returned commodities will be carried out. After the recovery processes, the products/commodities are distributed in the reuse markets (third stage) which is formed by the old or new customers as the case may be. If value recovery is not possible, which would be happening to a certain percentage of returned commodities, such commodities are disposed off.

To be effective, RL with many uncertainties and complications requires well thought about strategies, plans and supporting frameworks to execute the corresponding RL networks. Without these elements into it, coordinating or implementing RL in the systems is a difficult proposition, if not impossible.

Hence, Networking of Reverse logistics activities are the fundamental requirement in RL. RL networking is "the simultaneous coordination of various RL activities or processes to recover the value and to dispose the returns, starting from the end users back to the manufactures". The key benefits of RL networks are,

- Improved control and asset recovery
- Better information and supply chain visibility – full tracking to ensure accurate information
- Income generation

- Efficient route planning – returns collections matched with outbound deliveries.

RL networks need to be constructed with the determination of the number of layers in the network, the number and location of depots or intermediary points, the use of drop points in the collection, the issue of integrating the reverse chain with the forward chain, and finally the financing of the network **(Brito and Dekker, 2003)**.

While making the RL networks, it is important to consider the strategic points like, cycle time and various costs. Shortening of returns cycle time is important for handling returns well **Dawe (1995**). Some researchers put forward the strategic factors, like costs, which are to be considered when designing a RLN. Minimizing strategic costs is essential for a successful RL system **(Chang and Wei, 2000; Guide et al. 2003) and (Ginter and Starling, 1978)**.

Most of the cited works in modelling deal with single commodity. Only a few studies have addressed the problem of flow of multi-commodities from return centers.

In practical RL problems, especially in RSRL problems, dealing with more than one type of returned commodities is a norm rather than an exception. Besides the multi-commodities nature of RSRL networks, another normal feature is the recovery of the returned commodity value in more than one stage or in other words multi-stages.

These two common, yet important features have not been taken up or analyzed in the earlier works, and there is a need to study, analyze and model such features also in RL networks. This would help the RSRL practioners in a great way.

In order to take up these features in the RL context, this research work is an attempt to analyze the problem of flow of multi-commodities/multi-products, which exists in existing manufacturer's repair service facilities, producing consumer electronic goods. This problem has been analyzed with the formulation of various Reverse Logistics Network models. The aim of all the models proposed here, is to improve the profit of the manufacturer’s repair service facilities along with the satisfied service levels.

The objectives of the present research are,

1. **To form the framework for the multi-commodity Reverse Logistics Network**
2. **Formulate models for**
    - **a) Single-Level Multi-commodity Reverse Logistics Network**
    - **b) Multi -Level Multi-commodity Reverse Logistics Network**
    - **c) Single-Level Multi-commodity Reverse Logistics Network with quality variations**
    - **d) Multi-Level Multi-commodity Reverse Logistics Network with quality variations.**
3. **Solutions to the above models using simulation technique.**
4. **Applying GA to understand the effective commodity flow control.**
5. **Energy conservation measures through vehicle routing approach.**

All the models analyze the problems, which exits in existing manufacturer’s service facilities. The models deals with flow of multi-commodities with consideration of the following factors: customers’ demand and return, minimal disposal fraction, unit costs of demand, return, transport, disposal and penalty costs for non-satisfied demand and return, fixed costs for establishing service facilities and recurring costs of using service facilities.

In addition, the models also considers the following queueing Parameters: mean effective repair service time, the arrival rate of commodity, service rate of commodity, utilization level for commodity, expected time spent by the commodity and expected number of commodities in the repair service facility.

The models are applied with real time data obtained/collected for a period of one year, in existing service facilities. The various/type faults of multiple commodities in the network is taken into consideration while constructing the models. Better results obtained with satisfied service levels and improved profit through simulation and Genetic algorithm approaches.

Genetic Algorithm based heuristics is used to control the flow of multi-commodities to repair service facilities in a single level, multi-commodities flow. The results show that the channelizing/allocation of commodities to the service facilities based on the Genetic Algorithm heuristics highly improved the profit of the network and customer’s service levels when compared with simulation results.

An algorithm with improvement heuristics was applied for RL Networking with vehicle routing, to conserve the energy usage while transporting the commodities, which flows into the network. With the heuristic proposed, the model resulted satisfactory outcomes. The energy used during the transportation of commodities in the network for the period under consideration is significantly reduced after the application of the proposed heuristics.

RL Network models proposed here reduced total operating cost, increased service level, reduced waiting time of the commodities, delivery of the commodities after the repair service work at specified time intervals and reduced costs towards penalties due to not collecting the return or unsatisfied demand.

This research work may provide proper insights regarding how to make or plan an appropriate RL activities or tasks for repair service facilities. The RLN models constructed here may be useful for manufacturer’s service facilities to consider their repair service work effectively when and where they are required. The models may have practical value or importance in dealing the problems associated with multi-commodities flow.

RL practices can be varied based on the type of the industry and channel position. Manufacturing industries, where returns are accounted for a larger portion of operational costs likely to have better RL systems and processes. We believe that, this research work may provide useful insights for the manufacture’s repair service facilities while planning for their RL systems and processes.

The structure of this thesis is divided into eight chapters and the same is given below.

In first chapter, we describe and analyze the RL topic in general. We initially assess different definitions of RL found in the literature and, compare them by evaluating the different elements and contributions of each author. This chapter includes materials on difference between RL and Forward logistics and the importance, applications, the trends in RL implementation, process realization and the strategies employed. Finally, we present the scope of the present work.

On the second chapter we present the literature on RL networking and different RL network structures with different types of commodity flows at different levels followed with a conclusion.

Next, in third chapter we describe the analysis of RL network in multi-commodity environment. We present a general framework of RL Network for multi-commodity flows in single level. This network is modeled followed by a detailed evaluation of the returns process, which is taking place in existing service facilities through the data obtained. Simulation is used here to solve the proposed model. The methodology applied was a case study based on discussion with the working groups, surveys and the service facilities visit. This chapter ends with the results and discussion.

In Chapter 4 we present the model for the multi-level servicing with multi-commodity flows. First, we give the framework of RL Network model. Then the model is analyzed with real time data. The computational results are presented followed with the discussion on the results obtained. The main contribution of this research is a deep knowledge of the returns-recovery process in the manufacturers repair service facilities.

In Chapter 5, we propose RL Networking model of (both Single and Multi levels) multi commodity flows with the consideration of quality levels of the returns. Initially the framework considering the quality levels is presented. And the model of a single level and Multi-level is analyzed, within repair service environment. The benefit of this model is to help the manufacturer’s service facilities to do strategic and tactical RL network. Finally, we present the computational results for an example that represents the potential of this benefit. Finally we present the results obtained along with discussion.

In chapter 6, we introduce the concept of Genetic Algorithm for flow control in the RL context. The description and Analysis of commodity flows based on Genetic algorithm approach for a single level, multi-Commodity flow is given. We present the computational results for an example problem. Finally this chapter ends with the results and discussion.

In chapter 7, we give the description and Analysis of Single level, Multi-Commodity flow RL Networking with Vehicle routing. In this work we aim to evaluate the impact of several elements on the computing time. So, we proposed an algorithm with heuristics procedure to solve the model. This model evaluates the impact of the returns i.e., the flow of multi-commodities, and the number of existing service facilities under consideration. Finally we present the results and discussion.

In chapter 8, we conclude the models presented in the earlier chapters along with the scope for future work.

CHAPTER 2
REVERSE LOGISTICS NETWORKING – A REVIEW

2.1 Introduction

Effective management of reverse logistics activities is a key process in today's business, and a well-designed process can create competitive advantage for a manufacturing firm. The main activity of RL for return process involves the development of a network for returns with the corresponding flow options. The Networking of all RL activities needs effective coordination. Coordination, which means, bringing together, the various logistics activities and it can be, achieved through introduction of all the RL activities for recovering the value of the returns, in a network. This returns network can be referred as Reverse Logistics Network (RL Network).

The RL Network can be designed in such a way that it would deliver its service to satisfy the exact customer requirements. RL Network is an opportunity to generate additional revenue, differentiate market position, and support original product demand. Both retailers and manufacturers have realized these opportunities and RL is becoming an integral component of profitability and competitive position. RL Network allows for the efficient utilization of facilities, minimizing the cost of capacity, while making the service more responsive to customer demands.

The RL Network structure can be divided into two portions. A Convergent Network, in which a portion of the network accumulates the used commodities from individual sources and conveys them to some recovery facilities. Companies can set up dedicated returned commodities collection centers at specific locations or collect the commodities through retailers and distributors.

In a divergent network, the network part links recovery facility to individual customers purchasing reusable commodities. This portion of the network is very much similar to traditional forward supply chain distribution networks and integration with forward supply chain can be done here for maximized optimality.

The different RL networks, which are available in the literature and the possible types of network structures in the RL context, are discussed here.

2.2 Reverse Logistics Networks – A Literature Review

Network structure is generally stated to be of great strategic importance in RL **(Cristopher, 1998)**. RL Network addressed in the literature rely on mixed-integer linear programming and this approach allows for large-scale mathematical optimization. But deriving general insights of impact of various parameters from them is difficult. In order to overcome this difficulty, **Daganzo, (1999)** followed continuous approximation methodology. Later, authors in RL field formulated RL Network models as a mixed-integer non-linear programming (MINLP). In order to determine when reverse flows should be integrated with forward flows, **Fleischmann et al. (2000)** simulated the impacts of reverse flows in a logistics network.

When designing RL Network structures, the companies, also need to decide where to locate the various processes and how to design the corresponding transportation links and there is not usually an existing network that can be used **Fleischmann et al. (2001),** and they proposed a generic RL network model based on a mixed integer linear program and discussed the applications and extensions to the model.

RL Networks need to be constructed with the determination of the number of layers in the network, the number and location of depots or intermediary points, the use of drop points in the collection, the issue of integrating the reverse chain with the forward chain, and finally the financing of the network **(Brito and Dekker, 2003)**. **Fleischmann et al. (2003)** presented a continuous optimization model for RLN design. **Autry, (2005)** devised a framework of three typical RL Network structures namely bulk recycling, remanufacturing, and reuse RL networks. To get in-depth knowledge of uncertainties involved in reverse flows, **Lieckens and Vandaele, (2007)** introduced queueing effects in RL Network design to account for uncertainties and the model was formulated as mixed-integer non-linear programming (MINLP).

RL Network design models may vary from product to product, purpose for which it is intended, the extent, and the size of the operations. The following materials, taken from various sources and researches conducted elsewhere, through some light on the possible network design that can be considered for the given environment.

Kroon and Vrijens, (1995) presented a design of a closed- loop deposit based system for collapsible plastic containers, which can be rented as secondary packaging material. The design involves a central agency - a pool of reusable containers and a logistics service provider - responsible for storing, delivering, and collecting the empty containers, which needs a set of depots. The authors documented how this issue may be addressed by means of a standard warehouse location model. They emphasized that the overall network design problem is characterized by the interaction between the various parties involved and their respective roles. Depot location, pool size, and payment structures all have an important impact on the system's performance as a whole and its competitiveness with respect to traditional 'one-way' packaging.

Thierry et al. (1995) presented an integrated supply chain framework to demonstrate the reverse flows and various recovery options such as repair, refurbishing, remanufacturing, recycling, etc. **Dawe, (1995**) suggested that the shortening of returns cycle time is important for handling returns well.

Spengler et al. (1997) examined a single period steel by-products recycling network. During the production process of steel, a substantial volume of residuals generated. For this, they analyzed which recycling processes to install at which locations at which capacity level in order to minimize overall costs. They proposed a modified MILP warehouse location model for an arbitrary number of network levels, corresponding to individual processing steps, and an arbitrary number of end products, linked to alternative processing options. **Rogers et al. (1999)** argued that the short disposition cycle times related to return product decisions, movement and processing is critical element to successful RL management.

Barros et al. (1998) examined sand-recycling network – treating the waste/bye-products from construction works. Sand is to be cleaned before being reused. The cleaning of polluted sand requires an expensive treatment facility.

Regional depots are also to be set up for inspection and storage of the sand. For this purpose the authors developed a tailored multi-level capacitated facility location model. During the analysis, they emphasized that the need for a robust network structure to handle significant uncertainties due to supply and demand. **Listes and Dekker, (2005)** revisit this case and explicitly taken the uncertainty issue into account in their modeling approach. They proposed a multi-stage stochastic programming model where location decisions need to be taken on the basis of imperfect information on supply and demand while subsequent processing and transportation decisions were based on the actual volumes. The model maximized the expected performance for a set of scenarios with given probabilities. The authors emphasized that the solution needs not be optimal for any individual scenario and hence this approach was more powerful than simple scenario analyses.

Jayaraman et al. (1999) analyzed a RL Network design of an electronic equipment remanufacturing company. The network includes the activities of the core collection, remanufacturing, and distribution of remanufactured products (there is no coincidence of delivery and demand). With this setting, they analyzed about the optimal number and locations of remanufacturing facilities and the number of cores collected with consideration of the investment, transportation, processing, and storage costs. And they showed that the network design problem could be modeled as a standard multi-product capacitated warehouse location MILP. Finally they emphasized that managing the capacity was crucial for the performance system and it required different approaches than in a traditional production-distribution network.

Realff et al. (1999) provided a first step in the strategic transition of multi-period network design models from a stationary, single-period perspective. Few models explicitly incorporate uncertainty other than scenario analyses. Besides the stochastic programming model **Listes and Dekker, 2001, Newton et al. (1999)** made a robust network design model for carpet recycling. This approach resulted in different network structures when compared with scenario analysis. The cost advantages turn out to be limited in many cases.

Fleischmann et al. (2000) focused on the consequences for OEMs of adding product recovery operations to an existing production-distribution network. They presented a general MILP facility location model, which encompasses both forward and reverse product flows. The authors concluded that, based on numerical study, the overall network structure was fairly robust with respect to variations in the recovery volume and the RL networks can efficiently be integrated in existing logistics structures in many cases. They illustrated this case with an example of OEM copier remanufacturing and paper industry.

Brito and Dekker, (2004) provided a RL framework to take decisions in terms of strategic, tactical and operational aspects of the problem. Some researchers put forward the strategic factors, like costs, which are in need to be considered when designing a RL Network. Minimizing strategic costs is essential for a successful RL system **(Chang and Wei, 2000; Guide et al. 2003) and (Ginter and Starling, 1978)**. Few companies outsource their RL operation to third-party providers for the benefits of cost reduction, improved expertise and easy access to data, improved operation and customer services, and the ability to focus on core competencies and flexibility **(Castillo and Cochran, 1996)** and **(Fleischmann, 2004). Lu and Bostel, (2007)** gave a brief introduction to the basic concepts of RL with a two-level location problem with three types of facilities to be located in a specific RL system, with both forward and reverse flows and their mutual interactions.

Min et al. (2006) proposed a minimum-cost solution RL Network model with nonlinear mixed-integer programming to solve the RL problem involving product returns which include: defects, in-transit damage, trade-ins, product upgrades, exchanges for other products, refunds, repair, recalls, and order errors. The proposed model and solution procedure considered explicitly, the trade-offs between freight rate discounts and inventory cost savings due to consolidation and transshipment. The model and solution procedure may enable the reverse logisticians to determine the exact length of holding time for consolidation at the initial collection points and total RL costs associated with product returns. **Jeung Ko and Evans, (2007)** presented a mixed integer nonlinear programming model, a multi-period, two-echelon, multi-commodity, capacitated network design problem, considering both forward and reverse flows simultaneously.

Salema et al. (2007) proposed a generalized model for the design of RL Network. This model is based on the recovery network model (RNM) proposed by **(Fleischmann et al. 2001)**. This work extended the RNM model and developed a capacitated multi-product RL network model with uncertainty. The capacity constraints were imposed on total production/storage capacity of the facilities, which might be factories, warehouses or distribution centers. The model formulation allows any number of products, establishing a network for each product while guaranteeing total capacities for each facility at a minimum cost. They studied the network model in the context of uncertainty in both product demands and returns, through the use of a multi-scenario approach. This model attempts to overcome the limitation of generality in reverse distribution network model. This establishes a network for each product with minimum cost.

Listes, (2005) examined the design of networks comprising both supply and return channels, organized in a closed loop system for manufacturing/re-manufacturing type of systems with a decomposition approach. This approach can effectively exploit certain problem features, such as the flexibility offered by multiple capacity levels or by economies of scale. His findings on an overall analysis led to the main conclusion that volume was a powerful driver in integral networks with re-manufacturing options and the processes which can adjust as accurate as possible to the overall requirements generally enjoy a natural advantage, provided that their investment costs were not prohibitive.

Lieckens and Vandaele, (2007) examined a RL Network design using an extended version of models to determine which facilities to open that minimize the total cost. Finally, the authors showed that, the constraint could be improved when they were combined with a queueing model because it enables to account for some dynamic aspects like lead time and inventory positions, and the higher degree of uncertainty inherent to RL.

Lu and Bostel, (2007) gave a brief introduction to the basic concepts of RL with a two-level location problem with three types of facility to be located in a specific RL system, with both forward and reverse flows and their mutual interactions, named a Remanufacturing Network. This model was formulated as a 0–1 mixed integer programming. They demonstrated that reverse flows influence the decisions about location and allocation and the influence varied with the magnitude of the reverse flows, their distribution at demand sites and their correlation with forward flows.

Rico Wojanowski et al. (2007) presented a continuous modeling framework for designing a drop-off facility network and determining the sales price that maximize the firm’s profit under a given deposit–refund. Their analysis on an illustrative example showed that the returned product value was a key factor that determines the nature of collection in an industry. Products with high return value, the deposit refund voluntarily offered by the firms could be sufficient to achieve high collection rates.

The overall status of the literature on RL Network design shows that RL networks have close analogies with conventional production-distribution networks. From the mathematical perspective, the models that have been proposed differed fairly little from traditional MILP facility location models. Some special features reflect the particular role of testing and grading and alternative market conditions on the demand and supply side. One important aspect is the issue of uncertainty in supply. Very few models, in RL network, only incorporate uncertainty other than the scenario analyses. These approaches result in different network structures. Now closed-loop supply chains are in an emerging state and we can see that companies are gradually extending their operations from moderate pilot-study to full-scale business processes, in order to get competitive advantage.

The network structures constructed, formulated and discussed in literature resulted the availability of different types of Network structure since the flow of commodities/products in different levels categorizes the different patterns of flow.

2.3 Different Reverse Logistics Network Structures

Manufacturers in worldwide are increasingly facing the problem of assuming responsibility for their products at end of life and must provide for collection and product recovery or proper disposal **(Klausner et al. 2000)**. To satisfy the high expectations of customers, all manufacturing industries are in need to make very thriving process. Especially, with the rapid increase in the introduction of new and advanced technologies, the manufacturing industries increased their focus on Networks, which involves Reverse Logistics and Repair Services (RLRS).

Basically, there can be four different possibilites of commodity flow exists in RL. They can be given as,

- Single Level Single Commodity Flow (SLSCF)
- Single Level Multi Commodities Flow (SLMCF)
- Multi Level Single Commodity Flow (MLSCF) and
- Multi Level Multi Commodities Flow (MLMCF)

The figure 2.1 shows the different possiblities of the flow pattern of different comodities in different levels in a Rverese Logistics Network (RL Network).

