

Thesis
On
Cost Optimization in a Closed Loop Supply Chain
Network-A Case Study
Submitted in partial fulfillment of the requirement for the
award of the degree of
MASTER OF ENGINEERING
IN
PRODUCTION & INDUSTRIAL ENGINEERING

Submitted By:

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Under the Guidance of:

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DEPARTMENT OF MECHANICAL ENGINEERING
THAPAR UNIVERSITY
PATIALA-147004, INDIA

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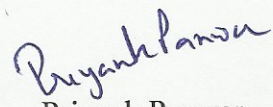
PATIALA-147004, INDIA

July 2013


DECLARATION

I hereby declare that the thesis entitled "Cost Optimization in a Closed Loop Supply Chain Network-A Case Study" is an authentic record of my study carried out as requirements for the award of the degree of **Master of Engineering in Production and Industrial Engineering** at **Thapar University, Patiala**, under the guidance of **Mr. Supreet Bhullar**, Associate Professor, Department of Mechanical Engineering, Thapar University, Patiala during July 2012 to July 2013. The matter embodied in this report has not been submitted in part or full to any other university or institute for award of any degree.

15 July 2013


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I hereby certify that the above statement made by the student is correct to best of my knowledge


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(PRIYANK PANWAR)

ABSTRACT

In the present scenario, the emphasis on environment concern and cost reduction has increased due to which it is necessary to concentrate on reverse logistics to get back the potential value from the used or end-of-life product by recycling, remanufacturing and reuse. The demand of lead is increasing due to the increase in demand of lead acid batteries in automobile and domestic purpose and to meet this increasing demand. End of life batteries are identified as a significant source of lead by recycling process as lead has a unique quality of being recycled up to 97%. A case study of lead acid battery manufacturing company has been presented. In this study, the closed loop supply chain network of a battery manufacturing unit has been investigated and with the objective of cost optimization. The study has been carried out in the context of two aspects- rate of return and recycling rate. Firstly, by using linear programming through TORA optimizing software Secondly, by using genetic algorithm through EVOLVER 6 software package. The results obtained during optimization expressed that as the rate of return and recycling rate of a company increases, the total supply chain cost reduces and the saving of the company increases. During study it is also comes into notice that if a company has recycling rate of lead above 67.56% then it is advisable to practice closed loop supply chain otherwise it is beneficial to practice forward supply chain alone. Comparison between the results obtained by two techniques has also been done which shows that the results obtained by both techniques are the same

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ABBREVIATIONS

ABC	Activity Based Costing
ACL	Agent Communication Language
AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
CDLP	Capacitated Dynamic Lot Sizing Problem
CED	Cumulative Energy Demand
CLDSC	Closed Loop Distribution Supply Chain
CLMEDIM	Closed Loop Multi-Echelon Distribution Inventory Supply Chain Model
COS	Cast-On-Strap
CRC	Centralised Return Centres
DEMATEL	Decision-Making Trial and Evaluation Laboratory
DRP	Disassembly/Recycling Plants
EEE	Electric and Electronic Equipment
EOL	End Of Life
FLMEDIM	Forward Logistics Multi-Echelon Distribution Inventory Supply Chain Model
FMCDM	Fuzzy Multi-Criteria Decision-Making
GA	Genetic Algorithm
GSC	Green Supply Chain
GSCM	GSC Management
IMSCM	Integrated Model for Supply Chain Management
KQML	Knowledge Query and Manipulation Language
MILP	Mixed Integer Linear Programming Model
MIP	Mixed Integer Programming
NRE	New Replacement
OE	Original Equipment
RA	Reusable Articles

RD	Reverse Dominant
RE	Replacement
RL	Reverse Logistics
RNM	Recovery Network Model
RP	Reusable Products
RPM	Returnable Packaging Materials
RSPs	Recovery Service Provider
RTI	Returnable Transportation Items
SC	Supply Chain
SMA	Sydney Metropolitan Area
TTP	Through The Partition
UK	United Kingdom
WEEE	Waste of Electric and Electronic Equipment
3PLs	Third Party Logistics
3PRLP	Third-Party Reverse Logistics Provider

CHAPTER 1

INTRODUCTION

In the present scenario reverse logistics has receiving increased attention as the knowledge and value of the potential reuse of the material waste has increased. Traditionally, supply-chain management dealt mainly with product manufacturing and product movement through the supply chain. This movement normally started at the supplier's end and terminated at the customer's end. Recently, as there are increasing environmental concerns, the operation of a company's supply chain does not necessarily end with consumer's initial purchase of an item, at least ethically. A company needs to consider the products returned or disposed of by customers (Gupta and Evans, 2009). This has necessitated the application of the concept of reverse logistics, an offshoot of supply chain management. It is important to understand the concept of the forward supply chain or forward logistics before going to the reverse logistics and closed loop supply chain.

1.1 FORWARD SUPPLY CHAIN

Forward supply chain can be explained as the network of the different facilities and distribution options that execute different functions like procurement of the material, conversion of these materials into the finished or semi finished products and distribution of finished products to the customer through different channel or nodes. This whole process of movement of the material starting from supplier to the customer represents the forward supply chain. The whole network of the forward supply chain is created by linking the different nodes. Node represents different facilities like the manufacturing plant, wholesaler and retailers etc. that are involved in different operations and activities. These nodes are linked with the help of the transportation or logistics operation which helps in transporting the material and finished product from one node to the other according to the requirement.

1.2 REVERSE SUPPLY CHAIN OR REVERSE LOGISTICS

Reverse logistics is defined as the 'process of planning, implementing, and controlling the efficient, 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 Tibben-Lembke, 1998).

“Reverse logistics has also been defined as the term most often used to refer to the role of logistics in product returns, source reduction, recycling, materials substitution, reuse of materials, waste disposal, and refurbishing, repair and remanufacturing” (Kannan et. al, 2009).

Reverse Supply Chain can be classified as open loop reverse supply chain and closed loop reverse supply chain. Open loop reverse supply chain is defined as ‘Recycling’ because the products are not returned to the original producer but can be used in other industries (Sasikumar and Kannan, 2008) and closed loop reverse supply chain is defined as closed loop supply chain where the end-of-life product (end of life product is one which complete its useful life) is returned to its original producer. In the reverse logistics the few nodes are different from the nodes that are present in forward supply chain. New nodes that are introduced in the network are collection centre, disassembly unit and recycling unit etc which perform their respective activities. To manage the return merchandise, companies are concerned to reuse them, resell them and dispose them. But companies are more likely benefited if returned product comes along with information and can make use of that information. The product can be returned due to many reasons that can either be by consumer or by the nodes at the distribution network. The reason of return of product from the consumer can be quality problem, for remanufacturing, for disposal, or failure to meet customer’s need and retail can return the product due to expire date code, damage during transportation, excessive retail inventory, less demand of product, model is outdated (Kannan et al., 2009).

The two main driving forces of Reverse Supply Chain are governmental regulation and customer perspectives on environmental issues (Gupta and Evans, 2009) like Regulation of Plastics Waste and particularly the manufacture and the use of recycled plastics carry bags and containers in India as per Recycled Plastics Manufacture and Usage Rules, 1999 and as amended in 2003, which stated that the minimum thickness of carry bags made of virgin plastics or recycled plastics shall not be less than 20 microns etc. To embrace more sustainable approach the drivers can be divided as external and internal drivers where external drivers are competition and from stakeholder. Reduced cost and less energy utilization known as internal drivers (Kumar et al., 2011).

The following are major functions associated with a typical reverse supply chain:

- i. **Collection:** This function primarily deals with setting up and operationalizing the process of return of used batteries from source (customer) to the sink (manufacturer, collection centre or disassembly unit).
- ii. **Remanufacturing:** Remanufacturing is defined as a function in which products are dismantled and their parts are used in the manufacturing of the same products (remanufacturing) or in different products (retrieval). The aim of remanufacturing is to bring the product into ‘as new’ conditions by carrying out the necessary disassembly, overhaul, and replacement operations. Industries or products that typically apply remanufacturing include automobiles, electronics and tyres (Sasikumar and Kannan, 2008). Remanufacturing is also defined as recycling-integrated manufacturing (Hoshino et al., 1995).
- iii. **Disassembly:** Disassembly is defined as a systematic method of separating a product into its constituent parts, components, subassemblies or other groupings and it is also used to remove toxic elements (Sasikumar and Kannan, 2008).
- iv. **Recycling:** Recycling refers to a process where the products are processed in order to obtain the desired quality following which they are reused. The goal of recycling is to recover the material without concern for the conservation of product structures (Sasikumar and Kannan, 2008).
- v. **Disposal:** Disposal means to destroy, discard, or hide embarrassing or incriminating material.

1.3 CLOSED LOOP SUPPLY CHAIN

Closed loop supply chain is integration of forward and reverse supply chain in which nodes of both type of supply chain get integrated and bigger network is formed. Development of a closed-loop supply can prove to be beneficial for companies, both economically and ecologically. One of the biggest challenges in this development is the integration of the forward and reverse supply chains (Gupta and Evans, 2009). Integration of forward and reverse supply chain means that when the merchandise reaches to the customer using forward supply chain, it gets collected and again reaches the manufacturer so that closed loop can be formed, that is initiated with producer and also terminates with the producer. The other challenge that encountered in developing closed loop supply chain is shortening product life cycle to recover maximum value out of the return (Gupta and Evans, 2009). Those organizations engaged in the automation of recovery process,

getting involved, in both the forward and reverse supply chain, through research are realizing greater recovery of returns. Better image of company among customers and cheaper raw material are the main advantages of closed loop supply chain along with less landfill.

1.4 LEAD ACID BATTERY AND LEAD RECYCLING

Lead acid battery is the oldest type of rechargeable battery. There are different kinds of lead acid battery are available in market like flooded type, sealed type, valve regulated type and gel type etc. The main components of the lead acid batteries are active mass of lead (in form of Pb and PbO₂), metallic grids & metallic connections, electrolyte, polypropylene case and other components (Kannan et al., 2010). The major portion of the lead acid battery contained lead about (70-75%), as lead is one of the most in demand product from last decade for its important usages but the main usage of the lead is in the lead acid batteries to store the electric energy. The leading producer of lead is by six countries USA, Mexico, China, Canada, Australia and Peru. Around 70 percent of the lead produced is used in lead acid batteries (Metal World January 2010). Due to the growth of the Automobile sector in the Indian market in specific & globally in general and also for domestic requirement, the demand of the lead acid batteries has increased significantly due to which the requirement of the lead has crept up every year. In India, the main source of the lead is the virgin material but now a days as the price of the virgin lead has increased and the demand is rising, the requirement of cheap source of lead is a necessity. As lead is one the material that can be recycled to 97 percent which makes it unique among other materials, it is necessary to look at the aspect of the recycling of the lead scrap and use of the recycled lead for manufacturing the lead acid batteries.

