DECISION SUPPORT USING MULTI-CRITERIA DECISION MAKING FOR REVERSE LOGISTICS NETWORKS

A Thesis submitted to Gujarat Technological University

for the award of

Doctor of Philosophy

in

Mechanical Engineering

by

Uday Kumudbhai Chhaya
Enrollment no. 11999719014

Under supervision of

Dr. M.B. Patel

GUJARAT TECHNOLOGICAL UNIVERSITY
AHMEDABAD

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----
2) (External Examiner 2) **Dr. T.N. Desai**

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3) (External Examiner 3) Name and Signature

Abstract

Logistics is a key enabler for growth of the retail commerce and product manufacturing industry, and is increasingly emerging as a differentiator in terms of customer service and satisfaction. The logistics sector specific to manufactured product retailing in India was valued at US $ 0.46 billion in 2016 and is projected to witness a CAGR of nearly 45-48 per cent in the upcoming five years to reach US $ 2.2 billion by 2020. (Source: Inc42 report, Mar 2017).

Reverse logistics has attained more and more pertinence during the recent years, as the economics and control over product returns is becoming far more crucial for industry, economy, and environment sustainability. Customers expect a seamless, economical and extended product usability, cost-efficient reuse thereof and safe disposal at its end-of-life. This focus leaves reverse logistics far more relevant in modern times.

Because of the fluctuation and uncertainty in both quantity and quality of the reverse product returns' flow, design and planning of reverse logistics network is much more complicated compared to the forward supply chain. Huge potentials and implications for acute optimization and seamless integration with the forward supply chain has necessitated focus on optimization of different entities/components of the reverse logistics components. This could be accomplished by development of decision support tools for designing reverse logistics network in an economically efficient and environment friendly manner.

This research work, largely set up in Indian perspective, develops a conceptual framework of multi-criteria decisions involved in reverse logistics network configurations, identifies sector-specific network configuration preferences and validates it through multi-sector industry survey. A sensitivity analysis that determines cross-overs of prioritization in network preference is also validated.

Further, a generic mathematical formulation using Mixed Integer Linear Programming is adapted for a typical multi-stage, multi-facility revere logistic network set up. The formulation is then optimized for actual inter-facility returns' flow, distance, and pertinent costs data for an existing automobile tire manufacturing organization.

Lingo 14 optimization tool is used to obtain optimized returns quantities, total costs, and decision support on numbers and locations for the facilities at each stage. Sensitivity to rise in quantity of returns is also evaluated and optimized.

Acknowledgement

They say, all good things come after lot of aspiration, inspiration and perspiration! I thank the almighty for the opportunity to experience this fact!

This doctoral work has had direct and indirect contribution from so many people, academic bodies, and industrial organizations, and credits could go on for pages, but I limit it to the entities that made most significant impact!

My sincere gratitude to two main bodies: The Commissionerate of technical education, Government of Gujarat, for the all-important nod to pursue the doctoral study, and the Gujarat Technological University, for enrolling me to the program. University's mechanism for continuous evaluation and review of the work at all stages by subject experts from India and abroad has truly tested, shaped and maintained the required quality of the work.

I am, and will forever remain hugely indebted to my supervisor ***Dr. M.B. Patel***, for taking me under his umbrella of technical expertise, rich academic experience, and global exposure. He has been the pushing force to maintain the work focus for achieving the coveted milestone.

I have been extremely privileged to have two stalwarts of the subject domain, ***Dr. M.G. Bhatt*** and ***Dr. D.A. Desai*** as the review committee members for my work. They have always set high benchmarks at each stages of my progress, and have thoroughly tested my perseverance through the rigors of achieving the set benchmarks. Without their crucial inputs and directions, this work could not have assumed the shape it is in, today.

Industries have been the principle resource for the data in this work, with access to literature being the next significant resource. I wish to express a heartfelt gratitude for the time, energy and critical inputs. In particular, I wish to express special thanks to Mr. Alok Jain, Ms. Moksha Sanghmitra, Dr. Subhash Rastogi, Mr. Amol Mategaokar, Mr. Anubhav Asthana, Mr. Paras Mishra, Mr. Mukul Golkonde, and Mr. Sampaad Trivedi, amongst a big list. Getting industrial inputs has been the defining factor in the shape and present form of this doctoral work.

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and my wonderful children, ***Shreeya*** & ***Amey***, for motivating me to achieve what I was set out to, in this sojourn!

Dedicated to…

The better world and better life…

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List of Abbreviation

AHP	Analytical Hierarchical Process
CAGR	Compound Annual Growth Rate
GST	Goods and Services Tax
MCDM	Multi-Criteria Decision Making
MILP	Mixed Integer Linear Programming
RL	Reverse logistics

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CHAPTER 1.

Introduction

1.1 Context

"*Artery and vein is the transportation system of blood in human body as well as all vertebrate. Two directional flows are simultaneously occurred in this circulation system and for this phenomenon it is called balanced circulation with nearly zero environmental impact. An industry is like a human body and logistic deals with the transportation system. But only when logistic and reverse logistic consistently play effective role, then the industry will be in a balance, more profitable and more environment friendly*" [1].

Supply chain management is all about the endeavors taken up by the organized and unorganized sectors to satisfy its customers' needs. The Council of Supply Chain Management Professionals (CSCMP) (http://cscmp.org/, retrieved on 23 Jan 2017) defines supply chain management as follows:

"Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies".

Holistically, Supply Chain Management integrates business functions and processes with a view to cohesively bond with customer aspirations. It includes all of the logistics management activities intertwined with manufacturing operations, and it spans across marketing, sales, product design, finance and information technology functions of the business endeavor.

Council of Supply Chain define Logistics as " a part of the supply chain process that plans, implements and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customer's requirements". In modern times, logistics scenario has grown complex, owing to over-fragmentation of distribution channels, increased numbers of product variants, and ever-growing needs for customized solutions for specific business conditions organization operates in.

Global economy thrives on commerce, and the industrial sector that provide for the manufacture, sale and services look up to efficiency of logistics sector to serve as a back-bone for the smooth flow of products at each stage. The logistics industry in India is evolving rapidly, it is the interplay of infrastructure, technology and new types of service providers, which defines whether the logistic industry is able to help its customers reduce their costs in logistics sector and provide effective services.

Manufacturing, retail and services sectors have up-kept steady rise even during a little period of lull in global economic scenario in last decade. This has lead logistics industry to grow and enhance its' strategic importance. Logistics sector was expected to grow 10-15% in the period 2013-14**,** as against the prediction of reaching over $2 Bn by 2019. As per the report of the Business Insider (http://www.businessinsider.com/reverse-logistics-and-reverse-supply-chain-research-returns-recalls-repairs-and-end-of-life-returns-2016-10?IR=T, [Accessed 14 Mar 2017], "rise of ecommerce logistics and increased domestic consumption will lead the way for the industry in the coming years. With a promise of growth and improvements, the service oriented logistics industry is ready to expand beyond the horizons in the latter half of this decade. An approach of Omni channelizing the returns management is way to go in order to reduce the costs on returned goods".

1.2 Logistics

[2] Describe logistics as the "management of the flow of goods between the point of origin and the point of consumption in order to meet some requirements, for example, of customers or corporations". The scope of logistics include physical items such as material and product in any form, and other associated entities of time, energy and information, so as to ensure

smooth flow of the product or service. Superior logistics performance demands syncing material movement (aligned with inventory management) and transport with information flow, and warehousing. Modern day software simulators model, analyse, and optimize logistics and supply chain. How to optimize the use of established resources has been the perennial concern of the supply chain manager and integrator.

It is interesting to observe here that, despite being commonly accepted, the above definition of logistics is not unified. The Council of Supply Chain Management Professionals refers to logistics as “the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements which includes inbound, outbound, internal, and external movements and return of materials for environmental purposes”.

Going by the Chinese translation of the word, the concept of logistics focuses on the flow of the product [2]. They derive that logistics focus on “product handling activities encompassing spheres of product storage, and it also puts emphasis on the activities of handling product, which include the storage, transportation arrangements, distribution, packaging and processing”.

Hence, while we ascertain that the spheres of logistics activity encompasses many relevant activities, it traditionally deals with aspects of facility location, transportation mechanism, and inventory planning and management.

1.3 Forward logistic network and Reverse logistics networks

Direction of the product flow designates a logistic flow as forward or reverse. Products returning towards the manufacturer (or repairer, recycler, or may be disposer, for that matter) constitute a part of reverse logistics problem. Returns of the products once supplied would involve higher supply uncertainty in terms of quality, quantity, time and some other aspects. This aspect of uncertainty complicates reverse logistics network, far more than the forward part of it. Supply chain performance in forward path can be acutely and accurately optimized, whereas, the uncertainties mentioned above leaves reverse logistics little vulnerable to profit-marring factors.

Fleischmann pointed out the distinctions between reverse logistic network and forward logistic network. Fig. 1.1 depict typical flows in forward and reverse logistics, and TABLE 1.1 gives the distinguishing and discrete features of the two flow types.

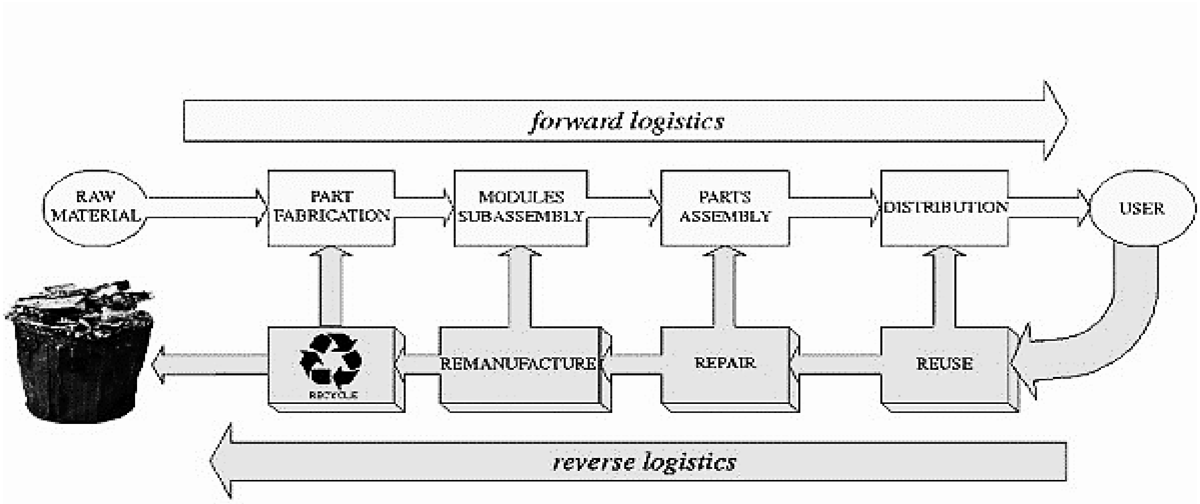

Figure 1.1 Flow between entities in forward and reverse logistics (Ref. http://cerasis.com/2014/02/19/what-is-reverse-logistics/)

Table 1.1 Differences between reverse logistics network and forward logistic network flows

Forward Logistics Network	**Reverse Logistics Network**
Have set/standard channel and direction for transportation	Generally driven by external force
Clearly defined disposal mode/ scrap definition	Non-standard processing mode: Recycle/remanufacture/disposal
Deterministic and certain destination	Uncertain destination
Defined costs	Costs influenced by many factors
Speed is very important	Speed is relatively unimportant
Uniform inventory	Various inventories for various products
Life stage of the product is explicitly definable.	At times, product stage cannot be explicitly defined.
Inter-stage dialogue possible for subsequent stages.	Subsequent stages uncertain sometimes, leaving Inter-stage dialogue difficult.
Real-time tracing for products being sold	Difficult to trace how remanufactured or repaired/ recycled products are treated
Quantity defined and deterministic	Quantity/condition uncertain
Transportation is unilateral to multilateral	Transportation is multilateral to unilateral
Homogenous quality of products	Heterogeneous quality/quantity of products

1.4 Supply Chain

There has been lesser agreement to the definition of supply chain management as compared to that of term logistics. [3] described that SCM "*has been poorly defined and there is a high degree of variability in people's minds about what is meant*." [4], in their rather comprehensive definition to supply chain that considered many underlying aspects as well, described that: "*Supply chain management is defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of* *improving the long-term performance of the individual companies and the supply chain as a whole*."

Industry and academia have used the terms quite interchangeably, as both logistics and supply chain refer to movement and circulation of the product in one or opposite directions, during the course of a product's life span. Further, both have gained interest of business model builders for the product commerce and life cycle. In a broader sense, supply chain interact and integrate with allied fields of network sourcing, supply pipeline management, value chain management, and value stream management [5] [6].

Also, we can infer from the concept of logistics that it doesn't really connect organization to organization, as logistics generally seen as a product flow/movement for one organization. In contrast, supply chain involves several organizations and associated agencies. An important notion in supply chain management is that the industry/organization doesn't seek or resort to cost or profit optimization in isolation of their supply chain solution partners, and seeks to involve them along for their supply chain more competitive. Hence, the gamut of focus in supply chain is competition amongst supply chains, and not individual companies [7]. An operations research concept of theory of games is also of interest of researchers so as to deduce pay-offs against strategies adopted by the competitors.

The present work primarily focuses on a supply chain set up in India, and intends to develop a decision support on configuration of the various key components of the reverse logistics network.

In the subsequent sections, we discuss how the logistic scene is set up, and how the challenges pan out, focusing on Indian perspective, in particular.

1.5 State-of-the-art of the logistics scenario in India

Recent thrust on manufacturing has pushed supply chain domain (spanning across and involving multiple organizations) to strive for economy and effectiveness of logistics component. Reliable and rugged logistics infrastructure is seen as the need of the hour by business industry and policy makers alike. Organizations and policy makers attach real value to establishment of infrastructure and economy associated with it. We deliberate on key challenges faced by Indian organizations in the next sub-section.

1.6 Indian Logistics Scenario: Key attributes of value creation

Bizztor India portal's report on Logistics – Functions and Challenges (as accessed in Mar 2017), states that "from 2015 to 2020, the Indian logistics industry is estimated to grow at a CAGR of 8.6%. The key contributing factors to this growth to be the e-commerce boost, 'Make in India' campaign and transport infrastructure. However, the Indian logistics sector is fraught with a few challenges like skill development, low IT penetration and fragmented market (especially in Tier B and Tier C towns and remote areas)" [8]. We can add challenges faced up on reverse logistics front to the list.

As per the report, the Indian logistics sector is facing challenges of utilization of resources, and looks to create value out of the following attributes:

- **Data Streamlined Resource Allocation**: The Indian logistics sector has a varied topographical network. Hence the assets or resources have to be allocated on the basis of real-time and current data.

- **Digitally- Enabled Processes**: There is a need for two-way digitization to boost productivity, i.e. digitizing core processes and reinforcement of IT-based business models throughout customers, competition and shareholders processes.

- **Inclusion of Risk and uncertainty management**: Risk management in the holistic logistics scenario can lend a supportive role in building of resources and use capabilities to converge on the opportunities. Services offered have to be in sync with changing laws and procedures. India's logistics solution provider, Gati, incorporates reverse logistics in its umbrella of offered solutions. Gati strives to maximize on their forte of customer satisfaction through accurate delivery promises, assets management.

1.7 Overview and challenges faced by logistics industry in India in recent times

A loss of value occurs in the logistics solution, if industries cannot have a seamless integration of transport network modalities, incorporation of information technology for the product tracking and for decision support, and aspects of locational decision for warehousing & distribution facilities. Law and regulations, laid down by local, regional or national authorities prevail, but they differ from location to location, resulting in to inept composite national network creation.

As per GoBolt India web report https://inc42.com/resources/indian-logistics-industry/ (as accessed on 14 April 2017), three key observations emanate:

- **Hub-and-Spoke enabler**: With the implementation of GST, logistics companies can now have fewer regional warehouses to cater to freight movement to the different manufacturing plants, retail outlets and various points of sales. Rise of e-commerce has really helped in this.

- **Composite solution provision:** Today's logistics industry has grown into an end-to-end solution provider, by means of collaborating and integration of specialist functions. This has paved the way for even higher growth in terms of size and capabilities of logistics and warehousing industry in the coming years.

- Thirdly, optimization of product flow and facility locations aid in making the supply chain lean.

Operationally, logistics is mainly divided into transportation, storage and warehousing, and distribution. Currently, India uses road transport more extensively vs. rail and waterways, thereby increasing cost of transportation. In storage and distribution, contribution of third party logistics (TPL) activity is significantly lower and major focus is on freight forwarding.

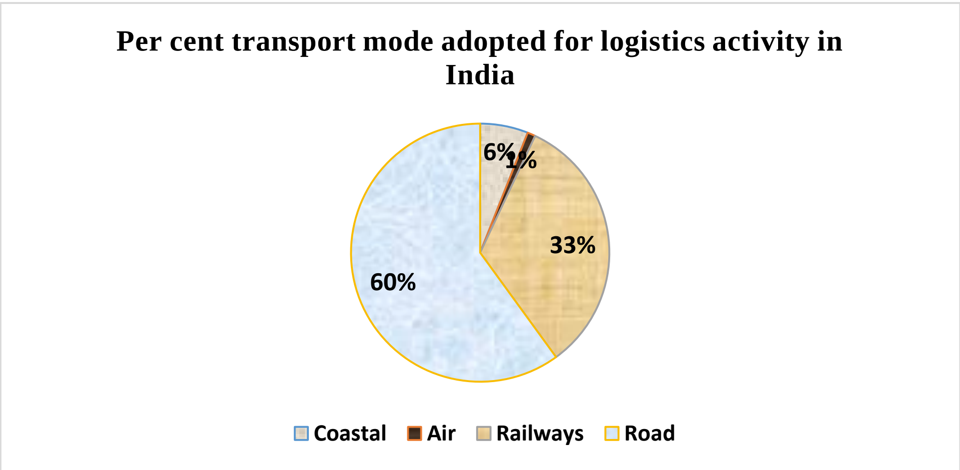

Figure 1.2 Break-up of transport modes in India
(Source: Industry, World Bank, PhillipCapital India research report, 2016)

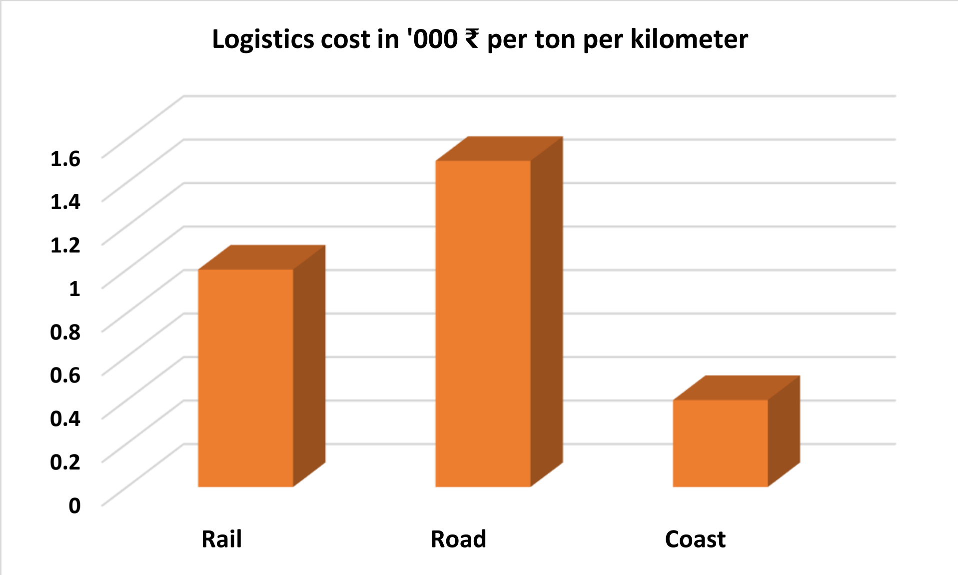

Figure 1.3 Typical cost comparison between various modes of logistics in India

Source: Industry, World Bank, PhillipCapital India research report 2016

In a new in-depth report from BI Intelligence [9], an omni-channel approach is discussed for reduction in the costs retailers/original manufacturer has to bear from the goods that are returned. The report brings about three major take aways:

- The rise of e-commerce has increased the need for an effective reverse logistics solution. E-commerce will account for 10% of total retail sales in 2018, up from 7.8% in 2015.
- There are four types of returns retailers face: commercial returns, product recalls, repairable returns, and end-of-life returns. Each requires a different reverse logistics cycle to handle it effectively.
- Retailers can reclaim up to 32% of the total product cost by having an effective reverse logistics function. This includes by reselling the product, recycling it, remanufacturing it, and more.

1.8 Types and nature of reverse logistics activities mapped

As per web blog https://blog.gopigeon.in/2016/02/22/reverse-logistics-and-its-pros-cons/ (assessed on 12 Mar 2017), reverse logistics refers to “the process of moving goods from their typical journey’s end, for the purpose of apprehending value or ensuring proper discarding. Remanufacturing or refurbishing and revamping activities also may be included in the definition of reverse logistics”.

Forward logistics refers to discrete flow of products towards the end user, whereas in reverse logistics the flow is in the opposite direction, that is, from end-user to repairer/remanufacturer/distributor, or the OEM.