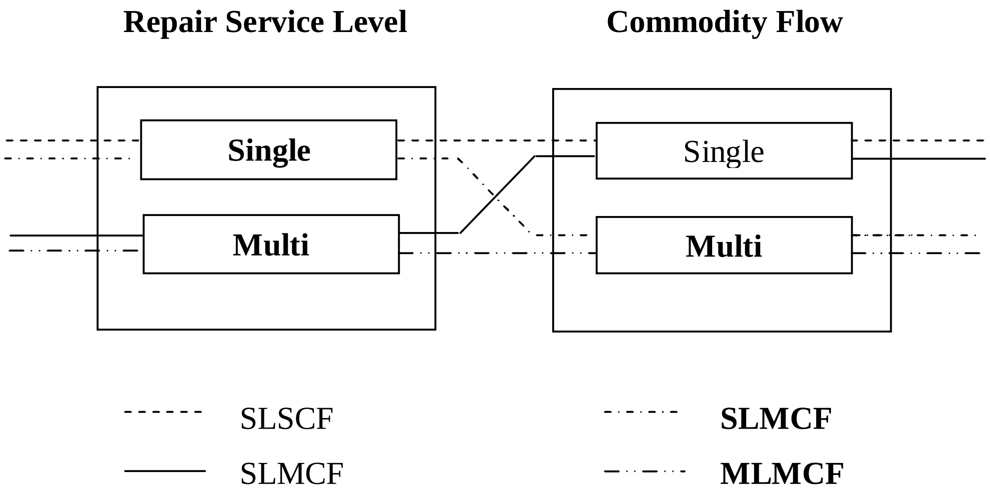

Figure 2.1 Possibilites of flow of commodities in Reverse Logistics Network

In this investigation, the flow of multi-commodities, which flows through multiple repair service facilities situated at single level and also at multi-levels are considered for the anayasis.

2.3.1 Single commodity flow/ Flow of single commodities in a RL Network

There are different types/varieties of commodities in different numbers flows in a RL Network. If only a particular variety of commodity flow exists in an RL network, then it is called as single commodity flow.

- Example: Flow of Refrigerators (single commodity) in a RL Network.

2.3.2 Multi commodity flow/ Flow of Multi commodities in a RL Network

If the flow of more than one type/variety of commodities exists in an RL Network, then it is called as a multi-commodity flow.

- Example: Flow of washing machines in addition to refrigerators (multi-commodities) in a RL Network.

2.3.3 Single Level RL Networking/ Single level Repair Servicing in a RL Network

The commodities, in reverse flows need some repair service work to be done to recover its value. The repair service may be carried out in a single facility or in number of facilities, which are situated at different locations, depending on the status or the condition of the commodities returned.

If the entire repair service work of a particular commodity is carried out in a particular repair service facility without sending it to any other service facility, then the type of the repair service performed in that repair service facility is known as single level servicing in a RL network.

To put in other words, if the repair service of a particular commodity, to recover its value is made specifically in a single repair service facility only, then it is called as Single level servicing and their corresponding flow is referred as a Single level RL Networking.

- Example: If the entire repair service work needed to recover the value of a refrigerator is performed only (by the servers) in a single repair service facility of the manufacture.

2.3.4 Multi Level RL Networking/ Multi level Repair servicing in a RL Network

In some situation, the returned commodities/products need some additional work to be done (any specialized work) due to the reason of unavailability of tools/equipments, spares, expertise, etc., to recover its full value, in addition to the work performed in the first level service facility.

In that situation they are sent to some other service facilities, which is, situated in different locations (may be the manufacturing plant-second level) to perform additional or specialized works. This type of service performed is known as multi-level servicing in a RL Network.

To put in other words, the repair service work of a commodity is carried out in more than one repair service facilities, which are located at different levels or locations is known as Multi level Servicing and their corresponding flow is referred as a Multi level RL Networking.

- Example: Entire repair service work needed to recover the value of a refrigerator is carried out in more than one repair service facility, which is situated in different levels.

2.4 Conclusion

Reverse Logistics Network review shows that, different types of network are analyzed with different recovery options/methods. The main recovery options followed can be listed as, recycling, remanufacturing, refurbishing/repair service, reuse, and disposal. The maximum works on RL networks found, are dealt with single commodity flow only. This paves the way to analyze the problems regarding the flow of multi-commodities in RL networks.

The possibilities of different network structure with commodities/products flows are also studied in this chapter. There are four different possibilities of RL Network. These are mentioned and explained. In this current research work, the flow of multi-commodities in both single and multi-levels are considered.

CHAPTER 3
REVERSE LOGISTICS NETWORKING IN MULTICOMMODITY ENVIRONMENT

3.1 Introduction

Reverse flow of commodities, from consumers to producer or manufacturer, does happen everyday in considerable quantities in Supply Chains because of number of reasons. In some industries, over 1/5 of all goods that are sold are eventually returned to the vendor **(Rogers & Tibben-Lembke, 1999)**. So, there is a need to have RL programs in place to handle the returns effectively. A commodity referred here is a specific product as said by **(Shen, 2005).**

Design of a product recovery network is one of the challenging issues in the field of RL, especially so with large-scale businesses that handle varieties of commodities. Here, the location and capacity of the recovery facilities and the flow of commodities between consumers and the manufacturer's recovery facilities are considered while designing. The nature of the flow of varieties of commodities, varying recovery processes and recovered value of the commodities, necessitates a proper RL network and the control of it.

Formulation of a RL Network model for repair service of multi-commodities is discussed here. Solution to the model is obtained and also discussed.

3.1.1 Repair Service

Repair service is one of the value recovery processes in the RL context. It includes all of the activities required to move a commodity from point of use to point of reclamation and redistribution. It can be seen as a viable option to handle the returns so as to improve customer satisfaction and profitability. So, Repair service process can be defined as the process of restoring the value of the returned faulty commodities by carrying out repair work on them.

The RL Network used for such repair service is called Repair Service Reverse Logistics Network (RSRL). It is characterized by, uncertainty in supplies, customer requirements, value recovery, multi-party coordination and lack of flexibility. When the returned commodities of more than one kind receive services at a single service facility or station to completely recover their values, then the network is called single level multi-commodity RSRL Network.

3.1.2 Basic structure of single level Multi-commodity RSRL Network

A RL network in general, establishes the flow of used commodities between the disposer markets/consumers and the repair service facilities. Then, it establishes the flow of serviced commodities between the repair service facilities and the reuse market.

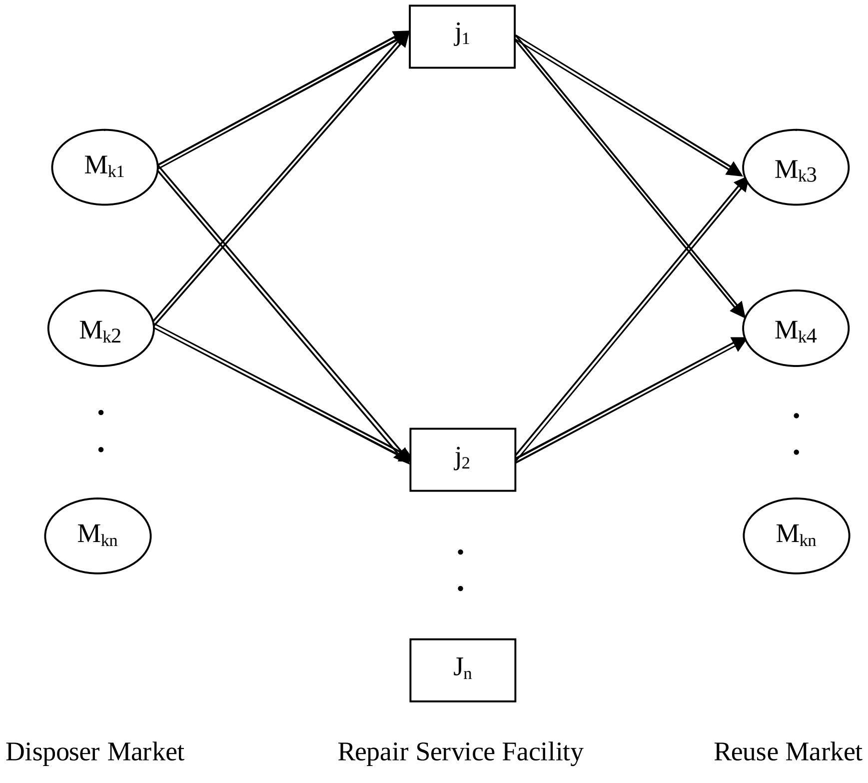

Figure 3.1 Structure of Single level Multi-Commodity RSRL Network

Figure 3.1 shows the basic structure of the single level, multi-commodity RSRL network. In this structure the disposer market or collection stations serve as a source, the repair service facilities serve as intermediary nodes and the reuse market serves as a sink. The structure incorporates the possible transportation links with the disposer market, repair service facilities, and reuse markets.

Often, in RSRL system the disposer market and reuse market turn out to be the same. If it is so, then the resulting network is a closed loop network **(Salema, 2007).**

The structure, paves the way to devise/make step-by-step procedure that has to be followed during the flow of returned multi-commodities in RSRL network, to recover their value. This step-by-step procedure is given as a framework in section 3.2.

3.2 Framework of Repair Service Reverse Logistics Network

The framework for the analysis of RSRL network model, with multi commodity flows, is given in figure 3.2. This framework enumerates the various stages in the reverse logistics process, which is meant for repair services.

The same framework with some modifications, with distinct relevance of the problem identified is applied to all the models proposed in this research work.

The process starts with the collection of defective commodities from the disposer markets. Defective commodities of different types, i.e., used commodities (multi-commodities), in varying quantities at various points of time are collected from the disposer markets and transported to repair service facilities. In the repair service facility, the commodities undergo preliminary inspection to know the status of the commodities, whether the commodity is serviceable or not. The serviceable commodities are then, subjected to detailed inspection to asses the exact nature of faults of the commodities and the necessary repair woks need to be carried out. The commodities that cannot be serviced or has no secondary value will not pass through any servicing but sent for disposal directly.

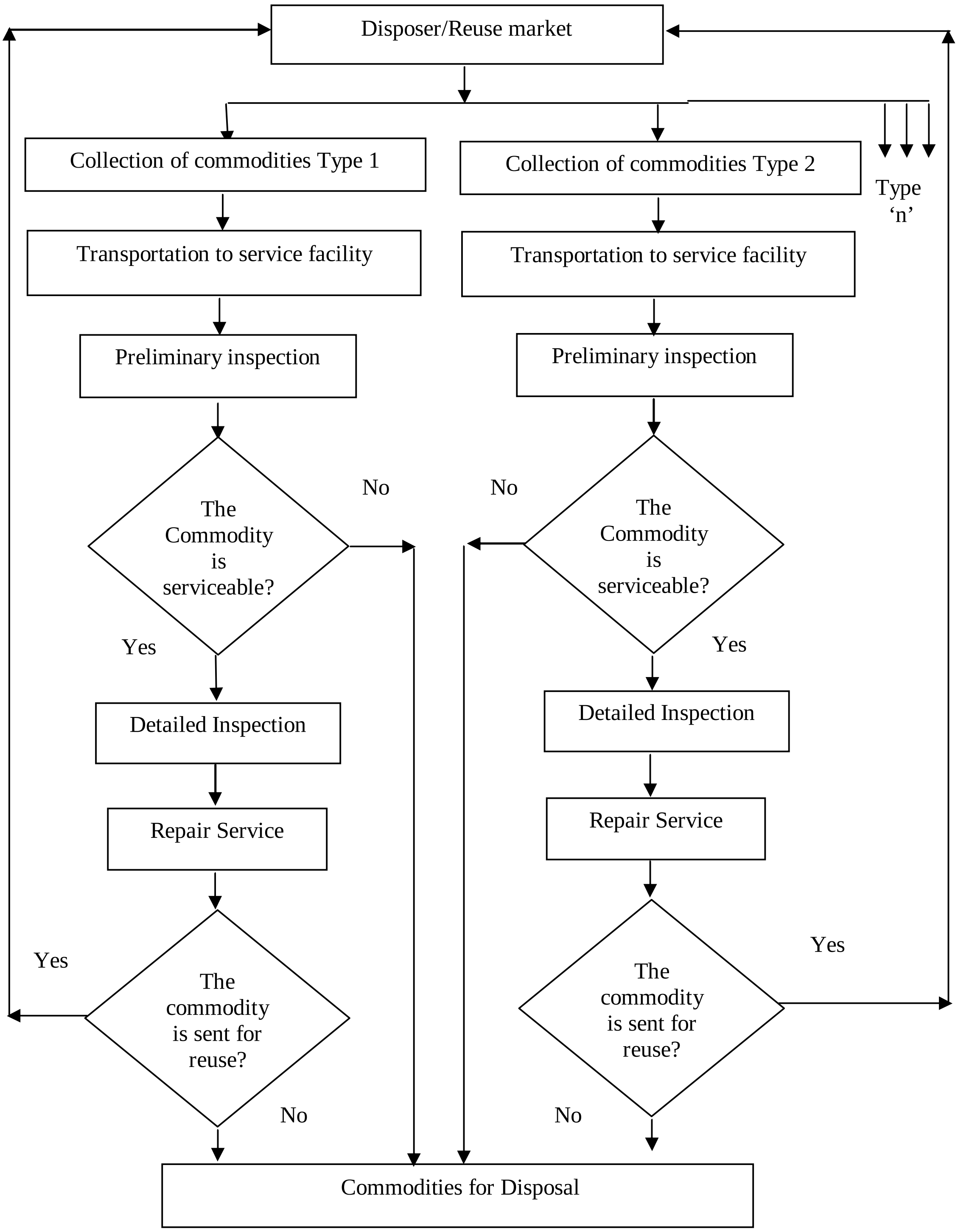

Figure 3.2 Frame work of a Single level Multi-commodity RSRL Network

After repair service, the commodities are sent to reuse markets. At this stage also there is a possibility that a few of the commodities need to be sent for disposal, if their value cannot be recovered even after the repair service work has been completed.

3.3 Data obtained

To analyze RL activities/process for a single level multi-commodity flow, the following data were obtained from an existing manufacturer's repair service facilities. The data have been collected for one calendar year. They are given in Tables 3.1 to 3.9 and Figures 3.3 and 3.4.

Table 3.1 List of Different faults/Problem for Commodity 1

Sl. No	Type of faults/Problem	No. of Commodities
1	Not working	881
2	Cooling Faults • Low cooling • Over ice formation	1463
3	Compressor/Fan faults • Freezer problem • Defrost • Body shake • Sound • Over heat	217
4	Door/Handle faults • Panel Broken • Handle broken • Crisper broken etc.,	230
5	Miscellaneous • Leg broken • Display timer fault • Rust • Spin lid broken • Water leakage • Bad smell • Bulb • Drainage problem etc.,	406
	Total no. of commodities	3197

The data regarding different faults/problems, attended by the repair service facilities, during the period under consideration, for the first commodity are given in Table 3.1. The frequencies of occurrence of the problems or faults for the first commodity are shown in Table 3.2 and Figure 3.3.

Table 3.2 Frequency of faults for First Commodity

l. No	Category of faults	No of commodities	Frequency of faults (%)
1	Not working **(T1)**	881	27.54
2	Cooling Problem **(T2)**	1463	45.76
3	Compressor/Fan **(T3)**	217	6.77
4	Door/Handle **(T4)**	230	7.20
5	Miscellaneous **(T5)**	406	12.70

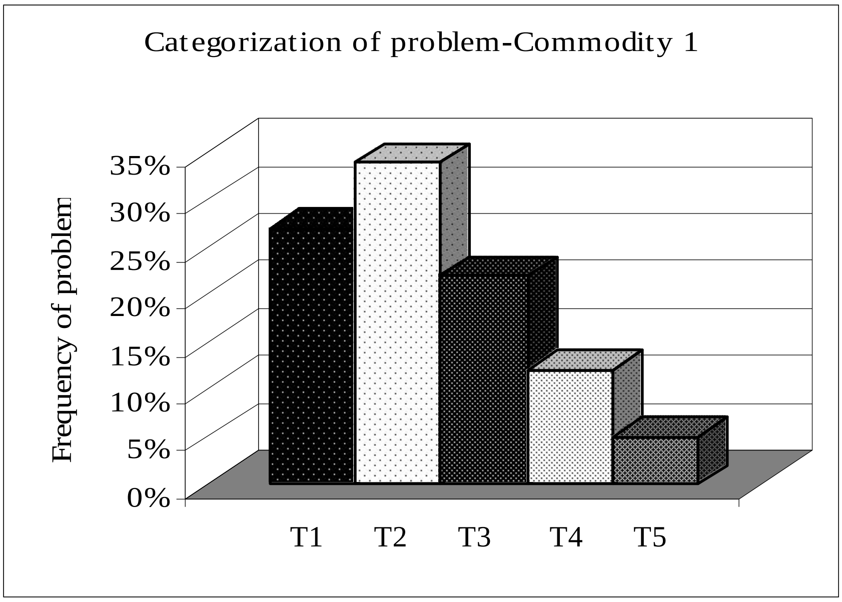

Figure 3.3 Types of problems identified for commodity 1

Similarly, data regarding the problems/faults identified for the second commodity are given in Table 3.3.

The frequencies of occurrence of the problem or fault has been arrived and shown in Table 3.4 and Figure 3.4.

Table 3.3 List of Different faults/Problem for Commodity 2

Sl. No	Type of faults/Problem	No. of Commodities
1	Not working	159
2	Water Leakage problem • Water not coming out • Water line fault • Leak etc.,	204
3	Gear box faults • Vibration • Sound/noise • One side run etc.,	136
4	Door faults • Knob Broken • Door broken etc.,	91
5	Miscellaneous • Spin lid broken • Indicator faults • Low temperature • Drainage problem etc.,	34
	Total no of commodities	624

Table 3.4 Frequency of faults for Second Commodity

Sl. No	Category of faults	No of commodities	Frequency of faults (%)
1	Not working **(T1)**	159	25.45
2	Water Leakage **(T2)**	204	32.72
3	Gear box faults **(T3)**	136	21.81
4	Door faults **(T4)**	91	14.54
5	Miscellaneous **(T5)**	34	5.45

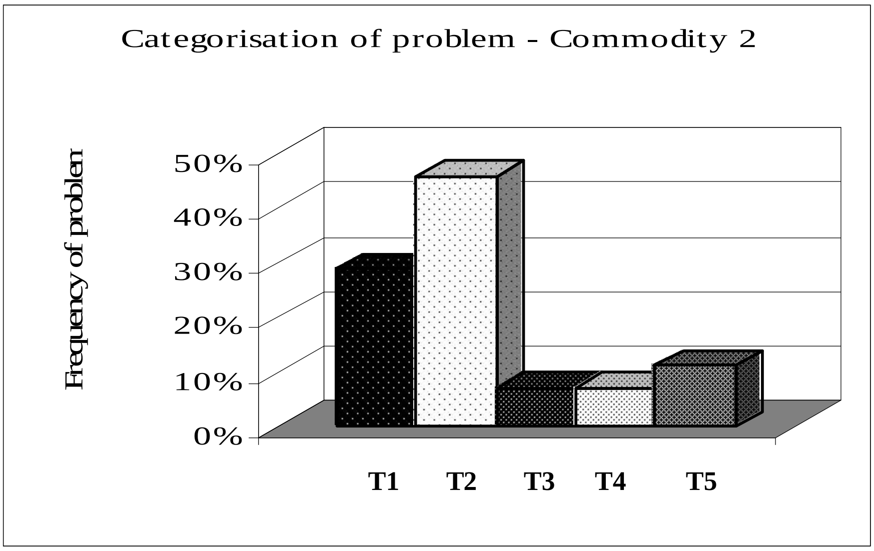

Figure 3.4 Types of problems identified for commodity 2

Customers return the defective/faulty commodities 1 or 2 to any one of the two disposer markets M_{k1} and M_{k2}, depending on the nearness of the service facilities to them. Table 3.5 gives the data about quantity of commodities 1 and 2 returned by the customers to the disposer market(s), M_{k1} and M_{k2} respectively during the period under consideration.