In case of the lead acid batteries the recycling process comes out to be the major reverse logistics function. In recycling process, products are processed in order to get the desired quality so that they can be reused. The main purpose of the recycling is to recover the material without conserving any product structures (Kannan et al., 2010). Plastics recycling, paper recycling, glass recycling, electronic waste recycling sand recycling are few examples of the recycling of products. As environmental protection and conservation of the natural resources become very important for the whole world and in the industrial countries, the handling of the hazardous waste is major concern (Kannan et al., 2010). As lead is a hazardous material so there is legislation on lead acid batteries to regulate the collection of lead acid batteries and channelize

batteries scrap to recycling facilities adopting environmentally sound processing technologies, the Batteries (Management & Handling) Rules, 2001 have been notified. The salient features of the Rules are 1) Consumers to return used batteries and manufacturers/assemblers/reconditioners/importers responsible for collection of batteries and transport to registered recyclers. 2) Auction of used batteries only in favour of registered recyclers 3) Dealers are also responsible for collection. 4) Level playing field (equal opportunities should be provide to all). 5) Collection of batteries 50% in the first year, 75% in the second year and 90% from the third year onwards. 6) Batteries have been categorized. The legislation proved to be effective which have direct impact on the demand supply of the lead acid batteries as making the dealer also the part of the legislation, the responsibility of the dealer is to pass the returned product to the registered recycler or smelting unit which ensures that the environmental concern are handled carefully. To see that the legislation is enforced correctly it is the duty of the state pollution control board to keep track of the record of the recycling or the smelting unit whether they are following the rules and regulation or violating rules (Ministry of Environment and Forest, India). All these legislation mainly focused on the handling the hazardous waste and how to recover the material from the waste and make sure the disposal of the hazardous waste should be as minimum as possible. Compare to the 55% of aluminum soft drink cans, 45% newspaper, 26% of glass bottles and 26% of tires, lead acid batteries top the list with 97% of recycling as the most recyclable consumer product (survey from Battery Council International). The lead from the batteries recovered by separating the other parts like acid, plastics from the lead by the processing of cutting and hammering then the lead is ready for its metallurgical processing by melting it in the furnace. As the new manufactured battery contains 70-80% of the recycled products which makes it special and the process of recycling can goes on indefinitely. This makes the disposal of lead acid batteries unbeaten from both environmental and cost perspective. Also the closed loop life cycle of the lead-acid batteries provides it an environmental advantage over other form. While dealing with lead acid batteries it is clear that the recycling has become an important aspect to consider not only for the environmental perspective but also from the cost point of view. So it's better to consider the closed loop for the company so that supply chain becomes economical.

As interest in increasing productivity and to decrease the landfill has been greater than before among companies, a lot of research is being carried out in this field. There are many optimization techniques that had been used to maximize the collected revenue because of the innate potential.

CHAPTER 2

LITERATURE REVIEW

2.1 REVIEW

Reverse logistics become a research area that has been of particular interest to the academic community in recent years and it has been reflected in the journals on production and operation management. In this chapter, the extensive review has been done to determine the evolution of reverse logistics over recent years and improve the understanding on reverse logistics by exploring the techniques and methodologies advocated delivered by researchers. The following are the gist of various research efforts.

Ferguson and Browne (2001) examined the emerging issues in reverse logistics, in particular the information requirement for reverse logistics within the extended enterprises. A study of End of Life (EOL) vehicle was used to illustrate the specific information flow between the key players within automotive industries. The study also addressed the initial development of possible distribution channel with operation and supporting information systems for the End-Of-Life.

Amini et al. (2005) discussed the competitive value of service management activities, mainly repair services, as well as the importance of the supporting role of effective reverse logistics operation for the successful and profitable execution of repair service activities. Along with it a case study was also presented of a major international medical diagnostics manufacturer to illustrate how a reverse logistics operation for a repair service supply chain was designed for both effective and profitability by achieving a rapid cycle time goal for repair service while minimizing total capital and operational cost. The study concluded that repair time more than 6 hours created unacceptably low customer satisfaction.

Sahyouni et al. (2007) developed three Generic Facility Location models for the integrated distribution and collection of products that accommodated a variety of applications and industries. The proposed models quantified the value of integrated decision making in the design of forward and reverse logistics networks throughout different stages of a product's life cycle. The study also developed a Lagrangian relaxation-based solution algorithm that was both quick and effective. The implications of integrated decision making by comparing the total facility and

transportation costs of joint optimization models with the cost of solutions in which forward and reverse facility location decisions were made sequentially or independently of one another was also assessed. The study suggested that, in forward dominant model, integrated network design was critical if excessive costs were to be avoided. The study also proposed that both the value and impact of integrated network design are minimal for a Reverse Dominant (RD) network structure. The implications of integrated decision making on network configuration were also discussed, The study introduced a new network similarity measure to quantify the analysis was introduced.

Bernon and Cullen (2007) contributed to the development of a literature on reverse logistics based on empirical findings in the United Kingdom (UK) retail sector. The study incorporated the argument that if organizations managed product returns in a holistic way, the level of returns experienced by retailers could be reduced significantly. The study put forward a framework for managing reverse logistics through adopting the three management approaches of integration, collaboration and evaluation. The research questions on which study was based were to identify the scale of returns in the UK retail sector; to explore and identify current management approaches related to reverse logistics; to develop a suggested framework for managing returns. The study found that the key drivers for reverse logistics flows were forecast accuracy and demand variability linked to purchasing policies, legislative factors, high on-shelf availability, new product introductions, logistics trade-offs, liberal returns policies customer no-faults found and cash flow management practices and highlighted the fact that most of the drivers were managerial in nature. The study concluded that the use of an integrated supply chain approach offered significant opportunities to reduce the cost of reverse logistics operations while maximizing asset recovery values.

Salema et al. (2007) studied the models proposed by different researchers in the area of design of reverse distribution network and suggested that most of the proposed models on the subject were case based and, for that reason, they lacked generality. The study made an effort to overcome this limitation and a generalized model of design of reverse distribution network was proposed. The study contemplated the design of a Generic Reverse Logistics Network where multi-product management, capacity limits, and uncertainty on product demands and returns were considered. This study proposed a generalized model for the design of reverse logistics networks. The model was based on the Recovery Network Model (RNM) proposed by

Fleischmann. In order to address the inadequacies of the Fleischmann model, this work extended the RNM model and developed a capacitated Multi-Product Reverse Logistics Network Model with uncertainty. The prolonged formulation of the research allowed for any number of products, establishing a network for every product while guaranteeing total capacities for each facility at a minimum cost. Furthermore, a common method was studied in the context of uncertainty in both product demands and returns, through the use of a multi-scenario approach.

Hammond and Beullens (2007) studied and expanded previous work dealing with oligopolistic supply chains to the field of closed-loop supply chains. The study presented a model which was formulated with the intent of examining issues surrounding the European Union directive regarding Waste of Electric and Electronic Equipment (WEEE) with the assumption that manufacturing and remanufacturing costs were dependent on the scale of operation, and displayed laws of diminishing return. The manufacturers attempted to make a profit by producing a homogeneous product for a set of consumer markets. It was assumed that these markets do not differentiate between products made by different manufacturers, and there was no perceived quality depreciation of goods made from both new and reused materials. The study first examined the behaviour and optimality conditions of each tier individually, and then the system as a whole. Exogenous parameters used to model legislation were the cost of landfill per unit of disposed material, the minimum ratio of used products collected to total quantity sold that each manufacturer must take-back and the fraction of usable material that could be recovered from one unit of collected product. The Extra-Gradient Method Algorithm selected had converged for all numeric examples tested and concluded that legislation that imposed some minimum recovery level of all new products could stimulate reverse chain activities within a supply chain.

Ko and Evans (2007) presented a mixed integer nonlinear programming model for the design of a dynamic integrated distribution network to account for the integrated aspect of optimizing the forward and return network at the same time. Since such network design problems belonged to a class of non linear programming (NP) hard problems, a genetic algorithm (GA)-based heuristic with associated numerical results was presented and tested in a set of problems by an exact algorithm. The solutions obtained from the proposed method were compared to the optimal solutions using the 18 test problems. The outcome indicated that the range of gaps with respect to solution quality was from 0.78% to 8.18%. In addition, the proposed heuristic solved all the

test problems in reasonable amount of computation time; the exact solution approach did not solve some of the test problems owing to complexity of the problem structure.

Lu et al. (2007) presented an innovative method using simple and efficient procedures to evaluate the effectiveness of projects supplying Green Supply Chain (GSC) concept. Particularly, a Multi-Objective Decision Making process for GSC Management (GSCM) was presented to help the supply chain manager in measuring and evaluating suppliers' performance based on an Analytical Hierarchy Process (AHP) decision-making method. In addition, to decreased subjective bias in designing a weighting system, a Fuzzy Logic process was used to modify the AHP. To develop a rational framework from many different types of environmental criteria, a group of supply chain managers from Common Wealth, a leading magazine in Taiwan, was used to survey 500 companies. These criteria were designed to encourage exploration by the supply chain manager of potential environmental impacts during the life cycle stages of a product. The supply chain managers could minimize the product's environmental impact based on the criteria like pre-manufacturing, manufacturing, packaging and distribution, use and maintenance, end of life. The study presented an efficient GSC approach to enable managers to evaluate various projects and established an environmentally benign product design and also a multi-objective decision making model to select the best project in the green supply chain.

Kara et al. (2007) presented a simulation model of a reverse logistics networks for collecting End-Of-Life (EOL) appliances in the Sydney Metropolitan Area (SMA). When designing a network structure of reverse logistics, there were many factors to be considered. These factors included the number and the type of participants in the system, the number and location of the disassembly centre, collection points, characteristics of the material flow and product characteristics. The study ensured that the factors in the chain worked together in order to ensure cost effectiveness of the system. For the integration of the disassembly activity into the network system, two main concepts were proposed regarding the disassembly centre considering location and quantity. In this study, comparisons between the simulation and calculated results were made. The associated parameters were set constant for calculating the transportation costs by using deterministic data. This included average truck load size, average speed of transporter, transporter cost per hour, and its travel distance. Simulation modelling, presented in this study, allowed the user to analyze the future performance of the network and to understand the complex

relationship between the parties involved. The study concluded that from the simulation, the model calculates the collection cost in a predictable manner.

Jayaraman et al. (2008) identified the reverse logistics supply-chain channels and presented the critical role that information technology and collaboration could play to mitigate many of the problems and deficiencies. The study concluded that sound use of the information system in collaboration with supply chain partners mitigates the high cost in supply chain.

Ostlin et al. (2008) identified seven different types of closed-loop relationships for gathering cores for remanufacturing. The relationships identified in the study were ownership-based, direct-order, service-contract, credit-based, deposit-based, buy-back and voluntary-based relationships. Developing theory around these different types of relationships, several disadvantages and advantages were described in the study. The study was based on empirical data linked to several case studies of different remanufacturing companies as well as previously documented research in the area of remanufacturing. This study aimed at building theory from case studies. The empirical data for this study was linked to a research project employing an explanatory multiple-case study concerning multiple types of products. The main source of data for the case studies was interviews. Other sources of data were direct observations made under the study visits to the companies and also paperwork like brochures, photographs and information from the Internet. The study concluded that the success of a remanufacturing business was dependent on the relationship between the remanufacturer and the customer, since the customer could both act as a supplier and a customer to the remanufacturing company. Since the retrieval of used products was crucial for the remanufacturer, supplier/customer relationship management was considered very important.

Efendigil et al. (2008) aimed to efficiently assist the decision makers in determining the “most appropriate” third-party reverse logistics provider using a two-phase model based on artificial neural networks and fuzzy logic in a holistic manner. A numerical example was also included in the study to demonstrate the steps of the proposed model. The study proposed method for selecting appropriate and desirable third-party vendors taking the subjective requirements of the company into account for evaluating supplier performance by considering conventional factors, e.g., price, quality, and flexibility. This study also aimed at contributing to the literature in two aspects by proposing a mathematical solution for a reverse logistics service provider selection

problem in an imprecise environment: (1) using artificial neural network structure for a reverse provider selection problem, and (2) penetrating fuzzy Analytical Hierarchy process (AHP) into the neural network architecture by effecting to input values for the first time.

Funte et al. (2008) examined supply chain management as implemented in companies which dealt simultaneously with forward and reverse logistics. Constraints for model included the strategic and operational alignments, information share, system interoperability and coordination of events. The proposed model of integrated supply Chain Management (IMSCM) was aimed at re-defining Demand Management Procedures, Order Management Procedures, Procurement Management Procedures, Manufacturing Management Procedures, Client Management Procedures, Distribution Management Procedures, etc. The complete analysis of the processes involved in Supply Chain Management, demonstrated that the integrated model IMSCM includes new processes taken from reverse logistics, which were necessary for designing a new processes model to manage the supply chain. The model offered a solution for supply chain performance at strategic, tactical and operational levels, incorporating the Forward Supply Chain together with Reverse Supply Chain processes. The IMSCM aimed at integrating management and sharing material and human resources. The model proposed that with reference to distribution management it was possible to reduce the transportation costs of returned materials by taking possession when delivering newly manufactured products in the area or to the same client. The application of the new IMSCM proposed identification of new business opportunities by showing how, from the existing processes of the forward chain, it was possible to integrate the operation of both chains by identifying new sub-processes for the reverse chain operation. It was proposed that this new relationship should be focused on an improved coordination and integration of distinct activities within a framework of collaborative inter-enterprise. In this collaborative framework, revising and redefining general processes improved combined supply chain management as well as the management of the manufacturing company and solved the problems observed in their day-to-day operation.