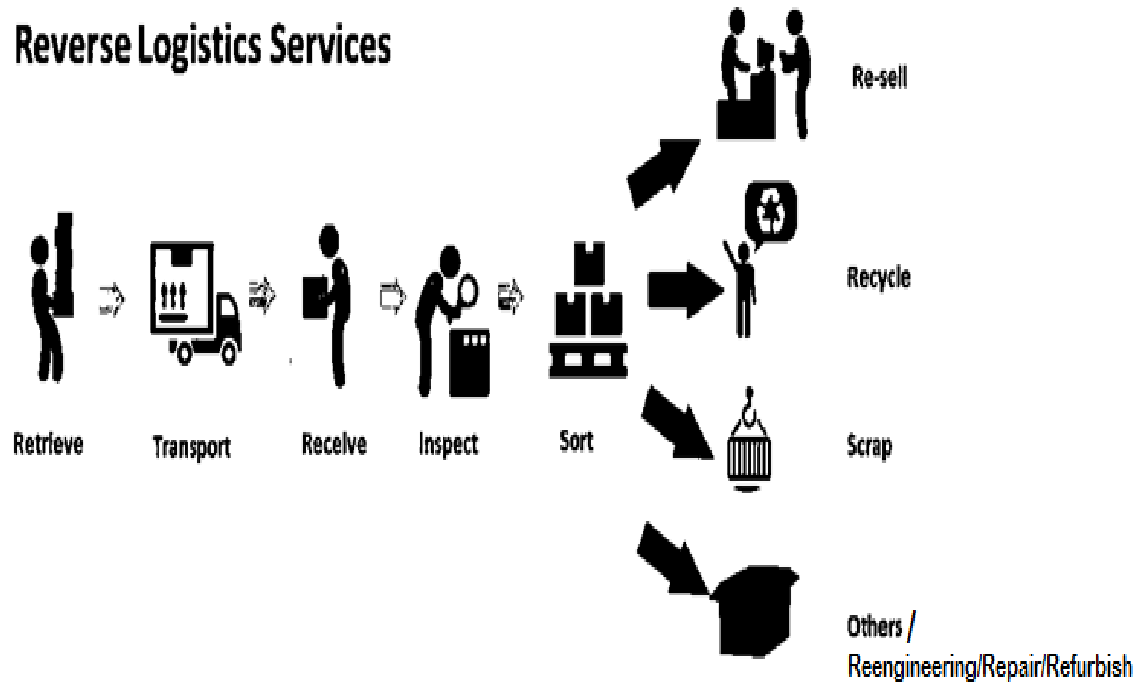

Figure 1.4 Typical flow of returns in reverse logistics

(Ref. http://www.suhasoft.com/reverse-logistics-solution)

As per the definition provided by European Working Group on Reverse Logistics, RevLog, “Reverse logistics is the process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal.” [10].

As the RevLog’s definition suggests, RL involves returns’ handling with an objective of value recovery or value re-establishment of the products in use. It also deals with responsible disposal of the product returns which have reached end-of-life of value chain.

While the forward logistics ensures the product flow towards the customer, reverse logistics activities involve return of the good back towards the manufacturer. This could be for the purpose of value retrieval in terms of performance by means of repair, recycle, or reuse. Also, recall of any defective items shipped by the manufacturer would fall in to category of reverse logistics.

Reverse logistics has evolved as a very prominent and important ingredient of supply chain solution suite. Yet, many organizations haven't fully comprehended its value in cost optimization and customer satisfaction. Reverse logistics is considered a profit-drenching exercise that brings along persistent headache on the part of manufacturer.

Industries, market data, and researchers in general, have come to one general consensus that the returns' quantum has grown very large, and is much more than what is perceived.

GoPigeon blog (https://blog.gopigeon.in/2016/02/22/reverse-logistics-and-its-pros-cons/) brings out a staggering statistics that on an average, "about 3% to (as high as) 50% of total shipments across all industries are just absolute returns caused in the companies. The research states that of total revenue of the organization, about 3%-5% of it go as a cost of returns. Prominence of reverse logistics is observed in the thrust need felt by organizations in ensuring customer responsiveness and building customer loyalty". (Blog: reverse-logistics and its' pros & cons, 2017).

Reverse Logistics bring in wide ranging socio-economic and environmental benefits, as listed below:

- It helps reducing composite costs for an organization by providing for product returns' collection from the consumer, and head the returns back to the manufacturer, for subsequent operations of disassembly/re-assembly or reprocessing.
- It stretches usable life-span of the product through retention of value of use. This would be key to customer retention, productivity and business growth. It also has to ensure sustainability and service- quality concerns.
- In some industry domains, more value is extracted out of secondary use of the product. Prime example of it could be an automobile or an expensive electronic gadget with high capital cost, whose technology has advanced faster than a reasonable life span of the original product.
- Reverse logistic provides an opportunity to strengthen customer relations, as maintenance and repairs would mean sustained communication.

Advantages of reverse logistics has its share of flip side. Few concerns could be:

- Resultant increased costs on maintenance, remanufacturing, reconciliation of add-on labour, warehousing, etc.

- Manufacturing/ service organizations having to partner with an external logistics service providers feel the lack of real-time control over product locations during movements and feel constrained about lack of information and have to base their decision making on communication/feedback from their customers/suppliers.
- Uncertainty in returned product conditions. This would result in increase of the processing cycle times, and would generally stretch the desired customer- response time.

Reverse logistics can be seen as an activity, rather a group of related activities, under the umbrella of product returns' management. Researchers have vividly explored various reverse logistics activities. [12]. [13], [14] have described ***direct reusage*** as the commonest reverse logistics activity. They discussed about re-use of packaging, pallets used for product movements, and product containers.

Another common reverse logistic activity is repair. These are the product returns with minor defects and generally travel back to the original user after minor rework or fine-tune. In the same vein, however, the returns requiring major up hauling or alteration in the shipped working condition would fall under classification of refurbishment in reverse logistics category. [15].

The product return requiring major overhaul, but still can be re-generated or re-integrated in to original manufacturing process, it would fall in to remanufacturing typology of reverse logistics. [16].

Recycling goes in as an important reverse logistic function, mostly leading to completely disintegrating the product to its' basic material form [13][17]. The recycled product can be re-shaped or put out as a similar product, for the maiden use in primary market, by reselling it.

Another reverse logistics function, that might not be exactly classifiable as reverse logistic activity, refers to extraction or retrieval of usable components that can be put to use in another product to restore its function. It can form a part of repair/refurbishment or remanufacturing, in many instances.

1.9 Key issues and challenges faced up by different industry sectors engaged in reverse logistics

The government has set an ambitious goal to improve the country's ranking in the ease of doing business index from number 142 to 50 by 2017, and substantially achieved this target by breaking in to top 100 by fag end of 2017. E-commerce continues to boom, with numerous start-ups expanding and receiving billions in funding and new smaller ones emerging every month. For logistics alone, India spends an unusually high amount—13 percent of its GDP. Comparable economies are spending anywhere between 4 and 8 percent. This is the first proof of inefficient supply chains.

The country still ranks low at number 54 in the Logistics Performance Index and on the United Nations Conference on Trade and Development B2C E-commerce Index. In terms of capacity, aggregate freight transport demand is expected to grow from 2,500 ton kilometers (tkm) to 10,000 tkm. And demand is far outpacing supply. In fact, logistics is growing at a CAGR of about 12 percent, lagging the demand created by e-commerce.

As suggested in Economic Times Supply chain summit (ATkerney report) July 2015, Infrastructure remains bottle necked with an urgent need to expedite crucial projects and create an integrated, multimodal network. Regulatory and clearance processes pose significant roadblocks that severely impact truck transit times and increase business complexity. Government and regulatory efforts in creating more infrastructure and capacity and simplifying processes are ramping up slowly, but more needs to be done. There continues to be an acute shortage of trained manpower.

Overall, four imperative challenges emerge out of ATkerney report on the economic times summit from the discussions. **Infrastructure and network capacity** are the biggest roadblocks, and expediting the execution of crucial projects is the need of the hour. Businesses and service providers will need to collaborate to create an overall systemic improvement. Developing new planning and process standards and enabling **transparency and easier flow of information** will help move from **optimization in siloes to overall supply chain improvement.**

Standardization of transport assets, systems, and processes will reduce complexity—improving overall business agility and further supporting collaboration.

1.10 Research genesis

As McIntyre of HP puts it, the primary output of today's production processes is waste. Across all industries, less than 10% of everything that is extracted from the earth (by weight) becomes usable products. The remaining 90% becomes waste from production. The biggest challenge manufacturing industries face today is to stretch this for socio-economic advantage.

The size of logistics sector in India is said to be $90 to $125 billion. The supply chain industry is growing at a rate of 15% per annum. India has jumped to 35th number in 2016 from 54th on logistics performance index (World Bank's biennial measures on SC Performance).

Key drivers have been:

- Make in India, Infra Investment associated with ports, Airports, Domestic demand growth, and increased trade
- Consumer requirement of seamless shopping experience with integrated reverse logistics mechanism
- Surge in practises for commercial value creation and retention

The economics and control over product return is far more complicated than that of the forward flow, for, reverse supply chain is generally not as much profitable as that of a forward supply chain. Contributing factors to this could be uncertainty over capacity utilization of transport facility and inexactness of forecast of requirements at various facilities in the reverse supply chain. Another aspect could be uncertainty over the quality variations of the returned products. Due to this, all the collected product returns cannot be re-manufactured or sometimes, more advanced operations are required for making the returned product resalable.

In recent years, Governmental and Non-Governmental Organizations (NGOs) have been vouching the manufacturers to improve their environmental performance by integrating safe disposal and environment-friendly practices into reverse supply chain. Also, fast growing economies like India observe a large and growing market for economic extension of product life through reuse and thereafter, a safe disposal.

This necessitates bringing the total cost down so as not to let it eat through the business profitability. Optimum salvage of economic value for extended product life, and environment consideration and legislation are main drivers of design of modern day reverse logistics networks. Design and integration of reverse logistic network with the forward supply chain has become a key thrust area in order to be a cost-effective product/service provider.

The present work identifies key reverse supply chain constituents contributing to sector-specific network through industrial survey for both types of product returns: end-of-life; and end-of-economic use. Further, the determination of the number and location of different facilities like collection centres, re-manufacturing centres, disassembly centres, recycling centres, disposal centres is demonstrated through real-field data of returns-flow and transportation costs of the products, components and materials between each stage in the network and also for the intra-stage quantity-flow between facilities in the reverse supply chain.

1.11 Definition of the Problem

Most contemporary manufacturing and distribution companies are investing a huge sum in processes, tools and resources to achieve seamless integration and operational efficiency in composite forward and reverse supply chain planning. They strive for integrated planning with the objective of increased customer service level, cost- responsiveness, and retention of proprietary knowledge to stretch value creation for an extended life.

Companies are compelled to adopt and integrate reverse logistics for the following key reasons:

- Companies can’t afford to produce products only to be tossed up in landfills in a few years.
- Huge costs involved in manufacturing and technology transfer
- Economic scenario rendering cost saving initiatives lucrative
- Growing recognition of recapturable value from returned merchandize
- Increased customer-responsiveness
- Increased returns ranging from 10% to 40%
- Legal requirements
- Improved Information- processing software for reverse logistics

The key issues related to a company's ultimate objectives have been addressed in this work, as under:

- Prioritization of principle business objectives pertinent to profit-drenching reverse logistics function from the multiple objectives present, and identification of crossover points through sensitivity analysis, through extensive multi-sector industry feedbacks
- Mathematically model a typical reverse logistic network for a representative industry sector featuring all entities with an optimization objective
- Determination of the number and location of different facilities to be established in the network and the quantity of flow of products, components and materials between each stage of the supply chain.

1.12 Objective and Scope of work

- Identification of key constituents and stages of reverse supply chain activity for the reverse logistics network by studying multi-criteria associated with network design for reverse logistics networks through multi-sector industry survey.

- Determination of principle business objectives associated with reverse logistics networks, and sub-objectives under each principle objectives. Further, exploring alternative methods exercised by industries for carrying out activities at each stage of reverse logistics, and establishing explicit preferences amongst these alternatives by different industry sectors through extensive industry feedback.

- Presentation of industry sector-independent mathematical formulation that involves optimization of various components of the reverse logistics network through mathematical modelling.

- Testing the formulation through optimization software for real-life industrial case, and establish values for key decision entities, and also, decision support for facilities creation or otherwise.

A multi-industry survey of 10 different prominent and diverse industrial sectors engaged in for reverse logistics activities in and around NCR and the state of UP, Gujarat, and industrial zone of Pune has been used for configuration of physical reverse logistics networks for both type of product returns: end-of-life; and end-of-economic use has been shown.

Further, use of optimized mixed-integer linear programming model to derive solution by Lingo solver is presented to determine numbers and locations of different key constituting facilities like collection centers, re-manufacturing centers, disassembly centers, recycling centers, re-treading facilities, disposal centers is demonstrated through real field data of returns-flow and transportation costs of the products, and also for the intra-stage quantity-flow between facilities in the reverse supply chain.

1.13 Research gaps and original contribution by the work

An exhaustive literature survey (presented in next chapter) of published related work (articles/books/proceedings) has been done for the period ranging from year 1995 till 2016 to ascertain the research gaps presented below. In addition to this, reports published by consulting and practicing firms on reverse logistics practices have been referred, in order to understand the variety and complexities pertaining to network design decisions for various parameters of reverse logistics networks. Research Gaps:

Table 1.2 present the year wise chronology of conceptual frameworks presented in literature describing critical decisions in reverse logistics and their considerations for network design:

Table 1.2 Chronology of conceptual frameworks presented in literature

Sr. No.	Author	Key contribution
1.	[18]	Tradeoff considerations for returns collection mode, network design, transportation modes , etc.
2.	[19]	Described the entities performing reverse logistics (e.g., collectors, reprocessors, etc.), which functions need to be carried out and where, and whether the forward and reverse flows should be integrated or separate
3.	[20]	Descriptive conceptual model that distinguishes among network types based on product function like recycling, remanufacturing, or reusing to propose specific network design considerations
4.	[21]	Identified non-quantitative characteristics of reverse logistics networks and described implications of those decisions on conceptual design. Framework to provide understanding of the principles of reverse logistics within the supply chain system.
5.	[22]	a decision-making model for third-party logistics providers (3PLs), marketing oriented model for decision making, identifying a specific niche and performed a feasibility study
6.	[23]	presented a framework composed of two categories of driving forces: 1) environmental factors (e.g., regulation and environmental friendliness), and 2) business factors (e.g., liberal customer returns and customer satisfaction)
7.	[24]	need for new research into strategic aspects and organizational frameworks for reverse logistics
8.	[25]	Described need for grounding framework for retail reverse logistics

Following research gap emanates out of the literature survey:

- ***While available quantitative models describe determination of detailed network layouts for specific industries, they don't map conceptual framework with validation through multi-sector industrial data.***

Present work addresses this gap through multi-sector multi-industry industrial survey to suffice the sync. A generic model that could be customized for specific industry domain is developed.

Table 1.3 summarizes the referred literature base advocating need for prioritization of objectives.

Table 1.3 Summarized literature base advocating need for prioritization of objectives

Sr. No.	Author	Summary
1.	[26]	Discussed two phases of the method as the prioritization of supply chain objectives; and the selection of risk indicators
2.	[27]	Discussed vagueness and need for a holistic approach for selecting a TPL service provider
3.	[28]	prioritized performance measures are determined and the assessment of various strategies, processes and capabilities for delivering objectives has been discussed to develop a comprehensive performance measurement (PM) framework
4.	[29]	Prioritization of objectives for the producer's cost (Prcost) and the Informal Waste Sector (IWS) Profit for Electrical and electronic equipment companies
5.	[30]	ANP technique to address the interaction issues between indicators when applying the Balance Score Card for performance measurements amongst objectives

This brings us to another research gap as

- ***The proposed models considered few elements of return and/or demand uncertainty, but doesn't reflect much on prioritization of objectives (Cross-overs)***

This work analyses sensitivity to the multi-objectives has been analysed in this work in order to incorporate the cross-over objectives through prioritization.

Further, the prevailing studies on reverse logistics network design are driven by an application-oriented approach. Majority of the papers focus primarily on recycling-only networks, and a few on remanufacturing focus.

Table 1.4 Classification of published case studies published during year 1996-2007

Sr. No.	Author	Application
1.	McGavis, 1994	Printer toner cartridge recycling
2.	Bartel, 1995; Del Castillo and Cochran, 1996	Reusable glass soft drink bottles
3.	Thomas, Jr., 1997; Guide Jr. and Wassenhove, 1997	Military aircraft remanufacturing
4.	Yender, 1998	Battery Recycling
5.	Linton and Johnston, 1999	Circuit board refurbishing
6.	Krikke et al., 1999	Copier refurbishing
7.	Fleishmann, 2000	Business Computer refurbishing
8.	Real et al, 2001	Carpet recycling
9.	Farrow et al, 2000	Recycled plastic Kayaks
10.	Rudi et al, 2000	Wheelchair refurbishing
11.	Duhaime et al, 2001	Reusable postal containers
12.	Guide Jr. and Wassenhove, 2001	Cellular phone remanufacturing
13.	Staikos and Rahimifard, 2007	Shoe recycling

More recently, in last decade, [31], [32] on rubber recycling, and [33] on paper recycling have presented frameworks on specific applications for the reverse logistics network design. Also, [34] presented work with remanufacturing focus for PCs and appliances. Notable research gap emanate as under:

- ***Very few researchers have addressed the issue of development of a general framework for the network design. Most of the works in this area are limited to either a single type of product return (e.g. end-of-life) or a single type of recovery option (e.g. remanufacturing).***

In this study, simultaneous incorporation of two types of product returns have been considered: end-of-life; and end-of-use.

Based on industry responses, another gap identified by industries, in particular, could be stated as under:

- ***Available literature doesn't offer a decision support model for defining framework of key reverse logistics entities and their key parameters. This is observed as crucial gap by the industry engaged in reverse logistics activities, and look to optimize the total cost of reverse logistics.***

This research gap has been extensively addressed in the present work. Although the proposed models are realistic representations of the network design problem concerning the specific application, they are not readily generalizable to a wide range of industries.

Inspired by the literature gap for a flexible and generic mathematical formulation and need for a more solid modelling framework for reverse logistics network design, we propose a new mathematical formulation that is flexible to incorporate most of the reverse network structures observed in industry set up. Mixed Integer Linear Programming, having better adaptability to Optimization of two types of variables: variables taking values in an integer domain, and variables taking values in a continuous domain.The present work looks to propose a model that is intrinsically simple, yet gives a strong basis for other industrial or application set ups to implement. We validate this theory through putting in rigors and inputs from a real life industrial case application of tire and rubber industry set in northern region of India.

Mixed Integer Linear Programming

In the present work, we address optimization problem that deals with mathematical cost optimization of overall cost of reverse logistics activity with two types of variables: variables taking values in an integer domain, and variables taking values in a continuous domain. The fact that mixed Integer Optimization problems naturally appear in many contexts has led to an increased interest in the design of strong algorithms for different variants of the problem. Unfortunately, mixed Integer Optimization problems are much less understood then their "non-mixed" counterparts, like Integer Programming or Linear/Convex Programming. This is not surprising, since to tackle mixed integer optimization problems one has to overcome several new technical challenges that do not appear in the better studied non-mixed counterparts. This is discussed at length in next chapter.

Moreover, the work also considers fluctuation (discrete rise) in number of incoming returns in determining the numbers and location of facilities for returns' processing.

The work, while predominantly set up in Indian perspective and geography, attempts to build a solution model that can be replicated for the similar reverse logistics problems.

1.14 Methodology of Research, Results / Comparisons

The flow of work embodied in to this work is presented in a flow diagram in Figure 1.5. The figure briefly present the different stages as per work progression along with the tool used to achieve objectives set out at each stage, in the presented work.

To meet the objectives defined for this work, as described in sections 1.10 and 1.11, work carried out is briefly narrated sequentially as under:

1. Build-up of conceptual framework through determination of industry sector-independent business objectives and sub-objectives thereof, pertinent to reverse logistics activity and returns' management as a whole. Subsequently, determination of alternatives exercised by the industries for carrying out reverse logistics activity at each stages.

2. AHP modelling for prioritization of alternatives based on industry-responses, and establishment of preferences for alternatives by different sectors, using AHP Excel Solver, based on Saaty's (linear) scale.

3. Validation of the framework for three different industrial sectors and sensitivity analysis.

4. Mixed-Integer Linear Programming formulation of a generalised multi-stage reverse supply chain with an objective of Minimising the total cost for the reverse supply chain, comprising of transportation cost, processing cost, fixed facility cost and disposal cost, with analysis of entities under different situations, for entities comprising of :

    a. Customer zones,
    b. Collection centres,
    c. Remanufacturing centres,
    d. Disassembly centres,
    e. Recycling centres and re-treading facility
    f. Disposal centres,
    g. Primary markets and secondary markets.

5. The problem instances solved using Lingo 14 (Optimization Modelling Software for Linear, Nonlinear, and Integer Programming) on a computer with Intel Core 2 Duo processor of 2.10 GHz speed and 2 GB RAM.