Table 3.5 Disposer Market Returned Quantities

Disposer Market	Yearly Returns (Numbers)	
	Commodity 1	Commodity 2
M_{k1}	1592	304
M_{k2}	1605	320

The yearly demand in the reuse market(s) M_{k3} and M_{k4} or the quantity of the commodities returned after the repair service work and their corresponding selling price for the two different commodities are given in Table 3.6.

Table 3.6 Yearly demand and selling price in Reuse Market

Reuse Market	Commodity		Selling Price (**Rs)**	
	1	2	1	2
M_{k3}	1592	300	3500	3750
M_{k4}	1595	320	3875	3625

Cost of Repair Service facilities to install and maintain the repair service facilities, the manufacturer incurs various costs: Fixed, operating, and transportation costs. Fixed costs consist of the following components:

- Initial set up cost including Tools
- Wages
- Rent
- Security

The data regarding the yearly fixed cost of the repair service facilities are given in Table 3.7.

Table 3.7 Yearly fixed cost in Rs

Capacity	Facility 1	Facility 2
q_1	150000	160000
q_2	100000	140000

The operating cost, i.e., the repair service cost, is the cost towards the recovery of various faults of the commodities. Table 3.8 shows the operating costs for both the commodities 1 and 2.

Table 3.8 Operating Cost in Rs

Capacity	Facility 1		Facility 2	
	Commodity 1	Commodity 2	Commodity 1	Commodity 2
q_1	2880	2520	3000	2640
q_2	2880	2520	3000	2640

The commodities 1 and 2 are collected and transported from the disposer market or customers to the repair service facilities through the company's vehicle. The cost towards the transportation of the commodities is calculated based on the distance travelled by the commodities. The transportation cost for the facilities are shown in the Table 3.9.

Table 3.9 Transportation cost in Rs

Disposer Market	Facility j_1		Facility j_2	
	Commodity 1	Commodity 2	Commodity 1	Commodity 2
M_{k1}	100	125	100	125
M_{k2}	100	125	100	125

This network also includes some penalty costs for the following reasons,

- If the commodities are not collected from the disposer market (M_{k1} and M_{k2}), penalty cost, PR is included.
- If the demand is not satisfied for the reuse markets (M_{k3} and M_{k4}), penalty cost, PD is included.
- If any commodity is disposed (When its value is not recoverable), disposal cost, DC is included in the network model.

Data assumed:

Each repair service facility has servers to make necessary repair service on the incoming returns to recover the value. The capacity level of the servers for both commodities 1 and 2 at each repair service facility is given in Table 3.10.

Table 3.10 Repair Service Facilities and Capacity levels

Capacity	Facility 1		Facility 2	
	Commodity 1	Commodity 2	Commodity 1	Commodity 2
q_1	800	180	800	180
q_2	820	200	820	200

Table 3.11 gives the data regarding the penalty costs incurred due to not collecting the returns from the disposer market (M_{k1} and M_{k2}),) and unsatisfied demand (PD), of the reuse market (M_{k3} and M_{k4}).

Table 3.11 Penalty Cost in Rs

Disposer Market/ Reuse Market	Returns not collected (PR)		Demand not satisfied (PD)	
	Commodity 1	Commodity 2	Commodity 1	Commodity 2
M_{k1}, M_{k2}	50	75	…	…
M_{k3}, M_{k4}	…	…	75	50

Table 3.12 shows the fraction of disposal of total quantity of commodity flows in each repair service facilities, j_1 and j_2. The cost towards number of the commodities disposed and the holding costs incurred, when, commodities stay in the repair service facilities, are also shown in the same table.

Table 3.12 Disposal fraction, Disposal cost, and Holding cost in Rs

Repair Service Facility	Disposal Fraction (D)	Disposal Cost		Holding Cost	
		Commodity 1	Commodity 2	Commodity 1	Commodity 2
j_1	6.5%	50	50	75	50
j_2	6.5%	50	50	75	50

3.4 Single Level Multi-Commodity RSRL Network Model

Here the modeling of a single level, multi-commodity RSRL Network with multi-commodities flow is presented. The model formulated to analyze the problems that are taking place during the recovery of value of the returned commodities in a manufacturer's repair service facilities. The model consists of following factors.

- Revenue: The total revenue of the network, which is the product of the number of repair serviced commodities and their corresponding selling price.

- Fixed Cost: The costs towards the Initial set up cost including Tools, Wages, Rent, and Security.

- Operating cost: Nothing but repair service cost. It is the cost towards the recovery of various faults of the commodities and it varies depending on the nature of the faults.

- Holding cost: The cost towards the inventory of the number of commodities stayed in the repair service facilities.

- Transport cost: Cost towards the transportation of the commodities collected form the disposer markets to the repair service facilities.

- Penalty Cost for not satisfying demand: a penalty cost is included in the model formulation, if the demand of the reuse market is not satisfied.

- Penalty Cost for not collecting the returns: another penalty cost is included, if the returned commodities are not collected from the disposer market or customers.

- Disposal Cost: Disposal cost is also included in the formulation, when the commodities are sent for disposal, if it has no secondary value.

It is taken that the fixed cost for repair servicing and capital investment, F, for a given repair service facility increases with the capacity level of that facility. The operating cost, R, incurred on servicing a commodity is the variable cost for different problems of a particular commodity that taken over a specified period under consideration. A fixed amount is taken as the unit inventory/holding cost, H, for the commodity, which stays in the repair service facility. The transportation cost, T, is assumed to be incurred on every commodity transported from the disposer market to the specified repair service facility.

This model simultaneously takes care of the flow, and allocation of multi-commodities, in a single level serving. The prime objective of the model formation is improving the total profit of the network. Hence,

Profit = Revenue – Total cost

Max

$$\begin{aligned}\sum_{k}\sum_{j}\sum_{i} C_{ijk}P_{ik} - \Bigg(&\sum_{q}\sum_{j}\sum_{i} F_{ij}(q)B_{ij}(q) + \sum_{q}\sum_{j}\sum_{i} R_{ij}(q)C_{ij}(q)\\ &\sum_{j}\sum_{i} H_{ij}E(N)_{ij} + \sum_{j}\sum_{k}\sum_{i} T_{ikj}C_{ikj} + \sum_{k}\sum_{i} D_{ik}U_{ik}P_{ik}^{u} +\\ &\sum_{k}\sum_{i} yr_{ik}w_{ik}P_{ik}^{w} + \sum_{j}\sum_{i} C_{ij}dc_{ij}\Bigg)\end{aligned} \tag{1}$$

With the following constraints

Repair service facility

$$R_{ik}(1-w_{ik}) = \sum_{j} C_{ikj} \qquad \forall_k, \forall_i \tag{2}$$

$$\sum_{k}\sum_{i} C_{ikj} - D_{ij} = \sum_{q}\sum_{i} C_{ij}(q) \qquad \forall_j, \forall_i \tag{3}$$

$$\sum_{q}\sum_{i} C_{ij}(q) = C_{ijk} \qquad \forall_j, \forall_i \tag{4}$$

Capacity

$$C_{ij}(q) \geq M_{ij}(q) \qquad \forall_i, \forall_j \tag{5}$$

$$\sum_{q} B_{ij}(q) \leq 1 \qquad \forall_i, \forall_j \tag{6}$$

Logical

$$B_j(q) = [0,1] \qquad \forall_j, \forall_q \tag{7}$$

$$C_{ij}(q) \geq 0 \qquad \forall_j, \forall_q, \forall_i \tag{8}$$

$$C_{ikj} \geq 0; \quad C_{ijk} \geq 0; \qquad \forall_j, \forall_k, \forall_i \tag{9}$$

$$0 \leq w_{ik} \geq 1 \qquad \forall_k, \forall_i \tag{10}$$

$$0 \leq u_{ik} \geq 1 \qquad \forall_k, \forall_i \tag{11}$$

Disposer markets (M_{k1} and M_{k2}) and reuse markets (M_{k3} and M_{k4}) are considered to be the subset of customer locations, M. Presently, because of the nature of the problem under consideration, the following assumption has also been made: Those who reuse the repair-serviced commodities are the same as those who have returned them to the RL network.

The constraint (2) is introduced to ensure that all, or at least a part of the returned commodities, multi-commodities, leave the disposer markets ‘M_{k1} and M_{k2}’ to a service facility ‘j’. All the incoming flow at each facility ‘j’ need not be repaired for various reasons. To account for this constraint (3) is introduced.

The commodity at facilities ‘j’, after repair service is sent to the reuse market ‘M_{k3} and M_{k4}’ and the same is given in constraint (4). It is assumed that each repair service facility works to its maximum installed capacity, M_{ij} (q). The constraints (5) and (6) take care of this aspect of the problem. Constraints (7) to (11) are logical constraints.

Customer in the disposer market is the source for the queuing network. The commodities arrive at the repair service facility, ‘j’ with an average arrival rate of λ_{ij} that is equal to C_{ikj}, which is the total commodity flow to the repair service facility ‘j’. Hence, the arrival rate of the commodity ‘i’ is given by,

$$\lambda_{ij} = R_{ikj}(1 - w_{ikj}) = \sum_{j} C_{ikj}$$

At a facility ‘j’, the average arrival rate equals to,

$$\lambda_{ij} = \sum_{k} \lambda_{ikj} = \sum_{j} C_{ij}(q)$$

The mean effective repair service rate μ_{ij}, which is the inverse of t_{ij} which, is equivalent to the maximum capacity level M_{ij} (q), at which the repair service facility ‘j’ is installed.

$$t_{ij} = \frac{1}{\mu_{ij}} = \frac{1}{\sum_{q} R_{ij}(q) B_{ij}(q)}$$

The expression for the expected yearly inventory cost at the facility ‘j’ can be formulated using Little’s law. Here, the relationship between the expected waiting time and the expected number of commodities in the facility has been taken into account.

$$H_{ij}[E(N)_{ij}] = H_{ij}[\lambda_{ij} E(W)_{ij}]$$

The expected waiting time of a commodity, $E\ (W)_{ij}$ consists of the expected waiting time of the individual commodities in the queue $E\ (Q)_{ij}$ and the expected repair service time ‘t_{ij}’. Hence, the expected cycle time is,

$$E(W)_{ij} = E(WQ)_{ij} + t_{ij}$$

The overall expression for finding out the yearly inventory cost of the commodities at facility ‘j’, taking into account the effective repair service time ‘t_{ij}’ and the effective utilization level ‘ρ_i’ can be given as,

$$IC = \sum_{i} H_{ij} \lambda_{ij} \left[\frac{\mu_{is} (\lambda_{is} / \mu_{is})^{c}}{(c_{is} - 1)! (c_{is} \mu_{is} - \lambda_{is})^{2}} \right] \times \frac{1}{\sum_{n=0}^{c-1} \left[\frac{\mu_{is} (\lambda_{is} / \mu_{is})^{n}}{n!} + \frac{\mu (\lambda_{is} / \mu_{is})^{c}}{c_{is}!} X \frac{c_{is} \mu_{is}}{c_{is} \mu_{is} - \lambda_{is}} \right]} + \frac{1}{R_{is}(q)}$$

3.5 Solution Methodology

RL is different from forward logistics in several ways. One of them is that the volume and types of returned goods are uncontrollable. The processes of managing, controlling and the allocation of multi-commodities into the repair service facilities in the RSRL Network involve many complexities. Despite of that, they can still be estimated. Simulation, which is one of the practical tools, is chosen to support the flow of multi-commodities in this proposed RSRL network.

Table 3.13 Computational Results

Variables			Setting 1 Commodity		Setting 2 Commodity		Setting 3 Commodity	
			1	2	1	2	1	2
C_{ikj}	Supply (k) → Facility (j)							
	1	1	755	140	770	150	800	140
	1	2	810	144	822	154	792	164
	2	1	800	165	785	155	810	170
	2	2	832	175	820	165	795	150
C_{ijk}	Facility (j) → Demand (k)							
	1	1	706	131	720	140	748	131
	1	2	757	134	769	144	741	153
	2	1	748	154	734	145	757	159
	2	2	778	164	767	154	743	140
R_i(q)	Facility (j) → Capacity(q)							
	1	2	800	180	800	180	800	180
	2	2	820	200	820	200	820	200
C_{ikj}	Satisfied demand (k)							
		1	1454	285	1454	285	1505	290
		2	1535	298	1536	298	1484	293
$E(N)_{ij}$	Facility(j)							
	1		199	6	199	6	199	6
	2		46	4	46	4	46	4
Profit in **Rs**			723752.43		724252.43		694582.43	

The data presented in tables 3.1 to 3.12 and Figures 3.3 and 3.4 are used in the proposed RSRL Network model. Different settings of allocation of flow of commodities into the repair service facilities are analyzed and the computational results obtained are tabulated in Table 3.13.

3.6 Validation of the Model

In this work, Reverse Logistics Networking model for multi-commodity flow have been analyzed. The theoretical simulations (results obtained from the model developed) have been validated with real time data from the organization which is under consideration.

3.7 Results and Discussion

RL network, in general, can provide an efficient management of return flows. The RSRL network model for multi-commodity flows, proposed here resulted better management of returned commodities into repair service facilities. The model simulated with real time data obtained from existing repair service facilities. The following are the outcomes.

Flow of multi-commodities into existing repair service facilities are analyzed with different settings.

Table 3.14 Analysis of Flow of Commodities (Setting I)

Supply	Repair service facility	Setting I Commodity		Profit **(Rs)**
		1	2	
1	1	755	140	723752.43
1	2	810	144	
2	1	800	165	
2	2	832	175	

Among the three different setting, the overall profit of the network along with the flows of commodities 1 and 2 from the disposer market to existing repair service facilities as per setting I, are shown in Table 3.14.

Table 3.15 show the flow of commodities handled with setting II, through simulation. The allocation of the commodities 1 and 2 to repair service facilities resulted improved profit when compared with setting I.

Table 3.15 Analysis of Flow of Commodities (Setting II)

Supply	Repair service facility	Setting II Commodity		Profit **(Rs)**
		1	2	
1	1	770	150	724252.43
1	2	822	154	
2	1	785	155	
2	2	820	165	

Setting III implies a low margin of profit when compared with the other two settings. Hence, from the three different settings, it is observed that the control of flow of commodities 1 and 2 into repair service facilities can be made effectively with simulation.

Table 3.16 Analysis of Flow of Commodities (Setting III)

Supply	Repair service facility	Setting III Commodity		Profit **(Rs)**
		1	2	
1	1	800	140	694582.43
1	2	792	164	
2	1	810	170	
2	2	795	150	

Multi servers are considered in this model and their capacity levels are assigned, in such a way that all the incoming commodities are serviced regularly, in the repair service facilities. Hence the arrival rate (λ) along with the service rate (μ) depends on the number of servers (c). So,

$$\lambda/c\mu < 1$$

Holding costs are taken into account based on the inventory of expected number of commodities 1 and 2, stayed at each repair service facilities as shown in Table 3.13.

A penalty cost is included in the model for not satisfied demand of the reuse market due to the disposal of the commodities, which are not serviceable.

Looking at the flow of commodities into repair service facilities, all the incoming commodities to the repair service facilities are serviced and sent to reuse market/customers. Hence best customer response obtained with satisfied service levels.

To sum up, simulation results help in taking a decision on how the reverse flow of the commodities can be handled by channelizing them suitably either to the first or to the second repair service facility. This type of approach in the allocation of the returned multiple commodities to the repair service facilities resulted in better performance of the repair service facilities and maximized profits.

CHAPTER 4
REVERSE LOGISTICS NETWORKING FOR MULTI COMMODITY FLOWS WITH MULTI-LEVEL SERVICING

4.1 Introduction

The objective of this chapter is to provide an overall understanding and analysis of reverse logistics network in multi-commodities environment with multi-level servicing. Network design assumes major strategic importance, especially when multi-commodities have to be handled in multi-levels. The problem of multi-level servicing with the flow of multi-commodities in the RSRL Network can be analyzed through mathematical modeling framework. This modeling can capture the practical aspects of network problems that deal with variety of returns, which require services at multiple levels to attain some market value.

To analyze the above said problem with flow of multi-commodities in multi-levels, a modeling has been done with the twin objectives of achieving maximum profit from the multi-level service facilities, which handle the returned commodities, and customer satisfaction. This model is formulated as a RSRL Network model. Solution to the model is obtained and also discussed here.

4.1.1 Basic structure of single level Multi-commodity RSRL Network

A RSRL network with multi-commodities flow, establishes the flow of used commodities between disposer markets/consumers and the repair service facilities at multi levels. Then, it establishes the flow of serviced commodities between repair service facilities at different levels and the reuse markets. Figure 4.1 shows the basic structure of the multi level, multi-commodity RSRL network. The structure incorporates the possible transportation links with the disposer market, repair service facilities at two-levels, and reuse markets.

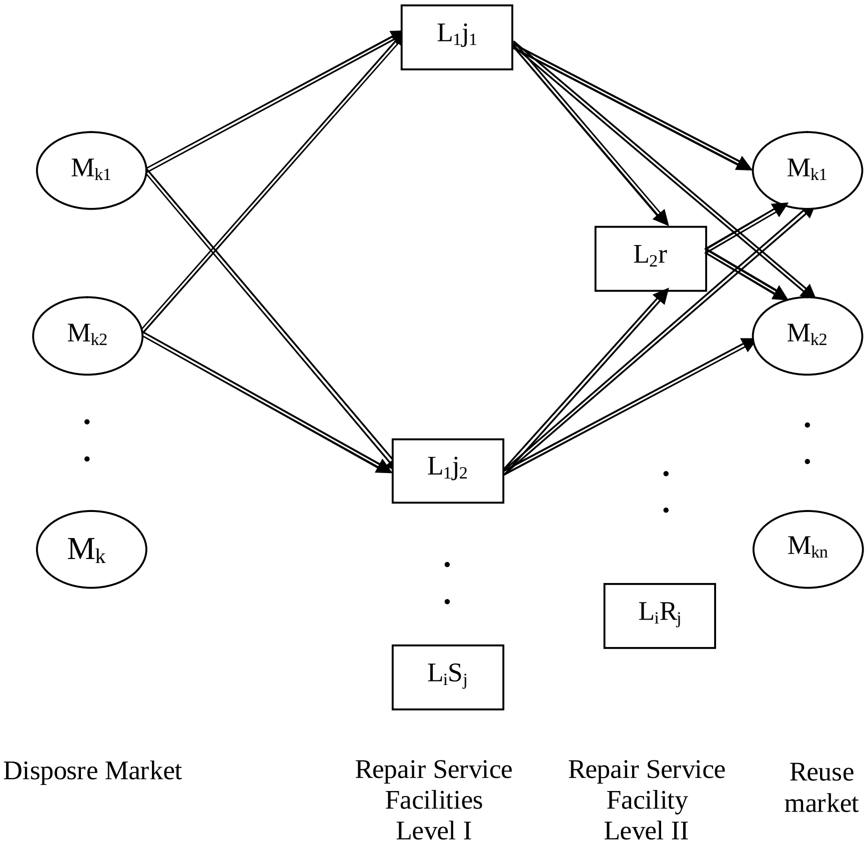

Figure 4.1 Structure of Multi level Multi-Commodity RSRL Network

The network structure, paves the way to devise/make step-by-step procedure that has to be followed during the flow of returned multi-commodities at different levels in RSRL network, to recover their value. This step-by-step procedure is given as a framework in section 4.2.