Min and Ko (2008) identified that only few studies addressed the problem of determining the number and location of repair facilities where returned products from retailers or end customers were inspected, refurbished and repaired for redistribution. To fill the gap in such a line of research, this study proposed a mixed-integer programming model and a genetic algorithm as decision-aid tool that was designed to find the optimal location, number, and size of repair

facilities/warehouses in the reverse logistics network under capacity limits and service requirements for third party logistics providers. A Genetic Algorithm (GA) was referred to as a stochastic solution search procedure that was designed to solve combinatorial problems using the concept of evolutionary computation imitating the natural selection and biological reproduction of animal species. The usefulness of the proposed model and algorithm was validated by its application involving Third Party Logistics (3PLs) offering value-added services.

Gupta and Evans (2009) identified that the implementation of closed-loop supply chains to handle the problem of increasing levels of electronic and electrical equipment waste could be beneficial both economically and ecologically. Three different problem analysis techniques—Fundamental Objective Hierarchy, Means Objective Network and Why–What’s Stopping Analysis were used to analyse the problem from various perspectives. A Non-Pre-Emptive Goal Programming Model and solution approach were also been developed, with goals being accredited different weights according to the respective goal priorities. The model considered multiple products, as well as operations related with the product, part, subassembly, and material levels. A major contribution of the research involved that objectives and related constraints for each member of the supply chain be explicitly modelled. Objectives of reverse logistics were to minimize collection costs; refurbishing costs, disassembly costs; testing cost; remanufacturing, recycling costs; inventory holding costs; disposal costs/number disposed; transportation costs; and maximize profits The model generated an output highlighting the deviational variable values based on the values of the input in the model. The values of the deviational variables (positive or negative) helped a decision maker to analyse the model. Looking at the values of deviational variable, the decision maker could decide whether, by changing the values of an input in the model, a member of the supply chain could achieve the target value.

Kannan et al. (2009) designed an integrated Forward Logistics Multi-Echelon Distribution Inventory Supply Chain Model (FLMEDIM) and Closed Loop Multi-Echelon Distribution Inventory Supply Chain Model (CLMEDIM) for the built-to-order environment using genetic algorithm and particle swarm optimisation. In this study, the proposed model was validated by considering two case studies: one for a tyre manufacturer and the other for a plastic goods manufacturer both located in the southern part of India. In order to achieve the optimum solutions through Genetic Algorithm (GA), the assumption of deterministic demands and unlimited supplier capacity were considered. The first phase of the study presented the

FLMEDIM, while the second phase of the paper presented a CLMEDIM. In this model the reverse logistics operation such as recycling was carried out with environmental concern and cost reduction. From the proposed model, it was revealed that the closed loop supply chain model was more beneficial to the customer in terms of cost aspects.

Pan et al. (2009) addressed the Capacitated Dynamic Lot Sizing Problem (CDLP) arising in closed-loop supply chain where returned products were collected from customers. These returned products could either be disposed or be remanufactured to be sold as new ones again; hence the market demands could be satisfied by either newly produced products or remanufactured ones. A general model of this problem was formulated, and several useful properties of the problem were characterized when cost functions were concave. The study considered the dynamic lot sizing problem with capacitated production and remanufacturing. The capacities were assumed constant during the planning horizon and all the returned products were to be remanufactured to be sold again within the planning horizon. Tests were conducted to examine the effect of capacity for returned products handling on the schedule plan. The study focused on how capacities of production and remanufacturing interacted with each other. CDLP-PR was solved under two different scenarios. First, the remanufacturing capacity was set to be large enough so that it could be omitted and called this problem as CDLP-PR1. Second, the production capacity was set to be large enough so that it could be omitted and this was termed as CDLP-PR2. Numerical experiments showed that non-polynomial algorithms were adequate to solve problems of practical sizes, and by examining the experimental results, it was observed that if the returned products existed in a relatively long planning horizon, it was helpful to improve the remanufacturing facilities so that the remanufacturing capacities could be expanded and the cost be saved; and if the returned products only existed in a relatively short planning horizon, e.g. seasonal products, the saving cost by increasing the capacity could be overwhelmed by the cost of expanding the capacities.

Ketzenberg (2009) explored the value of information in the context of a firm that faced uncertainty with respect to demand, recovery yield, product returns, and capacity utilization. Demand in a period was satisfied with new production, recovered return products, or a mix of both types. The general setting involved a supplier that could meet demand by producing new products, recovering returned products, or through a mix of both types. It was assumed that the quality and reliability of recovered product allowed the interchange and that the market was

indifferent between the two types. While, on average, it was less costly to process returns than procure new product, the rate of return was less than the rate of demand on average so that at least some portion of demand would be satisfied with new product. Both new production and recovery operations shared capacity depicted the material flow. This material flow was well studied in the literature on closed loop supply chains, and was predicated on a model developed. The study assumed a periodic review inventory system where the operational decisions of interest were the quantity of new product to manufacture, the quantity of returned product to recover, and the quantity of returned product to dispose. The studies indicated the conditions in which each type of information was most valuable. Yield information was most valuable with high rates of returns, high yield loss, high return variability, and high capacity availability. While capacity information was also most valuable with high rates of return and high return variability, high penalty costs and low yield loss generally increased its value. On the other hand, demand information was most valuable with high demand variability, high capacity availability and a high unit holding cost rate. No one type of information was dominant. Moreover, the value of capacity information was more robust with respect to information accuracy.

Tsai and Hung (2009) focused on the treatment and recycling system, and proposed a two stage Multi-Objective Decision Framework. The study proposed that it was necessary to established two types of decision models. For structural parsimony, this paper selected treatment stage (the first stage) and recycling stage (the second stage) to represent these two decision types, and modeled them, respectively, by multi-objective approach and profit maximization. The supply-chain characteristics and Activity Based Costing (ABC) were also adopted in this two-stage framework. In the treatment stage, the wastes were sorted, disassembled, de-polluted, and prepared for the subsequent processes. Suppliers were selected to serve for the multiple objectives. The objectives involved performance, risk, financial cost, activity, and speed. In this model, the environmental objective was embedded in the performance goal where environmental criterion was given a higher weight. In the context of activity based costing (ABC), cost driver could also be used as a measurement of efficiency. In the recycling stage, the recyclable materials from the first stage were transformed to reclaimed materials. Besides, the decision-maker in this stage took environmental costs, supply chain costs, and inventory holding costs into consideration. Waste emission tax and emission regulation were also incorporated in this

model. Proper identification and control of the activity quantities based on ABC provided a mechanism to filter out inefficient products or processes.

Wassenhove and Zikopoulos (2010) studied a simple reverse supply chain consisting of a remanufacturing facility and a number of independent locations where used products were returned by the end-consumers. At the collection locations, the returned products were graded and classified based on a list of nominal quality metrics provided by the remanufacturer. It was assumed that this classification was subject to errors; specifically, the returns condition was overestimated because of a stochastic proportion of returned units which were classified in classes corresponding to better quality than the actual. The scope of the study was to find how these classification errors affect the optimal procurement decisions of the remanufacturer as well as the associated profit. The conclusion drawn from analysis was that the economical impact of poor classification was primarily affected by the extent of quality overestimation and the difference of acquisition and remanufacturing costs of sequential quality classes at the same or different suppliers. The study dealt with the assessment of misclassification cost, and it helped in the evaluation of alternative methods that aimed at the reduction of classification errors, given that they were important. The determination of corrective actions depended on a number of problem parameters, like the relative market position of the suppliers and the remanufacturer. The study also concluded that demand uncertainty did not alter the suppliers' evaluation criterion and careful selection of acquisition prices decreased the impact of misclassification errors on the total profitability.

Simpson (2010) highlighted an under researched phenomenon where by firms engaged with one another to seek economical recycle of low value and after complex secondary material. Using eight case studies of manufacturing firms, the study developed few proposition on the basis on knowledge of waste and solution of disposal. Proposition 1: Firms that exhibited high levels of identification activities without seeking market information or inter-firm interaction were less likely to identify non-landfill disposal solutions, Proposition 2: Firms that exhibited high levels of information gathering about the quality and value of their waste were more likely to identify non-landfill disposal solutions such as recycling, Proposition 3: Interaction between supply chain partners specific to issues of recycling encouraged firms to identify non-landfill disposal opportunities. On the basis of proposition, it was concluded that study identified several

examples of innovative and valuable recycling solutions occurring through a range of inter-firm relationship types.

Anbuudayasanker et al. (2010) discussed simultaneous delivery and pick-up problem with constrained capacity (SDPC) and to solve that three unified heuristics based on extended branch and bound, genetic algorithm and simulated annealing to solve SDPC. These heuristics were also designed to solve standard travelling salesman problem (TSP) with simultaneous delivery and pick-up. The study concluded that the average deviation were 1.69%, .19% and 2.88% respectively from the optimal solution that was obtained by the classical approaches.

Neto et al. (2010) assumed that closed-loop supply chains were sustainable supply chains almost by definition. In this study it was analysed if and when this assumption holds. The study illustrated findings based on the Electric and Electronic Equipment (EEE) supply chain. For every phase of the supply chain, i.e. manufacturing, transportation, usage and end-of-life activities, the magnitude of the environmental impacts was assessed, based on a single environmental metric, namely the Cumulative Energy Demand (CED). In the manufacturing phase it was emphasised that product should be designed in such a way it consumes less energy when the product comes in the usage phase. The study also proposed in the end-of-life phase the product should have long life cycle so that was not phase out early stage. The study concluded that transportation did not appear to be significant for the overall environmental impact. Supply chains with a high proportion of manufacturing in energy consumption gained by extending the lifespan of the product. Bulk recycling was not a good option, or at least should be the last option after a long life. Supply chains with a high proportion of energy consumption saving gained by improving the product design and product management during use. The study also advocated that environmentally conscious product design might be expensive at the start of the product life, but saved money during the disassembly phase.

Kannan et al. (2010) studied the optimum usage of secondary lead recovered from the spent lead-acid batteries for producing new battery was presented. The study developed a multi period, multi echelon, multi product closed loop supply chain network model for product returns and the decisions were made regarding procurement, production, distribution, recycling and disposal. Heuristics based Genetic Algorithm (GA) was applied as a solution methodology to solve Mixed

Integer Linear Programming Model (MILP). Finally the computational results obtained through GA were compared with the solutions obtained by GAMS optimization software.

Kumar et al. (2011) studied the driver for sustainable approach for the reverse supply chain as internal and external. The study reported that external drivers stemmed mostly from stakeholders and competition whereas, internal drivers led to reduction of the wastes and costs. The study explored a simple model that was derived from a simple equation and also fragmented the model into simple compartment as design, suppliers and purchasing, manufacturing, transportation and consumption or disposal to reduce the waste by using better design and better manufacturing and management technique so that companies could understand and improve supply chain sustainability practices. The model was applied in two case studies, Coca-Cola, one of world-wide leader in sustainability, and Apple, a company that was newbie to develop a sustainability strategy. The case of Apple showed how much a well-respected and even admired company like Apple still had to improve in its approach. The case study of Coca-Cola showed significant improvements in its ability to reduce consumption of water and recoverability of their packaging. This study thus presented a framework that worked as a guideline for which improvements at which stages could be done to become a sustainably green supply chain.

Hazen et al. (2011) investigated the relationship between adoption of green supply chain management practice and competitive advantage and to examine the theory, data from 533 participants was gathered. ANOVA technique was used to test the proposed hypothesis and found that consumer perceive product made via some green supply chain practice to be inferior to brand-new product in terms of quality.