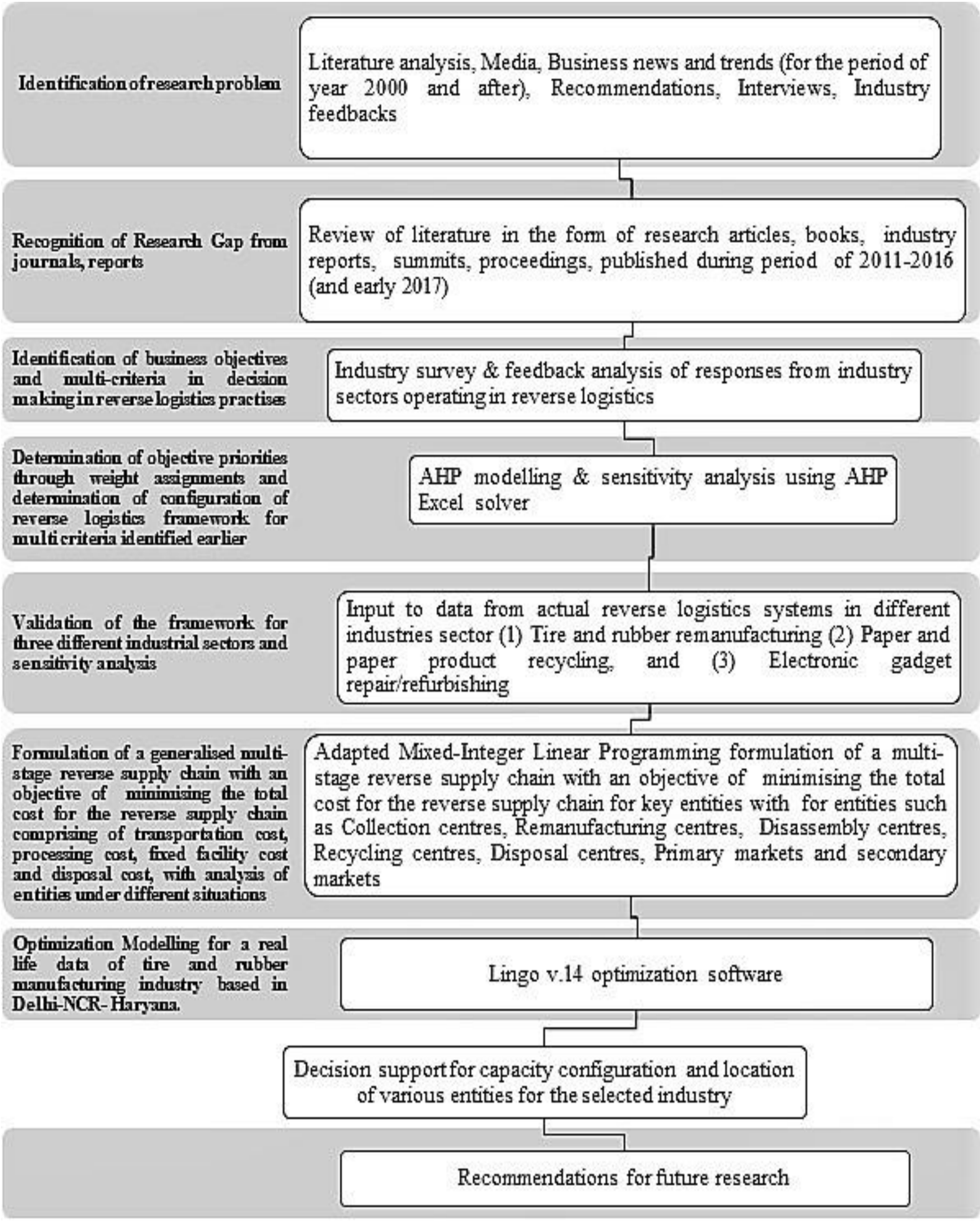

Figure 1.5 Research Methodology flow chart

1.15 Flow of presentation of chapters

Subsequent chapter 2 discusses literature base of relevance for the defined problem, and describes key issues of the reverse logistics while maintaining the flow and focus on the problem defined and methodology adopted.

Chapter 3 presents framework for establishing preferred constituents of reverse logistics network for different industry-sectors engaged in reverse logistics activity. The chapter integrates identification and synthesis of priorities for alternatives for network constituent activities, done on the basis of extensive industry survey. An AHP methodology is adopted, demonstrated, and validated for three case studies chosen from three different genre of reverse logistics frameworks. A sensitivity analysis is briefly included that identifies cross-over of priorities.

Chapter 4 presents mixed-integer linear programing model for tire manufacturing organization that represents all key entities of a typical reverse logistics network. Set up in geographical region of Delhi and NCR of India, where environmental impact in terms of carbon footprint of the industry-sector is also of key interest.

Chapter 5 presents Lingo 14 optimization exercise by first describing the background of the selected industry sector and details of eight entities of the reverse logistics network of the tire manufacturing industry being modelled, and presenting input data consisting of geographical locations of different entities, returns flow quantities, inter-facility distances in KM, and so on. The chapter also discusses the results of optimization exercise with a fleeting discussion on sensitivity of optimized results for the case of 10 and 20 % increase in the number of product returns.

Chapter 6 presents summary of the presented work, future scope and recommendations.

CHAPTER 2.

Literature Review

2.1 Review methodology

[35] Prescribed research methods to follow stages of question formulation, location of studies in literature, Evaluation out of these studies for the contribution with regard to narrowed down objective of a specific study, and ultimately, synthesis of the studies.

In this chapter, we zoom in and zoom out the research problem identified in chapter 1, from the point of view of literature search and analysis. We follow [35] and [36] proposed four-pronged survey of research problem: Context, Intervention, Mechanisms, and Outcome.

With a focus on our research problem, in this chapter, we begin with the context setting of reverse logistics and narrate how literature has addressed decision-making of reverse logistics problem characterized by multiple criteria and multiple alternatives. We further go on to how the problem is evaluated in the literature with regard to the alternatives using a multi-criteria decision-making method.

We further build on researchers' presentation of one or more decision-makers (experts) opinion, based on different applications studied, to identify the relative importance of different alternatives, with a view to establish suited MCDM method and method to mathematically formulate, model and optimize the reverse logistics problem.

The literature has been searched through search engines like Scopus and Google Scholar through key words and strings relating to key entities associated with reverse logistics, like remanufacturing, recycle, reuse, recovery. Also strings like MCDM methods, techniques, mathematical formulation, etc. have been fed to search engines, institute libraries and research database repositories. The literature review has been done during year 2014 to 2016, and it largely ranges to relevant literature published between 2008 and 2015, for zeroing on to analytical method for the multi-criteria decision making discourse, as a whole. We leave out present literature applied to other domains like medical and biology.

Increased number of publications in the field of MCDM methods in RL are presented in leading journals like increasing trend in the number of applications of MCDM methods in RL. Larger number of publications come from prominent journals like Journal of Cleaner Production, Journal of business logistics, International Journal of physical distribution and logistics management, International Journal of Production Economics, European Journal of Operations Research, Journal of purchase and supply chain management, Waste Management, Journal of Environmental Management, and more.

2.2 Context and pertinent literature

Recognition of logistics and supply chain as core to maintaining competitive edge dates back to 1980s, in literature. Still, industrial organizations have yet not been able to decompose key constructs of the supply chain in true essence. A lot of researchers have elaborated constructional definitions and conceptual frameworks of supply chain. It is well documented how supply chain management is considered a crucial business process improvement strategy, over a number of performance indicators.

While the forward or traditional logistics activity has received industrial organizations' attention for streamlining and ensuring smooth flow of the products to the end customers through all years, in recent years, reverse logistic component of the supply chain has received a large chunk of researchers' interest.

In this context, it is only fair to revisit the definition of reverse logistics: *"Reverse logistics is the process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal.*" - European Working Group on Reverse Logistics, RevLog (1998) [37]

As per the RevLog's definition, reverse logistics primarily targets to resurrect and retrieve economic and functional value of the product usage, and ultimately dispose-off the product or components that have reached end of life while safeguarding the environment.

This important consideration of value retrieval that distinguishes reverse logistics from conventional waste disposal management has been described as crucial in the literature. [10].

Table 2.1 below highlights some of the literature presented on broad domain of reverse logistics:

Table 2.1 Broader themes of reverse logistics presented in literature

Sr. No.	Author	Key contribution
1.	[19]	discussed integrated forward/reverse logistics networks in their review on quantitative models for reverse logistics
2.	[38]	Surveyed that product manufacturers integrate their product returns' management and reverse logistics network with their product distribution network
3.	[39] [40]	On premise of closed-loop supply chain, presented integrated logistics network that could typically have multi-layers and non-exclusive movements happening over multiple supply chains
4.	[41] [16]	Presented need of environmental focus and efforts to reduce or nullify the detrimental footprints of reverse logistics activities on the environment.
5.	[10]	Described green logistics as the term used to cover broader perspective of environment focus
6.	[42]	Described remanufacturing to be comprising of disassembly, replacement of components where necessary and assembly of a product to bring it back into as-good-as-new condition.

Reverse logistics constitutes more than one recovery options and product returns' management methods associated with each. This variety of alternatives make reverse logistics network design more complicated as compared to forward logistics.

Researchers have looked to explore use of mathematical modeling to quantify and improve forward flow of logistics. Materials management, aggregate planning for resource management and scheduling of production process are the most influenced decisions with respect to logistics. Inventory management and production planning has been of particular interest of researchers, as they are the ones that influence logistics decision making. On reverse logistics front, however, owing to the complication in inventory control and production planning per se, these models worked on premise of forward logistics doesn't provide adequate decision making support. This has necessitated development of comprehensive solution modeling that is exclusive for variety of reverse logistics networks.

Further, since the crux of theory is value retrieval in reverse logistics, it stays clear of traditional waste management activities.

Following Table describes how literature has addressed three key issues of reverse logistics decisions: Quality of returned products, Remanufacturing for product recovery, and closed loop supply chain.

Table 2.2 Key issues in reverse logistics decisions

Sr. No.	**Author**	**Contribution**
Returns' quality		
1.	[43]	• Described scheduling and inventory control decisions relate to quality aspect of returns • Quality grading systems for reuse, repair and minor rework, remanufacturing for restoring the functional condition, recycling for material retrieval, and, ultimately, disposal.
	[44]	Inspection for product returns for determination of recovery route
Remanufacturing for product recovery		
2.	[45]	Finds that up to 40% of part price is reimbursed by Caterpillar to dealers which return parts and engines depending on their conditions"
3.	[46]	Summarized advantages of RM as a. labour, material and energy cost savings, b. reduced production lead-times, c. balanced production lines, d. new market opportunities, and e. Positive environmentally concerned corporate image.
4.	[47]	Included landfill reduction, pollution reduction, and creation of new jobs and skills for product recovery
5.	[48]	Described how federal taxation and abiding-laws helped in encouraging users and manufacturing organizations delay/reduce disposal of the product through reuse and remanufacturing.
6.	[49]	discussed four characteristics that renders remanufacturing as a complex avenue for product recovery, namely, • Timing and volume of product returns, • Estimation of recovery percentage, • Syncing original manufacturing demand with that of remanufacturing demands and • Incorporating reverse logistics while estimating aggregate remanufacturing demand.
7.	[50]	discussed "technology evolution, take-back ratio, and inventory holding costs as critical factors in the manufacturing/remanufacturing system. The primary goal of remanufacturing should be a product whose quality meets customers' expectations and exceeds that of competitors' products.
8.	[51]	Categorized economic advantages and process improvement as key factors influencing remanufacturing decisions

9.	[52]	Have considered “economies of scale, transaction costs, coordination of needs, and tacit knowledge as the major factors affecting remanufacturing profitability
10.	[53]	Have studied the scenario where the manufacturer sells new and remanufactured product, wherein they have considered effects of remanufacturing unit costs, direct channel cost and customers' preferences in a multi-agent supply chain.
11.	[54]	Identified three reasons for remanufacturing failures: 1) high set-up cost of establishing reverse logistics networks, 2) high cost of quality assurance, and 3) the fact that product was not designed for remanufacturing.
12.	[55]	Studied remanufacturing of modular products with substitution of low quality modules by high quality modules and found that when the customer demand rate and return rate were equal, the cost would be minimized. Also, substitution became more desirable as the quantity of low quality and high quality returns got closer.
13.	[56]	Have noted Germany-based automotive industry statistics
14.	[57]	Lack of significant technical, environmental and quality data to convince customers to undertake remanufacturing”.
Closed Loop Supply chain		
15.	[58]	Described three options for product collection by the manufacturer
16.	[59]	have prescribed an algorithm for designing a reverse supply chain with five criteria for scheduling of recyclable products, namely: 1) material recovery revenue, 2) incoming product revenue, based on quantity and frequency of incoming products, 3) inventory space, 4) customer demand, based on material or recovered products that had high demand, and 5) material recovery revenue and inventory space which were a combination of 1) and 3).
17.	[34]	Developed a model to determine the most economical collecting centers and suggested that the distance of collection center from the customer, return processing time and costs, and return flow rates were key decision making parameters.

In later chapters, the present work demonstrates an optimization model for the mathematical formulation, by inputting real life values in terms of location and product transaction volumes and associated costs.

In the next section, we analyze literature base on multi-criteria decision making for reverse logistics network design.

2.3 Classification and analysis of literature on multi-criteria decision making for reverse logistics

Multi-criteria decision-making (MCDM) methods have been applied to various reverse logistics problems extensively by researchers. In order to develop a reliable knowledge base through accumulating knowledge from previous studies, we conduct a systematic review of the applications of different MCDM methods to different reverse logistics problems. We found about 80 relevant papers published in scientist journals, which are application of different MCDM methods to different reverse logistics problems.

We classify the literature based on two dimensions: problem context and methodology. The results show that recycling and AHP are the most researched problem and methodology respectively.

In the context of reverse logistics there are different decision-makers such as governmental bodies, buying companies and suppliers that are responsible for several decisions. One approach to formulate complex decisions is multi-criteria decision-making where a (or a group of) decision-maker(s) should evaluate a number of alternatives with respect to a set of decision criteria in order to select the (or a number of) best alternative(s). The methods which are used for this kind of decision-making problems called multi-criteria decision-making (MCDM) methods.

MCDM methods have been widely applied to many different areas, and we tabulate literature present in a summarized form in Table 2.3.

Table 2.3 Summary of literature accessed on MCDM and their contribution

Sr. No.	Author	Contextual contribution
1.	[60]	sustainable energy planning, review of more than 90 published papers to analyze the applicability of various MCDM methods
	[61]	supplier evaluation and selection
	[62]	financial decision-making
	[63]	natural resource management
	[64]	in construction
	[65] [66]	Supplier focused MCDM application: New supplier performance evaluation, in which a case study of integrated circuit (IC) packaging companies supplier performance was studied
	[67]	Implementation of a supplier evaluation model using Analytical Hierarchical Process
	[68]	a methodology of Supplier Quality Performance Assessment (SQPA) for industrial computer industry that introduces modified Importance-Performance Analysis (IPA) on supplier quality
	[69]	on a framework and a suitable method for selecting the best logistics supplier

	[70]	on a decision framework where analytic network process (ANP) integrated QFD and zero-one goal programming (ZOGP) models are used in order to determine the design requirements which are more effective in achieving a sustainable supply chain (SSC)
Quality Management Domain		
	[71]	On improvement of service quality among domestic airlines in Taiwan
	[72]	On process conditions for the transfer molding of electronic packages
	[73]	On a new AHP method for the expert evaluation of quality of learning scenarios
Production Management domain		
	[74]	Have presented work on prioritizing sustainable electricity production technologies using multi-criteria decision making method
	[75]	multi-person selection of the best wind turbine based on the multi-criteria integrated additive-multiplicative utility function
	[76]	dynamic schedule execution in an agent based holonic manufacturing system
	[77]	aspired intelligent global manufacturing & logistics systems
	[78]	Identification and modeling the links between machine tool alternatives and manufacturing strategy.

The next section describes work present in literature for the multi-Criteria decision making, confined to applications in reverse logistics.

2.4 Methodology-based classification of multi-criteria decision making in literature base

As documented by [65], [79] , “Multi-criteria decision methods cover a wide range of quite distinct approaches”. [80] have suggested that more formalized decision making tools are being researched about owing to grown complexity of the networks The last decades have intensified the interest in the application of formalized decision-analytical tools, due to the increased data availability to solve complexity of problems as well as the higher availability of data [80]. We find The available methods can be categorized into three schools [81] [82] [83] have discussed three approaches to solve the multi-criteria problems:

- Weight assignment and Value measurement models: A numerical score for each alternative is constructed. Furthermore, a weight w is assigned to each criterion, which represents the importance of the criterion (e.g., Weighted Sum Model, Analytic Hierarchy Process).

- Goal, aspiration and reference level models: These methods measure how good alternatives reach determined goals or aspirations (e.g., TOPSIS).

- Outranking models: These methods compare the alternatives pairwise for each criterion, finding the strength of preferring one over the other (e.g., ELECTRE, PROMETHEE).

2.4.1 AHP/ANP

[84] Proposed multi-criteria decision making method Analytic hierarchy process (AHP), which compares the criteria to determine the preference amongst them. In AHP, multiple criteria present in the decision making is expressed as a hierarchy of levels of decisions/objectives. These levels could be principal criteria, followed by sub-criteria(s), and alternatives amongst the sub-criteria. AHP methodology pairs the alternatives by including weight assigned to each alternative in relation to its paired alternative, resulting in to matrix of comparison.

Literature dating back to as early as 1979 present application of various multi-criteria decision making methods that operates on weight-assignments to the alternatives, namely, the principal eigenvector technique [84], the weighted least square method (WLSM) [85], the logarithmic least square method (LLSM) or geometric mean method (GMM) [86], goal programming method (GPM) [87] [88]. Assigned weights to the alternatives are synthesized to return the alternative with highest weight, and therefore, preference.

[89] Had also proposed another methodology that addresses the non-hierarchical processes, and relate to feedback issues amongst the defined criteria, name Analytical Network Process (ANP).

To model randomness (fuzziness) in weight assignments and preference comparisons of alternatives, versions of different fuzzy AHP and ANP models are described in literature. As compared to normal AHP/ANP, the fuzzy variants employ qualitative (linguistic) yardsticks and fuzzy numbers to compare the criteria/alternatives. Fuzzy AHP [90], [91] [92] [93] and fuzzy ANP [94] have been described in literature, along with other methods.

This category, by far, has the most number of applications in this field. From the total literature studied [36] on multi-criteria decision making, an overwhelming 40% have adopted the AHP (including fuzzy AHP), and around 8 % used ANP.

2.4.2 ELECTRE

Ror (1968) had proposed two indices: Concordance and discordance, “to find a kernel solution” for multi-criteria decision making using method ELECTRE (**EL**imination and **C**hoice **E**xpressing **RE**ality), that compares goodness of alternatives against each other. Also, the method relates and ranks alternatives by two indices, to determine the preference. Before this, a model named ELECTRE I was proposed to develop the kernel set that is used to compare the alternatives.

The model was further developed and improved later. [95] Proposed ELECTRE II that improved the decision making of the multiple criteria. Fuzziness quotient was added to further improve out rankings in ELECTRE III. [96] Presented ELECTRE IV that simplified earlier versions.

ELECTRE III extends the crisp outranking relations to fuzzy outranking relations, and ELECTRE IV [96] is an attempt to simplify ELECTRE III. [97], later, described different versions of the methods and improvements at each revisions.

However, in literature base thereafter, only two papers that addressed recycling decisions, and three addressing electronic waste management were found. This reflects relatively low adoption of this technique for solving multi-criteria problems.

2.4.3 PROMETHEE

[98] [99] referred to multi-criteria decision making method that had features of two methods discussed in earlier sub-sections, named PROMETHEE. For purpose of understanding the method integrities, we have referred to relatively recent work by [100]. In this method, multi-criteria and their pairwise comparisons are synthesized into a uni-criteria preference, and thereafter, criteria are compared by a degree of preference. Outranking of the alternatives is determined by the net difference in entering and leaving flows.

Going by the frequency of appearance in literature base, PROMETHEE has considerable presence, after AHP being distant largest. Most documented multi-criteria with applications that used PROMETHEE originate from waste management background. Of course, we exclude other hybrid methods (discussed in separate sub-section later) here.

2.4.4 TOPSIS/VIKOR

[101] introduced TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method, which was later improved by [102] and [103].

[103] Described that TOPSIS worked on premise of establishment of preference based on alternative's closeness to the ideal solution. Fuzziness of relative performance of alternatives is addressed by another add-on: Fuzzy TOPSIS. As described by [103], "The performance rating used in TOPSIS which shows the performance of each alternative with respect to different criteria usually involves uncertainty, which has called for fuzzy TOPSIS". [104] and [105] present applications of fuzzy TOPSIS methods.

VIKOR

[106] Came up with another tool for multi-criteria decision making. The method was similar to TOPSIS in a way that it also worked on premise of choosing preferred alternative based on closeness to ideal solution. The name VIKOR originated from Serbian word VIseKriterijumska Optimizacija I Kompromisno Resenje, which is translated into English as Multicriteria Optimization and Compromise Solution, and pronounced as VIKOR. [107] Conducted a comparative study of TOPSIS and VIKOR with two examples. He described that "In VIKOR linear normalization and in TOPSIS vector normalization is used to eliminate the units of criterion functions. The VIKOR method of compromise ranking determines a compromise solution, providing a maximum "group utility" for the majority and a minimum of an individual regret for the opponent".

Of late, the literature base finds that researchers use a combination of (fuzzy) AHP and (fuzzy) TOPSIS to solve multi-criteria problems, with preference for AHP for weight-assignments to criteria, whilst, TOPSIS for criteria rankings.