4.2 Frame work of RSRL with Multi-level Servicing

The framework of RSRL Networking for the analysis of multi-commodities flows with multi-level servicing is the modified one, which is used in chapter 3.2 with the relevance to the problem of multi-level servicing. The step-by-step flow of the commodities and service extended at various stages are clearly depicted in framework as shown in figure 4.2.

In the current instant, the transportation of commodities between collection sites and service facilities in first level (L_1) and second level (L_2) is considered on individual basis i.e., the returned commodities are not collected at one place and transported to the repair service facilities in batches (This assumption is mere suitable for more service facilities).

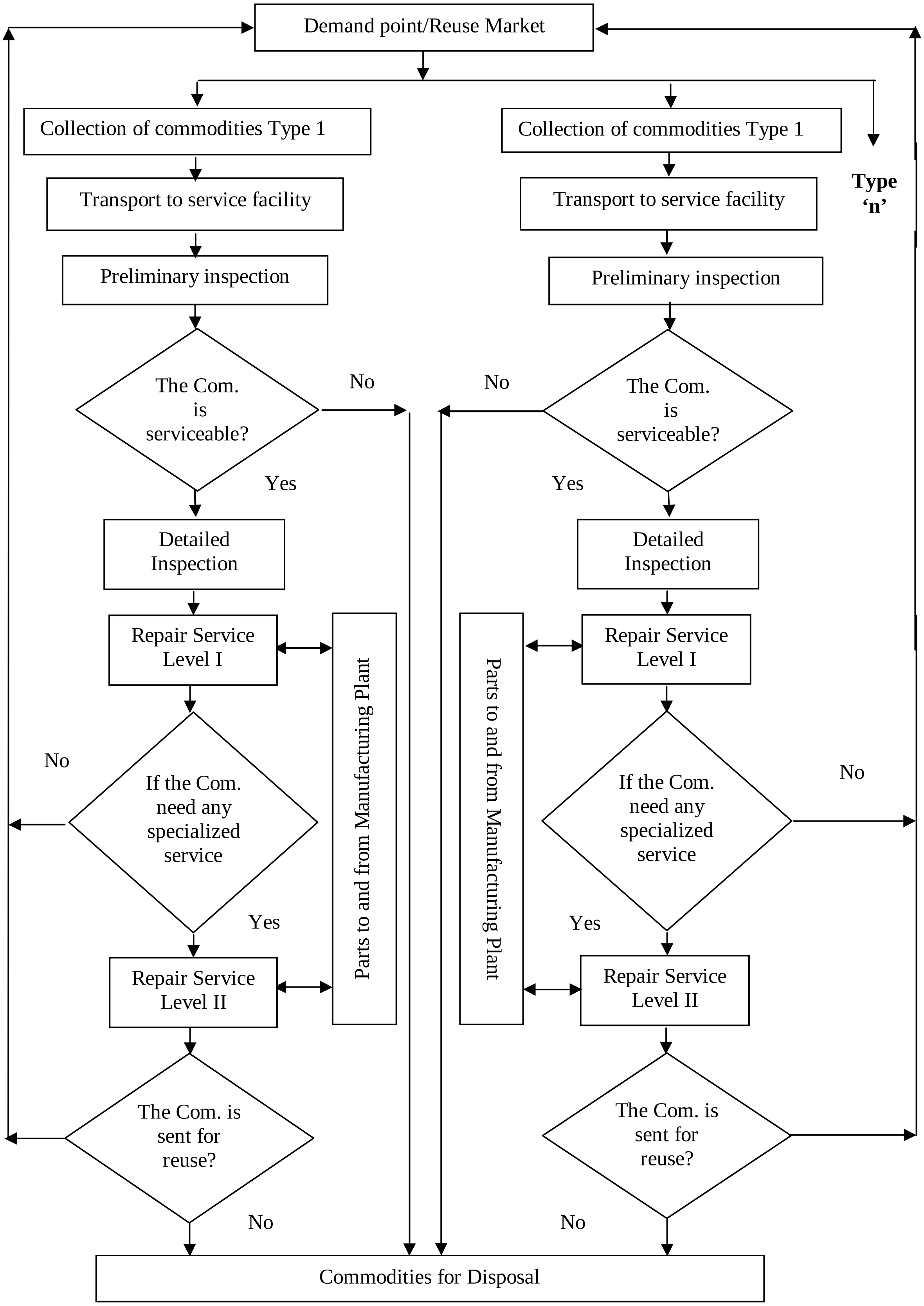

Figure 4.2 Multi level Multi-Commodity RSRL Network

The repair service process starts from the disposer market/customer, with the collection of defective commodities 1 and 2. Used commodities (multi-commodities), in varying quantities at various points of time are collected from the disposer markets and transported to repair service facilities. In the repair service facility, the commodities undergo preliminary inspection to know the status of the commodities, whether the commodity is serviceable or not. The serviceable commodities are then, subjected to detailed inspection to asses the exact nature of faults of the commodities and the necessary repair woks need to be carried out. The commodities that cannot be serviced or has no secondary value will not pass through any servicing but sent for disposal directly.

After repair service, the commodities are sent to reuse markets or otherwise it may sent to second level repair service facilities due to the reasons that full value of the commodities cannot be recovered in the first level repair service facilities. The reasons may be of insufficient tools/equipments, parts, expertise, etc., Hence the commodities are sent to second or next level repair service facilities to recover their full value.

It is assumed that all the incoming commodities in the second level repair service facilities are repair serviced and sent to reuse market i.e. there is no disposal. At this stage also there is a possibility that a few of the commodities need to be sent for disposal, if their value cannot be recovered even after the repair service work has been completed.

Periodically, the defective parts, which are to be replaced, are sent to the plants of the manufacturer for remanufacturing or for other purposes, and the replacements are transported to the service facilities from the manufacturer’s plant.

4.3 Multi- level Multi-Commodity Reverse Logistics Network Model

Here the modeling of a multi level, multi-commodity RL flow network is formulated, with repair service as a recovery process, in a manufacturer’s repair service facilities. The prime objective of the model is to achieve maximum profit of the network while imparting better service satisfaction to the customers.

Max Profit = Revenue – Total cost

Max

$$\sum_{k}^{o}\sum_{j}^{m}\sum_{i}^{n}C_{ijk}\,P_{ik}+\sum_{k}^{o}\sum_{r}^{s}\sum_{i}^{n}C_{irk}P_{ik}-\left(\sum_{q}^{p}\sum_{r}^{s}\sum_{i}^{n}F_{ij}(q)B_{ij}(q)+\right.$$
$$\sum_{q}^{p}\sum_{r}^{s}\sum_{i}^{n}F_{ir}(q)B_{ir}(q)+\sum_{q}^{p}\sum_{r}^{s}\sum_{i}^{n}R_{ij}(q)\,C_{ij}(q)+\sum_{q}^{p}\sum_{r}^{s}\sum_{i}^{n}R_{ir}(q)C_{ir}(q)+$$
$$\sum_{j}^{m}\sum_{i}^{n}H_{ij}E(N)_{ij}+\sum_{r}^{s}\sum_{i}^{n}H_{ir}(N)_{ir}+\sum_{j}^{m}\sum_{k}^{o}\sum_{i}^{n}T_{ikj}\,C_{ikj}+\sum_{r}^{s}\sum_{j}^{m}\sum_{i}^{n}T_{ijr}C_{ijr}$$
$$\left.\sum_{k}^{o}\sum_{i}^{n}D_{ik}U_{ik}P_{ik}^{u}+\sum_{k}^{o}\sum_{i}^{n}yr_{ik}w_{ik}P_{ik}^{w}+\sum_{j}^{m}\sum_{i}^{n}C_{ij}dc_{ij}\right) \tag{1}$$

with respect to the following constraints,

Repair Service (at level I)

$$R_{ik}\left(1-w_{ik}\right)=\sum_{j}^{m}\sum_{k}^{o}\sum_{i}^{n}C_{ikj} \qquad \forall_{k},\forall_{i} \tag{2}$$

$$\sum_{j}^{m}\sum_{k}^{o}\sum_{i}^{n}C_{ikj}-D_{ij}=\sum_{q}^{p}\sum_{j}^{m}\sum_{i}^{n}C_{ij}(q) \qquad \forall_{q},\forall_{j},\forall_{i} \tag{3}$$

$$\sum_{q}^{p}\sum_{j}^{m}\sum_{i}^{n}C_{ij}(q)=C_{ijk} \qquad \forall_{j},\forall_{k},\forall_{i} \tag{4}$$

Repair Service (at level II)

$$\sum_{q}^{p}\sum_{j}^{m}\sum_{i}^{n}f\,C_{ir}(q)=\sum_{r}^{s}\sum_{j}^{m}\sum_{i}^{n}C_{ir} \qquad \forall_{q},\forall_{i} \tag{5}$$

$$\sum_{r}^{s}\sum_{j}^{m}\sum_{i}^{n}C_{ir}=\sum_{q}^{p}\sum_{r}^{s}\sum_{i}^{n}C_{ir}(q) \qquad \forall_{q},\forall_{i} \tag{6}$$

$$\sum_{q}^{p}\sum_{r}^{s}\sum_{i}^{n}C_{ir}(q)=C_{irk} \qquad \forall_{k},\forall_{i} \tag{7}$$

Capacity (at level I)

$C_{ij}(q) \le M_{ij}(q)$ $\quad \forall_i, \forall_q, \forall_j$ (8)

$C_{ij}(q) \ge M_{ij}(q-1)$ $\quad \forall_i, \forall_q, \forall_j$ (9)

$\sum_q B_{ij}(q) \le 1$ $\quad \forall_j$ (10)

Capacity (at level II)

$C_{ir}(q) \le M_{ir}(q)$ $\quad \forall_i, \forall_q$ (11)

$\sum_q B_r(q) \le 1$ (12)

Logical (at level I)

$B_j(q) = [0,1]$ $\quad \forall_j, \forall_q$ (13)

$C_{ij}(q) \ge 0$ $\quad \forall_j, \forall_q, \forall_i$ (14)

$C_{ikj} \ge 0; \quad C_{ijk} \ge 0;$ $\quad \forall_j, \forall_k, \forall_i$ (15)

Logical (at level II)

$B_r(q) = [0,1]$ $\quad \forall_r, \forall_q$ (16)

$C_{ir}(q) \ge 0$ $\quad \forall_r, \forall_q, \forall_i$ (17)

$C_{ikr} \ge 0; \quad C_{irk} \ge 0;$ $\quad \forall_r, \forall_k, \forall_i$ (18)

Others

$0 \le w_{ik} \ge 1$ $\quad \forall_k, \forall_i$ (19)

$0 \le u_{ik} \ge 1$ $\quad \forall_k, \forall_i$ (20)

In order to facilitate the closed-loop RSRL Network modeling, the disposer market and the reuse markets are taken as one and the same. It literally means that in a closed-loop supply chain, those who reuse the commodities are the same as those who have disposed them. The constraints that link up the input and output streams at a facility are as follows: constraint (2) is introduced to ensure that all, or at least a part of the returned commodities, multi-commodities, leave the disposer markets (M_{k3} and M_{k4}), to a repair service facility, ‘j’. All the incoming flow at each facility ‘j’ need not be serviced for various reasons. To account for the part of the serviced flow, constraint (3) is introduced.

All the useful commodities at facility ‘j’ after servicing are sent to reuse markets (M_{k1} and M_{k2}), or to the next level (level L_2) for specialized service works, if the commodity needs and the same is considered in constraint (5). All the incoming commodities to the service level II are serviced and this is given in constraint (6). After the specialized service work, the commodities sent to demand points are taken care of by the constraint (7). Each facility was assumed be installed at its maximum capacity, and the constraints (8) to (12) are meant for that. Constraints (13) to (20) are the logical constraints.

The arrival rate of the commodity, the expected yearly inventory cost at the facility, the average expected waiting time (the cycle time) of a commodity, and the yearly cost of the repair service of the facilities are found by the same method followed in section 3.4.

4.4 Computational Results

The multi-level, multi-commodities flow RSRL Network developed in this work is an extension of the model developed in chapter 3. To analyze RL activities for a multi-level multi-commodity flow, data were obtained from an existing manufacturer’s repair service facilities. The data have been collected based on the different faults, which are attended by the repair service facilities, during the period under consideration, for the commodities 1and 2 are given in Table 3.1 to 3.4 and Figures 3.3 and 3.4.

The following Table 4.1 to Table 4.5 shows the data obtained form the repair service facilities at multi-levels (in this case two levels).

Customers return the defective commodities 1 or 2 to any one of the two disposer markets M_{k1} and M_{k2}. During the repair service, a few of the commodities cannot get recovered their full value, due to insufficient tools/equipment, spares, expertise etc. These commodities are sent to next level facilities to recover their full value. Table 3.5 gives the data about the quantity of commodities returned.

The yearly demand in the reuse market(s) M_{k3} and M_{k4} and their corresponding selling price for the two different commodities at two different levels are given in Table 4.1.

Table 4.1 Yearly demand and Seling price in Reuse Market (Two-Level)

Reuse Market	Demand		Level I		Level II	
			Selling Price (**Rs)**		Selling Price (**Rs)**	
	Commodity1	Commodity2	Commodity1	Commodity2	Commodity1	Commodity2
M_{k3}	1592	304	3000	2625	4563	3875
M_{k4}	1595	320	3125	2750	4750	4313

The fixed cost of Repair Service facilities to install and maintain the repair service facilities at different levels, are given in Table 4.2.

Table 4.2 Yearly fixed cost in Rs

Capacity	Level I		Level II
	Facility 1	Facility 2	Facility 1
q_1, q_2	250000	300000	325000

Table 4.3 shows the operating costs for both the commodities 1 and 2 at different levels.

Table 4.3 Operating Cost in Rs

Capacity	Level I		Level II
	Facility 1	Facility 2	Facility 1
q_1, q_2	250000	300000	325000

The transportation cost for the facilities are shown in the Table 4.4.

Table 4.4 Transportation cost in Rs

Capacity	Level I				Level II	
	Repair Service Facility 1		Repair Service Facility 2		Repair Service Facility 1	
	Commodity		Commodity		Commodity	
	1	2	1	2	1	2
q_1	50	50	50	50	75	75
q_2	50	50	50	50	75	75

Data assumed:

The capacity level of the servers for both commodities 1 and 2 at each repair service facility in level I and II are given in Table 4.5.

Table 4.5 Repair Service Facilities and Capacity levels

	Level I				Level II	
	Facility 1		Facility 2		Facility 1	
	Commodity		Commodity		Commodity	
	1	2	1	2	1	2
q_1	500	250	500	250	200	100
q_2	500	250	500	250	200	100

Table 4.6 gives the data regarding the penalty costs incurred due to not collecting the returns (PR) from the disposer market (M_{k1} and M_{k2}),) and unsatisfied demand (PD), of the reuse market (M_{k3} and M_{k4}).

Table 4.6 Penalty Cost in Rs

Disposer/ Reuse Markets	Level I				Level II	
	Repair Service Facility 1		Repair Service Facility 2		Repair Service Facility 1	
	(PR)		(PD)		(PR)	(PD)
	Commodity1	Commodity2	Commodity1	Commodity2	Commodity1	Commodity2
$M_{k1,}$ M_{k2}	50	50	--	--	--	--
$M_{k3,}$ M_{k4}	--	--	50	50	--	--

Table 4.7 shows the fraction of disposal of total quantity of commodity flows in each repair service facilities, j_1 and j_2 along with disposal costs and the holding cost.

Table 4.7 Disposal fraction, Disposal cost, and Holding cost in Rs

Repair Service Facility	Disposal fraction	Disposal cost		Holding cost	
		Commodity1	Commodity2	Commodity1	Commodity2
j_1	5%	50	50	50	50
j_2	5%	50	50	50	50
r_1	--	--	--	50	50

The simulation involves the number of returned commodities and the service facilities with operational costs, i.e., the fixed and using cost, service cost, transportation cost, holding cost, penalty cost and disposal costs.

Table 4.8 Returns to level II

Repair service facility	Returns (Numbers)		Price (Rs)	
	Commodity 1	Commodity 2	Commodity 1	Commodity 2
L_2r	454	89	1250	1000

In the service facility at level II, it is assumed that all the incoming commodities from level I facilities, are repair serviced. There is no penalty of not collecting the returns or not satisfied demand and also there is no disposal in level II facility. Table 4.8 shows the total number of commodities flows in level II repair service facility.

Table 4.9 Computational Results

Variables			Setting 1		Setting 2		Setting 3	
			Commodity		Commodity		Commodity	
			1	2	1	2	1	2
C_{ikj} Supply (k) to facility (j) to level I								
	1	1	665	152	733	142	769	161
	1	2	847	135	780	144	743	125
	2	1	755	138	745	147	765	157
	2	2	760	166	780	157	760	147
C_{ijj} Facility level I to level II								
	1	1	227	43	227	43	226	43
	2	1	227	46	229	46	229	46
C_{ijk} Facility (r)-level II to Demand (k)								
	1	1	565	129	623	121	654	137
	1	2	720	115	663	122	632	106
	2	1	642	117	633	125	650	133
	2	2	646	141	663	133	646	125
C_{ijk} Facility (r)-level II to Demand (k)								
	1	1	227	43	227	43	226	43
	1	2	227	46	229	46	229	46
$R_{ij}(q)$ Facility (j)-level I Capacity (q)								
	1	2	500	250	500	250	500	250
	2	2	500	250	500	250	500	250
$R_{ir}(q)$ Facility (r)-level II Capacity (q)								
	1	2	200	100	200	100	200	100
C_{ikj} Satisfied demand (k) from level I								
Facility 1			1207	246	1256	246	1304	270
Facility 2			1366	256	1326	255	1278	231
C_{ikj} Satisfied demand (k) from level II								
Facility 1			454	89	456	89	455	89
E $(N)_{ij}$ at Facility (j) at level I								
1			2	1	3	1	4	1
2			6	1	4	1	3	1
Facility (r) at level II								
1			4	1	3	1	4	1
E $(W)_{ij}$ at Facility (j) at level I								
1			5.163	6.346	6.224	6.265	7.047	6.426
2			10.191	6.124	7.354	6.280	6.429	6.144
Facility (r) at level II								
1			6.212	6.698	6.472	6.304	6.943	6.390
Profit in (Rs)			2249212		**2257835**		2255404	

The data presented in tables 3.1 to 3.4, Tables 4.1 to Table 4.8 and Figures 3.3 and 3.4 are used in this model. We analyzed the problem of flow control of multi-commodities into existing repair service facilities with different settings. The computational result obtained is given in Table 4.9.