Mishra et al. (2011) reported that integration of supply chain had a very complex structure and to resolve that complexity the study proposed a multi-agent architecture to handle recycling and reverse logistics issues, which had been neglected. The autonomous agents were categorised on the basis of their function such as reverse logistic agent, recycling agent, allocation agent, distribution agents and knowledge based agents. These proposed autonomous agents were capable of self-decision-making and work collaboratively with other agents as and when required for the effective recycling of waste as the success of a multi-agent architecture depended on effective communication between agents. The agents communicated among themselves by sending signals through different languages such as Knowledge Query and Manipulation

Language (KQML), Agent Communication Language (ACL) etc with expressivity, understandability and reusability as the three main attributes of the communication channel. The study argued that the proposed multi-agent framework was capable of resolving recycling issues and efficient logistics management during the execution of recycling tasks. The proposed multi-agent framework could be used under different manufacturing scenarios by modifying the framework according to industry-specific requirements.

Rahman and Subramanian (2011) proposed a framework for end-of-life (EOL) computer recycling operations. It identified critical factors such as legislation, customer demand, strategic cost/benefit, volume and quality, environmental concern, incentive, resource, integration and coordination for implementing EOL computer recycling operations and also investigated the causal relationship among the factors influencing computer recycling operations in reverse supply chains using the direct-relation matrix constructed by the cognition mapping process Decision-Making Trial and Evaluation Laboratory (DEMATEL). The DEMATEL analysis produced two categories of results. Firstly, it prioritized the factors based on their degree of importance in the decision-making context under consideration. Secondly, it classified factors either as net dispatchers/drivers or as net receivers depending on the net influence to the context. Results indicated availability of resource, the volume and quality of recyclable materials and coordination and integration of recycling tasks, were critical for computer recycling operations. Factors such as incentive, government legislation and customer demand were found to be the major drivers.

Azadi and Saen (2011) proposed a new chance-constrained data envelopment analysis (CCDEA) approach to assist the decision makers to determine the most appropriate third-party reverse logistics (3PL) providers in the presence of both dual-role factors and stochastic data. A numerical example validates the application of the proposed model. Mathematical model that was presented in this study provided better information that could be used by managers in making strategic or operational decision.

Sasikumar and Haq (2011) proposed a multi-echelon, multiproduct Closed Loop Distribution Supply Chain (CLDSC) network and integrated with the selection process of best Third-Party Reverse Logistics Provider (3PRLP) to achieve cost efficiency and delivery schedules in reverse logistics. A Fuzzy Multi-Criteria Decision-Making (FMCDM) model based on the VIKOR

method was used for the selection of best 3PRLP with evaluation criteria as quality, deliverability, reverse logistics cost, rejection rate, technical/engineering capability, inability to meet future requirement, willingness and attitude. This method determined the compromise ranking-list and the compromise solution which provided a maximum 'group utility' of the 'majority', and a minimum of the 'individual regret' of the 'opponent'. To optimise the proposed network, a mixed integer linear programming (MILP) model was developed and solved using LINGO 8.0 optimisation software package for the case of battery recycling and decisions were made regarding raw material procurement from the supplier, production, distribution of units and amount of reclaimed/recycled material. The results showed that a cost reduction could be achieved in the case of CLDSC network by using the proposed model.

Kader and Haque (2011) addressed sustainable benefits of remanufacturing tyres. An agent-based simulation approach was used to tackle this research problem by identifying different agents such as tyre, recycler, collector and remanufacturer. The TYRE agent called TYRE was considered the central agent, which represented the physical unit of a tyre that underwent different states through the life cycle. The new replicated TYRE agents were generated based on the Original Equipment (OE) and Replacement (RE) demands. After the EOL, tyre went to collection centre represented by collection agent or COLLECTOR. Based on the decision of the collection agent, tyres were either sent to recycling agent (RECYCLER) or to retreading agent (RETREADER). If recycled, the TYRE agents were removed from the system and a demand for new tyres was filled by New Replacement (NRE) tyre 'TYRE' agents (replicated agent). When successfully retreaded, the tyres were sold in secondary market as retread tyres. In the case of retreaded tyre, the customer decision of purchasing was largely based on price and quality perception of retreaded tyre, which could be represented as retread acceptance level (A) on a scale of 0–1. Another important point in the model was that tyre manufacturers were not defined as a separate agent. This was based on the assumption that manufacturers do not attempt to influence the decision of retreading to increase sales of new OE/RE tyres. The results showed that retreaded tyre could capture almost 25% of replacement (sales) market, resulting in considerable reduction in scrap tyres and raw material consumption.

Jayant et al. (2011) described modelling and simulation of reverse logistics networks for collection of end of life (EOL) products for a company of North India. The company involved in production of acid batteries for commercial use. The study stressed on the design of the forward

and reverse logistics network for battery recycling operation. In this study, a simulation model was developed by using Arena 11.0 simulation package. The simulation modelling helped the user to analyze the future performance of network and that the model was able to calculate the cycle time, transfer time, transfer cost and resource utilization in a predictable manner.

Native and Lee (2012) picked complex dynamics of environment decentralized supply chain and how these dynamics could affect environment and economic outcome and considered a supply chain with manufacturer and two different suppliers: a recycled material and a raw material supplier with authority to make individual inventory decision to satisfy demand and reduce cost. In study Radio Frequency identification (RFID) was implemented in the supply chain to determine if real- time inventory monitoring and information sharing could help the system to attain higher environmental benefits and higher economic benefits. The study concluded that the environmental benefits are higher than the economic benefits after using the RFID technique.

Gallego et al. (2012) explored the scientific literature on reuse and proposed a definition for reusable articles (RA) which defined as durable products intended to be used multiple times by different users in different locations of a supply-chain network. The study was built on a typology of Reusable Articles (RA) as Returnable Transportation Items (RTI), Returnable Packaging Materials (RPM) and Reusable Products (RP). The study also identified different categories like low level of disassembly, new and reused articles were perfect substitutes, assets were shared and mobile. The study proposed logistics networks entailing reusable article returns could be broadly classified in two categories: star systems and multi-depot systems. In star systems, RA return to the same plant or depot from where they were originally issued once they have been used. In multi-depot systems, it was not compulsory for RA to return to the issuing depot. The study also identified few challenges as defining the fleet size and defining purchase policies for new article. It was concluded that on the basis of the definition, typology and categories how reusable articles were different from other types of recovery, such as recycling or remanufacturing.

Das and Chowdhury (2012) proposed an integrated, reverse logistics supply chain planning process with modular product design that produced and marketed products at different quality levels. A Mixed Integer Programming (MIP) model was used to formulate the overall planning

process required to maximize profit by considering the recovery of modules, the collection of returned products and the proportion of the product mix at different quality levels. This model assumed that the cost of products increased as the number of modules increased. Although the study considered cost as the only criteria for selecting retailers to collect returnables, similar formulations could easily be applied for considering additional criteria such as location and the positional importance of retailers. This collection quantity was integrated into the overall Supply Chain (SC) planning. This model decision on returnable collection was the basis for subsequent Reverse Logistics (RL) decisions. Collected returnables were sent to the Recovery Service Provider (RSPs) so that modules could be recovered. The study assumed that RSPs will dismantle each returned product to modules. This was done to ensure quality and adapt the recovered modules to the optimum designs during the planning period of recovery. Even if the returned product was in good condition, dismantling the product for reconditioning or refurbishing would allow manufacturers to ensure quality and provide the required warranty to obtain good market impact from the second hand products made from the modules. To balance the ecological and profit-based aspirations, the study included incentive criteria for collecting returnables, agreement conditions for fixing the maximum collection quantity by the retailers.

Loomba and Nakashima (2012) examined the role of sorting used products before disassembly for parts retrieval and remanufacturing under stochastic variability based on customer demand using a Markov decision process. The study addressed a problem of managing costs in a remanufacturing environment with stochastically variable demand and modeled it for used parts. Each part type was assumed to have varying quality and acquisition costs. The cost function included manufacturing, holding and backlog costs components. The study computed optimal purchase policy that maximized the expected average profit per period and obtained the optimal ordering policy, which maximized the expected profit per period using a Markov decision process approach. The numerical results showed the implementation of the proposed modelling approach.

Dey and Cheffi (2012) developed and deployed an analytical framework for measuring the environmental performance of manufacturing supply chains. This work's theoretical bases combined and reconciled three major areas: supply chain management, performance measurement and environmental management. This study developed an innovative green supply chain (GSC) performance measurement framework by integrating supply chain processes like

supplier relationship management, customer relationship management and internal supply chain management with organizational decision at both strategic and operational level. The proposed framework suggested six levels. The first level was the goal, the second level consisted of the axes of the overall supply chain, the third level was the environmental practices and sustainable performances, the fourth level was the criteria, the fifth level was the sub-criteria and the last level was the alternative supply chains. The proposed framework was then applied to three selected manufacturing organizations in the UK. The study exhibited both theoretical and practical implications. Theoretically, it contributed holistic constructs for designing a GSC and managing it for sustainability; and practically it helped industry practitioners to measure and improve the environmental performance of their supply chain.

Buyukozkan and Cific (2012) examined the components and elements of green supply chain management (GSCM) and suggested a novel GSCM evaluation framework. The study proposed an analytic approach based on the fuzzy ANP methodology to assist in GSCM strategic decisions and realised two phases as conceptualization and analysis phase. In conceptualization phase there were few fundamental elements as green logistics dimension, green organizational activities dimension, organizational performance dimension and green supply chain alternatives where as an analytical phase had fuzzy analytic network process. The study also provided a real-case study of Ford Otosan, one of the leading organization about environmental subjects in turkey, to illustrate the industrial application of our theoretical assessment model. The study identified components that were integrated into a strategic assessment and evaluation tool using Analytical Network Process (ANP). The dynamic characteristics and complexity of the GSCM analysis environment made the ANP technique a suitable tool for this study. The study concluded that the fuzzy ANP methodology used in this study offered a more precise and accurate analysis by integrating interdependent relationships and should be targeted at more strategic decisions, particularly for long-term profit and long-term competitiveness considerations.

Kenne et al. (2012) dealt with the production planning and control of a single product involving combined manufacturing and remanufacturing operations within a closed loop reverse logistics network with machines subject to random failures and repairs. While consumers traditionally disposed of products at the end of their life cycle, recovery of the used products economically was more attractive than disposal, while remanufacturing of the merchandise also pursued sustainable development goals. Three types of inventories were involved in this network. The

manufactured and remanufactured products were stored in the first and second inventories. The returned products were collected in the third inventory and then remanufactured or disposed of. The research proposed a manufacturing/remanufacturing policy that would minimize the sum of the holding and backlog costs for manufacturing and remanufacturing products. The decision variables were the production rates of the manufacturing and the remanufacturing machines. The optimality conditions were developed using the optimal control theory based on stochastic dynamic programming. Finally, a numerical example and a sensitivity analysis were presented to illustrate the usefulness of the proposed methodology. The structure of the optimal control policy was discussed depending on the value of costs and parameters and extensions to more complex reverse logistics networks. By controlling both the manufacturing and remanufacturing rates, the study obtained a near optimal control policy of the system through numerical techniques yielding straightforward decision rules.

2.2 LITERATURE SUMMARY

- Reverse logistics or closed loop supply chain increases the profitability of an organisation.
- Reverse logistics is applied mostly in automobile industries, electronics industries, retail sectors etc.
- Reverse logistics or closed loop supply chain reduces the waste and land fill.
- Issues related to classification cost of material returned in the reverse logistics network.
- The governing parameters of reverse logistics are cost and legislation (Government rules and regulation).
- Problems related to management of low value and complex secondary material.
- Third party logistics providers in closed loop supply chain network.

2.3 GAP IN LITERATURE

Gaps have been identified on the basis of which aim for the study has been decided. Few gaps are as follow:

- The previous studies on reverse logistics in lead acid battery manufacturing industries were only limited to a Large Scale manufacturing unit but very few have been reported for Medium or Small scale.