2.5 Literature classified by nature of reverse logistics activity

In this section, we segregate and tabulate different multi-criteria decision making methods as available in the literature, for different reverse logistics activity classification as recycle, reuse/ remanufacture, Disassembly, waste management, and other uncommon reverse logistics activities.

2.5.1 Recycling

[108] Defined recycling as "*the process of systematically collecting, sorting, decontaminating and returning of waste materials to commerce as commodities for use or exchange"*. Going by a high percentage of papers relating to recycling, we can infer that it is the most researched reverse logistics activity. Most of the available work pertain to identifying sector-specific and product-specific technology for recycling, and the time frame thereof.

In recent years, [109], have presented work to examine the nutrient-recycling dilemma by analyzing the preferences of a group of residents in the city of Zurich for various management scenarios for recycling of anthropogenic nutrients from wastewater. They have used AHP for choosing the best management alternative. [110] [111] [112] [113] [114] have presented many studies focusing on determination of best strategy for recycle within the last decade or so. They presented their work on the premise of EU legislation restricting the use of hazardous substances in electrical and electronic equipment, named WEEE directive.

2.5.2 Remanufacturing and Reuse

As [115] describes, "*Remanufacturing is the transformation of used units, consisting of components and parts, into units which satisfy exactly the same quality and other standards as new units*". In another work, [116] describe that "*Reuse is the process of collecting used materials, products, or components from the field, and distributing or selling them as used*". No additional processing is done on the used products, materials or components.

In the recent years, [117] [118] have sought to determine best remanufacturing technology. [54] Have presented a remanufacturing decision-making framework (RDMF) and validated it for the automotive industry. They targeted the six parameters for remanufacturing: strategic product planning, design for remanufacturing, plant location, production systems, physical distribution, and cooperation among remanufacturing stakeholders.

[119] in their work based in China, introduces some basic concepts on automotive component remanufacturing in China and analyses its roles, and goes on to obtain main key technology factors influencing automotive component remanufacturing industry development in China. [120] have described Supply chain-based barriers for truck-engine remanufacturing in China.

Many researchers have investigated the influence of factors and/or barriers affecting remanufacturing processes. Other areas touched upon by researchers are: Assessment of re-manufacturability or re-usability, and proper material selection for the purpose of re-manufacturability or re-usability.

2.5.3 Disassembly and Design

Though not considered a direct and logical constituent of a typical reverse logistics activity, disassembly and design play a role in other key reverse logistics activity domains. In fact, many researchers [121] [122] [123] [124] [125] [126] have used multi-criteria decision making methods to determine best design of the product to maximize and ease their recyclability, re-manufacturability or re-usability..

[127] have presented a Kano model, fuzzy-AHP, and M-TOPSIS-based technique, to successfully find the optimal order of component removal using AND/OR precedence relation. [128] presents a new multi-criteria decision making (MCDM) model and uncertainty analysis method for the environmentally conscious materials selection problem.

2.5.4 Waste management

[129] describe waste management activities as “all the activities including collection, transport, handling, treatment, material and energy recovery and disposal of waste”. Waste management is a very broad topic. In this paper we include the following topics: management of wastewater, WEEE, Construction & Demolition, industrial waste, hazardous, hospital, and used oil, and do not include management of ‘municipal solid waste’ and ‘nuclear/radioactive waste’.

[130] described multi-criteria decision analysis to tackle waste management problems. [131] presented application of multi-criteria decision analysis for solving municipal solid waste management problems with more focus on the studies that have considered multiple stakeholders and offers solutions for such problems. They infer that AHP is the most common approach in consideration of multiple stakeholders.

Earlier, [132] discussed framework for soil suitability evaluation for sewage effluent renovation.

2.5.5 General

Published literature addressing multi-criteria decision making and reverse logistics problems also feature some other categories of reverse logistics activities. They generally relate to more than one problem in reverse logistics.

[133] discussed ranking of the motivating factors of end-of-life (EOL) tire management in India. [134] discussed integration of planning and assessment of environmental impact for a Waste Electrical and Electronics Equipment (WEEE) transportation network. [135] investigated centralized return centers location evaluation problem in a reverse logistics network.

[28] [136] have discussed about comprehensive performance measurement and causal-effect decision making model for reverse logistics enterprise. RL performance measurement is the topic of two papers. [137] have discussed selection of third-party logistics providers. [138] have described a robust hybrid multi-criteria decision making methodology for contractor evaluation and selection in third-party reverse logistics. [139] discuss outsourcing reverse logistics of high-tech manufacturing firms by using a systematic decision-making approach for TFT-LCD sector in Taiwan. Also, [27] presented a holistic approach for selecting a third-party reverse logistics provider in the presence of vagueness.

Literature presents most number of papers in this general categorization, because it can consider many domains in reverse logistics problem analysis. For a generic reverse logistics problem, it is always prudent to validate the problem solutions by hybrid methodology like AHP/TOPSIS and combine it with mathematical formulations.

2.5.6 Other/Hybrid methodologies

Over and above the discussed multi-criteria decision making methods, literature presents few other methods. As early as in 1974, [140] proposed a pairwise comparison method, named DEMATEL (Decision Making Trial and Evaluation Laboratory).

SAW (simple additive weighting) is another such method that uses a simple equation that is a multiproduct of the criteria weights by the alternative utilities with respect to the criteria method. This method was initially applied by [141].

[142] presented decision making technique called MACBETH (Measuring Attractiveness by

a Categorical Based Evaluation Technique), that qualitatively compares different criteria with respect to their attractiveness. He discussed construction of cardinal value function using MACBETH.

More recently, [143] described best vendor selection for conducting the recycled material based on a hybrid decision making model, combining DANP with VIKOR. They solve the recycled materials vendor selection problems of multiple dimensions and criteria that are interdependent, instead of the independent assumption of an analytic hierarchy process.

[133] analyzed the drivers of end-of-life tire management using interpretive structural modeling (ISM). They proposed a framework to analyze the motivating factors of End-of-Life tire management, and validated with the assistance of a multi-criteria decision-making (MCDM) approach, in the Indian scenario. [144] presented an integrated qualitative and quantitative approach to the development of a balanced scorecard for a real life case of organic food Sector Company in India.

Table 2.4 below summarizes presented literature for different multi-criteria decision making techniques for different reverse logistics activities.

TABLE 2.4 Problem/methodology classification of the literature that use different MCDM methods

	Recycling	**Remanufacturing/ Reuse**	**Disassembly/ Design**	**Waste Manage.**	**General**
(fuzzy) AHP	[111], [145], [109], [110], [128], [146], [102], [147], [148]	RM: [119], [54],[149], [118], [124] Reuse: [150]	[125], [124], [123], [122]	[151], [130], [152], [153]	[47], [154], [28], [155], [27], [86], [156]
ANP	[157]		[121]	[158]	[139], [159], [160]
ELECTRE	[161], [114]			([162], [114]	

Tabulated classification indicates clear majority of use for AHP/Fuzzy AHP by the researchers, and that spans for all categories of reverse logistics activity.

Figure 2.1 displays number of publications during the year 2008 and 2014 on multi-criteria decision making for reverse logistics.

Table 2.5 displays numbers and percentage of applications of different multi-criteria techniques.

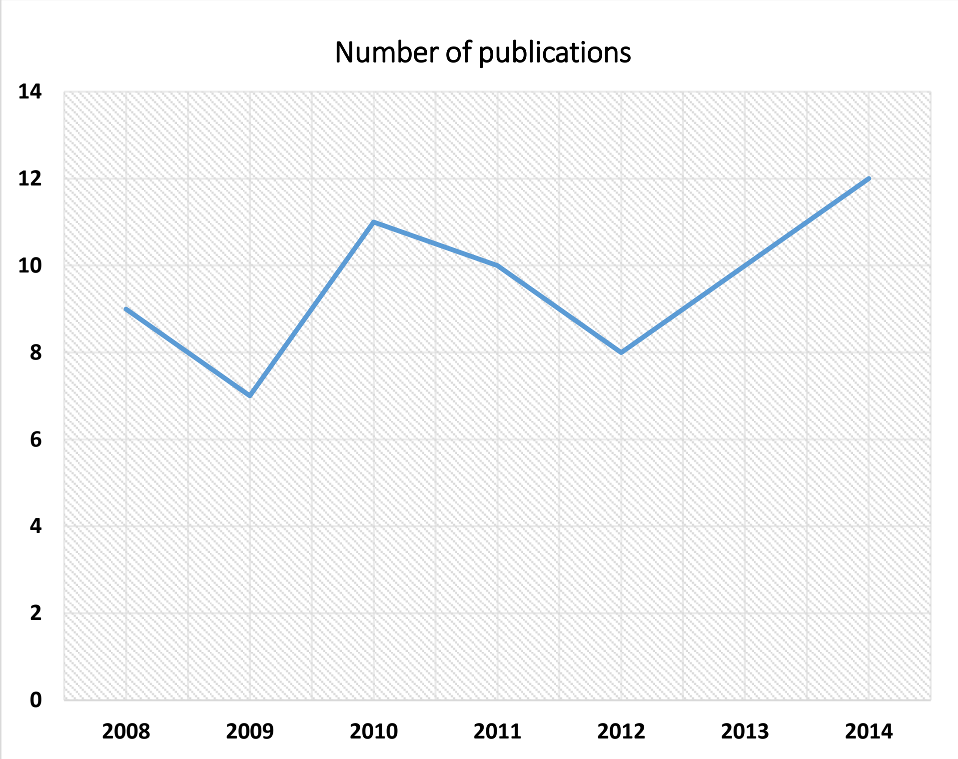

Figure 2.1 Recent publications on use of MCDM

TABLE 2.5 Percentage of applications of different decision making techniques
Adapted from [65]

MCDM method adopted	Number of papers/instances	Percentage
AHP	128	32.57
ELECTRE	34	8.65
DEMATEL	7	1.78
PROMETHEE	26	6.62
TOPSIS	45	11.4
ANP	29	7.38
Aggregation methods	46	11.70
Hybrid	64	16.28
VIKOR	14	3.56
Total	**393**	**100.0**

2.6 Summary of the multi-criteria decision making methods

Analytical Hierarchy Process (AHP): Developed by Saaty, AHP is one of the most used technique for complex decision-making problems. Designed to reflect the way people actually think, AHP continues to be the most highly regarded and accepted decision-making method. AHP can efficiently deal with tangible (i.e., objective) as well as non-tangible (i.e., subjective) attributes, especially where the subjective judgments of different individuals constitute an important part of the decision process. [163] has discussed AHP decision making in Manufacturing Environment Using Graph Theory and Fuzzy Multi Attribute Decision Making Methods.

AHP is capable to represent many levels necessary to define the decision model that characterize the situation, by decomposing the decision-making problem into a system of hierarchies of objectives, attributes (or criteria), and alternatives.

Principal merits of the AHP lies in the flexibility it offers, and in its capability to comprehend inconsistencies. Also, since it adopts the geometric mean of alternative pairs, it leads to effective group decision making.

Demerit of AHP is substantial length of calculations for synthesis of pair-wise comparisons. Also, the point-scale sometimes lead to confusion in exactly determining weight of preference.

In the next section, we survey the literature presented for quantitative models used to solve reverse logistics network design problem.

2.7 Quantitative Models for reverse logistics network

Available literature presents many mathematical models that were used to solve reverse logistics network design problem. Operations research has been the most dominant optimization tool most researchers have opted for. [164], in their work on literature review on reverse logistics networks, infer that models presented after year 2000 till 2013 (in order of preference and use-frequency) include Mixed Integer Linear Programming (MILP) model, Mixed Integer Non-Linear Programming (MINLP) model, Mixed Integer Goal Programming (MIGP) model.

[165], in Proceedings of IEEE international engineering management conference presented a multi-objective and multi-period MILP model for reverse logistic network design for modularized products which determines the number of existing forward flow facilities to be used and the number of dedicated facilities to be setup for handling return flows. A mixed integer goal programming (MIGP) model was established to determine the facility location, route and flow of different varieties of recyclable wastepaper in the multi-item, multi-echelon and multi-facility environment.

[33] Presented an analysis to formulate a mixed integer goal programming (MIGP) model to

assist in proper management of the paper recycling logistics system. They studied the inter-relationship between multiple objectives (with changing priorities) of a recycled paper distribution network. They considered cost reduction, product quality improvement and environmental benefits through increased wastepaper recovery as the objectives for their study.

[166] presented a structured reverse logistic network to collect end-of-life appliances. They presented a simulation model of a reverse logistics network.

[167] have addressed the problem of determining the number and location of centralized return centers. They proposed a nonlinear mixed-integer programming model and a genetic algorithm to solve the reverse logistics return processing problem for on-line sales.

[168] presented a nonlinear integer program to solve the multi-echelon, multi commodity closed loop network design problem involving product returns. [169] presented an optimization-based model to deal with integrated logistics operational problems of green-supply chain management (G-SCM). They formulated a linear multi-objective programming model to optimize the operations of both integrated logistics and corresponding used-product reverse logistics in a green-supply chain.

[20] presented comprehensive analysis of logistics networks in a product recovery environment in their work aimed at characterization of logistics networks for product recovery.

Table 2.6 below classify different quantitative operations research models presented in literature, indicating a clear preference for Mixed Integer Linear Programming (MILP) modelling, amongst other models, for reverse logistics network design.

An important issue in reverse logistics network design is integrating forward and reverse flow management, in terms of logistics management (for sharing transportation and warehouse, for instance). A disaggregated logistics solution raises the product recovery cost substantially higher.

TABLE 2.6 Quantitative models in reverse logistics network

Quantitative modelling method	Author
Linear Multi-objective Programming	[169]
Mixed Integer goal programming	[33]
Mixed Integer Linear Programming	[170], [171], [172], [173], [174], [175], [176], [177], [178], [179], [171], [165], [180], [181], [43], [115], [182], [183]
Mixed Integer Non-Linear Programming	[184], [168], [167]

A closed-loop supply chain (CLSC) consists of both forward supply chain and reverse supply chain. Correspondingly, an integrated supply chain generally spans to multiple organizations/agencies operating for different supply chain operations.

[181] developed to hybrid model to establish a closed-loop supply chain model for spent batteries. They described a hybrid approach that combines an optimization model for planning a reverse-supply network and a flow-sheeting process model that enables a simulation tailored to potential recycling options for spent batteries in the steelmaking industry. They deduce that almost complete recycling of spent batteries can be achieved by transforming current structure into a modified recovery network.

[169] described a linear multi-objective programming model to optimizes the operations of both integrated logistics and corresponding used-product reverse logistics in a given green-supply chain. They deduce that the chain-based aggregate net profits can be improved by 21.1%, compared to the existing operational performance in the particular case they studied.

[179] presented a generic stochastic model for the design of networks comprising both supply and return channels in a closed loop system. They presented a decomposition approach based on the branch-and-cut procedure known as the integer L-shaped method.

[185] proposed a multi-echelon closed loop supply chain network design with forward and reverse logistics components. They develop a mixed integer non-linear programming model for this problem with different costs so that the sum of the total cost is minimized subject to different constraints pertaining to capacities of the entities of the system, demands of first customers and second customers.

[186] have presented logistics network design for end-of-lease computer products recovery by developing a deterministic programming model for systematically managing forward and reverse logistics flows. They describe a two-stage heuristic approach to decompose the

integrated design of the distribution networks into a location–allocation problem and a revised network flow problem.

[187] proposed Integrated Model for Supply Chain Management (IMSCM) that redefines Demand Management Procedures, Order Management Procedures, Manufacturing Management Procedures, Procurement Management Procedures, Distribution Management Procedures, Client Management Procedures, etc. They validated proposed integrated model in the metal-mechanic sector industry.

[188] presented a case study at a company providing repair services on behalf of a computer manufacturer in the Asia-Pacific region. They examined the manufacturing company's redesign of its repair network. [170] presented a work on optimum usage of secondary lead recovered from the spent lead-acid batteries for producing new battery. They proposed heuristics based genetic algorithm (GA) as a solution methodology to solve mixed integer linear programming model (MILP).

Generalized models have also been developed by many researchers. [177] proposed design of a reverse distribution network that considered repairing and remanufacturing options simultaneously. They used mixed integer formulation which is solved using standard Branch and bound method. [171] propose a generalized model that considers capacity limits, multi-product management and uncertainty on product demands and returns, and solve it using standard branch and bound technique.

As established earlier, ascertainment of returning products' quality and quantity for product recovery is particularly complex and difficult in reverse networks, essentially owing to uncertainty factor. Some researchers have addressed this issue under stochastic environment. [189] presented a stochastic programming based approach wherein uncertainties are accounted for in a deterministic location model. They applied stochastic models to a representative real case study based in the Netherlands on recycling sand.

In the same breath, researchers have proposed risk modelling as well. [175] developed a multi-period multi-echelon forward–reverse logistics network design under risk model. They formulated a stochastic mixed integer linear programming (SMILP) decision making form as a multi-stage stochastic program.

[186] demonstrated a heuristic approach to logistics network design for end-to-lease computer products recovery. Later, [190] proposed a two-stage stochastic programming model that is further developed such that a deterministic model for multi-period reverse logistics network design can be extended to account for the uncertainties. They proposed a solution approach integrating a sampling method with a heuristic algorithm, along with a numerical experiment.

Another important area that has emerged for research attention is Third Party Logistics (TPL). TPLs are preferred by industrial organization for the principle reasons of expertise and economy of scales they bring to the table. [191] proposed developing logistics competencies through third party logistics relationships. Recently, [192] summarized research on quantitative models for forward supply chains.

[184] presented a genetic algorithm-based heuristic for the dynamic integrated forward/reverse logistics network for TPLs. [174] suggested a bi-objective reverse logistics network analysis for post-sale service.

[176], in their work on dynamic design of a reverse logistics network from the perspective of third-party logistics service providers, proposed a mixed-integer programming model and a genetic algorithm that can solve the reverse logistics problem involving the location and allocation of repair facilities for TPLs.

2.8 Summary

The literature studied gave an insight in to the categories of logistics and supply chain problems, and threw light on the varieties of spheres researched by the researchers in the broad domain of supply chain, with a reverse logistics focus. We focused on literature pertaining to different aspects of reverse logistics with a view to build comprehensive returns' management framework.

Although AHP is a decision-making methodology in itself, its ability to get ratio-scale measurements and combine them across multiple criteria has led to AHP applications in conjunction with other decisions support tool and methodologies. In this chapter we analysed AHP, FAHP, ANP, TOPSIS, VIKOR, WSM, PROMETHEE and ELECTRE for MCDM in reverse logistics. We consider the results, ability of having detailed sensitivity analysis, ability of using graphical design model, ability of the team decision support, ability of considering variable weights for alternatives, accuracy in determining the results and velocity in the use of decision making methods as defining parameters, and AHP emerges among the study methods as the optimal and most- preferred choice for decision making in reverse logistics framework management.

The next chapter describes AHP model building for MCDM framework for reverse logistics, along with the validation of framework through quantified industries' responses.

CHAPTER 3.

AHP model building and validation

Modern day industries respond to an opportunity to leverage and prolong profitability of their business operations by adopting lean framework and decision making. This chapter demonstrates build-up for developing and evaluating key decision parameters for industry-independent reverse logistics network, further quantify the parameters by incorporating them into Analytical Hierarchical Process (AHP), a multi-criteria decision-making (MCDM) method, and further set a tone for further analysis through mathematical modelling for sole objective of network optimization for such reverse flows.

3.1 Background and key research question addressed

Modern day industries respond to an opportunity to leverage and prolong profitability of their business operations by adopting lean framework and decision making. This chapter demonstrates build-up for developing and evaluating key decision parameters for industry-independent reverse logistics network, further quantify the parameters by incorporating them into Analytical Hierarchical Process (AHP), a multi-criteria decision-making (MCDM) method, and further set a tone for further analysis through mathematical modelling for sole objective of network optimization for such reverse flows.

In the context of our work, fundamental decision pertaining to reverse logistics is that of evaluation and selection of reverse logistics channels. Clearly, the decision is a Multi criteria decision making (MCDM), requiring the decision maker choose the best option from the available alternatives.

In this chapter, we identify and establish a reverse logistics framework structure that can be applied to a wide variety of industries like automobile, electronic, chemical, paper, plastic, etc., and would have different operating channels. Multi criteria for selection of these channels would vary depending up on economic factor focus, as described by [193] or on reverse logistics functions like recycle, remanufacture, disposal, as documented by [51],

[194] and [195]. Here, the subsequence of the reverse logistics functions could vary as to where the product end up, e.g., recycle, remanufacture, or disposal. Also, RL activity may vary on the decisions like OEM Operation, Third Party Operation (TPO), or a combined one.

When the RL is cost intensive, as in remanufacturing case, costs may be reduced by adopting a third party. On the other dimension, if organization adopts TPL, they can be freed of lot of hassles, but that is at the compromise on customer interactions.

Thus, the lead up to selection of RL modality incorporates understanding fundamental flows prevalent in varied industry domains. In this chapter, we build an AHP model that attaches weights to components of RL channel on the basis of the industry responses. The exercise leads up to establishment of preferences of configurations for different industry domains.

The model identifies the preferential rankings to key reverse supply chain entities and parameters through industry feedbacks, and analyses it with AHP methodology. The work goes on to explore the weights assigned to key business objectives of cost considerations and efforts to retain customers by surveyed industries, and thereafter, evaluate the sensitivity of the solution.