4.5 Validation of the Model

In this work Reverse Logistics Networking model for multi-commodity flows with multi-level servicing have been developed and analyzed. The theoretical simulation results obtained from the model developed have been validated with real time data from the organization under consideration.

4.6 Results and Conclusion

Reverse Logistics, whose importance has been heightened by increasing concerns about the environment, customer service, and cost reduction, is considered as an integral part of the supply chain of many manufacturing companies. Determining how much of the returning commodities should be sent to which existing facilities in order to maximize the total cost incurred has been the focus of this work. The formulated model adequately takes care of the service activities carried out in multi-level repair service facilities.

The results implies that, among the three different settings of the analysis of the flow of multi-commodities in multi-level servicing, setting II gives better performance of the network and the same is given in table 4.10.

Table 4.10 Analysis of Flow of Commodities (Multi-Level)

Supply	Repair service facility (L1)	Setting II Commodity		Profit **(Rs)**
		1	2	
1	1	733	142	2257835
1	2	780	144	
2	1	745	147	
2	2	780	157	
Level I	Level II			
	r			
1	1	227	43	
2	1	229	46	

Effective control of flow of multi-commodities into the repair service facilities and their chanalization and allocation into which repair service facilities, depending on the capacity of the servers has been attained through simulation.

All the incoming commodities to the repair service facility at level II are fully repair serviced and sent to reuse market/customers. Table 4.11 shows the demand satisfied in level II (no disposal at Level II, since the problem of the commodities is exactly identified in level I repair service facilities and hence, the respective repair service work is performed at level II).

Table 4.11 Demand satisfied in level II

Supply to Level II		Demand satisfied from level II	
Repair service facility ‘r’		Repair service facility ‘r’	
Commodity 1	Commodity 2	Commodity 1	Commodity 2
227	43	456	89
229	46		

Demand of the reuse customer is satisfied from level I, after disposing 5% of the incoming commodities. This is done, to account for the number of commodities, where it is not possible to recover their value or it, posses no secondary value.

The expected number of commodities stayed in each repair service facilities, in setting II is minimized when compared with other settings and it is shown in Table 4.9. The average expected waiting time of the commodities is found and is given in the Table 4.12.

Table 4.12 Expected waiting time of the commodities (Min)

Level I		Level II	
Commodity 1	Commodity 2	Commodity 1	Commodity 2
7.065	6.205	6.542	6.464

The table shows the average expected waiting time of the commodities 1 and 2 in two level repair service facilities. The waiting time of the commodities as per setting II (Table 4.9) is lower when compared with other settings and it is almost same for commodities 1 and 2.

To sum up, the analysis of the problem of multi-commodities with multi-level serving through three different settings resulted better management of the flow of the commodities in RSRL network. Handling of returned multi-commodities in a repair service facility, **as per setting II** with queueing system reduces the expected number of commodities and the waiting time of the customers and it gives an opportunity to increase customer satisfaction levels.

Also, the results help in planning for the number of repair service facilities for the given capacities to reap maximum profit from the manufacturer's repair service facilities perspective.

With multi-level servicing, the repair service cost of the commodities may increase due to the additional work performed in level I. Even though the cost is increased, the model resulted better customer satisfaction since, the repair service facilities itself takes the responsibility of sending the commodities to level II from level I, for any additional work to be performed.

CHAPTER 5
MULTI-COMMODITY REVERSE LOGISTICS NETWORKING WITH QUALITY LEVELS

5.1 Introduction

In Reverse Logistics, for an effective value recovery, it is important to know the extent of fault or problem in the returned commodities to be attended to. But, there exists uncertainties in the condition of the commodity returns are, for the reasons for service requirements may multifaceted and it may happen in varying quantities. The arrival time of the commodities may also be varying. So, when these problems are also taken into account in RL, the network design becomes more complicated.

The returned commodities, with different quality levels cannot be treated in the same way because of the varying levels of problems involved in it. To handle such cases in the multi-commodity environment, a new method in the reverse logistics context is proposed to consider the inherent quality variations in the returned commodities through a Random Variation Approach (RVM). Mathematical model has been built with such additional constraint to characterize the Multi-commodities flow in Reverse Logistics Network with different levels.

This method provides a basis for assessing the status of the commodities in the reverse flow and to take a decision on the repair service activities that can be made available. This treatment considers the cost structure for the repair service process dependent logically on the status of the commodity. It is expected that the proposed approach may reduce or eliminate some of the inaccuracies involved in arriving at the characterization of the network wherein an average fixed service cost is assigned for the commodities returned and it is much essential in the phase of the rush for diversification of commodities and to thwart the competition in the market. This model basically aims at minimizing the total cost, which includes setting up and repair service costs incurred on the returned commodities in one or more service facilities.

The formulation of RSRL Network models with the consideration of quality/status of the returned commodities in single level and multi level are analyzed and the discussion on the results obtained, through simulation are presented in this chapter.

5.1.1 Basic Structure of Multi-commodity Reverse Logistics Network with quality level

With detailed explanation, the structure of a single level multi-commodity RSRL Network is given in Figure 3.1 and the structure of a multi-level multi-commodity RSRL Network given in Figure 4.1. The same networks are taken as basis to study the problem of multi-commodities flow with the consideration of quality of the returned commodities. The commodities are checked for their quality through a randomized variational approach before they allowed to take up their repair service work.

5.2 Frame Work of Reverse Logistics Network with Quality Levels

The modified framework, relevant to this particular application is shown in Figure 5.1 and 5.2.

The returned, used products from the disposer market is collected and transported to the repair service facility after identifying the type of the commodities (commodities 1 and 2). At Repair Service Facility, a preliminary inspection is performed on the incoming commodities to asses the condition, whether, the commodities can be serviceable or not. The serviceable commodities are then allowed for detailed inspection. Others are disposed.

During the detailed inspection, the faults of the commodities are identified and compared with Random Variation method. RVM, categorize the different problems into different groups. These different groups need different service work to be performed, each involves variable service costs. This step allows for an incoming commodity, to get what type of service to be performed. Then the repair work is carried out and the commodity is sent back to the reuse customer. There is a possibility of disposal of a few commodities, which may not regain their value, after taking up the services also. Figure 5.1 shows the framework for single-level multi-commodity RSRL Network with Random Variation Method. The same framework, i.e. the step-by-step procedure is applicable for different type of commodities. The frame work for multi-level network with RVM, is shown in the figure 5.2

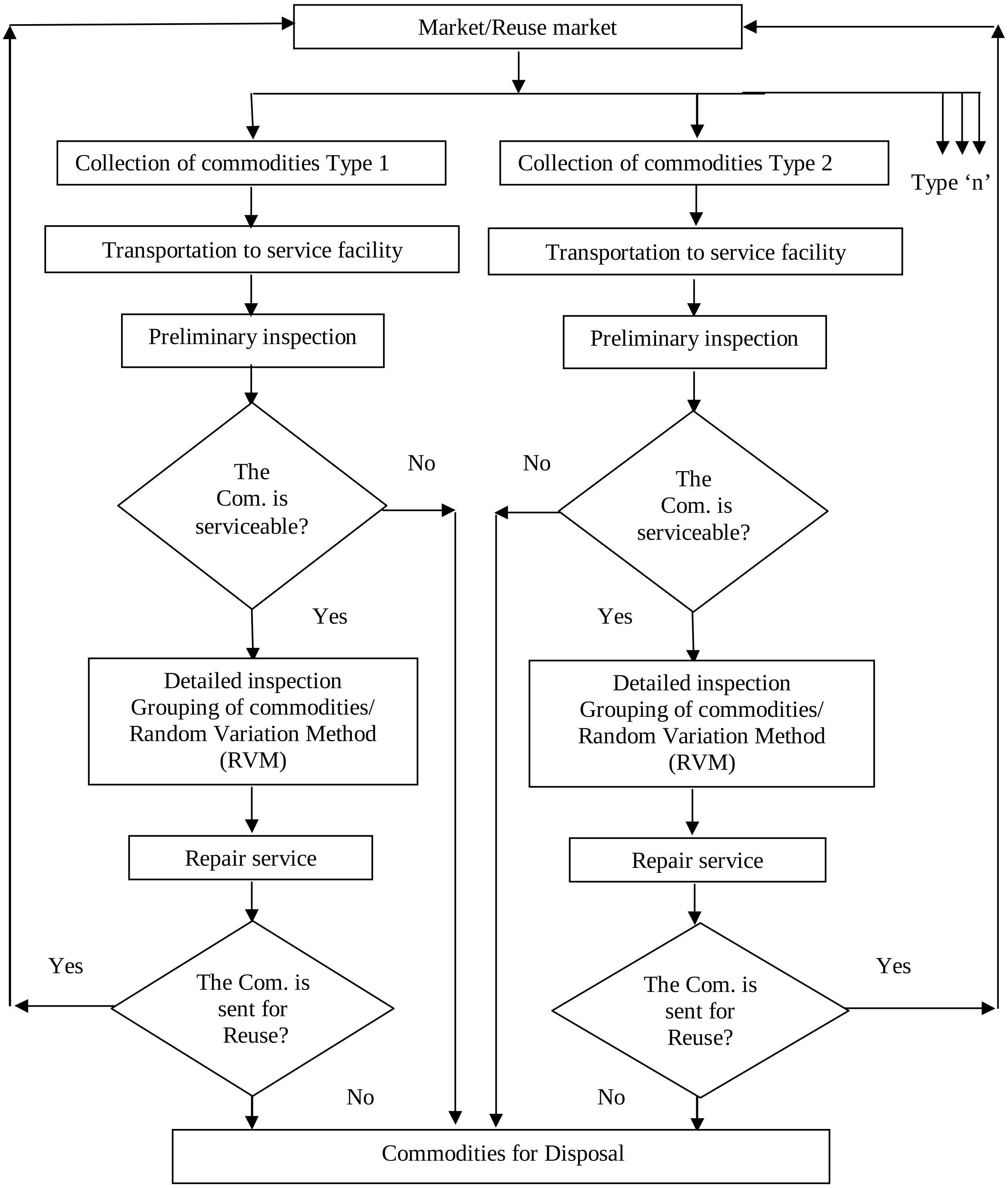

Figure 5.1 Frame work for single-level multi-commodity RSRL Network with RVM

In addition to the first level facilities, the multi-commodities, as per this model (multi-level servicing), are sent to next level repair service facilities in order to recover their full value. This may happen when the commodities are not able to

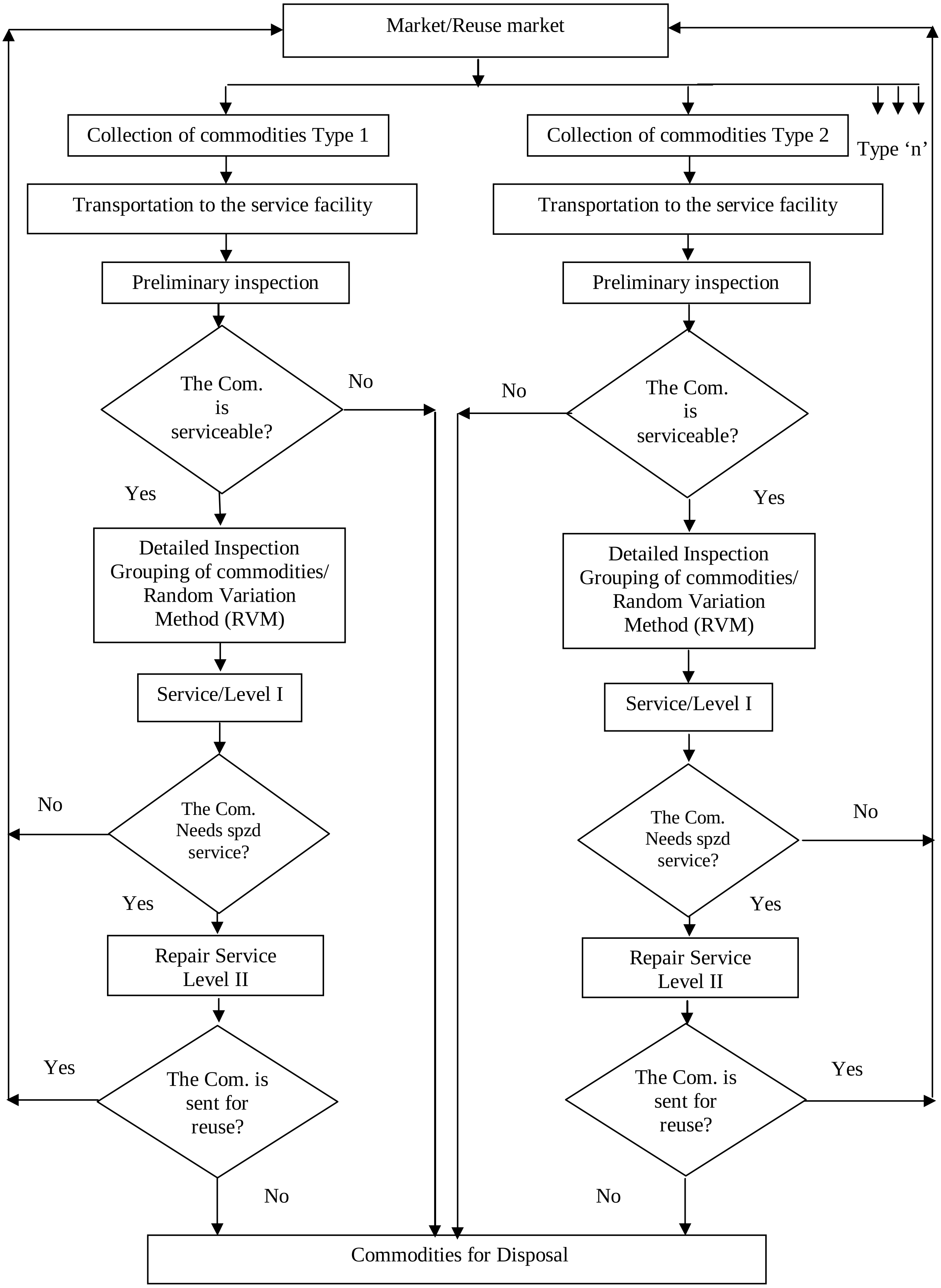

Figure 5.2 Frame work of RLN with Multilevel multi commodity flow with RVM

recover their value after getting serviced from the first level facilities alone. This may be due to non-availability of tools/equipment, spares, shortage of expertise etc. or the condition of the returned commodities.

After the repair service from level II, the commodities, which have regained their full value, are sent to disposer market. Others are disposed as scrap.

5.3 Single-level Multi-commodity Reverse Logistics Network Model with RVM

A single level, multi-commodity RSRL closed loop network model with multiple service facilities with a random variation approach is constructed to have better control on the cost, revenue, and render predefined service level. This model also takes into account the cycle time, which is found by introducing queueing relationships into the network. The main difference of this model as compared to the model discussed elsewhere is that it is capable of handling quality variations in the multi-commodity environment.

This model assumes that the location of the repair service facilities are specified in advance and all facilities are installed at maximum capacity with different costs. The details of the different cost involved in the RSRL Network are given in section 3.4.

In the stated situation, the major consideration is deciding on the capacity levels of the repair service facilities satisfying both minimum investment and operational costs and maximum customer satisfaction. The capacity level of any repair service facility depends on the number of servers installed at that repair service facility.

The RSRL Network model for a single level multi-commodity network given in chapter 3 is used here with the application of Random Variation Method. Only the difference is that, in this model, the returned commodities after detailed inspection is compared with random variation approach to know the exact problem it has and the corresponding repair service that can be made available.

A Service cost depending on the extent of repair service work was performed is claimed. This service cost differs according to the nature of the problem of the returned commodities.

Data regarding the different types of the faults, the frequency of occurrence and their categorization of faults identified, yearly supply and demand of the returned commodities and the various costs, disposal fractions for commodity 1 and 2 in first level, which are used in previous chapter is used here also.

5.4 Multi Level Multi-Commodities RSRL Network Model with RVM

This model is the extension of the single level multi-commodity RSRL Network. The commodities after getting repair serviced in first level facilities (Leve1I) may be sent to other facilities, if a few of the commodities need to get any additional or specialized repair service work, which are not available in the first level facility. To analyze the problem of this kind, i.e. multilevel servicing for the incoming returns in RL, a multi-level, multi-commodities RSRL Network model is proposed. For this analysis, the model discussed in chapter 4 is used here with the consideration of the quality levels. To assess the flow of multi-commodities into second level facilities, here, it is assumed that about 25% of the incoming commodities to the repair service facilities at Level I is, on need to get some additional or specialized work at level II.

During the survey at repair service facility, it was found that, 2 to 3 commodities among the arrival of every 10 commodities are sent for getting additional or some specialized service. Hence It is assumed that approximately 25% of commodities needs multi-level (here, it is second level) repair service works. This flow of commodities in level II is given in the following tables.

Table 5.1 shows the type of faults and their frequency of occurrence for specialized work that has to be done at second level repair service facilities for the commodities 1 and 2.

Table 5.1 Frequency of Specialized work at Level II

Type of fault	Commodity 1		Commodity 2	
	Frequency of occurrence **Level I**	Assessed through RVM **Level II**	Frequency of Occurrence **Level I**	Assessed through RVM **Level II**
T1	46%	11.5%	34%	8.5%
T2	7%	1.75	22%	5.5%

The variable costs involved in the RSRL network for repair service of multi-commodities at level I and II are given in Tables 5.2 to 5.5.

Table 5. 2 Repair service cost and selling price at Level I

Type of fault	Repair service cost (R), **(Rs)** Level I		Market price (P) **(Rs)**	
	Facility 1	Facility 2	Commodity 1	Commodity 2
T1	2400	2300	3000	2875
T2	1350	1250	1687.5	1562.5
T3	2000	2000	2500	2500
T4	1000	900	1250	1125
T5	750	750	937.5	937.5

Table 5. 3 Repair service cost and selling price at Level II

Type of fault	Repair service cost (R), **(Rs)** Level II		Market price/Selling Price (P) **(Rs)**	
	Commodity 1	Commodity 2	Commodity 1	Commodity 2
T1	2000	1800	2500	2250
T2	1750	1500	2187.5	1875

Table 5.4 Different cost involved in Repair service facilities at Level 1, (Rs)

Facility (L_1j_1)	F	H	T	PD	U	PR	w	D
Commodity 1	25000	50	100	75	0.02	50	0.0	100
Commodity 2	125000	50	100	75	0.02	50	0.0	100
Facility (L_1j_2)								
Commodity 1	150000	50	125	50	0.02	75	0.0	100
Commodity 2	150000	50	125	50	0.02	75	0.0	100

Table 5.5 Different cost involved Repair service facility at Level II, (Rs)

Facility (L_2r_1)	F	H	T	PD	U	PR	W	D
Commodity 1	300000	50	125	50	0.02	75	0.0	100
Commodity 2		50	125	50	0.02	75	0.0	100

5.5 Computational results

In order to make services based on the extent of faults of the returned commodities, the RVM is used to appraise the status of the commodity returned. To obtain best results, we used simulation, which is one of the practical tools. It is chosen in order to manage, control and to allocate the flow of multi-commodities in the RL Network.