- Although different analytical tools have been used for optimizing cost, very few studies have actually drawn comparison of these assessments tools for superior results.
- For selecting third party logistics system, only one technique has been proposed by the researchers, which has been validated through a case study. No comparison has been drawn with other potential techniques for logistics in the closed loop supply chain that can be used for selection
- None of the studies in the literature indicates variations in costing in terms of battery types manufactured. Most studies have assumed that the production and purchasing cost is same for all types of batteries.
- Very few studies reported work on the alternative closed loops in the supply chain and a comparison among them.
- Very few studies have reported work in extending the forward chain into forming the part of the reverse chain.

OBJECTIVE AND PROBLEM DESCRIPTION

3.1 OBJECTIVE

The main objective of this research has been to study the reverse logistics (closed loop) of an organization with the intent of optimizing the total cost of the reverse logistics chain in the Lead–Acid Battery Manufacturing Companies in Punjab, using the statistical tools. Since the study has been cost centric, the various costs considered comprise of the following the total cost involve purchasing cost, production cost, transportation cost, battery recycling cost, battery disposal cost, collection cost.

3.2 PROBLEM DESCRIPTION

In the present scenario, the Lead Acid Battery manufacturing units in Punjab focus more on the forward supply chain. The network for the reverse supply chain is weak and disintegrated at best. Preliminary inputs from the Lead Battery manufacturing units have revealed the following as the primary reasons of weak network in the reverse supply chain:

- i. Poorly designed network of reverse supply chain – overall cost.
- ii. Logistics – Cost / Source.
- iii. Recovery – Cost / Reuse.
- iv. Trade-off between the use of virgin material and used material.

These lacunae have been the focus of the study in the supply chain in the Lead Battery manufacturing units into the forward and reverse supply chain of the Lead Battery units of Punjab.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 RESEARCH DESIGN

In the design of the study, a lead acid battery manufacturing company was identified. The main aim of this study has been to estimate the total cost of the closed loop supply chain. Extensive use of literature on reverse logistics led to the formulation of a model. The model (Sasikumar and Haq, 2010) has been used as the fundamental block of the study. Alterations made in the model have been made primarily to encompass additional constraints. Firstly, the generalized model of closed loop supply chain been developed and secondly, a case study of Medium Scale battery manufacturing industry has been presented.

In the forward supply chain, the main raw materials such as lead, sulphuric acid and plastic box have been procured from different suppliers to manufacture new batteries. After the manufacturing of batteries in plant, the product is distributed through distributors, wholesalers, retailers and then customers. Reverse logistics starts with the collection of the used batteries from customers.

For the purpose of the study, a set of conditions defining the network architecture of the closed loop supply chain have been defined. It has been assumed that a certain amount of used products, defined as a percentage of demand must be collected in the retailer's shop. Demand at each retailer is deterministic in nature and it must be satisfied. Customer could also return the end-of-life product at centralized return centre CRC. The collected end-of-life products at retailers should be transported to the disassembly/recycling plant (DRP) via CRC or end-of-life product or these may also be shipped directly to DRP. At DRP, end-of-life products have to go through the quality test and sorted for recycling. After inspection, the non-recyclable batteries must be disposed of and recyclable batteries have to pass through the disassembly process followed by recycling. Disassembly/recycling costs cover all the collected products that have been appropriate for recycling and disposal cost dealt with the products which failed to clear inspection test. The company has to purchase raw materials either from external supplier or acquire them from recycling the used products. To minimize the total supply chain cost, company has to decide about the number of units has to recycle (Kannan et al., 2010).

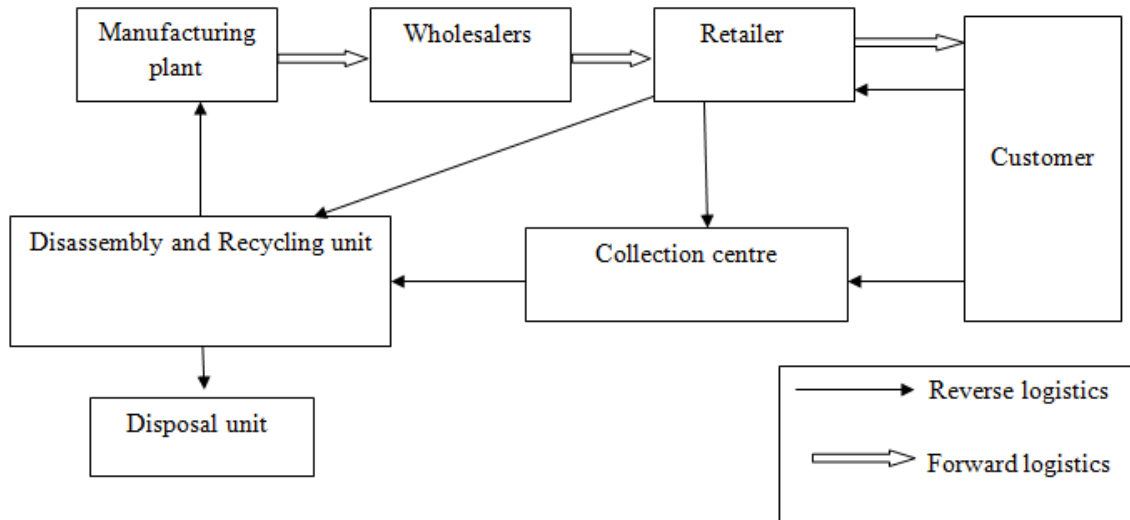


Figure 1: Closed loop supply chain network

i. Indices and Sets:

- i Index for manufacturing plants; $i \in I$.
- j Index for wholesalers; $j \in J$.
- k Index for retailers; $k \in K$.
- l Index for centralized return centers; $l \in L$.
- m Index for disassembly/recycling plants; $m \in M$.
- n Index for products; $n \in N$.

ii. Input Parameters:

- TC Total supply chain cost.
- TPUC Total purchasing cost.
- TPUC_r Total purchasing cost of recycled product.
- TPC Total production cost.
- TTPW Total transportation cost from manufacturing plants to wholesalers.
- TTWR Total transportation cost from wholesalers to retailers.
- TTRC Total transportation cost from retailers to CRCs
- TTRD Total transportation cost from retailers to DRPs.
- TTCD Total transportation cost from CRCs to DRPs.

- TTDP Total transportation cost from DRPs to manufacturing plants.
- TDC Total disassembly/recycling cost.
- TD Total disposal cost.
- TCC Total collection cost of the returned items.
- PUC Purchasing cost of one unit of raw material from the original supplier.
- PUC_r Purchasing cost of one unit of raw material from the recycle material supplier.
- PC_{ni} Production cost per unit of product n at manufacturing plant i .
- OC_{ni} Operation cost per unit of product n at manufacturing plant i
- MHC_{ni} Material handling cost per unit of product n at manufacturing plant i .
- OHC_{ni} Other over-head cost per unit of product n at manufacturing plant i .
- ICC_{ni} Inventory carrying cost per unit of product n at manufacturing plant i .
- TC_{nij} Transportation cost per unit of product n from manufacturing plant i to wholesaler j .
- TC_{njk} Transportation cost per unit of product n from wholesaler j to retailer k .
- TC_{nkl} Transportation cost per unit of product n from retailer k to CRC l .
- TC_{nkm} Transportation cost per unit of product n from retailer k to DRP m .
- TC_{nlm} Transportation cost per unit of product n from CRC l to DRP m .
- TC_{mi} Transportation cost for one unit of raw material from DRP m to manufacturing plant i .
- TD_n Total demand of product n .
- a_n Fraction of total demand returned from the retailers for product n .
- b_n Fraction of returned product n satisfying the quality specifications for recycling.
- RC_{nm} Disassembly/recycling cost per unit of product n at DRP m .
- DC_n Disposal cost per unit of product n .
- CC_n Collection cost per unit of product n .
- CP_{ni} Production capacity of product n at manufacturing plant i .
- RD_{nk} Demand for product n at the retailer k .
- r_n Amount of raw material required to produce one unit of product n .
- d_n Lead recycling rate of product n .
- CD_{nm} Disassembly/recycling capacity of product n at DRP m .

- RS_i Raw material storage capacity at manufacturing plant i .
- WS_{nj} Storage capacity of product n at the wholesaler j .
- SR_{nk} Storage capacity of product n at the retailer k .
- CS_{nl} Storage capacity of product n at the CRC l .

iii. Decision Variable:

- RP_i Amount of raw material purchased from original supplier to the manufacturing plant i .
- RP_{ir} Amount of raw material purchased from recycle material supplier to the manufacturing plant i .
- QP_{ni} Quantity of product n produced at manufacturing plant i .
- QT_{nij} Quantity of product n transported from manufacturing plant i to wholesaler j .
- QT_{njk} Quantity of product n transported from wholesaler j to retailer k .
- QT_{nkl} Quantity of product n transported from retailer k to CRC l .
- QT_{nkm} Quantity of product n transported from retailer k to DRP m .
- QT_{nlm} Quantity of product n transported from CRC l to DRP m .
- RR_{mi} Amount of reclaimed/recycled material transported from DRP m to the manufacturing plant i .

iv. Mathematical Model Formulation

The objective function of the closed loop distribution supply chain model is formulated as follows:

$$\text{Minimise TC} = (\text{TPUC} + \text{TPC} + \text{TTPW} + \text{TTWR} + \text{TTRC} + \text{TTRD} + \text{TTCD} + \text{TTDP} + \text{TDC} + \text{TD} + \text{TCC} + \text{TPUC}_r) \quad (1)$$

The objective of the model shown in Equation (1) minimizes the total supply chain cost and the cost components in the objective function can be calculated by using the following relations:

- **Purchasing Costs:** The total purchasing costs of virgin raw material can be determined as follows:

$$TPUC = PUC \sum_i RP_i$$

- If DRP is not in-house then the total purchasing cost of recycled raw material can be determined as follow:

$$TPUC_r = PUC_r \sum_i RP_{ir}$$

- **Production Costs:** The total production costs involved in all manufacturing plants can be determined as follows:

$$TPC = \sum_n \sum_i (QP_{ni} * PC_{ni})$$

- Where $PC_{ni} = \sum_n \sum_i (OC_{ni} + MHC_{ni} + OHC_{ni} + ICC_{ni})$

- **Transportation Cost:** The total transportation costs involved in both forward and reverse supply chain include the transportation costs from each manufacturing plant to all wholesalers, from each wholesaler to all retailers, from each retailer to all CRC, from each retailer to all DRPs, from each CRC to all DRP, from each DRP to all manufacturing plants.