We validate AHP model and sensitivity analysis by applying it to three specific and varied industry-domains operating in product recovery and reverse logistics, namely tire remanufacturing, paper recycling, and electronic gadgets repair.

In the next section, we begin with conceptual framework by identifying key business objectives in reverse logistics and channel components.

3.2 Fundamental flows of typical reverse logistics networks

It has been documented and established that a typical reverse logistics consists of three primary entities/activity flows, as

a) Mode and means of collection of product returns

b) Scrutiny, location and classification of returns, and

c) Mode and location for processing on returns

[37] Opines that:

"In particular, companies need to choose how to collect recoverable products from their former users, where to inspect collected products in order to separate recoverable resources from worthless scrap, where to re-process collected products to render them remarketable, and how to distribute recovered products to future customers."

Fig. 3.1 describes hierarchical stages involved in a reverse logistics network and the flow of product returns.

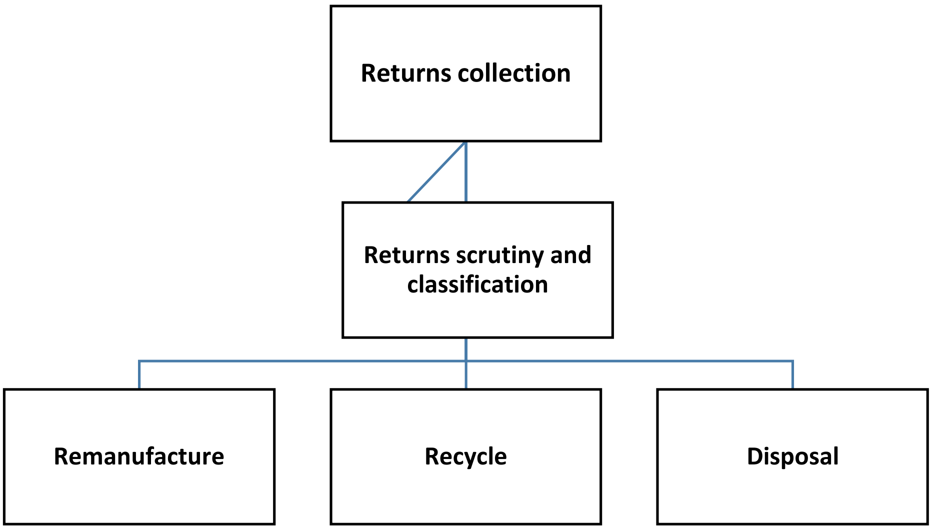

Figure 3.1 Hierarchical stages of reverse logistics activity

Product returns from the end-user are collected, and further scrutinized for its' condition, and classified for its' worthiness for remanufacture or reuse after recycle (including recovery of reusable spares/components/raw materials, as applicable). If returns have reached end of its' usable life, they head to disposal.

Original product/service offering organizations (and also players specializing in logistics activities) adopt different strategies for these three main activities involved for returns' management, i.e., returns' collection, returns' scrutiny and classification, and subsequent business activity, e.g., remanufacture, recycle or disposal.

248 industries operating in reverse logistics in and around NCR and UP, Pune, and in Gujarat state of India, were surveyed, for establishing their preferred method of managing their

returns, of which, 197 industries responded. The criteria for selecting industry targeted industries ranged from the structure and exclusivity with which they operate reverse logistics activity, the size and volume of their reverse logistics activity, and initial positive response and readiness to participate in the exercise. Industries approached had a returns' handling turnover of ₹. 1000000.

The respondents were authorized officials operating in various capacities responsible for reverse logistics activities in their respective organizations.

Stratified random sampling has been considered as probability sampling methods to separate the total target population into different strata by their industry domain (in terms of reverse logistics activity they undertake), so that the population in each stratum is as homogeneous as possible while the population between strata is as heterogeneous as possible.

Practically, the determination of stratum is based on business needs expressed, to satisfy the interest of research. Furthermore, the stratified probability sampling could increase the efficiency of estimator of overall population parameters by the choice of strata and administer the research process in logical steps.

In our industry survey, we consider confidence level of 95% and margin of error as 5%.

Table 3.1 displays summary of associated reasoning/consideration expressed by these industries operating in varied reverse logistic activity, for preferring particular choice/mode for carrying out activities at three-stages. As shown, each stage offers two alternatives, each having own merit, and responding industry opts for either of the alternatives. In some cases, industries also indicated use of a mixed-mode for particular return-variety, but for the purposes of simplicity, this work ignores such instances.

TABLE 3.1 Summary of considerations associated by the industry respondents for the choice of framework alternatives (Based on interviews/responses)

	Alternatives	**Considerations**
Returns' Collection	Producer- managed (P)	• Maximizes the producers' control • Protects trade-secrets • Provides better opportunities to maintain rapport with end customer
	Third-party/ Industry (T)	• Preferable for consumer products operating in high volumes • Potential for cost sharing

Returns' scrutiny & classification	Central- location (C)	• Preferable for specialized and expensive sort-test • Preferable for consumer products operating in high volumes • Opportunity to share transport means used for forward supply chain
	De-centralised location (D)	• Preferred for simple testing infrastructure requirements • Reduced transportation for shipping scrap, resulting in reduced costs • Can adopt TPL partner
Returns' processing	Original facility processing (O)	• Makes sharing of installed facility possible • Better control over remanufacturing/reprocessing/recycle • Saves cost of establishing separate
	Secondary facility processing (S)	• Preferable for consumer products operating in high volumes • Potential for cost sharing with other similar producers • Frees original facilities from complicating processing schedules

3.3Analysis of the responses

3.4Stage 1: Collection of returns

The reverse logistic activity featuring product returns begin with the user initiating product return from his/her facility. The collection process for manufacturer's own returns is either exclusively managed by the product producer, or returns from several industries are collected together by the third-party agency, to be segregated later. The two categories are named P and T, respectively, for producer-managed and third-party collection.

3.5 Stage-2: Scrutiny and classification of returns

Stream of the Product returns has to be further scrutinized for their conditions, to classify them as a candidate of remanufacture/recondition/refurbish/repair, or recycle. Responding industries from various expressed to be doing this after bringing them at a centralized location (proprietary managed) (C), or at decentralized distributed facilities (D).

3.6 Stage-3: Processing of returns

The classified returns undergo further processing at either original manufacturers' facility (O) or at a facility created at secondary location (S).

The choice of alternatives were identified after interviewing the respondent from the surveyed industries and further analyzing the responses. The pattern was substantiated by literature available also. It is observed that the choice they make has critical implication on the business objectives the responding industries wish to meet.

Responding industries represented diverse product domains active in reverse logistics activities. Table 3.2 shows broad industry domains representing in the work.

TABLE 3.2 Broad domains of responding industries

Industry domain
Paper and packaging
Rubber and tire (Butyl, Granules, Liquid Latex)
Plastic (Polypropylene Terephthalate-PET, PVC, Low density Polyethylene- LDPE, Acrylonitrile butadiene styrene (ABS), Polypropylene)
Automobile (Industrial, Passenger, farm)
Building material
Bottling (LPG, Soft drinks)
DC Batteries
Toner and cartridge
Electronic parts (Incl. Cellphones, Toys, ICs)
Apparel & other on-line merchandize

Table 3.3 provides statistics of identified network configuration preferences classified and synthesized on the basis of industry responses obtained for the survey as per Appendix-1.

TABLE 3.3 Response statistics

	Preference (Sector-independent)	No. of Responses	%
1	P,C,O	13	6.6 %
2	P,C,S	19	9.6 %
3	P,D,O	17	8.6 %
4	P,D,S	15	7.6 %
5	T,C,O	35	17.8 %
6	T,C,S	34	17.25 %
7	T,D,O	31	15.74 %
8	T,D,S	33	16.75 %

3.7 Analysis

After thorough research through literature via research papers, yellow pages, and traders' directory, 10 major industry domains operating actively in reverse logistics activity in India were identified, and researched for geography of their logistics practices. A preliminary communication was sent to them, followed by telephonic talk. Out of 248 communications, 197 responses were received, affirming further responses.

A questionnaire (Appendix-1) was shared with all of confirmed responders, along with the research objectives of the work they were being sought for.

Out of the 197 responses, 6.6 % demonstrated to be adopting PCO framework, most of them from Automobile (Industrial, Passenger, farm) sector. 9.6 % indicated adopting PCS framework, with DC batteries being the prominent industry sector. PDO framework was practiced by about 8.6 % of industry-respondents, Toner and cartridge replacement and some Electronic parts (Incl. Cellphones, Toys, ICs) manufacturing/service organizations indicated to be using P,D,S framework (7.6 %).

Bottling (LPG, Soft drinks) sector responded to be adopting TCO with 17.8 % of the responses. TCS framework is adopted by 17.25 % of respondents, mainly in to Rubber and tire (Butyl, Granules, and Liquid Latex) domain. 15.74 % of the respondents representing Paper and packaging sector and Plastic (Polypropylene Terephthalate-PET, PVC, Low density Polyethylene- LDPE, Acrylonitrile butadiene styrene (ABS), Polypropylene) preferred TDO arrangements. Lastly, from building material and apparel & other on-line merchandize reverse supply chain sector, 16.75 % of respondents show to be adopting TDS framework.

During the follow-up interview with the industry respondents, other reverse logistics related data was also sought, which will be discussed in next chapter.

In the next section, we build further on the identified preferred framework, by formulating them in to objective and sub-objectives by analyzing preference of framework at each of three-stages. We further go on to develop an AHP model to rank and synthesize these preferences.

3.7.1 Stage-1: Collection of returns: The decision parameters

Manufacturers of products can choose to only collect their own product returns, for further scrutiny, classification and processing thereon. By doing this, they would have liberty to customize their own routing and frequency of pick-ups. Manufacturers willing to attach exclusivity to their services, intertwine marketing and also look to retain their product-secrecy prefer this type of arrangements, despite higher transportation costs that may result due to this. They look to off-set this higher costs by sharing their forward logistics transportation arrangements.

Manufacturers and/or service providers have two options for returns' collection: Exclusive arrangement to collect own product returns for recovery, or, in-exclusive arrangement where similar type of product returns for more than one manufacturers are collected for subsequent processing. Exclusive arrangement has an advantage of optimizing routes and frequency of collection, whereas the in-exclusive arrangement would benefit by economy of scale for third-party arrangement.

Producer-managed exclusive arrangement often provides for and result in strengthening direct customer relations. Many a times, products offered with warranty clause helps the cause of stronger customer feedback opportunities. Perfect example of this could be computer and accessories market and automobile post-delivery services. [10]. The exclusive collection arrangement also tend to support marketing and sales efforts.

However, transportation costs for the producer-managed collection arrangement could be higher than that of a third-party collection arrangement, because the former cannot take advantage of economies of scale available to higher volumes that a third-party system will accommodate.

For an exclusive collection arrangement organization may opt for customizable design transport vehicles. This would also contribute to the motive of protection of design secrecy and also an opportunity of integrating forward flow and reverse flow transportation arrangements. Such provisions of use of drop-off and pick-up of standardized reusable cargo containers have also been described in late last century by [196]. This arrangement is particularly suitable for relatively fewer collection sites, such as warehousing arrangement. As described earlier, the principle drawback of the system is higher costs. Producer managed collection arrangement is generally preferred by the manufacturers wherein remanufacturing is a general norm for product function and value recovery.

The alternative of adopting third-party collection mechanism is advantageous if collection has to happen from large number of collection centers. This arrangement can achieve economies of scale, but at a cost of reduced control over freight movement and product design secrecy breach. For an instance, recycling industries like paper and paper products prefer third-party collection arrangements. These systems are also prevalent for computers and electronic products, owing to the regulatory framework on e-waste collection systems.

Major advantage of the arrangement of third-party collection arrangement is in achieving economy of scale, for, high volumes transport saves individual costs. Also, separate arrangements for forward and return flows result into better control and accountability. At times, industries adopting third-party arrangement includes provisions for moving hazardous scrap (like e-scraps, chemical residue, etc.) separately by the third-party providers.

3.7.2 Stage B: Scrutiny-Classification of returns

Predominantly, organizations relate this decision of location of assessment of product returns to two issues: Condition assessment (classification), and routing of returns. The location for this activity could be either at a centralized site, or at distributed locations strategically located closer to the market base.

When the product return requires dedicated specialized treatment, for an example, A construction sand recycling [197] or carpet recycling [180], it is preferred to have a centralized location for scrutiny-classification.

This is also advantageous for handling larger volume of returns. Also, when a product return calls for an elaborate and expensive condition assessment procedure on sophisticated equipment, it is generally preferred to have a centralized location for scrutiny test. A clear disadvantage of having a centralized location for the scrutiny-classification is that of excess and at times, unproductive transport of potential scrap to first scrutiny center and then to scrap yard.

Product returns requiring low-cost scrutiny assessment procedures are candidates for decentralized location scrutiny classification, for an example, work on environmental life cycle optimization model for the European pulp and paper industry for paper recycling

([198] [199]), machine refurbishing ([42], [182]) , or reusable containers and equipment [200] [196] [201].

It is worth reiterating that decentralized scrutiny classification can really help reducing transportation costs, as it provides for early identification of scrap proportion in the product returns, and would re-direct it to disposal centers rather than routing it to subsequent stage of product processing. However, it will also involve certain amount of risk for loss of value, for, if returns are wrongly assessed, it would be difficult to retrieve them from the route it headed for.

3.7.3 Stage C: Processing of returns

Key pre-requisite to this all-important stage in reverse logistics is determination of processing requirement on the returns: Whether it goes to recycling, repair/remanufacturing, cannibalization-reuse, or disposal. Important stage-decision here is whether to treat/re-process the returns at the OEM site, as presented by [202] for the return processing for copiers, or at a secondary facility available, as described by [203], for return processing of carpets.

Logically, for instance, returns like machine or a component requiring remanufacturing like fuel injectors, or cam shafts, would be preferably processed at original facility having all support equipment. One disadvantage of this arrangement could be that of having to provide for that extra capacity at original facility.

For recovery activity having prominence of recycling, however, it would be a good idea to utilize expertized dedicated secondary facilities created. It also saves manufacturer by not having to establish a facility. The example of such products could be building material and construction sand. This, however, could come at a cost of losing a little processing efficiency.

3.8 AHP decision making model

The Analytic Hierarchy Process (AHP) developed by Saaty (2000) establishes relative weights of alternatives in a multi-criteria decision making problems. As [204] describes "AHP determines the relative importance of a set of activities in a multi-criteria decision problem. The process makes it possible to concurrently incorporate judgments on intangible qualitative criteria with tangible quantitative criteria into an analysis of alternatives".

Key feature of AHP is its' ability to comprehend, prioritize and solve intricate multi-criteria in decision making. As per [205], AHP method encompasses problem modelling, pair-wise comparisons of alternatives, judgment scales, derivation methods, consistency indices, incomplete matrix, synthesis of the weights, sensitivity analysis and group decisions.

Fig. 3.2 shows typical hierarchy of decisions modelled in AHP.

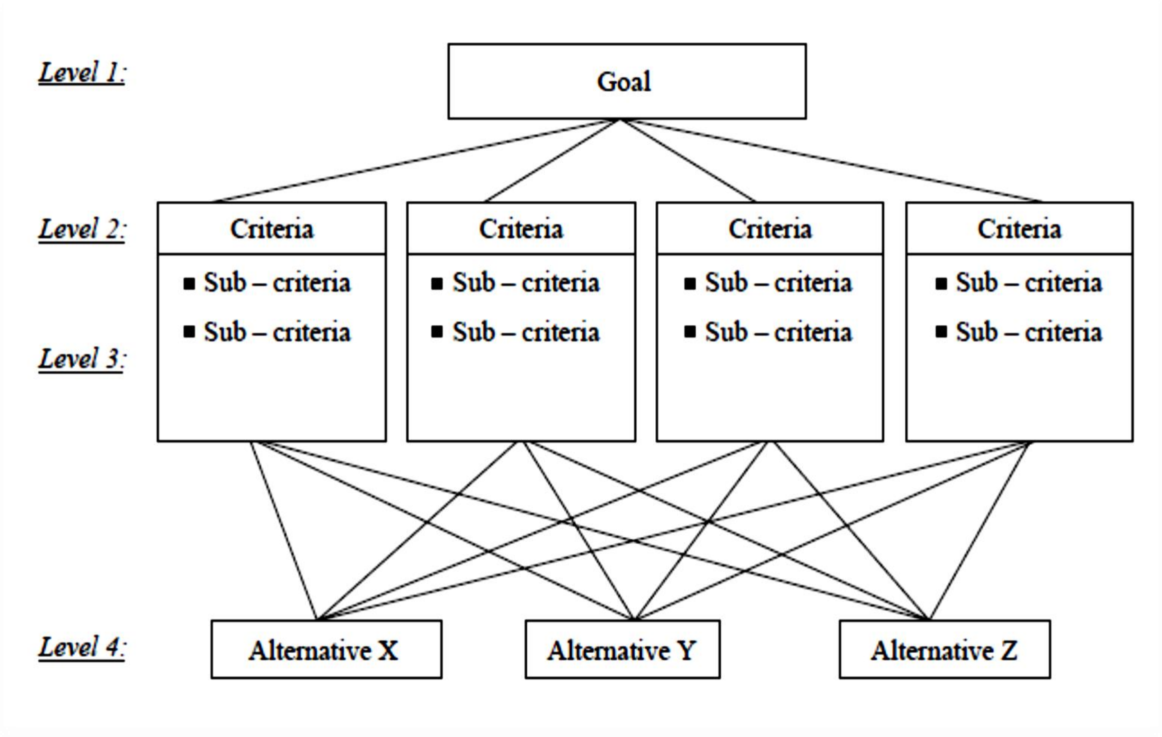

Figure 3.2 General structure of an AHP

A decision sought to prioritize between alternatives in business objectives is a candidate for AHP. The business objective is represented as a hierarchy of alternatives under the business objective(s) and sub-objective(s) under them. The second step is the comparison of the alternatives and criteria. Further, prioritization of alternatives against each other out of pairwise comparison is done through assignment of relative weights. Generally, the pair-wise comparisons begin at the sub-objectives level, and go through the alternatives pair comparisons.

In the present case, AHP, multiple pair-wise comparisons are based on a standardized comparison scale of eight levels. This section presents a multi objective AHP decision model for network design. We follow 4-stage chronology for the AHP model: 1) in the first step, we identify alternatives available for the reverse flow management. Next, in 2) we lay down objectives and sub-objectives with reference to discussion in previous section. In third stage, 3) we pair matrices with a view to rank them relative to each objectives and sub objectives, and lastly, in 4) we develop a vector that gives an overall rank or order of preference for the logistic network combinations.

3.9 Objective and sub-objective

In order to ultimately rank the alternatives, we first need to identify and rank individual alternative with reference to the objectives sub-objectives. TABLE 3.2 summarizes considerations for alternatives as opined by the industry respondents.

Figure 3.2 (adapted from [206] [37]) depict the decision hierarchy, that optimizes network configuration. Here, we look to classify business objectives (pertinent to reverse logistics network design) amongst sub-objectives and alternatives, as discussed in following sub-sections. We discuss two objectives of 1) cost optimization, and 2), fortifying customer relations) and the sub-objectives thereof, next.

3.9.1 Objectives: Cost optimization and customer relations

All logistical activities are configured on first and foremost objective of optimization of resultant cost. In our case, we map this primary objective with four sub-objectives that are influenced by this primary objective. Further, the second crucial business objective, particularly for returns' management, is mainly that of retaining the customers who have used the product/service in its first/subsequent usage. We call it customer relation objective. Further, we derive two sub-objectives, i.e., protection of design/proprietary knowledge, and maintaining customer interactions.

The cost optimization objective primarily looks to avenues that result into cost savings, whereas customer relations criteria ranks those alternatives high that provide avenues for strengthening business relations, be it by collection of returns themselves or by processing the returns at their original facility.

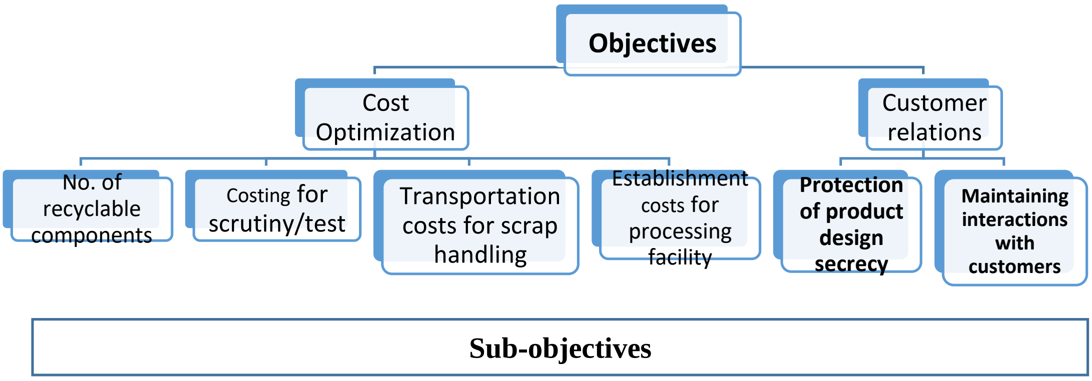

Figure 3.3 Derived objectives and sub-objectives for returns' management for AHP

Depending upon the product genre, different organizations weigh and balance these objectives as per the suitability and own logic. For example, manufacturers not having stringent requirements for product design secrecy protection and do not look for numerous interactions with customers, will rank cost optimization higher than customer relations objective. For an example, sector of building material returns would rank cost optimization higher than customer relations.