The models were simulated with the real time data obtained from existing service facilities for consumer electronic goods for a period of one year. The data presented in Tables 5.2 to 5.5 are used in the proposed RL Network models. The simulation involves the number of returned commodities and the repair service facilities with different repair service cost towards the different types of problems in different levels. The commodities collected from the disposer markets are allocated based on their quality; to different repair service facilities at different levels with different settings and the computational results obtained (level 1) are tabulated in Table 5.6 to Table 5.8.

Table 5.6 Simulation result based on RVM (Run 1 and 2)

Flow	Supply (k)	Facility (j)	Commodity (i)		E (N) in (j)		E(W) in (j)		Market (k)		Profit (Rs) **(Total)**
			1	2	1	2	1	2	3	4	
Run 1	1	1	770	155	199		0.125		765	149	927905.25
	1	2	822	150		6		0.019	769	162	
	2	1	785	165	46		0.028		780	155	
	2	2	820	154		4		0.014	804	151	
Run 2	1	1	770	155	199		0.125		770	155	960661.25
	1	2	822	150		6		0.019	822	150	
	2	1	785	165	46		0.028		785	165	
	2	2	820	154		4		0.014	820	154	

By regulating the allocation of commodities to the service facility, the model gives increased profit as shown in table 5.7, as below.

Table 5.7 Simulation Result based on RVM (Run 3 and 4)

Flow	Supply (k)	Facility (j)	Commodity (i)		E (N) in (j)		E(W) in (j)		Market (k)		Profit (Rs) **(Total)**
			1	2	1	2	1	2	3	4	
Run 3	1	1	720	150	14		0.009		720	150	987031.31
	1	2	722	140		5		0.015	722	140	
	2	1	835	165	0		0.000		835	165	
	2	2	870	169		6		0.017	870	169	
Run 4	1	1	720	150	14		0.125		715	150	958937.31
	1	2	722	140		5		0.019	722	140	
	2	1	835	165	0		0.028		826	160	
	2	2	870	169		5		0.014	865	165	

Similarly the multi-level network model is simulated with the data obtained and the results are tabulated in table 5.8.

Table 5.8 Computational results

Variables			Setting 1		Setting 2		Setting 3	
			Commodity1	Commodity2	Commodity1	Commodity2	Commodity1	Commodity2
C_{ikj} Supply (k) → facility (j) to level I								
	1	1	852	180	810	170	700	160
	1	2	740	129	782	132	892	142
	2	1	828	178	805	165	795	145
	2	2	773	142	800	155	800	175
C_{ijj} Supply → Facility level I → level II								
	1	1	226	44	226	43	227	43
	2	1	228	45	229	46	227	46
C_{ijk} Facility (j)- level lI → Demand (k)								
	1	1	809	174	769	161	665	152
	1	2	703	123	743	125	847	135
	2	1	787	169	765	157	755	138
	2	2	734	135	760	147	760	166
C_{ijk} Facility (j)-level II → Demand (k)								
	1	1	226	44	226	43	227	43
	1	2	228	45	229	46	227	46
$R_{ij}(q)$ Facility (i)-level I → Capacity (q)								
	1	2	500	250	500	250	500	250
	2	2	500	250	500	250	500	250
$R_{ij}(q)$ Facility (i)-level II → Capacity (q)								
	1	2	250	100	250	100	250	100
from level I C_{ikj} Satisfied demand (k)								
	1		1512	297	1512	286	1512	287
	2		1521	304	1526	304	1515	304
from level II								
		1	454	89	455	89	454	89

Table 5.8 Computational results (cont…)

Variables		Setting 1		Setting 2		Setting 3	
		Commodity1	Commodity2	Commodity1	Commodity2	Commodity1	Commodity2
Facility(j) → level I $E(N)_{ij}$ Expected no of commodities (No)							
	1	5	1	4	1	3	1
	2	3	1	4	1	6	1
Facility (j) → level II							
	1	1	1	1	1	10	1
Facility(j) → level I $E(W)_{ij}$ Expected waiting time (minutes)							
	1	8.33	8.88	6.22	7.35	5.16	8.41
	2	5.69	7.95	8.23	8.27	10.19	8.12
Facility (j) → level II							
	1	0.022	0.012	0.026	0.012	0.023	0.012
Profit in **Rs**		4049097.25		3807865.12		3643428.30	

In summary, the profit is increased (**Rs. 59,126.06 in single level and Rs. 4, 05,668.95 in Multi level facilities)** when if all the incoming commodities are serviced or if there is no disposal of returned commodities. The proper allocation of the commodities to the service facilities, based on the knowledge of the waiting time and the expected number of commodities to be stayed in the facilities may result in increased profit.

5.6 Validation of the Model

In this work Reverse Logistics Networking model by considering the inherent quality levels of the returned commodities have been developed and analyzed. The results obtained have been validated with real time data from the organization under consideration.

5.7.1 Results and Discussion

In this work, a closed loop RSRL Network model is formulated with the consideration of problem of flow of multi-commodities with different quality level in repair service facilities. Here the problem of the flow of multi-commodities into existing repair service facilities with different flow patterns in multiple levels has been analyzed with different flow settings. This model resulted improved profit along with satisfied service levels.

The network model was simulated with real time data obtained in existing repair service facilities. The results can be listed as follows.

Random Variation approach gives an appropriate direction to fix, repair service cost depending on the type and extend of the fault attended and it is varies from fault to faults.

A single level multi-commodity flow RSRL Network model with RVM is analyzed through four different runs. Settings I and II, resulted with a possibility of having more number of commodities to be stayed in the repair service facilities with less profit.

But the profit was improved with simulation runs 3 and 4. During this runs, the number of commodities stayed is reduced considerably when compared to runs 1 and 2. And the run 3 gives better results when compared with other settings.

Table 5.9 Overall Profit at Level I

Run	No. of commodities Stayed		Overall Profit (Rs)
	1	2	
1	245	10	927905.25
2	245	10	960661.25
3	14	11	987031.31
4	14	10	958937.31

The flow of commodities into existing repair service facilities with the run 3, resulted an optimized flow, with less no of commodities to be stayed and Table 5.9 shows the same.

The model with Multi-level servicing with RVM resulted, good control on the allocation of the multi-commodities into multi-levels. The number of commodities stayed in different levels is minimized. Table 5.10 depicts the same.

Table 5.10 Overall profit at Level II

Setting	No. of commodities Stayed		Overall Profit (Rs)
	1	2	
1	8	2	4049097.25
2	8	2	3807865.12
3	9	2	3643428.30

Effective control on handling and allocation of commodities to repair service facilities were established with Random variation Method.

Allocation of multi-commodities to the repair service facilities through Random Variation Method, with queueing, reported better results.

The application of Random Variation Method overcomes the constraints of fixing common service cost towards all the faults of a particular commodity. It helps in fixing different repair service cost structures for commodities depending on the extent of repair service requirement, which is more appropriate and practical.

CHAPTER 6
GENETIC ALGORITHM BASED FLOW CONTROL IN REVERSE LOGISTICS NETWORKS

6.1 Introduction

The flow control of multi-commodities in RL Network is analyzed by presenting the nature and magnitude of a RL problem, which arises in manufacturer's repair service facilities, where the repair services of the commodities are made using Genetic Algorithm approach.

RSRL Network formulation with multi-commodities flow into repair service facilities is analyzed and the results obtained with genetic heuristics presented along with the comparison of simulation results.

6.2 Single Level Multi-Commodity RL Network Model – Genetic Algorithm Approach

The structure and frame work for a single-level, multi-commodity flow in RL Network is given in figure 4.1 and in Figure 4.2. In this work, the flow of commodities into the existing repair service facilities is made based on the Genetic Algorithm approach. From the Disposer market, commodities are collected, and channelized, based on the Genetic Algorithm approach. That is, GA assigns which commodity should flow into which repair service facility. Then the commodities are sent to the repair service facility, where it undergoes repair service work. The model of a single level, multi-commodity RL flow network proposed in chapter 3 is used here. The difference is, here the multi-commodity flow control and their allocation into different repair service facilities are made based on GA algorithm.

Customers return their commodities, when it needs any repair service work, to the respective disposer market. From the disposer market, the commodities are sent to repair service facilities. The controls towards the assignments of flow of commodities into repair service facilities are made based on GA heuristics. After the repair service, the commodities are returned back to the reuse market i.e. the customers who have returned them.

The situation stated here has the major consideration of assigning the flow of multi-commodities into repair service facilities through GA based heuristics and to decide on the capacity levels of the repair service facilities, while satisfying both minimum investment and operational costs and maximum customer satisfaction.

6.3 Development of Genetic Algorithm

The concept of GAs was first proposed by Holland and then described by Goldberg. GA is referred to as a stochastic solution search procedure that is designed to solve combinatorial problems using the concept of evolutionary computation imitating the natural selection and biological reproduction of animal species **(Goldberg, 1989)**. In the past, GA has been successfully applied to classical combinatorial problems such as capacitated plant location **(Gen et al. 1999),** fixed charge location,**(Jaramillo et al. 2002)** minimum spanning tree **(Zhou and Gen, 1999),** network design **(Palmer and Kershenbaum, 1995)** and warehouse allocation **(Zhou et al. 2003)**. Given this proven effectiveness of GA for various combinatorial problems, GA is suitable for solving the RL network design problem.

Another application of GA includes its flexible solution search process that can convert constrained problems into unconstrained problems and then cross the feasibility boundary to find near-optimal or optimal solutions in an intelligent (probabilistic) manner rather than relying on random enumerations or iterations. In particular, GA is chosen over other meta-heuristics procedures due to its ability to generate a collection of solutions rather than a single solution at each stage. Prior to the application of GA, the genetic representation (or chromosome) of the candidate solutions has to be designed. Herein, a chromosome represents each solution in the initial solution set of solutions (population).

The size of the population depends on the size and the nature of the problem at hand. The chromosome evolves through a crossover operator and a mutation operator to produce children, improving on the current set of solutions. The chromosomes in the population are then evaluated through a fitness function and the less fit chromosomes are replaced with better children. The processes of crossover, evaluation and selection are repeated for a predetermined number of iterations called generations, usually up to the point where the system ceases to improve or the population has converged to a few well performing chromosomes.

GA works with a population of binary strings, not the parameters themselves. To solve the RL Network design problem for commodities returns, here Genetic Algorithm approach (GA) is proposed. For simplicity and convenience, binary coding is used in this paper. With the binary coding method, the RSRL, Multi-commodity flow problem would be coded as binary string of 0’s and 1’. Each parameter has upper and lower bounds.

6.4 Genetic Algorithm Applied to Reverse Logistics

The step-by-step procedure for the GA algorithm proposed to solve the given problem for taking the decision on allocating the returned commodities is given in figure 6.1.

Encoding

The basic requirement in using GA for any problem is the proper representation of the chromosome (design variables) because, it applies probabilistic transition rule on each chromosome to create a population of chromosomes, representing a good candidate solution. Here, each chromosome developed is based on single dimensional array, which consists of binary values, representing the decision variables.

Each commodity in the network flow has five design variables that uniquely characterize a commodity flow. All of these variables vary between pre-specified bounds that are determined based on the servicing/manufacturing constraints. Each of these variables is represented as a binary-coded variable in the genetic algorithm. Since this problem deals with different commodity flows, the total number of design variables is the product of the number of design variables (in this case five) and the total number of commodities (in this case 2 commodities) in consideration. The representation of a typical population string is shown in Figure 6.2. Each of these variables determines the commodity flow across the existing repair service facilities

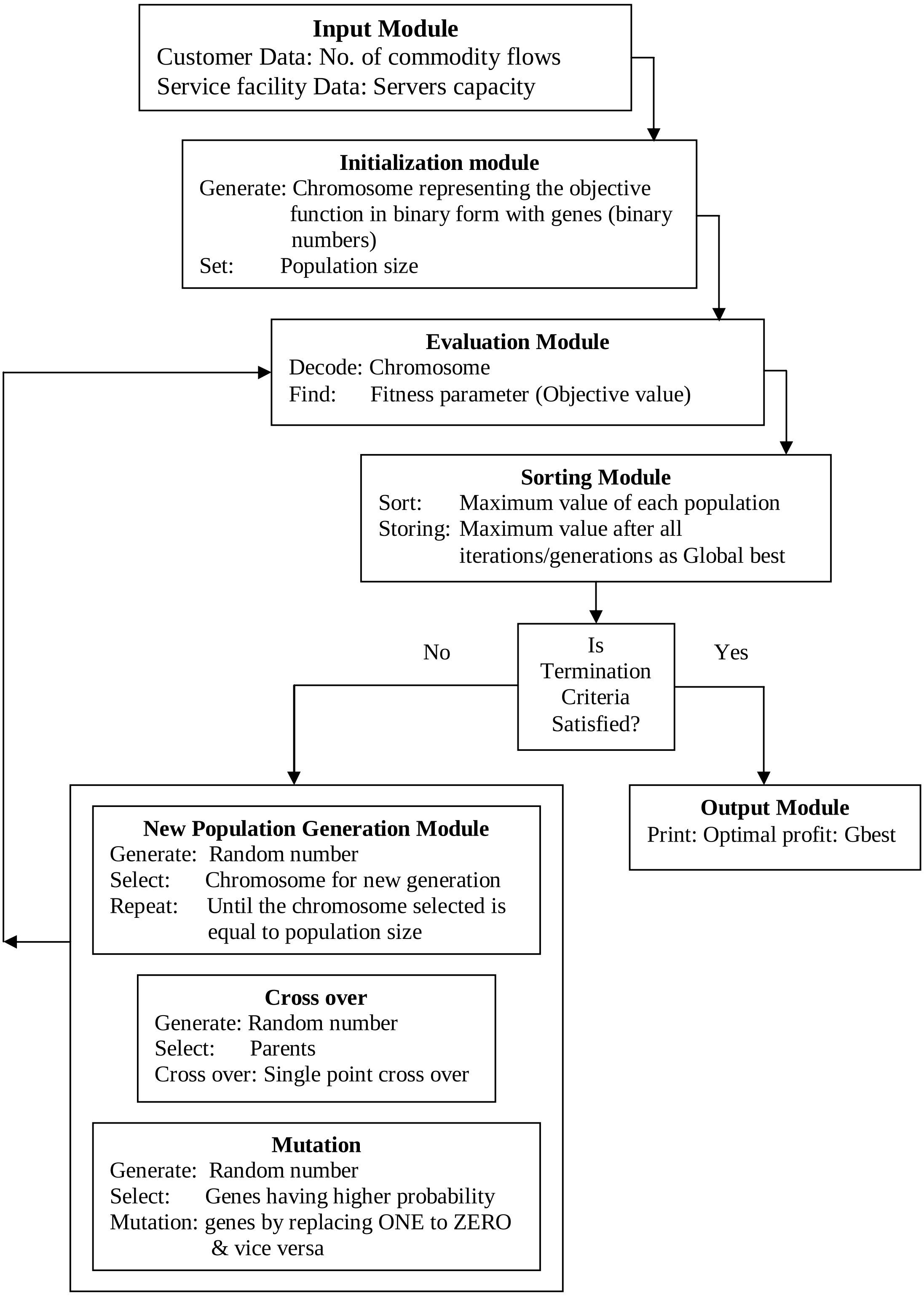

Figure 6.1 Genetic Algorithm applied to reverse logistics

The design variables and their representation, which have been used to solve the problem allocation in RSRL Network of multi-commodity flow, are shown in figure 6.2.

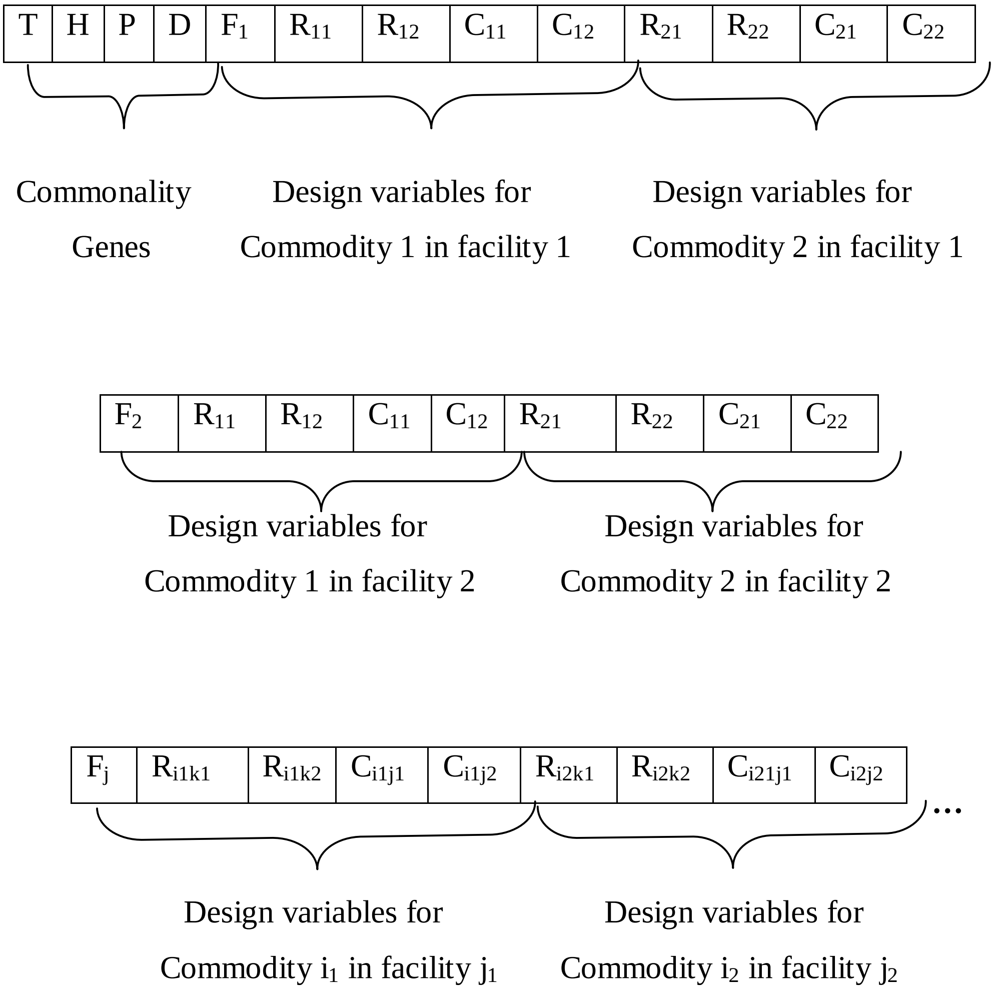

Figure 6.2 GA Representation of design variables for the commodity flows

The design variables are as follows:

- Fixed cost of a service facility F,
- The repair service cost for commodity 1 in facility 1, which is coming from disposer market 1, R_{11}
- Repair service cost for commodity 2 in facility 1, which is coming from disposer market 2, R_{12}
- The number of flow of commodity 1 in facility 1, which is coming from disposer market 1, C_{11}
- Number of flow of commodity 2 in facility 1, which is coming from disposer market 2, C_{12}

- Respective commonality variables viz., Transportation cost T, holding cost H, Penalty cost P, and disposal cost D.