- The total transportation cost from each manufacturing plant to all wholesaler can be determined as follows:

$$TTPW = \sum_n \sum_i \sum_j (QT_{nij} * TC_{nij}).$$

- The total transportation cost from each wholesaler to all retailers can be determined as follows:

$$TTWR = \sum_n \sum_j \sum_k (QT_{nj k} * TC_{nj k}).$$

- The total transportation cost from each retailer to all CRC can be determined as follows:

$$TTRC = \sum_n \sum_k \sum_l (QT_{nkl} * TC_{nkl}).$$

- The total transportation cost from each retailer to all DRP can be determined as follows:

$$TTRD = \sum_n \sum_k \sum_m (QT_{nkm} * TC_{nkm}).$$

- The total transportation cost from each RCR to all DRP can be determined as follows:

$$TTCT = \sum_n \sum_l \sum_m (QTnlm * TCnlm).$$

- The total transportation cost from each DRP to all Manufacturing plants can be determined as follows:

$$TTDP = \sum_m \sum_i (RRmi * TCmi)$$

- **Recycling /Retaining Cost:** The total cost disassembly/recycling cost involve in all DRP can be determined as follows:

$$TDC = \sum_n \sum_m (TDn * an * bn * RCnm).$$

- **Disposal Cost:** The total disposal cost can be calculated as follows:

$$TD = \sum_n (TDn * an * (1 - bn) * DCn).$$

- **Collection Cost:** .The total collection costs of returned products can be determined as follows:

$$TCC = \sum_n (TDn * an * CCn).$$

Subject to be Constraints:

Constraint (2) stipulates that production quantity of each product should not exceed the production capacity of production plant.

$$QPni \leq CPni, \quad \forall n, i. \quad (2)$$

Constraint (3) requires total outgoing flows from each manufacturer should be as big as quantity of manufactured products.

$$QPni = \sum_j QTnij, \quad \forall n, i. \quad (3)$$

Constraint (4) ensures that demand for each product should fully be met

$$\sum_j QTnj = RDnk, \quad \forall n, k. \quad (4)$$

Constraint (5) is the flow constraint balancing the quantity of returned products

$$\sum_l QTnkl + \sum_m QTnkm = an \sum_j QTnij, \quad \forall n,k. \quad (5)$$

Constraint (6), (7) and (8) are balance equation for disassembly /recycling, wholesaler and RCC: the quantities that enter these facilities should be equal to the amount of product and raw material that leaves these facilities.

$$\sum_i RRmi = \sum_n \sum_k QTnkm * bn * rn * dn + \sum_n \sum_l QTnlm, *bn * rn * dn \quad \forall m, \quad (6)$$

$$\sum_i QTnij = \sum_k QTnjk, \quad \forall n,j, \quad (7)$$

$$\sum_k QTnkl = \sum_m QTnlm, \quad \forall n,l. \quad (8)$$

Constraint (9) is the constraint ensuring that the quantity transported to DRP cannot exceed the DRP capacity

$$\sum_l QTnlm + \sum_k QTnkm \leq CDnm, \quad \forall n,m, \quad (9)$$

Constraint (10) is the existing capacity constraints of manufacturers of raw materials

$$RPi + \sum_m RRmi \leq RSi, \quad \forall i. \quad (10)$$

Constraint (11), (12), and (13) restricted the capacity of wholesalers, retailer and CRC

$$\sum_i QTnij \leq WSnj, \quad \forall n,j, \quad (11)$$

$$\sum_j QTnjk \leq SRnk, \quad \forall n,k, \quad (12)$$

$$\sum_k QTnkl \leq CSnl, \quad \forall n,l. \quad (13)$$

Constraint (14) provides the required quantities of raw materials for manufacturing

$$\sum_n QPni *rn = RPi + RRmi \quad \forall i. \quad (14)$$

Constraint (15) indicates that total demand of each product is equal to retail's demands for the product

$$TDn = \sum_n RDnk \quad \forall n. \quad (15)$$

Constraints (16) enforces the non negativity restriction on the decision variables

$$QTnij, QTnj, OTnkl, QTnlm, OTnkm, QPni \geq 0 \quad (16)$$

And integers

$$RPi, RRmi \geq 0.$$

CHAPTER 5

CASE STUDY

ABC Private Limited was established in year 1974 and is ISO 14000 certified located in the northern part of India, Punjab and is also registered with Punjab Pollution Control Board for handling and controlling the hazardous waste. The company is a well known name in the field of lead load sub-oxide, battery plates and batteries in Punjab region. It produces a variety of batteries for both automobiles and for domestic use. The company is having its own recycling unit for two fundamental reasons 1) Government regulation 2) reduction in the manufacturing cost of the products. The present recycling capacity of the company is about 300 ton per year of lead and the company also plans to start a new recycling plant with recycling capacity of 3000 ton per year of recycling of lead. By increasing the recycling capacity the company will not only reduce the usage of virgin lead but also supply the lead oxide to other small scale battery manufacturing units saving considerable natural resources by decreasing the extraction of the lead from the mines and also reduces landfill space.

The supply chain that the manufacturing company follows has a different pattern from the supply chain model shown in Fig 1. Due to limited volumes, the company has optimized the supply chain by eliminating the wholesaler and as such has only two nodes in its supply chain loop, the manufacture node and the retailer node. Retailer's node plays dual role, one to sell the product and the other to act as the collection point for the End of life products returned. After collecting the returned product it is transferred to the disassembly/ recycling centre (DRP) where the operation of disassembly of the product is carried out along with the recycling process of the lead from the product. After the recycling operation, the amount of the reclaimed lead is transported to the manufacturing node of the network. A complete supply chain network of company is shown in Fig 2.

During this study of reverse logistics few assumptions have been considered.

- a.** Demand of a product is known to the manufacturing company.
- b.** Amount of demand at retailer's end is fulfilled by the manufacturer.
- c.** Overall transportation cost per unit of product from manufacturer to retailer is equal to the transportation cost from retailer to the DRP.
- d.** Only recycling operation is considered in reverse logistics.

- e. The inspection cost per item for the returned product has been included in the return item collection cost.
- f. The inventory carrying cost has been considered to be insignificant.
- g. The transportation cost of the raw material from supplier has been included in the purchasing cost for forward supply chain.
- h. The time taken for transporting the product is homogenous and not considered during study.

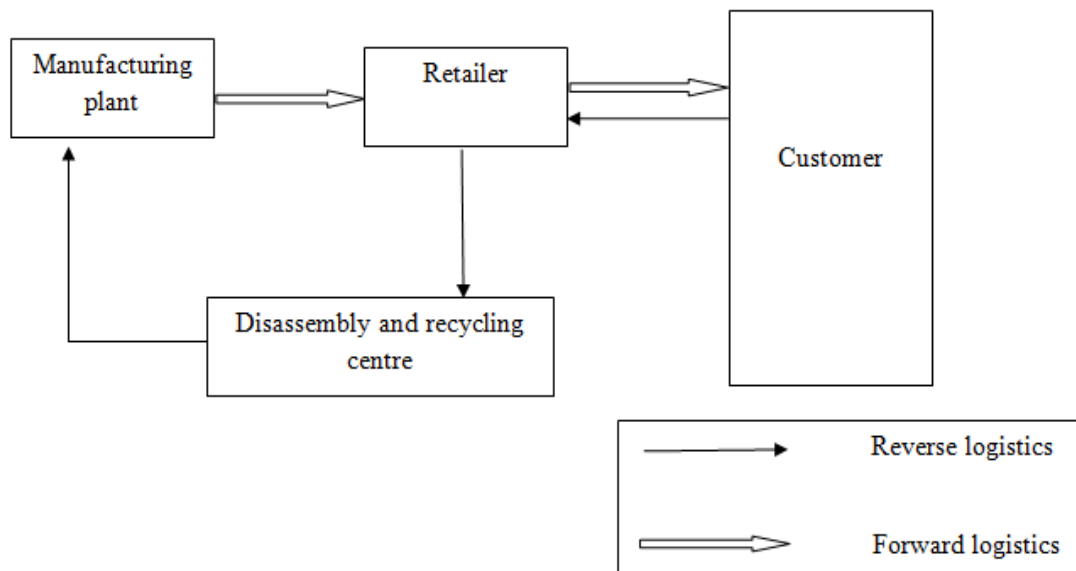


Figure 2: Closed loop supply chain of ABC Private Limited

5.1 SOLUTION METHODOLOGY

i. Tora Software

Tora is a software designed to solve the different problems of operation research by analysing the data feed by the operator. The different types of optimizing technique such as linear programming, transportation problem, integer programming etc can easily be solved with precise solution. The different techniques used in this study are as follow:

- a) Linear programming.

a) Linear Programming

Linear programming (LP or linear optimization) is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships. Linear programming is a specific case of mathematical programming (mathematical optimization).

More formally, linear programming is a technique for the optimization of a linear objective function, subject to linear equality and linear inequality constraints. Its feasible region is a convex polyhedron, which is a set defined as the intersection of finitely many half spaces, each of which is defined by a linear inequality. Its objective function is a real-valued affine function defined on this polyhedron. A linear programming algorithm finds a point in the polyhedron where this function has the smallest (or largest) value if such a point exists (Taha, 2010).

ii. Evolver 6 software

a) Genetic algorithm

It has been observed that most of the researches that carried out were using traditional supply chain for optimizing the supply chain problem. The only problem encounter with the traditional optimizing and search technique is that they do not fare well over a broad spectrum of problem domains. The robustness of traditional techniques is quite low as they are not efficient with large practical search space.

Genetic algorithms (GA) are search algorithm based on the mechanism of natural selection and natural genetics. These have been developed by John Holland, his colleagues, and his students at the University of Michigan. The goals of their research are

- 1) To abstract and rigorously explain the adaptive process of natural system.
- 2) To design artificial system software that retains the important mechanism of natural science system.

The GA is an example of a search procedure that uses random choice as a tool to guide a highly exploitative search through a coding of parameter space.

GA is one of the non-traditional optimizing and search algorithms which is different from traditional ones due to the following reasons

- a. GAs work with a coding of the parameters set, not the parameters themselves.
- b. GAs search from a population of points, not a single point.
- c. GAs use payoff (objective function) information, not derivatives or other auxiliary knowledge.
- d. GAs use probabilistic transition rules, not deterministic rules.

GAs require the natural parameter set of the optimizations problem to be coded as a finite-length string over some finite alphabet. A simple genetic algorithm that yields good results in many practical problems is composed of three operators

- a. Reproduction
- b. Crossover
- c. Mutation

Reproduction is a process in which individual string are copied according to their objective function values, f (biologist call this function the fitness function). Intuitively, function can be taken as some measure of profit, utility or goodness that what is required to maximize. Copying string according to their fitness value means that string with higher value, have higher probability of contributing one or more offspring in the next generation.

After reproduction simple crossover may proceed in two steps. First, members of newly reproduced string in the mating pool are mated at random. Second, each pair of string undergoes crossing over as follow: an integer position K along the string is selected uniformly at random between 1 and the string length less one $[1, L-1]$. Two new strings are created by swapping all characters between positions $K+1$ and L inclusively.

In the simple GA, mutation is the occasional (with small probability) random alteration of the value of a string position (Goldberg, 2011).

5.2 ABC Private Limited Company - Case illustration

The following data was used for validating the closed loop supply chain.

Number of manufacturing plant =1

Number of retailers = 5

Number of disassembly/ recycling plant =1

Table 1: Average Transportation cost/unit (Rs).

From / To	Retailers				
	R1	R2	R3	R4	R5
Manufacturing plant	30	15	25	20	20

Table 2: Average demand details at retailer.

	Retailers				
	R1	R2	R3	R4	R5
Demand	40	100	110	80	80

Table 3: Input Parameters

Average Collection cost	2450 Rs/return product
Average Purchasing cost of raw material (Lead)	138 Rs/ kg
Production Cost	560 Rs/ product
Average Disassembly and Recycling cost	4 Rs/ kg
Amount of raw material required to produce 1 unit of product	28 kg
Fraction of return product satisfying the quality inspection for recycling	100%
Transportation cost from DRP to Manufacturing Plant	1 Rs/kg
Production capacity	90000 units / year

In this study, to develop a clear idea of the saving (difference between closed loop supply chain and forward supply chain), different values of “rate of return” and “recycling rate” have been considered. This information has been extended to determine the breakeven point. The breakeven point has been indentified between 67% and 68%. Such an indicator also aids in process improvement.

To solve this problem the Tora software and Evolver 6 software have be used and the methodology used in solving linear programming and Genetic Algorithm in which the main objective has been to minimize the total cost of the supply chain.

6.1 FROM LINEAR PROGRAMMING

By using the data Tabulated in chapter 5 and by applying the linear programming method for optimality using the TORA software at different levels of the rate of return of the product and the different levels of the recycling rate for the closed loop supply chain the following results are obtained.

Total cost of the forward supply chain consists of three cost components i.e. purchasing cost, production cost and the transportation cost. The total forward supply chain cost is shown in Table 4.