In the same vein, if manufacturer does feel the need to stringently manage entire product recovery process in proprietary mode, for the reasons of design secrecy protection or with a view to bank on customer interactions, they would rank customer relations objective higher as compared to the cost optimization objective.

3.9.2 Sub-objectives mapped with two objectives

The two business objectives derived earlier, are further associated with sub-objectives for each of them. Depending on the type of product returns, single or a combination of sub-objective could assume a priority. We shall first describe each of the sub-objectives, and the reasoning for associating them to a particular business objective, i.e., cost optimization and customer relations, respectively.

We shall first analyze and associate sub-objectives for principle objective of cost optimization:

a) **Number of Recyclable components in product returns**: For product returns from industry-sectors such as paper, textile, some plastics, some rubbers, and some consumer electronics products, number of recyclable parts/components would be higher. This provides for more opportunities of cost optimization out of product returns' management, and would be aptly ranked higher.

As against this, for the products such as returns from on-line merchandize or bottling etc., the returns are more likely to be reused/remanufactured or refurbished. As it would have fewer recycle components/opportunities, it would have lower ranking preference. This sub criterion affects the collection stage decision and the processing stage decision.

It is logical to infer that this sub-objective would come into play at the returns' scrutiny and classification stage.

b) **Costing for scrutiny/test**: This makes for an important cost outlay proposition for the organizations requiring specialized high-cost equipment for determining quality of returns, and classification, thereafter. If the scrutiny and testing doesn't involve high financial outlay, the ranking would be lower, and vice-versa. Understandably, this sub objective would influence scrutiny/classification stage of the reverse flow management.

c) **Transportation costs for scrap handling:** Some product returns, such as badly worn-out tyres, heavily damaged plastic and vinyl parts etc. frequently have to be disposed-off as a scrap. If a product returns' lot consists of a large quantity of products that heads-off to scrap, it will result into high transportation cost, and hence, will assume higher rank. As against this, if there is very little scrap content expected out of product returns, this sub objective would assume lower ranking, as there would be lesser potential for cost savings.

d) **Establishment costs for processing facility:** Some product returns require setting up a specialized set up to process the returns. If the manufacturer has capacity and space to process at his original facility, and also is willing to dedicate a part of his capacity to reprocessing machinery (labour, equipment, material, etc.), there would be a potential to cost savings, and would be ranked higher.

If the manufacturer has to set up an exclusive facility at other location, for any reason, it would limit the opportunity to optimize cost, and would be ranked low.

This sub-objective will be associated with the location of the processing site, amongst the 3-stages of returns' management.

Similarly, two sub-objectives is associated with customer relations objective:

a) **Protection of product design secrecy:** The primary question asked here is: how crucial is the design and technology of the product as compared to that of the competitor? Would manufacturer need to save the design secrecy, by keeping his returns safe from prying hands of his competitors? If the answer is yes, it would suitably assume higher order preference. Here, the manufacturer would naturally strive to maintain close customer relations so that the design secrets are not shared.

   Similarly, a lesser requirement for the design secrecy would be ranked lower, for the customer relations objective.

   This sub-objective would influence the returns collection stage of reverse logistic network.

b) **Maintaining interactions with customers:** If the product returns' characteristic/performance/maintenance/ service requirements demand that manufacturer has to frequently interact with customers, this sub-objective would be ranked higher, and also such manufacturers would prefer collecting their returns by an exclusive arrangement.

   As against this, if there is no such requirement, this sub-objective would be ranked relatively lower.

In the next section, we prioritize these sub-objectives defined under principle objectives, by pairing with one-another.

3.10 Prioritization of sub-objectives through pairing-comparisons

To assess the priorities amongst alternatives under a given objective, it is often very hard for Decision makers to assign an absolute score. Qualitative and quantitative data may be unavailable or necessary information to quantify the performance of alternatives may be incomplete. Therefore, the Pairing comparison method is used to determine the relative importance or weights of the alternatives and criteria with respect to each criterion in the decision problem.

Under this approach, the decision maker has to analyze only two elements at a time. To make this comparison, the decision maker has to choose a value indicating how many times more important, preferred or dominant one element is over another element in terms of a given criterion. This value has to be given in reference to a predefined scale. Saaty proposed a ratio scale from 1 to 9 (see table 3.4 below). Other scales have also been proposed in 1990s. [207] had suggested that there is no clear evidence of one particular scale that would outrank all others.

The Saaty scale is commonly used to denote the relative importance of one element to another [84], [89]. In this work, extensive industry survey was kept as a base to develop relative rankings. Preferences out of a pair of alternatives were collected, and synthesized in to solution vector using AHP methodology.

The pairwise comparison synthesis was done to derive a solution vector for all 10 identified sectors operating in reverse logistics activities. AHP Excel solver was used to synthesize the pairwise rankings for each of the sub-objectives throughout the 8 network configurations identified earlier.

Out of the responses obtained, most responsive 3 sectors were chosen to describe the AHP methodology in more detail.

3.11 Saaty’s scale:

The standard for the AHP method presents the Saaty's scale for ranking of alternatives, as given in the following Table 3.4. Here, importance of a particular factor against another is expressed by assigning numerical weight on the scale of 1 to 9, with intensity of importance increasing with the weight on scale.

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over the other.
5	Much more important	Experience and judgment strongly favor one over the other.
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity.
2, 4, 6, 8	Intermediate values	When compromise is needed.

Figure 3.4 Saaty's scale

3.12 Priority rankings using AHP Excel solver

In this section, we describe the rankings given by the industry-respondents for each of the objectives and sub-objectives, classified in to 8 network frameworks identified earlier. As derived in earlier section, the objective of cost optimization has 4 sub-objectives associated with it. Pairwise ranking of a particular sub-objective against each subsequent sub-objective as per Saaty's scale is obtained and used. Similar method was followed for another objective of maintenance of customer relations.

We begin with demonstration of synthesis of priorities for the four sub-objectives derived under the principle objective of cost optimization, and further move on to synthesize priorities assigned to two sub-objectives associated with objective of maintaining customer relations. We use Saaty's scale for assigning weights to the priorities.

Synthesis of rankings is also obtained through matrix mathematics, and has been included in Exhibit 1.

3.12.1PCO framework

The responses classified in to PCO configuration were compiled, and fed-in to an AHP Excel solver, to develop percent rank priority. Following figure is a screenshot of the Excel-solver with the compiled industry-responses fed-in.

The figure displays comparative weights assigned to sub-objectives vis-à-vis each other, using Saaty's scale, in the ranking matrix.

As seen in the normalized score table, the solver yields 28.17% on percent ratio scale priority to the sub-objective of costing for scrutiny/testing, as highest percent priority. Another sub-objective that attains next priority is cost of establishment for processing facility, and yields second priority with 27.18 % ratio scale.

AHP Ranking matrix

Framework: PCO	•No. of recyclable components	•Costing for scrutiny /test	•Transportation costs for scrap handling	•Establishment costs for processing facility
•No. of recyclable components	1	4	1	3
•Costing for scrutiny/test	7	1	2	2
•Transportation costs for scrap handling	4	2	1	3
•Establishment costs for processing facility	2	7	2	1
COL. TOTAL	14	14	6	9

NORMALIZED SCORE TABLE						Percent ratio scale of priorities
•No. of recyclable components	0.07	0.29	0.17	0.33	0.86	21.43
•Costing for scrutiny/test	0.50	0.07	0.33	0.22	1.13	**28.17**
•Transportation costs for scrap handling	0.29	0.14	0.17	0.33	0.93	23.21
•Establishment costs for processing facility	0.14	0.50	0.33	0.11	1.09	27.18
COL. TOTAL	1	1	1	1	4	

Figure 3.5 Cost optimization objective: AHP normalized priority for PCO framework

3.12.2 PCS framework

The PCS framework features cost optimization potentials for sub-objective of numbers of recyclable components, and scrutiny/testing at central location. Since the number of recyclable components would be larger for the genre of product, it would result into highest ranking for percent ratio of priority scale.

Another sub-objective of cost for scrutiny testing attains second priority, as suggested by the percent scale priority of 30.75.

AHP Ranking matrix				
Framework: PCS	•No. of recyclable components	•Costing for scrutiny/ test	•Transportation costs for scrap handling	•Establishment costs for processing facility
•No. of recyclable components	**1**	**3**	**5**	**5**
•Costing for scrutiny/test	**5**	**1**	**5**	**3**
•Transportation costs for scrap handling	**3**	**4**	**1**	**1**
•Establishment costs for processing facility	**2**	**3**	**2**	**1**
COL. TOTAL	**11**	**11**	**13**	**10**

NORMALIZED SCORE TABLE						Percent ratio scale of priorities
•No. of recyclable components	**0.09**	**0.27**	**0.38**	**0.50**	**1.25**	**31.21**
•Costing for scrutiny/test	**0.45**	**0.09**	**0.38**	**0.30**	**1.23**	**30.75**
•Transportation costs for scrap handling	**0.27**	**0.36**	**0.08**	**0.10**	**0.81**	**20.33**
•Establishment costs for processing facility	**0.18**	**0.27**	**0.15**	**0.10**	**0.71**	**17.71**
COL. TOTAL	**1**	**1**	**1**	**1**	**4**	

Figure 3.6 Cost optimization objective: AHP normalized priority for PCS framework

3.12.3 PDO framework

The PDO framework offers highest cost optimization potentials for the activity of transportation costs for scrap handling, as the scrap is identified at the stage of scrutiny. The highest percent scale priority of 33.02 is also suggestive of this.

Framework: PDO	•No. of recyclable components	•Costing for scrutiny/test	•Transportation costs for scrap handling	•Establishment costs for processing facility		
•No. of recyclable components	1	2	1	2		
•Costing for scrutiny/test	3	1	2	2		
•Transportation costs for scrap handling	5	7	1	3		
•Establishment costs for processing facility	7	5	2	1		
COL. TOTAL	16	15	6	8		
NORMALIZED SCORE TABLE						Percent ratio scale of priorities
•No. of recyclable components	0.06	0.13	0.17	0.25	0.61	15.3
•Costing for scrutiny/test	0.19	0.07	0.33	0.25	0.84	20.94
•Transportation costs for scrap handling	0.31	0.47	0.17	0.38	1.32	33.02
•Establishment costs for processing facility	0.44	0.33	0.33	0.13	1.23	30.73
COL. TOTAL	1	1	1	1	4	

Figure 3.7 Cost optimization objective: AHP normalized priority for PDO framework

3.12.4 PDS framework

The PDS framework is suggestive of cost optimization potentials at scrutiny/test level, as the distributed/decentralized sorting would result into cost savings of not having to spare resources facilities at original facility. As seen in the solver screenshot, the priority on a percent scale is 29.5.

The second priority stems from cost optimization potentials on account of transportation costs for scrap handling.

Priority rankings using AHP Excel solver

AHP ranking Matrix				
PDS	•No. of recyclable components	•Costing for scrutiny/test	•Transportation costs for scrap handling	•Establishment costs for processing facility
•No. of recyclable components	1	7	3	7
•Costing for scrutiny/test	3	1	2	7
•Transportation costs for scrap handling	5	4	1	7
•Establishment costs for processing facility	4	5	2	1
COL. TOTAL	13	17	8	22

NORMALIZED SCORE TABLE						Percent ratio scale of priorities
•No. of recyclable components	0.08	0.41	0.38	0.32	1.18	29.5
•Costing for scrutiny/test	0.23	0.06	0.25	0.32	0.86	21.4
•Transportation costs for scrap handling	0.38	0.24	0.13	0.32	1.06	26.6
•Establishment costs for processing facility	0.31	0.29	0.25	0.05	0.90	22.4
COL. TOTAL	1	1	1	1	4	

Figure 3.8 Cost optimization objective: AHP normalized priority for PDS framework

3.12.5 TCO framework

The decisions of mode of returns' collection determines the cost optimization avenues, that is, if number of recyclable components are higher, a third-party collection yields higher cost optimization. Hence it attains highest priority. Moreover, since it is a third-party collection of returns, scrutiny at centralized location can also be mapped such that it results in costs savings.

AHP Ranking matrix						
TCO	•No. of recyclable components	•Costing for scrutiny/test	•Transportation costs for scrap handling	•Establishment costs for processing facility		
•No. of recyclable components	1	2	5	7		
•Costing for scrutiny/test	3	1	5	5		
•Transportation costs for scrap handling	4	3	1	2		
•Establishment costs for processing facility	3	3	4	1		
COL. TOTAL	11	9	15	15		
NORMALIZED SCORE TABLE						Percent ratio scale of priorities
•No. of recyclable components	0.09	0.22	0.33	0.47	1.11	27.8
•Costing for scrutiny/test	0.27	0.11	0.33	0.33	1.05	26.3
•Transportation costs for scrap handling	0.36	0.33	0.07	0.13	0.90	22.4
•Establishment costs for processing facility	0.27	0.33	0.27	0.07	0.94	23.5
COL. TOTAL	1	1	1	1	4	

Figure 3.9 Cost optimization objective: AHP normalized priority for TCO framework

3.12.6 TCS framework

Third-party collection of returns becomes a viable option if scrutiny/condition test is expected to be less expensive, and the testing doesn't require big expenditure on equipment or other resources. Put in other words, costing for scrutiny test attains gains highest potential and priority for cost optimization in TCS framework. It is evident from the ratio scale as found out in the figure below.

AHP ranking matrix				
Framework: TCS	•No. of recyclable components	•Costing for scrutiny/test	•Transportation costs for scrap handling	•Establishment costs for processing facility
•No. of recyclable components	**1**	**3**	**3**	**3**
•Costing for scrutiny/test	**5**	**1**	**7**	**3**
•Transportation costs for scrap handling	**4**	**7**	**1**	**2**
•Establishment costs for processing facility	**4**	**5**	**4**	**1**
COL. TOTAL	**14**	**16**	**15**	**9**

NORMALIZED SCORE TABLE						**Percent ratio scale of priorities**
•No. of recyclable components	**0.07**	**0.19**	**0.20**	**0.33**	**0.79**	**19.8**
•Costing for scrutiny/test	**0.36**	**0.06**	**0.47**	**0.33**	**1.22**	**30.5**
•Transportation costs for scrap handling	**0.29**	**0.44**	**0.07**	**0.22**	**1.01**	**25.3**
•Establishment costs for processing facility	**0.29**	**0.31**	**0.27**	**0.11**	**0.98**	**24.4**
COL. TOTAL	**1**	**1**	**1**	**1**	**4**	

Figure 3.10 Cost optimization objective: AHP normalized priority for TCS framework

3.12.7 TDO framework

The framework having combination of third-party collection and distributed-site testing augurs well for cost optimization owing to products having fewer recyclable components, and also on savings possible on account of transportation costs for the scrap direct from the sorting stage.

AHP Ranking matrix				
Framework: TDO	•No. of recyclable components	•Costing for scrutiny/test	•Transportation costs for scrap handling	•Establishment costs for processing facility
•No. of recyclable components	1	7	5	3
•Costing for scrutiny/test	5	1	2	3
•Transportation costs for scrap handling	4	7	1	3
•Establishment costs for processing facility	4	5	4	1
COL. TOTAL	14	20	12	10

NORMALIZED SCORE TABLE						Percent ratio scale of priorities
•No. of recyclable components	0.07	0.35	0.42	0.30	1.14	28.5
•Costing for scrutiny/test	0.36	0.05	0.17	0.30	0.87	21.8
•Transportation costs for scrap handling	0.29	0.35	0.08	0.30	1.02	25.5
•Establishment costs for processing facility	0.29	0.25	0.33	0.10	0.97	24.2
COL. TOTAL	1	1	1	1	4	

Figure 3.11 Cost optimization objective: AHP normalized priority for TDO framework

The TDO framework is suggestive of cost savings potential at collection stage, owing to the third-party collection. As the scrutiny testing happens at decentralized location, the transportation cost for scrap handling could be minimized. Similarly, the third priority could be justified for the establishment costs, as the processing happens at original facility.

3.12.8 TDS framework

The framework having combination of third-party collection and distributed-site testing augurs well for cost optimization owing to products having fewer recyclable components, and also on savings possible on account of transportation costs for the scrap direct from the sorting stage.

AHP Ranking matrix				
TDS	•No. of recyclable components	•Costing for scrutiny/test	•Transportation costs for scrap handling	•Establishment costs for processing facility
•No. of recyclable components	1	5	5	7
•Costing for scrutiny/test	3	1	3	7
•Transportation costs for scrap handling	4	5	1	7
•Establishment costs for processing facility	4	5	2	1
COL. TOTAL	12	16	11	22

NORMALIZED SCORE TABLE						Percent ratio scale of priorities
•No. of recyclable components	0.08	0.31	0.45	0.32	1.17	29.21
•Costing for scrutiny/test	0.25	0.06	0.27	0.32	0.90	22.6
•Transportation costs for scrap handling	0.33	0.31	0.09	0.32	1.05	26.4
•Establishment costs for processing facility	0.33	0.31	0.18	0.05	0.87	21.8
COL. TOTAL	1	1	1	1	4	

Figure 3.12 Cost optimization objective: AHP normalized priority for TDS framework

Next, we discuss pairwise comparison for sub-objectives of another primary objective of maintenance of customer relations.

3.13 Pairwise ranking for primary objective: Maintenance of customer relations

In this section, we analyze pairwise comparison for two sub-objectives of protection of product design secrecy, and maintaining interactions with customers, for all 8 possible frameworks.

3.13.1 PCO framework

The practice of proprietary collection of returns is predominantly adopted for the products wherein the manufacturer strives to upkeep product design secrecy, and doesn’t wish to let the product reach in to prying hands of competitors. Specialized engineering products, automobiles, proprietary design electronic items, etc. fall in to such category. Such producers attach slightly higher priority to protection of design secrecy, as compared to interactions with the customers, as is evident from the percent ratio of 51.3 priority to the former.

It is quite obvious to understand the reasoning behind getting a close second priority to customer interactions, as the returns are processed at original facility by the producers, and the opportunities to maintain customer interactions are in abundance for this arrangement.

AHP Ranking matrix				
Framework: PCO	•Protection of product design secrecy	•Maintaining interactions with customers		
•Protection of product design secrecy	**1**	**9**		
•Maintaining interactions with customers	**7**	**1**		
COL. TOTAL	**8**	**10**		
NORMALIZED SCORE TABLE				**Percent ratio scale of priorities**
•Protection of product design secrecy	**0.13**	**0.9**	**1.03**	**51.3**
•Maintaining interactions with customers	**0.88**	**0.1**	**0.98**	**48.8**
COL. TOTAL	**1**	**1**	**2**	

Figure 3.13 Custo. Rel. objective: AHP normalized priority for PCO framework

3.13.2 PCS Framework

AHP Ranking matrix				
Framework: PCS	•Protection of product design secrecy	•Maintaining interactions with customers		
•Protection of product design secrecy	**1**	**4**		
•Maintaining interactions with customers	**5**	**1**		
COL. TOTAL	**6**	**5**		
NORMALIZED SCORE TABLE				**Percent ratio scale of priorities**
•Protection of product design secrecy	**0.17**	**0.80**	**0.97**	**48.3**
•Maintaining interactions with customers	**0.83**	**0.20**	**1.03**	**51.7**
COL. TOTAL	**1.00**	**1.00**	**2**	

Figure 3.14 Custo. Rel. objective: AHP normalized priority for PCS framework

Pairwise ranking for primary objective: Maintenance of customer relations

The PCS framework has the only difference in having slightly lower priority for design secrecy protection, as the processing has to happen at secondary facility. However, the scale priority is very slender.

3.13.3 PDO framework

AHP Ranking matrix				
Framework: PDO	•Protection of product design secrecy	•Maintaining interactions with customers		
•Protection of product design secrecy	**1**	**6**		
•Maintaining interactions with customers	**7**	**1**		
COL. TOTAL	**8**	**7**		
NORMALIZED SCORE TABLE				**Percent ratio scale of priorities**
•Protection of product design secrecy	**0.13**	**0.86**	**0.98**	**49.1**
•Maintaining interactions with customers	**0.88**	**0.14**	**1.02**	**50.9**
COL. TOTAL	**1**	**1**	**2**	

Figure 3.15 Custo. Rel. objective: AHP normalized priority for PDO framework

Another case wherein preferences are almost same. As the mode and location for processing vary, as compared to earlier framework, it results in slightly lower percent scale priority to customer interaction, but still getting slight preference over design secrecy sub objective.

3.13.4 PDS framework

As the collection and processing modes for the returns' management changes, also change the weights assigned to priorities. It is logical to infer that more the product is out for operation on it by decentralized agencies, the manufacturer would attach lower weight or preference for the product secrecy sub-objective, in comparison with customer interactions sub-objective.

This is signified in figure 3.16 below.