The design variables presented above are examples and used for multiple commodities that are flows into a single service facility. The design variables for the multiple service facilities have been adopted following the same approach.

Genetic operators

The proposed GA solution procedure used four genetic operators described below:

Cloning operator

The cloning operator involves keeping the best solutions. In the proposed GA, the procedure works in such a way that it copies 20 percent of the current best chromosomes to a new population.

Parent selection operator

The parent selection operator is an important process that directs a GA search toward promising regions in a search space. Two parents are selected from the solutions of a particular generation by selection methods that assign reproduction opportunities to each individual parent in the population. There are a number of different selection methods, such as roulette wheel selection, tournament selection, rank selection, elitism selection, and random selection **(Gen and Cheng, 2000).** For this experimentation, a binary tournament selection method is used by forming two teams of chromosomes. Each team consists of two chromosomes randomly drawn from the current population. The two best chromosomes that are taken from one of the two teams are chosen for crossover operations. As such, two offspring are generated and enter into a new population.

Crossover operator

The crossover operator generates new children by combining information contained in the chromosomes of the parents so that new chromosomes will have the best parts of the parents’ chromosomes. The crossover probability indicates how often a crossover will be performed. There are several types of crossovers, including single-point crossover, multi-point crossover, and uniform crossover **(Gen and Cheng, 2000).** Herein, the multi-point crossover is applied.

Mutation operator

After recombination, some children undergo mutation. Mutation operates by inverting each bit in the solution with some small probability, usually from zero to 10 percent. The rationale is to provide a small amount of randomness, and to prevent solutions from being trapped at a local optimum. The type of mutation varies depending on the encoding as well as the crossover. In the proposed GA, the mutation operator first randomly selects a bit value on a chromosome, and then, flips a bit value from 0 to 1 or from 1 to 0.

Fitness function

Decoding the chromosome generates a candidate solution and its fitness value based on the fitness function. The fitness value is a measure of the goodness of a solution with respect to the original objective function and the amount of infeasibility. In this work, the fitness of an individual is directly related to its objective function value. The fitness of an individual can be calculated by evaluating the components of the objective function (Revenue and Total cost (fixed, service, transportation, holding, penalty and disposal cost). After several generations, the best solution converges, which hopefully represents the optimum or sub optimal solution to the problem.

Genetic Algorithm solution procedure

Once the representation scheme is selected, the overall algorithm of the proposed GA can be described as follows:

- Read the required data and generate an initial population based on population size, in which each chromosome is a one-dimensional array representing decision values.
- Set the generation zero and evaluate the fitness function of each chromosome in a population. The fitness function is the sum of the objective function.

- Create a new population by repeating generation operations (cloning, parent selection, crossover, and mutation) until the new populations are complete. Multi-point crossover and random mutation are used for positioning a chromosome.
- Replace new offspring in a new population.
- Stop the iteration if the end condition is satisfied; otherwise go to the next generation.

Hence the overall procedure for the proposed heuristic can be outlined as,

```
Read Data ();
Initialize Population ();
while (not terminate condition) do
    Evaluate_Fitness function
    {
    Check_Feasibility ( )
    Retain chromosome of maximum value ();
    }
    Cloning ()
    Select_Parents ( );
    Crossover ();
    Mutation ();
end while
Generate Outputs
```

Chromosome coding and decoding

The choice of bit length for the parameters is concerned with the resolution in the search space. In the binary coding method, the bit length Bi and the corresponding resolution Ri is related by,

$$R_i = U_i - L_i / 2^{Bi} - 1$$

As a result, the objective function can be transformed into a binary string (chromosome) and then the search space is explored. Here, each chromosome presents one possible solution to the problem. The parameter sets can be coded according to the parameter set given in Table 6.1 to Table 6.3. The objective function of the problem can be represented as,

Profit (X, Y) = {(REV (X)) (FC (Y) + SC (X) + TC (X) + PC (X) + DC (X) +IC (X) }

If the candidate parameters' set is (100, 50, 50, 50, 730, 135, 740,140, 780, 160, 800,150, 250000, 300000, 3500, 3750, 3875, 3625,), then the chromosome is a binary string as given below:

10101011111000110011010001010000100110101011110000110001010001010010.

The decoding can be done by the reverse procedure as explained above.

Table 6.1 Coding of Ci Parameter Set

Facility 1(flow from k_1)				Facility 2 (flow from k_1)			
FlowC1	Code	Flow C2	Code	FlowC1	Code	Flow C2	Code
700	0000	120	0001	710	0010	125	0011
710	0001	125	0010	720	0011	130	0100
720	0010	130	0011	730	0100	135	0101
730	0011	135	0100	740	0101	140	0110
740	0100	140	0101	750	0110	145	0111
750	0101	145	0110	760	0111	150	1000
760	0110	150	0111	770	1000	155	1001
770	0111	155	1000	780	1001	160	1010
780	1000	160	1001	790	1010	165	1011
790	1001	165	1010	800	1011	170	1100
800	1010	170	1011	810	1100	175	1101
810	1011	175	1100	820	1101	180	1110
820	1100	180	1101	830	1110	185	1111
830	1101	185	1110	840	1111	190	0011
840	1110	190	1111	850	0010	195	0100
850	1111	195	0000	860	0011	200	0101

Table 6.2 Coding of Ci Parameter Set (Contd..)

Facility 1 (flow from k_2)				Facility 2 (flow from k_2)			
690	0000	115	0001	710	0010	105	0011
700	0001	120	0010	720	0011	110	0100
710	0010	125	0011	730	0100	115	0101
720	0011	130	0100	740	0101	120	0110
730	0100	135	0101	750	0110	125	0111
740	0101	140	0110	760	0111	130	1000
750	0110	145	0111	770	1000	135	1001
760	0111	150	1000	780	1001	140	1010
770	1000	155	1001	790	1010	145	1011
780	1001	160	1010	800	1011	150	1100
790	1010	165	1011	810	1100	155	1101
800	1011	170	1100	820	1101	160	1110
810	1100	175	1101	830	1110	165	1111
820	1101	180	1110	840	1111	170	0011
830	1110	185	1111	850	0010	175	0100
840	1111	190	0000	860	0011	180	0101

Table 6.3 Coding of Ci and Ri Parameter Set

		F	Code	Ci	Code	Ri	Code
Facility 1	Commodity 1	250000	0000	3500	0010	2800	0110
	Commodity 2			3750	0011	3000	0111
Facility 2	Commodity 1	300000	0001	3875	0100	3100	1000
	Commodity 2			3625	0101	2900	1001

Table 6.4 Coding of T, H, P and D Parameter Set

T1 &T2	Code	H1&H2	Code	D& R (1&2)	Code	D1& D2	Code
100	1010	50	1011	50	1110	50	0011

Table 6.4 Illustrates a generation of a GA process.

Table 6.5 Generation of a GA Process

C	Population	Profit
1	10101011111100011001101000101000010011010101111100000000110001010001010010	1803443
2	10101011111100011101111001101111001010110011110000000000010010001101000101	1800837
3	10101011111100011100010011010101110111100110111100000000010010001101000101	1800910
4	10101011111100011000100100011010011110000001101010000000010010001101000101	1801446
	Sum	7206636
	Average	1801659
	Max	1801446

6.5 Computational Results

To get effective control on the allocation of multi-commodities into various existing repair service facilities, so as to improve the profit of the network and service levels, here, genetic algorithm approach is used. The flow of commodities is supported by the genetic algorithm based heuristics. The algorithm gives better results when compared with the results obtained by simulation approach.

Table 6.6 Flow of Commodities with Different settings

	Setting I	Setting II	Setting III
Flow at facility 1 from Disposer market (k_1)			
Commodity 1	750	810	805
Commodity 2	170	158	160
Flow at facility 2 from Disposer market (k_1)			
Commodity 1	842	782	787
Commodity 2	130	142	140
Flow at facility 1 from Disposer market (k_2)			
Commodity 1	825	790	788
Commodity 2	170	150	152
Flow at facility 2 from Disposer market (k_2)			
Commodity 1	770	805	807
Commodity 2	150	170	168

The data presented in the Table 6.1 to Table 6.6 have been used in this work. The commodities collected from the disposer markets are allocated to different repair service facilities with different settings.

Table 6.7 Genetic operators

	Setting I	Setting II	Setting III
Population size	50	50	50
Mutation Rate	0.1	0.1	0.1
Crossover Rate	0.5	0.5	0.5
Total Recalcs	15000	10000	11000
Valid trials	6374	5048	5218
Optimization time (sec)	52.00	63.00	50.00
Occurred on trial	6340	5035	5108
% Trails converged	99.46	99.74	97.89
Best value (Opt)	1800252.24	1800837.27	1807497.32

The control and allocation of flow of commodities into the repair service facilities obtained by both GA approach and with simulation approach is given in Table 6.7.

Table 6.8 Computational results

Setting	Simulation		Genetic heuristic	
	OBJ value (Rs)	Time (sec)	OBJ value (Rs)	Time (sec)
I	1800174.37	45.68	1800252.24	42.00
II	1800825.37	102.76	1800837.27	63.00
II	1801427.37	59.02	1807497.32	50.00

6.6 Validation of the Model

In this work Reverse Logistics Networking model with GA based multi-commodity flow control has been analyzed. The results (obtained from the model developed through simulation and GA) have been compared and validated with the real time data from the organization under study.

6.7 Results and Discussion

In this chapter, RSRL Network with multi-commodities flow into repair service facilities is analyzed. This work represents an attempt to apply the technique of GAs to solve a comprehensive set of problems in RSRL Network, which deals with the recovery of used commodities in repair service facilities.

Effective control on the allocation of flow of Multi-commodities into existing service facilities is obtained though Genetic heuristic proposed. The flow control problem is analyzed with different settings (Table 6.9).

Table 6.9 Analysis of flow control with GA

Settings	Genetic heuristic	
	OBJ value (Rs)	Time (sec)
I	1800252.24	42.00
II	1800837.27	63.00
III	1807497.32	50.00

All the times, i.e. for all settings, genetic heuristic resulted better results (Table 6.8). The performance of the model is greatly improved.

Table 6.10 Analysis of Flow Control with Simulation

Settings	Simulation	
	OBJ value (Rs)	Time (sec)
I	1800174.37	45.68
II	1800825.37	102.76
III	1801427.37	59.02

Genetic heuristics proposed reduces the computational timings to a greater extent when the results are compared with the simulation results (table 6.9 and 6.8).

For all the settings of flow of multi-commodities, almost 99% of the trials have been converged. Hence the heuristics proposed results better performance (Table 6.6).

To sum up, Genetic heuristics gives best results with considerable reduction in computational timings, when compared to the simulation approach and it is better suited for channelizing or controlling the flow of multi-commodities.

CHAPTER 7
REVERSE LOGISTICS NETWORKING: VEHICLE ROUTING WITH ENERGY CONSERVATIVE MEASURES

7.1 Introduction

Vehicle routing, which is effective and efficient, is a dominant aspect of supply chain management in general and RL in particular. It is also a right step towards the fuel conservation and environmental concern in disposing used commodities. Economics of Logistics and transportation plays a major role in deciding the competitiveness of the product, either new or used, in the market. In order to reduce environmental impacts and the energy consumption, it is mandatory, more than desirable, for firms/companies to reduce the emissions and noise by way of reduced truck trips or finding shortest truck routes. With the upwards trends of fuel and logistics costs, manufacturing industries have little option other than keeping the cost of transportation lowest. Many organizations now started implementing lesser expensive and proper transport modes to keep the maintenance of supply chain cost to the minimum.

Proper handling of returned commodities to recover value without affecting the environment may need appropriate techniques or methodologies. This paper deals with the routing of vehicles with energy conservation as the agenda in value recovering method named as repair service work. It is done through a mathematical modelling of RL networking, in a multi-commodity environment. Here, the transportation of commodities to repair service facilities is given an in depth focus to reduce the energy use. The minimization of the distance travelled by the truck fleet, reduce the energy consumption by the trucks.

The distribution of goods based on road services in urban areas contribute to traffic congestion, generates environmental problems and in some cases results in high logistics costs **(Barceló et al. 2006).** Reduction in traffic congestion with efficient pick-up or delivery system is a must so as to reduce the fleet size and to maximize the load factor **(Taniguchi et al. 2001).** The present work is an attempt towards addressing the mentioned issue by way of introducing the concept of energy conservation in RL network with ever increasing reverse flows. For this model, the vehicle routing for the transportation of the returned commodities are taken into account in detail. Vehicle routing is made only for the collection of returned commodities from the disposer market to the repair service facilities.

7.2 Vehicle Routing - A literature review

This problem belongs to the vehicle routing problems studied by a number of authors including Min**, (1989)**, **Mosheiov (1994), Nagy and Salhi (1998 and 2005)**, **Salhi and Nagy (1999)**, **Gendreau et al. (1999)**, **Dethloff (2002), Gribkovskaia et al. (2001)**, **Angelelli and Mansini (2002)**, **Tang and Galvão (2002 and 2006), Süral and Bookbinder (2003), Wasner and Zäphel (2004), Gribkovskaia et al. ,(2007) and Hoff et al., (2006)**. Most of the works in vehicle routing problems with pickups and deliveries are based on heuristics. In few cases, the chosen algorithms are unable to solve instances of realistic sizes. For example, **Süral and Bookbinder (2003)** solve exactly small instances of a particular case of vehicle routing problem in which each customer has a pickup or a delivery demand, but not both, and hence is visited only once. Heuristics include classical procedures such as nearest neighbour or sweep constructive procedures, as well as improvement procedures making customer relocations.

7.3 Energy Conservative Measure in Reverse Logistics Network

Studies, in a repair service facility, show that the trucks pick the commodities, individually after getting the complaint from the customers or from the dispose markets. Therefore, the truck makes a number of trips, which may be equal to as many number of complaints received. Hence, the energy usage by the truck is proportional to the number of complaints. This also increases the emission and noise that add to the environmental pollution. With these observations, a methodology as detailed below is proposed in order to reduce the energy usage of the truck.

7.3.1 Objective

This work is different from the RL network given in the earlier chapters. Because, this model is concentrating on the transport of the returned commodities from the customer market into repair service facilities to conserve the energy used by the trucks through a vehicle routing algorithm. To analyze such a type of problem, a network modeling of a single level, multi-commodity RL Network with Vehicle routing is formulated here. The network model is developed with the objective of optimizing or reducing the number of routes used to pick the commodities and to reduce the logistics costs.

7.3.2 The Proposed Methodology

Step 1: Complaints received by the repair service facility may be consolidated for a particular period of time (say one day).

Step 2: The consolidation of the complaints may be done with a fixed time frame (9am to 5pm).

Step 3: After the completion of the time, the commodities can be grouped based on specific areas or specific routes, the commodities belong or they can be picked.

Step 4: After grouping the complaints based on step 3, truck trips may be enabled to collect the commodities to repair service facilities, based on the capacity of the truck and distance to be covered. This lead to considerable reduction in number of truck trips and hence the energy use for the transportation of the commodities.

7.3.3 Framework of Vehicle Routing

The framework for the analysis of the RL network design is given below: Defective, different types of used commodities (multi-commodity), in varying quantities at various points of time are collected from the disposer market (Mk) and transported to repair service facilities (J). After service, the products are delivered back to the collection sites, i.e., to the reuse market (Mk). Transportation of commodities to the repair service facilities is considered as a vehicle routing problem, to optimize the routes followed during the collection of returns.

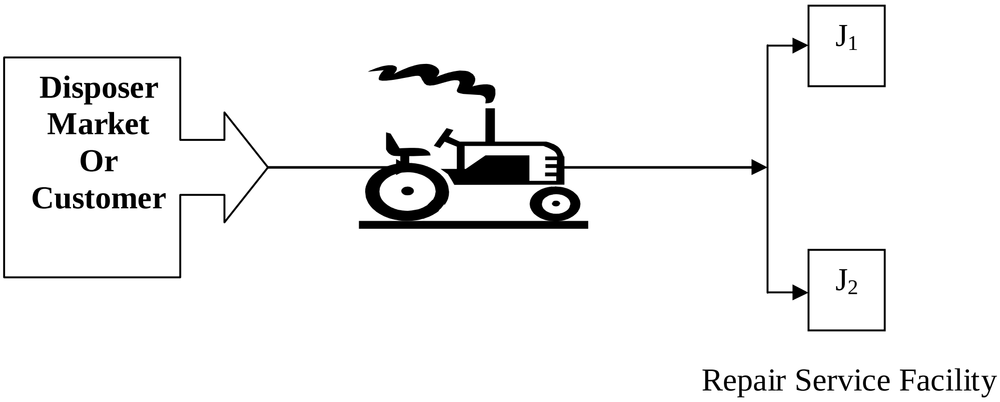

Figure 7.1 Transportation of commodities

Fig. 7.1 shows the transport of the returned commodities from the disposer market or from the customer.

7.3.4 Factors considered

The factors considered for a successful RL vehicle routing are the number of commodities picked or customer served, the number of repair service facility locations and the number of possible routes and their distances, the cost of transportation, Boolean operator to indicate the status of the repair service facility (open or not).

7.4 Single Level Multi-Commodity RL Network Model with vehicle routing

Here, the modeling of vehicle routing for a single level, multi-commodity RL flow network is formulated, based on the problems which are taking place during the transportation of commodities from the customer market into repair service facilities. This modeling considers various factors as listed above while formatting the network.

In the stated situation the major consideration is deciding on the number of trips performed by the trucks of manufacturer's repair service facilities so as to reduce the number of trips, and there by to reduce the total cost of transporting the commodities.

The main objective of this work is to develop a simple method for solving the real logistic problem considered, that is the picking of the commodities from the customer market to the repair service facility.

The objective function,

$$\text{Min} \sum_{i=0}^{N} \sum_{j=0}^{N} C_{ij} X_{ij}$$

Subject to the constraints:

$$\sum_{i=1, i \neq j}^{N} X_{ij} = 1, \qquad \forall_j, j \in \{1, ...N\},$$

$$\sum_{i=1, j \neq i}^{N} X_{ij} = 1, \qquad \forall_j, j \in \{1, ...N\}$$

$$\sum_{i=0}^{N} \sum_{j=0, j \in S}^{N} X_{ij} \leq |S| - 1$$

$$\sum_{i=0}^{N} \sum_{j=0, j \in T}^{N} X_{ij} \leq |T| - k$$

Parameters:

N = number of customers or truck stops

Q = capacity of the vehicle

d_i = demand of customers i, i > 0,

C_{ij} = distance between the customers i and facility j

Variables:

$$X_{ij, i \neq j} = \begin{cases} 1, if\ a\, truck\ goes\ from\ facility\ 'j'\, to\, customer\ 'i' \\ 0, otherwise \end{cases}$$

Where $j \in \{0, ..., N\}$ being 0 the origin (the service facility).

T is set of customer and every set satisfies $\sum_{i \in T} d_i > Q$

“k” is the minimum number of customers that have to be taken from T to avoid overloading.