Table 4: Optimal cost details for forward supply chain

Cost components	Optimal cost(Rs.)
Purchasing cost	1584240
Production cost	229600
Transportation cost from plant to retailer	8650

- i. At 65% lead recycling rate:** Total cost of closed loop supply chain on the basis of its cost components at the optimal solution for rate of return of product at 65% lead recycling rate has been shown in Appendix A, Table 1. From the analysis of data it has been observed that closed loop supply chain is not beneficial to practice as at this recycling rate, the total cost of forward supply chain is less than that of closed loop supply chain. The increase in rate of return results in the increase of loss percentage from .2% to 2%.
- ii. At 75% lead recycling rate:** By analysing the data that has been shown in Appendix A, Table 2. It has been observed that the total cost of closed loop supply chain proved to be lesser in terms of cost as compared to the forward supply chain and the saving percentage increases from .6 % to 6.6% with increase in rate of return.
- iii. At 85% lead recycling rate:** Data shown in Appendix A, Table 3 has been studied and it has been observed that the closed loop supply chain becomes beneficial to practice when

recycling rate of lead reached to 85% and the saving increased from 1.5% to 15% with increased in rate of return. The main reason for such increase in saving percentage has been found out to be the decline in purchasing cost of the virgin material from the suppliers.

iv. At 95% lead recycling rate: The total cost on the basis of the cost components at the optimal level for varying rate of return of product at 95% lead recycling rate has been shown in Appendix A, Table 4. From the analysis of the data it has been observed that the total cost of closed loop supply chain is more economical to practise as the cost of supply chain is the same but the closed loop cost reduces considerably because of economics of scale in recycling of lead. The saving percentage reached to a maximum value of 24% (approximately). The main reason for such a huge reduction in the cost of supply chain has been due to reduction of the purchasing cost of virgin lead from suppliers. At 95% recycling rate the cost effectiveness is not the only positive outcome but the decrease in the amount of the waste landfill has also been an environmental aspect should also be appreciated.

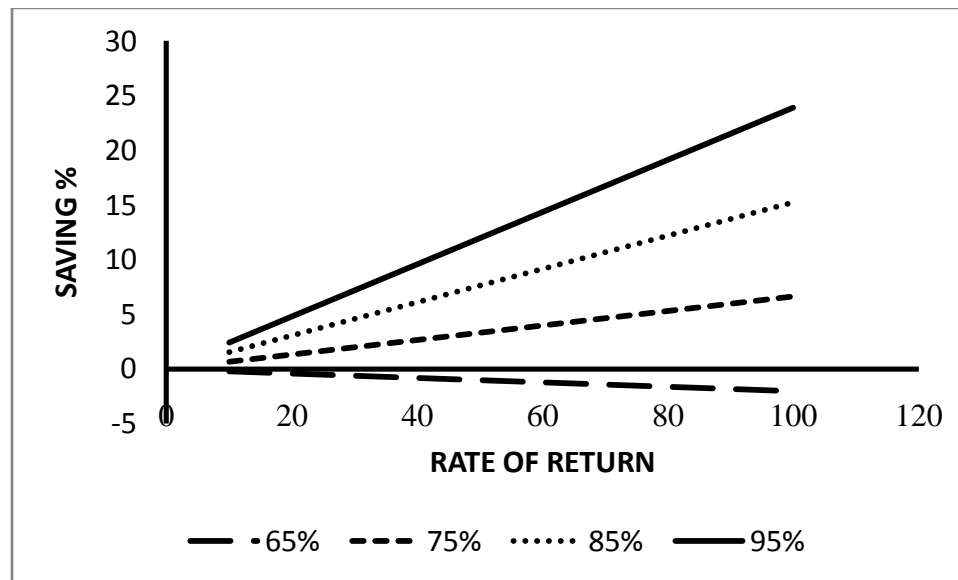


Figure 3: Saving % vs Rate of return at different recycling rate

The graph between saving percentage and rate of return at different recycling rate has been shown in Fig 3. The graph showed the linear relation between saving percentage and the rate of return, as the rate of return increases, the saving percentage increased linearly in case of 75%,

85%, 95% recycling rate and the saving percentage decreased linearly in case of 65% recycling rate.

6.2 FROM GENETIC ALGORITHM

Genetic Algorithm has been applied on the data given in Table 1, Table 2 and Table3. The data has been shown in Table 5 used as the Evolver software setting parameters.

Table 5: Evolver software optimizing setting parameters.

S. No	Genetic Algorithm parameters	value
1	Cross over rate	1
2	Population size	100
3	Mutation rate	.05

- i. **At 65 % recycling rate:** By analysing the data that has been shown in Appendix B Table 1, it has been observed that the total cost of closed loop supply chain proved to be expensive in terms of cost as compared to the forward supply chain and the loss percentage increased from 0.2% to 2% . It has been observed that loss percentage increased with increases in the value of rate of return of the end of life of product. The main reason for further increase in loss percentage has been the aggregate of transportation cost, disassembly/recycling cost, collection cost which comes out to be more than the cost reduction in purchasing the virgin lead from supplier.
- ii. **At 75 % recycling rate:** Total cost of closed loop supply chain on the basis of its cost components at the optimal solution for varying rate of return of product at 75% lead recycling rate has been shown in Appendix B, Table 2. From the data it has been observed that the reduction in the value of purchasing cost of virgin lead dominates combined cost of reverse loop transportation, disassembly/recycling and collection which makes the total cost of closed loop supply chain less than the cost of forward supply chain. It also has been observed that the saving percentage increased from 0.6% to 6.6% with increase in the amount of rate of return of product.
- iii. **At 85% recycling rate:** Data shown in Appendix B, Table 3 has been studied and it has been observed that the closed loop supply chain becomes beneficial to practice when

recycling rate of lead reached to 85 % and the domination of decreased cost of purchasing of virgin material over the reverse logistics cost enhances, even this domination of decreased in purchase cost of virgin lead is far better than the result obtained at 75% recycling rate. The saving increases from 1.5% to 15 % with increase in rate of return.

iv. At 95% recycling rate: The total cost on the basis of the cost components at the optimal solution for varying rate of return of product at 95% lead recycling rate has been shown in Appendix A, Table 4. From the analysis of the data it has been observed that the total cost of closed loop supply chain is inexpensive to practise as the cost of the closed loop supply chain is lesser when compared with the forward supply chain. The saving percentage reached to a maximum value of 24% (approximately). The main reason for such a reduction in the cost of supply chain has been due to reduction of the purchasing cost of virgin lead from suppliers. The reduction in the purchasing cost is about 18.1 times with the increases in the value of rate of return from 10% to 100%. At 95% recycling rate the cost effectiveness is not the only positive outcome but the decrease in the amount of the waste landfill has also been an environmental aspect should also be appreciated.

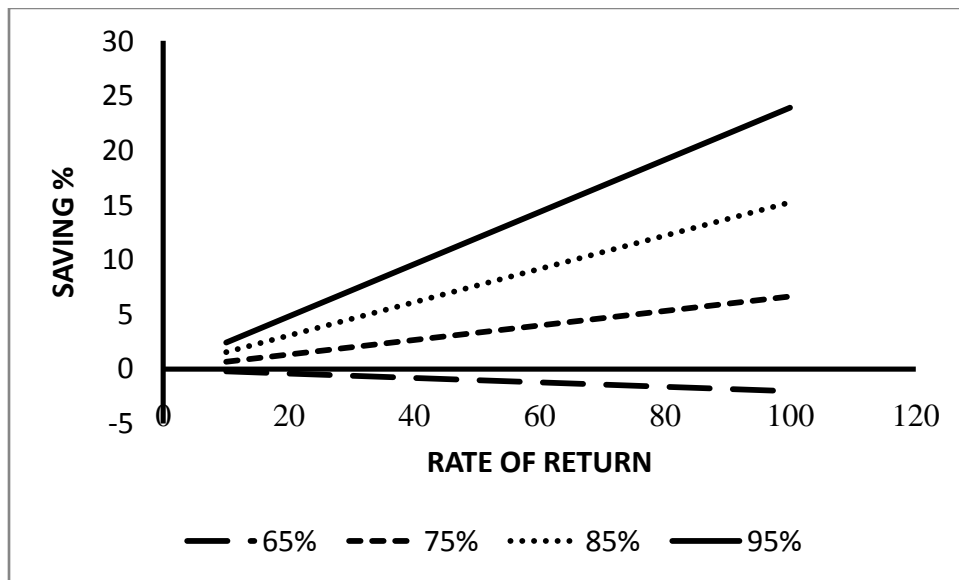


Figure 4: Saving % vs Rate of return at different recycling rate

The graphical representation of the saving percentage and rate of return of end of life of product has been shown in Fig 4. From the figure it has been observed that the saving percentage increased or decreased linearly with rate of return at different values of recycling rate.

6.3 COMPARISON OF SAVING PERCENTAGE BETWEEN LINEAR PROGRAMMING AND GENETIC ALGORITHM

The results have been obtained using two different optimizing techniques with the objective of minimizing the total cost of closed supply chain and with the objective of cross verifying/checking the optimality attained in total cost in a closed loop supply chain environment. Also to draw comparison, if any, between two techniques.

- i. At 65% recycling rate:** The comparative study of the results obtained by using linear programming and genetic algorithm has been showed in Appendix C, Table 1. By examining the data it has been observed that both optimizing technique gives the same result in terms of saving percentage.
- ii. At 75% recycling rate:** During the comparison of results at 75% recycling rate, it has been observed that the optimizing cost of the objective function comes out to be the same for both the optimizing technique. The result of the comparative study has been shown in Appendix C, Table 2.
- iii. At 85% recycling rate:** The comparative study of result obtained by using linear programming and genetic algorithm at 85% recycling rate has been showed in Appendix C, Table 3. By examining the data it has been observed that both optimizing technique gives the same result in terms of saving percentage and it also has been observer that after 60% rate of return the saving become impressive in nature.
- iv. At 95% recycling rate:** After comparing the result obtained by using two techniques has been shown in Appendix C, Table 4. From the analysis of data it has been observed that optimized cost of the closed loop supply chain has unique solution and both techniques generate identical solution for both saving percentage as well as for total cost of closed loop supply chain.

CHAPTER 7

CONCLUSION

In this study of closed loop supply chain two different techniques have been used to compare the percentage of the saving at different levels of the rate of return of the product and at different level of the recovery of the lead from the returned product. The data has been collected from the medium scale industry of lead acid batteries in Punjab region. The results have been obtained by applying two different techniques, first is optimizing technique Linear Programming (LP) and other, optimizing technique Genetic Algorithm (GA). The results generated through the application of the two techniques to the data obtained through a questionnaire have been similar in terms of value at all levels of rate of return and at all recovery level. The results generated have indicated some glaring outcomes with respect to the study points out with a glaring outcome that saving percentage is mainly dependent of three factors: rate of return of product, recovery level of lead and length of the supply chain.

1. The first factor Rate of Return of product plays a vital role as it has been clear from the result. Also, if the Rate of Return increases it increases the saving percentage in positive direction after the recovery level from product increases from the threshold point 67.56% otherwise the loss increases with increases in value of Rate of Return.
2. The second factor also has a sizeable impact on the closed loop supply chain's saving percentage as increase in the value of the recycling of the lead beyond 67.56% increases the total saving of the company using the closed loop supply chain otherwise it is not recommended to practice closed loop supply chain.
3. The third factor also plays a role in the saving of the company. The results have indicated that smaller the length of the supply chain network lesser the amount spends on the transportation cost and the saving percentage increases.

Profitability is not the only reason to introduce the closed loop supply chain in company but also it has an environmental effect too. As rate of return and the recovery level increases the use of the virgin lead decreases and also the land fill and disposal of the hazardous waste decreases to a greater degree. This decrease in the usages of the virgin material results in the cost effectiveness of the supply chain, with replacement of virgin material by recycled material. From the data it has been observed that the cost of reverse logistics along with the cost of forward supply chain

become less than the cost of forward supply chain and this difference between the total cost of closed loop supply chain and forward supply chain keeps on increasing.

The results obtained from the study have indicated that the company could save cost using the reverse logistics up to maximum of approximately 23% and it just need to increases the capability of the process of DRP so that the maximum amount of the lead can be recovered from the returned product and also the rate of return of end of life batteries can be improved by building KCRM. Knowledge Based Customer Relationship Management through which customer can educated with respect to environmental hazards.