AHP Ranking matrix				
Framework: PDS	•Protection of product design secrecy	•Maintaining interactions with customers		
•Protection of product design secrecy	**1**	**4**		
•Maintaining interactions with customers	**7**	**1**		
COL. TOTAL	**8**	**5**		
NORMALIZED SCORE TABLE				**Percent ratio scale of priorities**
•Protection of product design secrecy	**0.125**	**0.8**	**0.925**	**46.3**
•Maintaining interactions with customers	**0.875**	**0.2**	**1.075**	**53.8**
COL. TOTAL	**1**	**1**	**2**	

Figure 3.16 Custo. Rel. objective: AHP normalized priority for PDS framework

3.13.5 TCO framework

In this framework, despite the third-part collection methods, rest of the management of returns have manufacturers' control. This would result into assignment of slightly higher priority to protection of product design secrecy sub-objective.

AHP Ranking matrix				
Framework: TCO	•Protection of product design secrecy	•Maintaining interactions with customers		
•Protection of product design secrecy	**1**	**6**		
•Maintaining interactions with customers	**5**	**1**		
COL. TOTAL	**6**	**7**		
NORMALIZED SCORE TABLE				**Percent ratio scale of priorities**
•Protection of product design secrecy	**0.17**	**0.86**	**1.02**	**51.2**
•Maintaining interactions with customers	**0.83**	**0.14**	**0.98**	**48.8**
COL. TOTAL	**1**	**1**	**2**	

Figure 3.17 Custo. Rel. objective: AHP normalized priority for TCO framework

3.13.6 TCS framework

AHP Ranking matrix				
Framework: TCS	•Protection of product design secrecy	•Maintaining interactions with customers		
•Protection of product design secrecy	**1**	**3**		
•Maintaining interactions with customers	**3**	**1**		
COL. TOTAL	**4**	**4**		
NORMALIZED SCORE TABLE				**Percent ratio scale of priorities**
•Protection of product design secrecy	**0.25**	**0.75**	**1.00**	**50.0**
•Maintaining interactions with customers	**0.75**	**0.25**	**1.00**	**50.0**
COL. TOTAL	**1**	**1**	**2**	

Figure 3.18 Custo. Rel. objective: AHP normalized priority for TCS framework

Industry responses suggest that TCS framework suggests no clear preference of one sub-objective over the other. This results into equal priorities for both sub-objectives, as the figure below suggests.

3.13.7 TDO framework

The responses for the TDO framework is suggestive of slight preference to design secrecy protection, as indicated by 52.1 percent on priority scaling. This may be owing to the fact that despite third-party collection and decentralized scrutiny, manufacturer still prefers doing the processing at the original facility.

Priority percentage of 47.9 to maintenance of interactions with customers is suggestive that the priority to preference to sub-objective of design secrecy is not an over-whelming one.

AHP Ranking matrix			
TDO	•Protection of product design secrecy	•Maintaining interactions with customers	
•Protection of product design secrecy	**1**	**7**	
•Maintaining interactions with customers	**5**	**1**	
COL. TOTAL	**6**	**8**	
NORMALIZED SCORE TABLE			**Percent ratio scale of priorities**
•Protection of product design secrecy	**0.17**	**0.88**	**1.04**	**52.1**
•Maintaining interactions with customers	**0.83**	**0.13**	**0.96**	**47.9**
COL. TOTAL	**1**	**1**	**2**	

Figure 3.19 Custo. Rel. objective: AHP normalized priority for TDO framework

3.13.8 TDS framework

This is another framework which displays no clear preference over one another. This is signified by equal priorities.

AHP Ranking matrix				
Framework: TDO	•Protection of product design secrecy	•Maintaining interactions with customers		
•Protection of product design secrecy	**1**	**7**		
•Maintaining interactions with customers	**7**	**1**		
COL. TOTAL	**8**	**8**		
NORMALIZED SCORE TABLE				**Percent ratio scale of priorities**
•Protection of product design secrecy	**0.125**	**0.88**	**1.00**	**50.0**
•Maintaining interactions with customers	**0.875**	**0.13**	**1.00**	**50.0**
COL. TOTAL	**1**	**1**	**2**	

Figure 3.20 Custo. Rel. objective: AHP normalized priority for TDO framework

Sections 3.8.1 through 3.8.8 and sections 3.9.1 through 3.9.8 tabulate and display outcomes of excel solver results for the pairwise comparison of alternatives in all 8 network configurations for cost optimization objective and maintenance of customer relations. In ranking matrices for each framework, alternative with highest percentage scale priority denotes the preferred alternative/configuration.

3.14 Summary and further analysis:

In the earlier section, we derived preference ranking for four different sub-objectives associated with principle objectives of cost optimization and two under maintaining customer relations. Percent ratio scales determined for all eight frameworks is suggestive of preferences for particular alternative adopted by the responding industry-sector for a particular stage activity in reverse logistics of returns management.

Appendix-2 describes the AHP methodology calculations that lead to the ranking scores.

Table 3.6 below shows rankings scores returned by the excel solver. Some of the results show equal rankings between two sub-objectives. This is indicative of no clear preference.

In the same light, it can be inferred that higher the score, higher the priority.

TABLE 3.4 Ranking scores for framework alternatives (AHP Solver)

Frame works	No. of recyclable compo.	Costing for scrutiny/test	Trans. costs for scrap hand.	Esta. costs for processing facility	Protection of product design secrecy	Maint. Interaction with customers
Produ. managed coll. (P), Central-location s & c (C), and Original facility proc.(O)	1	4	1	3	6	6
Produ. Man. coll. (P), Central-location s & c (C), Seco. Fac. Proc. (S)	2	4	1	1	4	4
Produ. Man. coll. (P), De-Cent. Loc. S & C (D), Original	1	1	6	3	6	6

Frame works	No. of recyclable compo.	Costing for scrutiny/test	Trans. costs for scrap hand.	Esta. costs for processing facility	Protection of product design secrecy	Maint. Interaction with customers
facility proc.(O)						
Produ. Man. coll. (P), De-Cent. Loc. S & C (D), Seco. Fac. (S)	2	1	6	1	4	4
TP Coll. (T), Central-location s & c (C), and Original facility proc.(O)	4	4	1	3	2	1
TP Coll. (T), Central-location s & c (C), Seco. Fac. Proc. (S)	6	4	1	1	1	1
TP Coll. (T), De-Cent. Loc. S & C (D), Original facility proc.(O)	4	1	6	3	2	1
TP Coll. (T), De-Cent. Loc. S & C (D), Seco. Fac. Proc. (S)	6	1	6	1	1	1

In some cases, as seen for preferences for TCS and TDS framework for customer relations sub-objective, we might observe a cross-over of priorities.

In the next section we elaborate on three industry sectors, and also carryout sensitivity analysis.

3.15 Implementation of AHP model for three industry sectors and sensitivity analysis

In this section, we validate the preferences described by different industry reverse logistics sectors at-large, for three different industries featuring different network framework. These industries also fall into different geographical regions of India. Also, we validate them for three diverse reverse logistics activities, so as to derive more inclusive understanding of different reverse logistics activities. As all input data for the industrial cases have been gathered from three industries, it brings along flair of the particular sector for reverse logistic activity.

We present these three case studies by briefly describing it first, following it up by relating to the network framework identified in earlier sections, and then going on to validate the framework identified by the AHP analysis.

3.16 Case study of three different industry-sectors

We discuss and analyze case studies from real-world applications to validate and map them to frameworks identified earlier through MCDM method of AHP modeling. We choose three cases that represent three key attributes of reverse logistics and returns' management: Remanufacturing, recycling and/or disposal thereof, and repair/refurbishment. The case studies are taken from actual reverse logistics systems, and they are: (1) Tire and rubber remanufacturing (2) Paper and paper product recycling, and (3) Electronic gadget repair/refurbishing.

We can infer that these case studies would reflect varied preferences as they represent different product with varied use and cost, and hence, different network frameworks. We input rankings provided by industry-respondents from these three industry-sectors to construct and authenticate our study. We, thereafter, touch upon sensitivity analysis for objectives, sub-objectives, and alternatives.

We shall first discuss salient features of three different industry-domains constituting case studies, and take it further to AHP analysis and plotting sensitivity charts.

3.16.1 Case study 1: Tire and rubber products remanufacturing.

A leading global tire manufacturing subsidiary based in Ballabgarh, Faridabad of UP state has been case-studied in this work. The organization specializes in tires for passenger automobiles, performance automobiles and SUVs/ 4 x 4 vehicles. The company operates for the reverse logistics of its product returns as per the following modus-operandi.

Collection & scrutiny testing: The Company has a dedicated provision for collection of its used tires (and tires on warranty) from primary customers spread all-over the UP and overlapping trade regions of Gurgaon. A weekly or fortnightly collections of returns are sent to original facility plant in Faridabad, and the scrutiny test is done on the returns through highly specialized condition-monitoring infrastructure set up at the plant facility. The company follows pre-cured process for retreading.

The scrutiny stage also provides for identification and judgment measures for the product returns that go to disposal. An exclusively set up value-chain stream mapping considers the environment aspect, and use of the tire-rubber crumbs for road construction, and is beyond scope of this study.

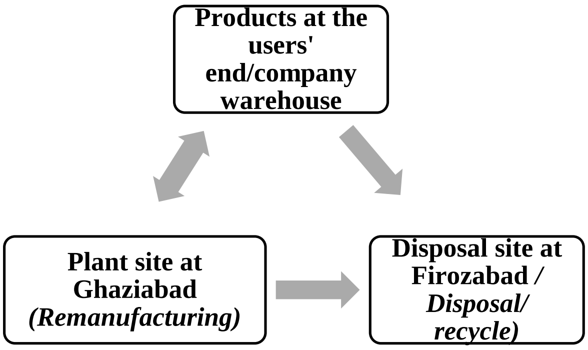

Figure 3.21 Flow diagram for case study on tire remanufacturing

Since the manufacturer has the proprietary collection arrangement, it can take advantage of transporting the end-of-life products straight to disposal site or material recycle for alternative use.

This system has the following advantages:

- Quality assurance conformance, as scrutiny check happens in proprietary environment, at centralized arrangement.
- Ensures optimized transportation cost as only remanufacturable products return to secondary facility for processing. Also, transportation cost saving is possible for returns that are headed to disposal.
- Flexible material (rubber) recovery, as material can be recovered either by the recycler or at the manufacturing plant.

> This system's major challenge is uncertainty in supply and demand. The volume and condition of return products is highly variable, complicating sales forecasting and inventory control of used tires.

Clearly, the industry adopts PCS Framework, wherein customer relations maintenance sub-objective also gains dominance.

3.16.2 Case study 2: Paper packaging recycle

A very reputed industrial house operating in Rajkot-Morbi and Ahmedabad industrial zones of Gujarat state has been case studied. The company operates on paper and packaging recycle. The company provides recycling solutions for its own products, and also for paper and packaging products produced in similar industries, in general.

Apex Paper Recycling Pvt. Ltd., provides recycling services for many waste materials including cardboard/office papers and all kinds of paper waste. The company operates pan-Gujarat, and has three collection centers at Rajkot, Makansar (near Morbi), and Mehmadabad.

The company is collecting wastepaper from offices, banks, industries, BPO, printing presses, factories, educational institutions, and from domestic merchants. They also collect materials from supermarkets, packaging units, printing presses, banks, offices & manufacturing companies.

The material is sorted and baled at any one of their collection centers. The material is then dispatched in totality to paper-mills for recycling into finished paper. The sellers can get in return either money or any products of paper.

The company has a third-party logistics partner who operates its own transport facility which includes 12 pick-up vans, and also provides shredding and pulping services, near Surendranagar district.

The set up for the paper recycling requires simple facility creation for Hydra-pulper, Beater, Univat and Screw Press (forming the wet section), and Calendaring machines and Cutting machines (forming the dry section). A total area of 600sqft works well, which is required for works well, for storage of the waste paper and the recycled paper; and for the unit itself.

The industry collects used paper and paper-board from a number of individual third-party recycling centers located nation-wide. Used paper and paper products (not limited to only the company, but industry-wide) are accepted from all users. Some un-organized collectors also add their collected products to the collections. The returns are sorted at decentralized locations and sent to recycling/reprocessing plant at either of three locations, depending upon the proximity to collection.

This system has the advantage of Economies of scale. Having an industry-wide collection mechanism helps promote efficiencies in transportation and processing of used paper.

Framework: network configuration (TDS): The paper and paper products returns' management and recycling case study has third-party collection, Scrutiny-test at decentralized locations, and processing at secondary facility.

3.16.3 Case study 3: Electronic gadgets repair/refurbishment

A major player located in Noida, UP operating in forward and reverse logistics of reverse logistics of refurbishment for STBs, LED TVs, Mobiles, Modems and Computer Peripherals has been case-studied. The organization has arguably largest domestic capacity for manufacturing set top boxes and also repair and refurbishment services for LED TV and Mobile Phones. The organization claims to have 22% of market share in Set Top Boxes (STB) repair and 30% in refurbishment.

Started in 2012, the company have established leadership in refurbishment for STBs, LED TVs, mobiles, modems and computer peripherals. Also, they are one of the few companies to have panel repairing facility, and boast of manufacturing expertise and OEM relationships.

The company takes up refurbishment, mobile display repair, LED panel repair, asset recovery to customers' satisfaction, warranty management, and also, module & product repair in general.

Capabilities

Repair and Rework, Refurbishment, Component Recovery, Final Assembly Material management, Data Analysis, Data Feedback & Engineering Support to Current Products –

LED Television, Washing Machine, Lighting Solutions, Mobile Phones and Network Devices.

Company has provision for owned mechanism for return collection pan-India through its distributors. The company provides for L4 services for scrutiny test and identification of level of repair/refurbishment required for the product returns. The company have set up 10 fully-owned refurbishment centers across India, with warehouse and facilities up to L4 products.

This system has the following advantages:

- Direct customer relationships. Providing a lifetime product support, Warrantee supporting strong direct customer relationships, potentially increasing sales.
- Reduced scrutiny test expenses, owing to L4 service capability backbone

Capacity utilization of the established facilities is seen as a challenge at times, but the organization settles it by combining manufacturing operation with forward flow. Returns volumes have been sufficient in the past few years.

Framework: network configuration (PDO): The organization follows PDO framework for returns' management. Although the products in consideration are commodity-type products, but the company opts to protect design secrecy and also wish to retain control over the refurbishment. The higher cost to establish company-managed returns' management infrastructure gets off-set by retention of direct customer relationships that reflects in increased sales over the years. Also, owing to use of the dedicated identical original facility manufacturing set up for processing returns, albeit at 10 geographical locations, results in to cost optimization of setting up a returns' processing facility. Company-managed returns collection has a potential to further cost optimization as identification of end-of-life products is done closer to the customer end, and a service-providing model in which company delivers the service of a product.

We tabulate the relative preferences for objectives and sub-objectives as obtained from AHP analysis, for three industry cases in Table 3.7.

TABLE 3.5 Prioritized weights for objectives and sub-objectives in the case studies

Objective/sub-objective	Tire and rubber products remanufacturing	Paper and paper products recycling	El. Gadgets repair and refurbishment
Cost optimization potentials	1	5	1
Customer relations	5	1	5
No. of recyclable components	3	6	3
Costing for scrutiny/test	4	2	2
Transportation costs for scrap handling	5	5	4
Establishment costs for processing facility	3	6	4
Protection of product design secrecy	5	1	5
Maintaining interactions with customers	5	1	7

In the next section, we discuss the AHP decision analysis for these three case studies, and go on further to discuss sensitivity analysis for the case studies.

3.17 AHP validation and sensitivity analysis for three case studies

The results obtained through the deliberations with respondents from industries operating in these three industry-sectors yielded relative priorities as per the Table 3.7 above. The priorities obtained are for the objectives of cost optimization and maintenance of customer relations, and the sub-objectives associated to each.

It is imperative to note here that the priorities for each sub-objectives for eight different frameworks that were obtained as in Table 3.8, holds good for these three case studies as well, because they are independent of company's business position, and only the priorities for objectives and sub-objectives vary for these three case studies.

The sensitivity analysis refers to the points were priorities for the sub-objective under consideration and the subsequent sub-objective assumes equal value, and the points beyond, where priorities even change. More specifically, we discuss an expression for points at which the priority observes a cross-over.

We adopt mathematical formula (as per exhibit-1) to find the solution vectors returning the solution vectors that determine the preference of network framework for these three case studies, and are shown below in Table 3.6.

TABLE 3.6 Priority scaling for three case studies

Frame works	**Tire and rubber products remanufacturing**	**Paper packaging recycle**	**El. Gadgets repair/refurbishment**
	Percent ratio scale of priorities		
Produ. managed coll. (P), Central- location s & c (C), and Original facility proc.(O)	21 %	11 %	18%
Produ. managed coll. (P), Central- location s & c (C), Seco. Fac. Proc. (S)	16%	11%	17%
Produ. managed coll. (P), De-Cent. Loc. S & C (D), Original facility proc.(O)	**23%**	12%	19%
Produ. managed coll. (P), De-Cent. Loc. S & C (D), Seco. Fac. Proc. (S)	16%	12%	**20%**
TP Coll. (T), Central- location s & c (C), and Original facility proc.(O)	8%	11%	7%
TP Coll. (T), Central- location s & c (C), Seco. Fac. Proc. (S)	6%	12%	5%
TP Coll. (T), De-Cent. Loc. S & C (D), Original facility proc.(O)	7%	14%	6%
TP Coll. (T), De-Cent. Loc. S & C (D), Seco. Fac. Proc. (S)	6%	**17%**	7%

The next section describes analysis of each case studies.

3.17.1 Case study 1: Tire and rubber products remanufacturing.

In this product genre, it is a regular practice to receive returns that require re-manufacturing, predominantly, re-treading. The return has 80-20 proportion of remanufacturing to disposal, depending on the type of automobile it is used for.

The manufacturer of automobile and farm equipment tire attaches priority to maintaining customer relations. Producer-managed collection arrangement provides the opportunity for this. Also, the warranty and condition-monitoring contract arrangement helps maintaining the relations.

With technology advances in technology for bolstering tire strength and wear-resistance, and increasing competition, the producer has a significantly high investment in design, and therefore, need for design/technology knowledge to protect. The producer has also invested heavily in proprietary product design, and needs to protect proprietary knowledge in its product. Weight of 5 for customer relations as opposed to benchmark score of 1 for cost optimization signify this.

Out of Among the four cost optimization sub-objectives, the manufacturer attaches maximum weight on cost optimization of transportation costs for scrap handling, and sub-criteria for establishment costs for setting up processing facility as lowest weight out of cost optimization sub-objectives, as seen from the priority table.

Testing costs are not very high, as the testing assessment is based more on visual and physical inspection for the model type, wear and year of manufacture. This leaves fewer cost optimization potential at scrutiny test stage, as evident from relatively low preference of weight 3.

The manufacturer, having ample owned plant capacity, equipment for pyrolysis and skilled labour to handle processing at original manufacturing facility. This results in cost optimization opportunity for not having to establish a facility afresh. Also, cost optimization is feasible by identification of scrap and possibility to ship them straight to disposal facility, and save on freight. It is aptly ranked higher, with score of 5.

The solution matrix after synthesis of normalized values shown in the TABLE 3.13 show a clear preference for customer-owned collection, with P on highest percent scale priority, vis-à-vis T frameworks. Also, the difference is significantly high, making it an obvious choice. (Refer to 23%, 21 % and 16 %, as compared to 6, 7 & 8 % for third-party collection alternatives.

The results also show PDO and PCO as two main alternatives with only 2 % more weight for PDO. This difference is predominantly on the choice for scrutiny and classification stage.

It is interesting to note here that many of the similar industries operating in to rubber & tire showed a slight preference for PCO over PDO. This can be attributed to overlapping preferences and business positioning of the particular industry in consideration. Also, this is suggestive of customization of strategy in the scrutiny/classification mechanism adopted by a particular industry.

3.17.2 Case Study 2 Paper packaging recycle

In this case, paper and packaging material return to the scrutiny test location through third-party logistics partner, who would collect the returns from small regional collectors, and are sorted by either the small collectors or at the next scrutiny junction, at decentralized facility. The sorting mainly involves separating and dimension sorting of the paper, before it is sent for baling, pulping and refining at the processing/recycling center in the next stage.

Cost optimization assumes key priority in this sector of returns' handling, for, recovery and retrieval of economic value remains the key motto for the product domain, through recycling. Hence, cost optimization will over-weigh customer relations objective. This is evident from a weight of 5 to cost optimization over benchmarking value of 1 of customer relations. This is typical for a product returning maximum recycling potential as a part of waste-stream, and maintenance of customer interaction doesn't have clear relevance. This is a major shift from the PDO framework priorities discussed in earlier case.

If we look at the scores for the sub-objectives under cost optimization objective, number of recyclable components and transportation costs for scrap handling assume highest priorities, as evident from scores of 6 and 5, respectively. As there is a universal dedicated facility for paper recycling at a decentralized location, it is obvious that manufacturers don't consider manufacturer-controlled collection or processing. This is also a shift from earlier case study, where the processing was preferred at producer's original facility. Further, as recycling is more relevant as compared to scrap handling.

Since the separation and classification of returns doesn't need any specialized or expensive equipment or skills, the scrutiny stage score returns a low score, and therefore the preference for a decentralized location scrutiny classification. This is evident from a low score of 2 for scrutiny testing.

Moving on to maintenance of customer relations objective, the design secrecy and customer interactions assume low scores, as evident from equal scores of 1 each.

Table 3.13 indicates that for the case study of paper and paper packaging industry, the weights are closely clustered, with TDS framework showing clear lead, with TDO as second preference. The TDO framework is favored by the organizations who also operate in to business of making customized containers and packaging, over and above normal recycling. Logically also, TDS and TDO have 2/3rd of framework as common, their weight scales having close rankings and overlapping priorities in some cases is understandable.