7.5 Algorithm Used

Clarke-Wright savings algorithm

Randomization: Instead of choosing the best pairing of routes at each step, one of the k best pairings, chosen randomly. Repeat several times and choose the best overall solution.

Improvement Heuristics: After an initial solution is built, various improvement heuristics are performed. These include the well-known 2-opt and Or-opt operations (the Or-opt uses group sizes of 1, 2, and 3), as well as a swap operation in which two customers on different routes may be removed from their routes and inserted into the opposite route.

Testing

The model developed in this work has been applied to a real situation. The Table 7.1 shows the energy conserved by the truck for collecting the commodities on a particular day in an existing service facility, before and after the application of methodology proposed. An individual truck trip is used to collect the commodities separately before the application of the methodology.

Table 7.2 shows the approximate cost and time savings after the optimization. The cost savings is based on the calorific value of fuel used, i.e. combustion of one litre fuel release 9.6 KWh **(based on the gross calorific value from the Digest of UK energy statistics 2005)** and the time savings (considering 45 Km/liter as base).

Table 7.1 Energy conserved by the truck

No of commodities picked (**Nos**)	Distance (**km**)		Energy use by the truck (**kWh**) per Week		Energy use by the truck (**kWh**) per Year
	Before	After	Before	After	
24	195 (With 24 routes)	58.27 (With 6 routes)	187.2	55.9392	6300.518
Total Energy conserved				131.2608	

Table 7.2 **Energy, Cost and Time savings**

Energy Saved **(KWh)**	Fuel used (**litre**) **(@ 9.6 KWh / litre)**	Cost savings (**Rs**) **(@ Rs 48/litre)**	Time savings (**hrs**) **(@45 Km/hr)**
6300.518	656.304	31502.59	145.7778

In order to reduce the energy used by the truck trips, we used the proposed methodology. The model is solved with VRP SOLVER, V (1.3). This results a minimum of 6 routes with truck capacity 4, to pick up 24 no of commodities with a total distance of 58.27 km, against 24 different routes with a distance of 195km.

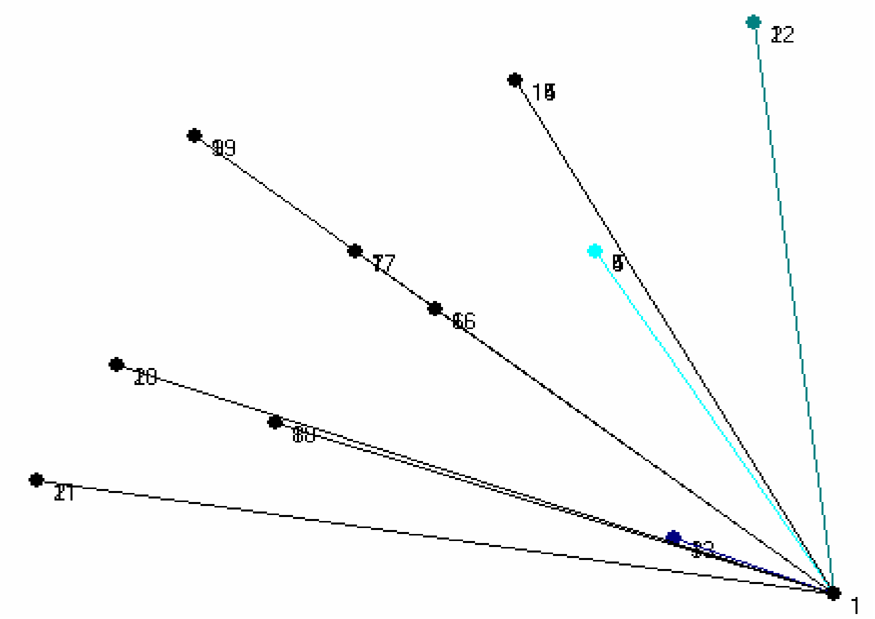

Fig. 7.2 Routes used before optimization

The number of routes followed/used to pick up the returned commodities (multi-commodities) from the customer/disposer market before the application of the heuristics proposed is shown in Figure 7.2. Individual truck trips were followed to collect the returns before the application the heuristic procedure.

Optimal routes are obtained after the application of the proposed heuristics. The routes obtained are shown in Figure 7.3.

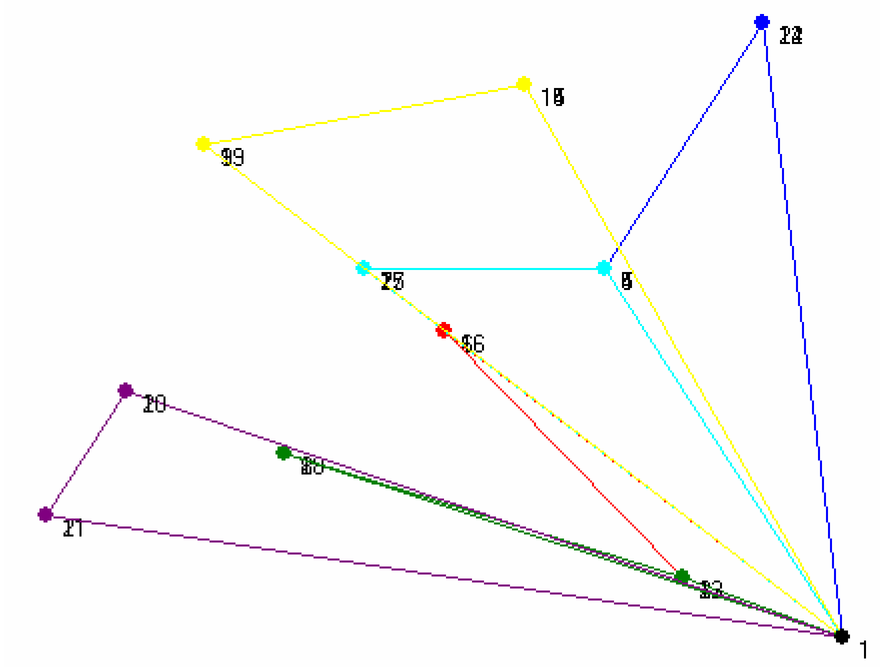

Fig. 7.3 Optimal routes obtained

The optimal routes obtained to pick the returns (multi-commodities) after the optimization process was compared with the individual routes followed before the optimization. The comparison results of the routes are shown in Table 7.3.

Table 7.3 Comparison of Routes

Result	Before Optimization	After Optimization
Total Distance	195 Km	58.27 Km
Number of Routes	24	06
Truck Capacity	1 Commodities/trip	4 Commodities/trip

7.6 Computational Results

The model was simulated with a real time data obtained from a service facility. The simulation involves the flow of returned commodities to the repair service facilities. The simulation results shows that the vehicle routing problem proposed along with the methodology for energy conservative measures, reduces the energy use by the trucks and the emission and noise of the trucks to a large extent.

7.7 Validation of the Model

In this work vehicle routing with energy conservative measures in Reverse Logistics Networking analyzed. The results obtained have been validated with the real time data from the organization under study.

7.8 Results and Discussion

In this work, we formulated a vehicle routing problem for solving the real logistic problem involved in a RL networking with multi-commodity flows. The model formulation has been done with the objectives of reducing the energy use by the trucks while transporting the commodities to existing service facilities and thereby reducing the emission and noise, which impact the environment greatly.

The vehicle routing heuristics optimized the routes to be followed to pick retuned multi-commodities; hence there is considerable reduction on the logistics cost, **Rs.31502.59** saved with improved customer's satisfaction.

Energy conservation measures as suggested would further reduce the transportation time and it was found that, **145.7778 hrs** of time saved and operating cost of the repair service facilities while conserving the precious fuel.

CHAPTER 8
CONCLUSIONS AND SCOPE FOR FUTURE WORK

8.1 Conclusions

The analysis of the Reverse Logistics Network models, proposed here, have shown that the appropriate assignment of commodities is a single major issue, which determines the profit or revenue for the provider. The allocation of the multi-commodities in the network, by channelizing them to the repair service facilities resulted better performance. It has also been found that both in single and multi-level Reverse Logistics Network modelling, the volume is the powerful driver in improving the total profit.

The frameworks arrived at for all the model(s) proposed in this work give step-by step instructions to follow, in order to control the flow of multi-commodities in the network at both single and multi levels. The simulation and GA approaches give better insight into this problem, which would, inurn, enable to have effective control of the entire operation.

Further, a vehicle routing model addresses the problem of energy conservation during the transportation of the returned commodities into the repair service facilities. The following are the findings from the current research:

- The application of Random Variation Method overcomes the constraints of fixing common service cost towards all the problems/faults of a particular commodity. It helps in fixing different repair service cost structures for products/commodities depending on the extent of repair service requirement, which is more appropriate and practical. The overall profit of the network increases with satisfied customer service levels.

Table 8.1 Overall profit at Level I

Run	No. of commodities Stayed		Overall Profit (Rs)
	1	2	
1	245	10	927905.25
2	245	10	960661.25
3	14	11	987031.31
4	14	10	958937.31

- Energy conservation measures as suggested would further reduce the operating cost of the repair service facility while conserving the precious fuel. **With Vehicle**

routing, the logistics cost saved per year is Rs. 31502.597 and the time saved is 145.84 hours.

Table 8.2 Total Savings

Energy saved(**KWh**)	Fuel used (**litre**) **(@ 9.6 KWh / litre)**	Cost savings (**Rs**) **(@ Rs 48/litre)**	Time savings (**hrs**) **(@45 Km/hr)**
6300.518	656.304	31502.59	145.84

- The type of Reverse Logistics Networking needed can be decided based on the forecast of yearly number of returned multi- products/commodities and it could be obtained using the past records available, technical data, from the manufacturers' repair service facility. It holds well with the remarks given by **Lieckens, and Vandaele., (2007).**

- Penalty for not collecting the returns, which may considered as a deficiency in the operations could be reduced to the extent of 0 levels. In other words no commodities go uncollected, and which in turn improves customer satisfaction.

- For a given yearly market demand and supply, the model(s) resulted an increased profit and customer satisfaction.

- Pεported results, helps in planning for the number of repair service facilities for the given capacities to reap maximum profit from the manufacturer's repair service facilities perspective. **This matches with the suggestion given by Blumberg, D., (1999).**

- Handling of returned multi- products/commodities in a repair service facility, with queueing system reduces the waiting time of the customers and it increases customer satisfaction levels.

- Optimization of shortest routes resulted in minimum number of routes for the transport of the retuned multi-commodities with considerable amount of time and energy savings. **The results matches with the work of Ruiz et al., 2004.**

Table 8.3 channelizing the flow with different settings

	Setting I	Setting II	Setting III
Flow at facility 1 from Disposer market (k_1)			
Commodity 1	750	810	805
Commodity 2	170	158	160
Flow at facility 2 from Disposer market (k_1)			
Commodity 1	842	782	787
Commodity 2	130	142	140
Flow at facility 1 from Disposer market (k_2)			
Commodity 1	825	790	788
Commodity 2	170	150	152
Flow at facility 2 from Disposer market (k_2)			
Commodity 1	770	805	807
Commodity 2	150	170	168

- GA heuristics is better suited for channelizing or controlling the flow of multi-products/commodities. **This matches with the remarks given by Min., et al., (2006) and Jeung Ko and Evans, (2007).**

- Genetic heuristics gives best results with considerable reduction in computational timings, when compared to the simulation approach.

Table 8.4 Comparison of Results

Setting	Simulation		Genetic heuristic	
	OBJ value (Rs)	Time (sec)	OBJ value (Rs)	Time (sec)
I	1800174.37	45.68	1800252.24	42.00
II	1800825.37	102.76	1800837.27	63.00
II	1801427.37	59.02	1807497.32	50.00

To sum up, the results of simulation and Genetic Algorithm approach of the proposed Reverse Logistics Networking models are encouraging that for the known market supply, it helps in arriving at efficient way of handling/controlling the returned multi-commodities in existing repair service facilities. Proper handling of flow of multi-commodities with a practical tool (simulation, heuristics procedures) gives positive increase in profit of the network with satisfied customer service levels. The vehicle routing algorithm helps to find out the shortest possible routes through optimization, which in turn gives considerable reduction on the logistics cost.

All the results (obtained from the models developed through simulation and Genetic Algorithm and heuristics approach) have been validated with real time data from the organization under consideration.

A reference frame work as shown in figure 8.1, may guide the future researchers in carrying out a systematic study to solve number of problems in the reverse logistics context.

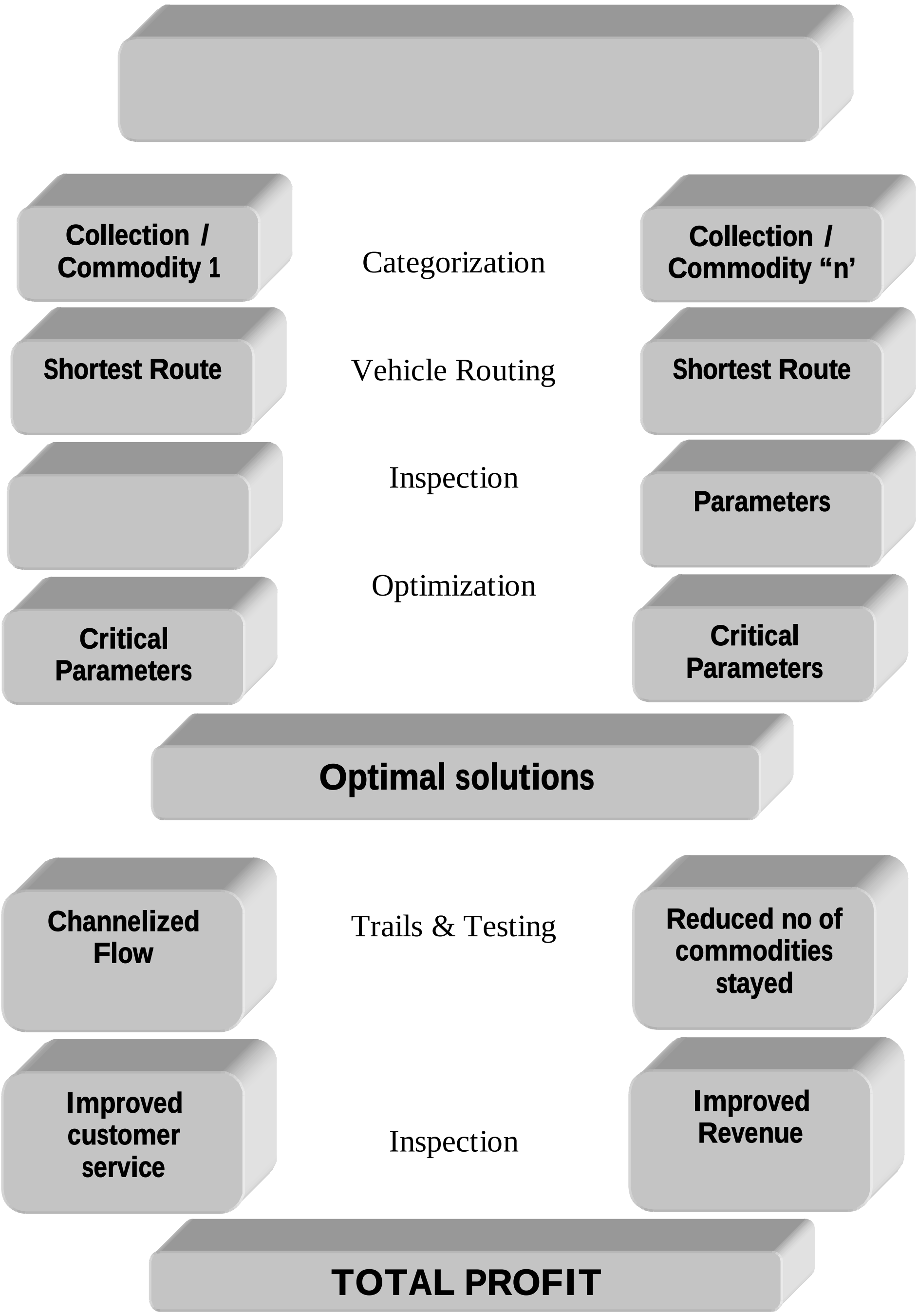

Fig. 8.1 The General Study Pattern to be followed in RL Networking

8.2 Scope for future work

This investigation has thrown light on the improvement of customer satisfaction and profit of Reverse Logistics Networking through optimizing the parameters considered in the model by applying Simulation and Genetic algorithm approach. This study also shows that proper allocation of multi-commodity flows in the Reverse Logistics Network leads to positive improvement in revenue.

This optimization study can be applied to various Reverse Logistics process to achieve improved profit and customer satisfaction in the competitive business environment. Further, the Modeling approach for channelizing and allocating the flow of multi-commodities can be attempted to any kind of commodities. This work can be extended to

- the consideration of inventory, (inventory control) of commodities, which are repair serviced
- varying the capacities of servers in the repair service facility
- service facilities where replacement of faulty parts or component is done without resorting to repair work.

Apart from the above, considerable work can be done in this area to get unique solution/optimal solution to achieve better customer satisfaction with overall profit of the Reverse Logistics Network.

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1. “Reverse logistics Trends and Models – A review”, The International Journal for Manufacturing Science & Production, Vol.8, No. 1, 2007 (ISSN 0793-6648), pp. 1-14.

2. “Reverse Logistics Networking for Multi-commodity Flows with Multi-level Servicing”, The International Journal for Manufacturing Science & Production, Vol. 8, Nos. 2-4, 2007, pp145-157.

3. “Reverse Logistics Networking Model in Multi-commodity Environment”, The International Journal for Manufacturing Science & Production, Vol.8, Nos. 2-4, 2007, pp. 159-168.

4. “Supply Chain Management: Implications and Directions for future Research”. IX Annual International Conference of Society of Operations Management, 16-18th December-2005, School of Management, Pondicherry University, Pondicherry, India, p. 10.

5. “Multi-commodity model for supply-return network design”, International Conference on Global Manufacturing and Innovation (An Advanced Optimization Technology Approach),(GMI 2006), 27 – 29th July-2006, Department of Mechanical Engineering, CIT college of Technology, Coimbatore, India, p.82

6. “e-Logistics Implementation through e-Fulfillment: A case study:”, Third International Conference on Logistics and supply chain Management, (ILSCM 2006), 2 – 4th August-2006, Department of Mechanical Engineering, PSG College of Technology, Coimbatore, India, P. 5.

7. “Multi-commodity Reverse Logistics network with different quality level of returned commodities – A mathematical Model”. National Conference on Theory and Practice of Operational research in Information Technology and Supply Chain Management, (ORITSCM 2007), 6-8th September-2007, Department of Mechanical Engineering, Thiagarajar College of Engineering, Madurai, India. pp 201-208.

8. “Reverse Logistics Networking: Vehicle routing with Energy Conservative Measures”. XI Annual International Conference of Society of Operations Management, 21-23rd December - 2007, SIOM, Nasik, India, p. 23.

9. “Multi-commodity reverse logistics network design for different quality levels of returned commodities with multi-level servicing”. In the International Conference on issues and Challenges in Supply Chain Management, (ICSCM 2008), 26-28th March - 2008.BHU, Varanasi, India.

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