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- 3 <http://www.batterytender.com>

APPENDIX A

Result obtained by linear programming:

Table 1: Model experiment for varying rate of return at 65% lead recycling rate

Rate of return (%)	Optimal Cost components									
	TPUC	TPC	TTPR	TTRD	TCC	TDC	TTDP	TC	TFSCC	Saving %
10	1481264.4	229600	8650	865	100450	4592	746.2	1826167.6	1822490	-0.201789
20	1378288.8	229600	8650	1730	200900	9184	1492.4	1829845.2	1822490	-0.403579
30	1275313.2	229600	8650	2595	301350	13776	2238.6	1833522.8	1822490	-0.605369
40	1172337.6	229600	8650	3460	401800	18368	2984.8	1837200.4	1822490	-0.807159
50	1069362	229600	8650	4325	502250	22960	3731	1840878	1822490	-1.008949
60	966386.4	229600	8650	5190	602700	27552	4477.2	1844555.6	1822490	-1.210739
70	863410.8	229600	8650	6055	703150	32144	5223.4	1848233.2	1822490	-1.412529
80	760435.2	229600	8650	6920	803600	36736	5969.6	1851910.8	1822490	-1.614318
90	657459.6	229600	8650	7785	904050	41328	6715.8	1855588.4	1822490	-1.816108
100	554484	229600	8650	8650	1004500	45920	7462	1859266	1822490	-2.017898

Table 2: Model experiment for varying rate of return at 75% lead recycling rate

Rate of return (%)	Optimal Cost components									
	TPUC	TPC	TTPR	TTRD	TCC	TDC	TTDP	TC	TFSCC	Saving %
10	1465422	229600	8650	865	100450	4592	861	1810440	1822490	0.66118333
20	1346604	229600	8650	1730	200900	9184	1722	1798390	1822490	1.32236665
30	1227786	229600	8650	2595	301350	13776	2583	1786340	1822490	1.98354998
40	1108968	229600	8650	3460	401800	18368	3444	1774290	1822490	2.6447333
50	990150	229600	8650	4325	502250	22960	4305	1762240	1822490	3.30591663
60	871332	229600	8650	5190	602700	27552	5166	1750190	1822490	3.96709996
70	752514	229600	8650	6055	703150	32144	6027	1738140	1822490	4.62828328
80	633696	229600	8650	6920	803600	36736	6888	1726090	1822490	5.28946661
90	514878	229600	8650	7785	904050	41328	7749	1714040	1822490	5.95064993
100	396060	229600	8650	8650	1004500	45920	8610	1701990	1822490	6.61183326

Table 3: Model experiment for varying rate of return at 85% lead recycling rate

Rate of return (%)	Optimal Cost components									
	TPUC	TPC	TTPR	TTRD	TCC	TDC	TTDP	TC	TFSCC	Saving %
10	1449579.6	229600	8650	865	100450	4592	975.8	1794712.4	1822490	1.52415651
20	1314919.2	229600	8650	1730	200900	9184	1951.6	1766934.8	1822490	3.04831302
30	1180258.8	229600	8650	2595	301350	13776	2927.4	1739157.2	1822490	4.57246953
40	1045598.4	229600	8650	3460	401800	18368	3903.2	1711379.6	1822490	6.09662604
50	910938	229600	8650	4325	502250	22960	4879	1683602	1822490	7.62078256
60	776277.6	229600	8650	5190	602700	27552	5854.8	1655824.4	1822490	9.14493907
70	641617.2	229600	8650	6055	703150	32144	6830.6	1628046.8	1822490	10.6690956
80	506956.8	229600	8650	6920	803600	36736	7806.4	1600269.2	1822490	12.1932521
90	372296.4	229600	8650	7785	904050	41328	8782.2	1572491.6	1822490	13.7174086
100	237636	229600	8650	8650	1004500	45920	9758	1544714	1822490	15.2415651

Table 4. Model experiments for varying rate of return at 95% lead recycling rate

Rate of return (%)	Optimal Cost components									
	TPUC	TPC	TTPR	TTRD	TCC	TDC	TTDP	TC	TFSCC	S%
10	1433737.2	229600	8650	865	100450	4592	1090.6	1778984.8	1822490	2.387129696
20	1283234.4	229600	8650	1730	200900	9184	2181.2	1735479.6	1822490	4.774259392
30	1132731.6	229600	8650	2595	301350	13776	3271.8	1691974.4	1822490	7.161389089
40	982228.8	229600	8650	3460	401800	18368	4362.4	1648469.2	1822490	9.548518785
50	831726	229600	8650	4325	502250	22960	5453	1604964	1822490	11.93564848
60	681223.2	229600	8650	5190	602700	27552	6543.6	1561458.8	1822490	14.32277818
70	530720.4	229600	8650	6055	703150	32144	7634.2	1517953.6	1822490	16.70990787
80	380217.6	229600	8650	6920	803600	36736	8724.8	1474448.4	1822490	19.09703757
90	229714.8	229600	8650	7785	904050	41328	9815.4	1430943.2	1822490	21.48416727
100	79212	229600	8650	8650	1004500	45920	10906	1387438	1822490	23.87129696

APPENDIX B

Result obtained by Genetic Algorithm:

Table 1: Model experiment for varying rate of return at 65% lead recycling rate

Rate of return (%)	Optimal Cost components									
	TPUC	TPC	TTPR	TTRD	TCC	TDC	TTDP	TC	TFSCC	Saving %
10	1481264.4	229600	8650	865	100450	4592	746.2	1826167.6	1822490	-0.201789
20	1378288.8	229600	8650	1730	200900	9184	1492.4	1829845.2	1822490	-0.403579
30	1275313.2	229600	8650	2595	301350	13776	2238.6	1833522.8	1822490	-0.605369
40	1172337.6	229600	8650	3460	401800	18368	2984.8	1837200.4	1822490	-0.807159
50	1069362	229600	8650	4325	502250	22960	3731	1840878	1822490	-1.008949
60	966386.4	229600	8650	5190	602700	27552	4477.2	1844555.6	1822490	-1.210739
70	863410.8	229600	8650	6055	703150	32144	5223.4	1848233.2	1822490	-1.412529
80	760435.2	229600	8650	6920	803600	36736	5969.6	1851910.8	1822490	-1.614318
90	657459.6	229600	8650	7785	904050	41328	6715.8	1855588.4	1822490	-1.816108
100	554484	229600	8650	8650	1004500	45920	7462	1859266	1822490	-2.017898

Table 2: Model experiment for varying rate of return at 75% lead recycling rate

Rate of return (%)	Optimal Cost components									
	TPUC	TPC	TTPR	TTRD	TCC	TDC	TTDP	TC	TFSCC	Saving %
10	1465422	229600	8650	865	100450	4592	861	1810440	1822490	0.66118333
20	1346604	229600	8650	1730	200900	9184	1722	1798390	1822490	1.32236665
30	1227786	229600	8650	2595	301350	13776	2583	1786340	1822490	1.98354998
40	1108968	229600	8650	3460	401800	18368	3444	1774290	1822490	2.6447333
50	990150	229600	8650	4325	502250	22960	4305	1762240	1822490	3.30591663
60	871332	229600	8650	5190	602700	27552	5166	1750190	1822490	3.96709996
70	752514	229600	8650	6055	703150	32144	6027	1738140	1822490	4.62828328
80	633696	229600	8650	6920	803600	36736	6888	1726090	1822490	5.28946661
90	514878	229600	8650	7785	904050	41328	7749	1714040	1822490	5.95064993
100	396060	229600	8650	8650	1004500	45920	8610	1701990	1822490	6.61183326

Table 3: Model experiment for varying rate of return at 85% lead recycling rate

Rate of return (%)	Optimal Cost components									
	TPUC	TPC	TTPR	TTRD	TCC	TDC	TTDP	TC	TFSCC	Saving %
10	1449579.6	229600	8650	865	100450	4592	975.8	1794712.4	1822490	1.52415651
20	1314919.2	229600	8650	1730	200900	9184	1951.6	1766934.8	1822490	3.04831302
30	1180258.8	229600	8650	2595	301350	13776	2927.4	1739157.2	1822490	4.57246953
40	1045598.4	229600	8650	3460	401800	18368	3903.2	1711379.6	1822490	6.09662604
50	910938	229600	8650	4325	502250	22960	4879	1683602	1822490	7.62078256
60	776277.6	229600	8650	5190	602700	27552	5854.8	1655824.4	1822490	9.14493907
70	641617.2	229600	8650	6055	703150	32144	6830.6	1628046.8	1822490	10.6690956
80	506956.8	229600	8650	6920	803600	36736	7806.4	1600269.2	1822490	12.1932521
90	372296.4	229600	8650	7785	904050	41328	8782.2	1572491.6	1822490	13.7174086
100	237636	229600	8650	8650	1004500	45920	9758	1544714	1822490	15.2415651

Table 4: Model experiments for varying rate of return at 95% lead recycling rate

Rate of return (%)	Optimal Cost components									
	TPUC	TPC	TTPR	TTRD	TCC	TDC	TTDP	TC	TFSCC	S%
10	1433737.2	229600	8650	865	100450	4592	1090.6	1778984.8	1822490	2.387129696
20	1283234.4	229600	8650	1730	200900	9184	2181.2	1735479.6	1822490	4.774259392
30	1132731.6	229600	8650	2595	301350	13776	3271.8	1691974.4	1822490	7.161389089
40	982228.8	229600	8650	3460	401800	18368	4362.4	1648469.2	1822490	9.548518785
50	831726	229600	8650	4325	502250	22960	5453	1604964	1822490	11.93564848
60	681223.2	229600	8650	5190	602700	27552	6543.6	1561458.8	1822490	14.32277818
70	530720.4	229600	8650	6055	703150	32144	7634.2	1517953.6	1822490	16.70990787
80	380217.6	229600	8650	6920	803600	36736	8724.8	1474448.4	1822490	19.09703757
90	229714.8	229600	8650	7785	904050	41328	9815.4	1430943.2	1822490	21.48416727
100	79212	229600	8650	8650	1004500	45920	10906	1387438	1822490	23.87129696

Table 1: Comparison of saving percentage at 65% recovery rate.

Rate of return %	Saving percentage (Linear Programming)	Saving percentage (Genetic Algorithm)
10	-0.201789	-0.201789
20	-0.403579	-0.403579
30	-0.605369	-0.605369
40	-0.807159	-0.807159
50	-1.008949	-1.008949
60	-1.210739	-1.210739
70	-1.412529	-1.412529
80	-1.614318	-1.614318
90	-1.816108	-1.816108
100	-2.017898	-2.017898

Table 2: Comparison of saving percentage at 75% recovery rate.

Rate of return %	Saving percentage (Linear Programming)	Saving percentage (Genetic Algorithm)
10	0.66118333	0.66118333
20	1.32236665	1.32236665
30	1.98354998	1.98354998
40	2.6447333	2.6447333
50	3.30591663	3.30591663
60	3.96709996	3.96709996
70	4.62828328	4.62828328
80	5.28946661	5.28946661
90	5.95064993	5.95064993
100	6.61183326	6.61183326

Table 3: Comparison of saving percentage at 85% recovery rate.

Rate of return %	Saving percentage (Linear Programming)	Saving percentage (Genetic Algorithm)
10	1.52415651	1.52415651
20	3.04831302	3.04831302
30	4.57246953	4.57246953
40	6.09662604	6.09662604
50	7.62078256	7.62078256
60	9.14493907	9.14493907
70	10.6690956	10.6690956
80	12.1932521	12.1932521
90	13.7174086	13.7174086
100	15.2415651	15.2415651

Table 4: Comparison of saving percentage at 95% recovery rate.

Rate of return %	Saving percentage (Linear Programming)	Saving percentage (Genetic Algorithm)
10	2.387129696	2.387129696
20	4.774259392	4.774259392
30	7.161389089	7.161389089
40	9.548518785	9.548518785
50	11.93564848	11.93564848
60	14.32277818	14.32277818
70	16.70990787	16.70990787
80	19.09703757	19.09703757
90	21.48416727	21.48416727
100	23.87129696	23.87129696