It is important to recollect here that the third-party collection mechanism also mean that collections of product returns for several manufacturers is done together by the third-party collector. This is a shift from producer –arranged collection mechanism in the earlier case study.

It is also worth noting here that, in general, for products where recycling dominates the product recovery, TDS and TCS are the most favored frameworks, as also found out by [206] that in 15 recycled product case studies in USA, all had either of the network framework.

3.17.3 Case study 3: Electronic gadgets repair

The third case study we undertook is that of a fiercely competitive, profit cutting profile of repair and remanufacturing organization. We studied reverse logistic activities at an Electronic gadgets repair and refurbishment organization, also repairing LED TVs, mobiles, modems and computer peripherals STBs, mobile phones, which run on a warranty clause and subject to repair on accidental failure or disruption of intended function or feature.

The common practice at the organization is producer-managed collection of returns, wherein the individual product is collected by proprietary arrangement of collection at the service center of the product. This necessitates frequent end-customer interactions for the original manufacturer.

As the relative ranks tabulated under Table 3.8 show, the company attaches higher weight on customer interactions and protection of design secrecy. This results in prioritization (score of 7 of objective of maintaining customer relations over cost optimization (benchmarking score of 1).

It is also evident that four cost optimization sub-objectives return similar values that we observed for tire remanufacture case studies, except for establishment costs for processing facilities returning highest weight of 5. As the company provides L4 services, the processing facilities are made competent to handle processing of returns. Also, for this particular industry case, the organization has made provisions to even make some original product parts at these processing centers. This slightly changes the priority at the processing stage.

If we look at the synthesized priority percentage rankings of the frameworks, we find that PDS and PDO return close preferences, with PDS scoring marginally higher with 20% over 19% in PDO. The scrutiny test will have no clear preference, but the company preference of setting up a secondary facility- albeit sharing some of the original plant capacity with it- returns PDS as a preferred framework for this case.

In the next section, we discuss sensitivity of the frameworks preferred over other frameworks, for these case studies.

3.18 Sensitivity for the three case studies

Primary purpose of the sensitivity analysis here is to determine the points at which the preferred framework has equal preference with that of the subsequent sub-objectives. That is, when the most preferred framework as per the ranking on priority scale is i, we would be interested in finding the point at which the j^{th} framework would equal the preference score of i^{th} framework. This can be accomplished by setting value of the said framework in the priority table as equal to the percent priority scale of the subsequent framework. At this point, we can say, that cross-over of priority happens. Also, since the value of the sub-objective has to be an integer greater than 1 by definition, any value outside interval 0 and 1 wouldn't make sense.

Sensitivity analysis was performed using equations as per Exhibit 2. Sensitivity for the three case studies for objectives and sub-objectives was performed, and TABLE 3.14 shows the sensitivity results for two objectives and also, 4 sub-objectives under cost optimization and 2 sub-objectives under maintenance of customer relations sub-objective.

We also demonstrate graphical illustration of sensitivity to cost optimization objective for the eight network frameworks established. Using the same methodology, sensitivity to customer relations objective and sensitivity for sub-objectives under both sub-objectives can also be plotted. We use Excel charts to plot the sensitivity.

TABLE 3.7 Sensitivity to objectives and sub-objectives for case studies

Objective/ Sub-objective	Sensitivity		
	Tire and rubber products remanufacturing	**Paper and paper boards**	**El. Gadgets**
Cost optimization objective	Slightly Sensitive	Sensitive	Sensitive
Customer relations objective	Insensitive	Sensitive	Slightly Sensitive
No. of recyclable components sub-objective	Insensitive	Sensitive	Insensitive
Costing for scrutiny/test sub-objective	Sensitive	Sensitive	Sensitive
Transportation costs for scrap handling sub-objective	Sensitive	Sensitive	Sensitive
Establishment costs for processing facility sub-objective	Insensitive	Sensitive	Insensitive

Table 3.7 presents the sensitivity to different objective and sub-objectives for three case studies.

3.19 Discussion on sensitivity to cost optimization objective

Figure 3.22, 3.23, and 3.24 illustrate the sensitivity plot for the cost optimization objective relative to both the objectives, for the three case studies, respectively. They show relationships among the different eight frameworks with regard to cost optimization objective.

Here, we plot values of objective cost optimization over sum of cost optimization and customer relations as a linear path on x axis, against all network frameworks. The solid vertical lines on the plots indicate 1). The current value of cost optimization objective relative to both the objectives for each case study, and 2). Current value of customer relations objective, with respect to both objective. This point represent the network framework with the highest preference on the vertical axis as the most preferred framework in the solution. The dotted crossover point is the point at which the most preferred alternative has an equal preference with another alternative.

All three case study solutions are sensitive to cost optimization objective over both the objectives combined. As evident in the first case study on tire remanufacturing, as we go farther from 0 on horizontal axis, preference for third-party collection increase in preference over producer-managed collection.

Specifically, in the tire products remanufacturing case study, the TDO framework becomes preferred over PDO if ratio of cost optimization objective over both the objectives combined exceeds 95%, while in the paper and packaging products' case study, TDS becomes preferred over PDS if the ratio is greater than at 72%. In the electronics gadgets case study, there are, this figure is 12%. (Crossover points: PCO is preferred over PDS at level above 40 %.)

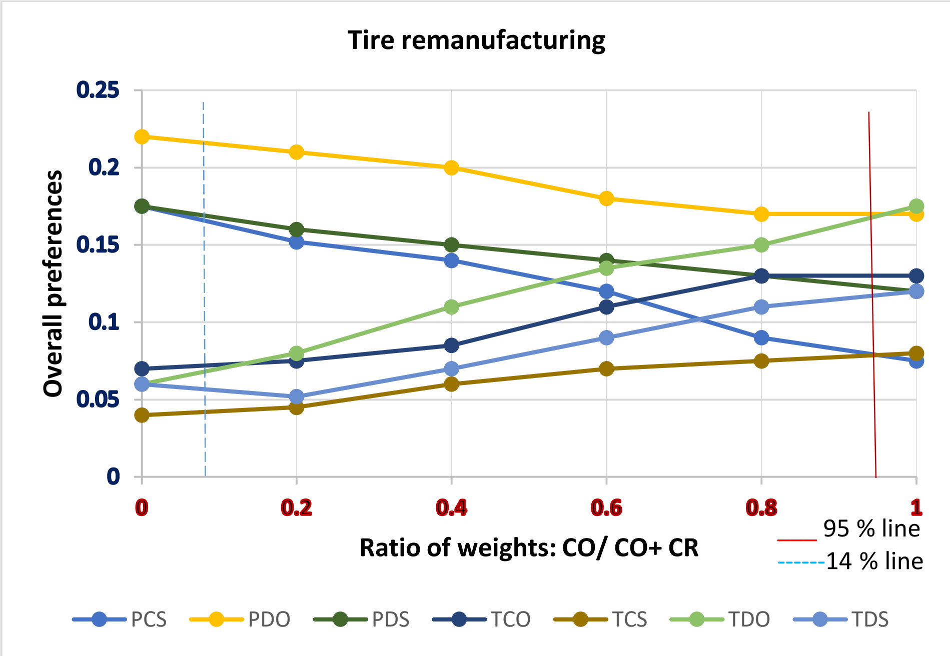

Figure 3.22 Sensitivity to cost optimization objective for overall rankings for tire remanufacturing case study

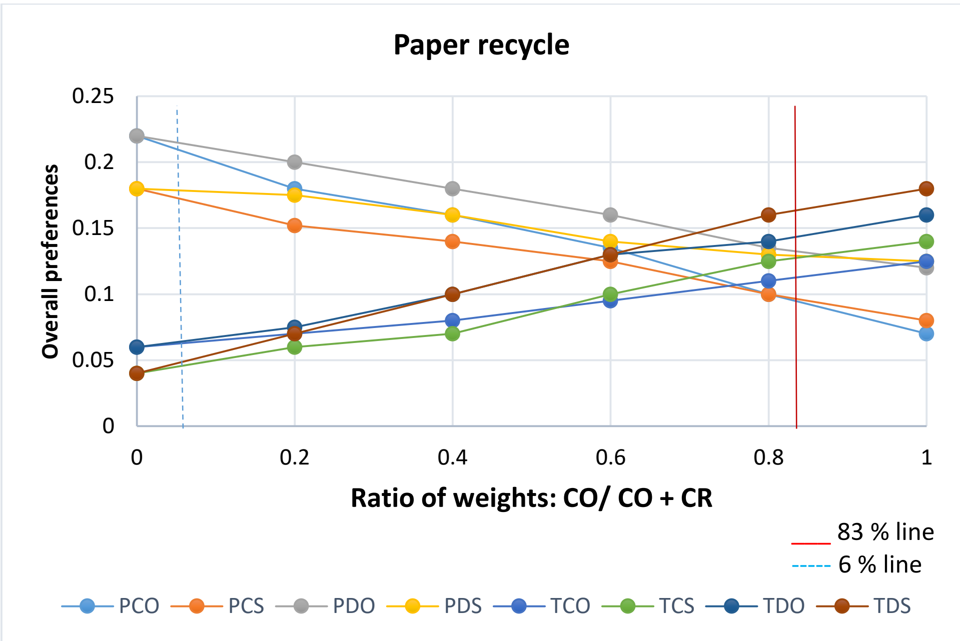

Figure 3.23 Sensitivity to cost optimization objective for overall rankings for Paper recycle case study

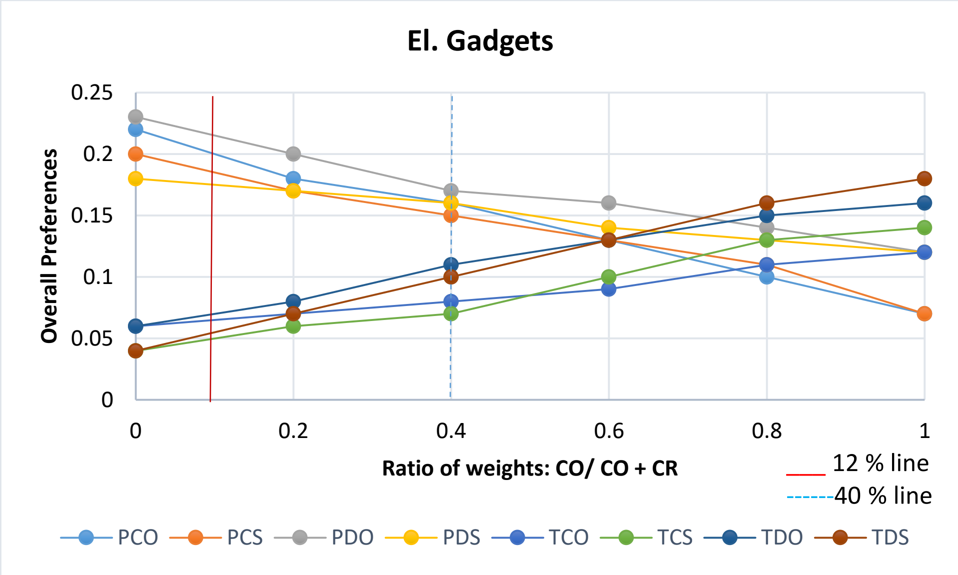

Figure 3.24 Sensitivity to cost optimization objective for overall rankings for El. Gadgets case study

Overall, the ratio of weights largely impact the collection decision (producer managed v/s third-party), with secondary effects on the scrutiny classification and processing stage decisions.

Sensitivity analysis for sub-objectives of customer relations objective (i.e., protection of design secrecy over both sub-objectives) and also, for each sub-objectives under cost optimization objective with respect to all cost optimization sub-objectives can be plotted in the same way.

Overall sensitivity: Generally speaking, the cost optimization objective with respect to both cost optimization and customer relation sub-objective impacts collection mechanisms, whereas, the processing decision is influenced by customer relations objective.

3.20 Summary and discussion

Reverse logistics framework of a manufacturing/service industrial organization principally operates in three stages of collection, scrutiny and classification of returns, and thereafter, a mechanism for remanufacture/repair/recycle or disposal. This chapter discussed the framework in terms of configuration options available to the organization, and the preference to a particular option by the industrial organization. Eight different network frameworks for carrying out reverse logistics and returns management were discussed on the basis of industry responses from 10 varied industry sectors engaged in management of returns.

On the basis of rankings/ preferences given in the industry responses, an AHP model was built, wherein two principal objectives of the returns' management, namely, cost optimization and maintenance of customer relations were evaluated and prioritized. Further, both the objectives were classified into four and two sub-objectives each, under them.

Three stages of returns management and two options under each resulting into eight combinations of frameworks, and four and two sub-objectives, respectively, under two principal objectives resulting in to six alternatives yield a matrix of eight by six. Each pair of alternatives were ranked in accordance with the priorities assigned to them by industry respondents, and the rankings were synthesized for AHP methodology using AHP excel solver, to yield percent priority scales. This was done to determine the priorities for each of eight frameworks by particular industry-sectors.

In order to evaluate these priorities for a specific industry decision support, three case studies were discussed, wherein feedbacks for preferences were tested against overall preferences. This was done with a view to find out sensitivity of chosen framework for overlapping preferences amongst alternative frameworks.

As a major take-away, the responses validated usefulness of the decision support model we proposed and could be used to explore many intricacies of network design alternatives. While the industry sectors operate in different reverse logistics modalities, the framework identified would well adapt to similar genre product industries, which would suffice to generalizability of the suggested framework.

The AHP decision model provide insights into further configuration decisions as to number and locations of sites for returns management that optimizes the total cost for reverse logistics network. The next chapter discusses software simulation of actual geographical locational and flow data, which will be used to develop a decision support mechanism.

CHAPTER 4.

Optimization of network configuration for the entities in reverse logistics through MILP

4.1 Introduction and background

The previous chapter dealt with evolution of possible network framework for the product returns and their subsequent processing or disposal. We discussed typical flow of returns and also the alternatives exercised by the industrial set ups for the collection, scrutiny and processing of returns, before it heads again to either the original customer (after repair), or secondary customer (after remanufacture) or to the scrap or disposal facility.

An important ultimate outcome of the present work, further, is to optimize the reverse logistics network, in terms of facility establishment and processing operations and cost of transportation for all movements of product returns. While the mathematical formulation can adapt to varied individual entities of reverse logistics, like remanufacturing, recycle, and disposal, but we follow a network configuration that features a mathematical formulation that involves all three reverse logistics operations. We primarily adapt a mixed integer linear programming formulation [183] with an added provision for incorporation of entity for retreading facility at the location of recycling center, by additional formulation. We present a composite solution that optimizes the total cost of the reverse logistics network.

Subsequently, we use this formulation to optimize the cost and location-decisions by LINGO optimization software application, in upcoming chapter.

We consider the case of tire and rubber product returns, which is a real representative sector for the returns' management, for, it involves all key attributes of logistics, repair, remanufacture and also, the crucial environmentally safe disposal. Especially, the environmental importance of this produce, owing to its carbon and metal constituents gains significance in the state of UP, India, that strives and struggles for up keeping clean and pollution-free air.

We begin with formulating the problem as a mixed-integer linear programming problem involving eight entities involved in the reverse logistics network, including incorporated entity of retreading.

4.2 Optimization of return flows

The present work intends to recommend and model a generalized multi-stage reverse supply chain and analyze it under different situations. We consider a reverse supply chain for a global major tire production, distribution, and remanufacturing organization, having manufacturing plant based in state of UP. The company has 4 manufacturing plants across India, and we limit our focus to reverse logistics and returns management framework for the manufacturing location catering primarily to the region of UP, Haryana, and NCR.

We model the reverse logistics practices for the existing entities namely customer zones, collection centers, remanufacturing centers, disassembly centers, recycling and retreading centers, primary markets, secondary markets and disposal centers with collected industrial data for the number and location of different existing facilities present in the network and the quantity of flow of products, components and materials between each stage of the reverse supply chain, with an objective to minimize the total cost comprising of transportation cost, processing cost, disposal cost and fixed facility cost.

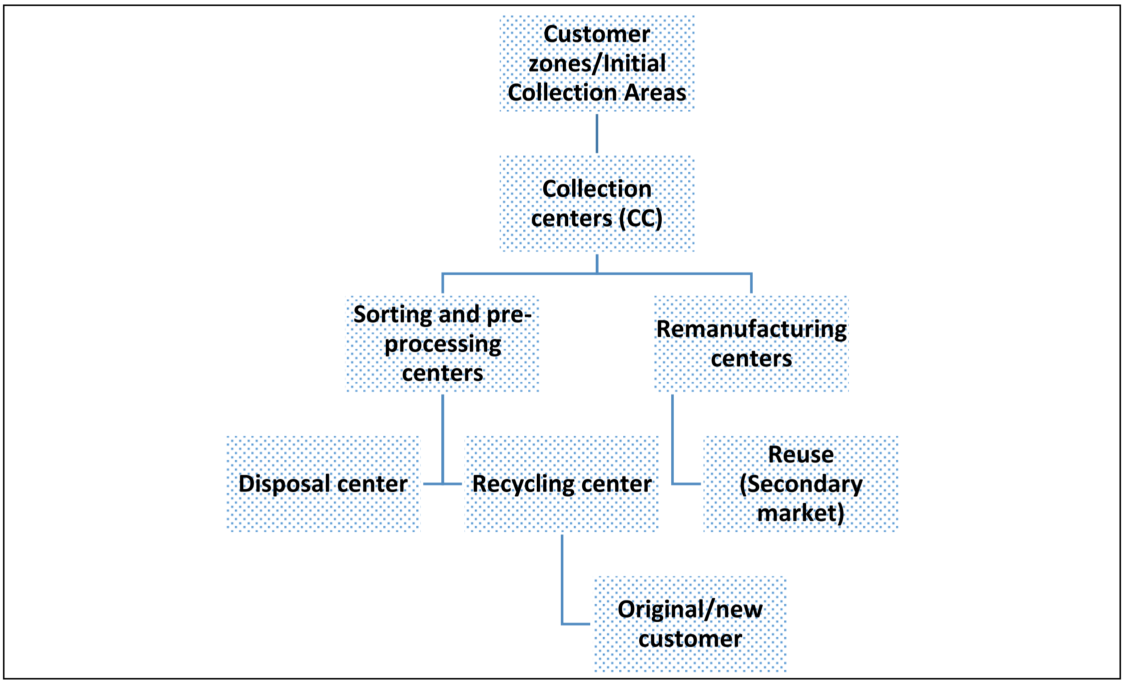

Figure 4.1 Flow of reverse logistics activities for the tire manufacturer

We first adapt mathematical formulation of the an automobile reverse logistic network using mixed-integer linear programming, and go on further to solve a real life network design problem using Solver Lingo (v. 15 running on Intel i-5, 2.20 GHz, 4 GB RAM computer) to obtain the optimum design of the returns' network. We obtain and propose a framework with optimized numbers and locations for the facilities for different entities, and also, optimized flow quantity between each stages of this reverse supply chain.

Primary take-away from the exercise is to obtain the optimal locations and numbers of the entities, and optimized inter-facility flow, that minimizes the total cost of the returns' management activity for the original manufacturer, so as to aid him with the decision support for returns classified in to end-of-life (heading to disposal) and end of economic use (heading to remanufacturing).

4.3 MILP formulation for the reverse logistics networks for tire manufacturing industry

Figure 4.1 represent typical flow of the existing seven stage reverse supply chain for the tire manufacturing organization under study. The network has different entities such as customer zones, collection centers, and remanufacturing centers, disassembly centers, recycling centers, primary markets, secondary markets and disposal centers.

We partly adapt the formulation by [183] for the following existing operating conditions:

1. The returns have been recorded for a single period (as per the prevalent schedule), and for multi-products.
2. The returns flow only sequentially/hierarchically.
3. Capacities at different entities as per existing situation, and inter-facility transportation cost is determinable, and
4. We limit our work to existing transportation mean and its optimization, rather than exploring other transportation modes for cost-effectiveness.
5. The manufacturing company intends to add retreading option to their existing recycle facilities. Our formulation is suitably modified to incorporate costs for retreading facilities, which would further be cost and location optimized.

The products from the customers from customer zones are collected at the collection centers, having provisions to classify the returns into remanufacturable or recyclable/disposable. Recyclable or those classified to be heading to disposal are further sorted to disassemble usable components out of them. In sequence, they had to either recycle plant or disposal site.

Returns classified as remanufacturable are further remanufactured at remanufacturing centers, and finally head to the secondary markets for a fresh sale.

We reiterate that with an objective of minimizing the total cost comprising of transportation cost, processing cost, disposal cost and fixed facility cost, we propose an optimum configuration of reverse networks with location and numbers of different facilities already established in the existing network and also the optimized returns' flow between each stage of the reverse supply chain. For this, the formulated MILP model will be subjected to Lingo optimization modelling, in the next section.

4.3.1 Nomenclature:

- Z set of market zones
- C set of collection centers
- R set of remanufacturing centers
- RT set of retreading centers
- D set of disassembly centers
- L set of recycling centers
- M set of primary markets
- S set of secondary markets
- K set of disposal sites
- P products returned
- EU end-of-use products
- EL end-of-life products
- RC recyclable components
- DI disposable items
- RM recycled materials
- RP remanufactured products
- Rt retreaded products
- PR_m returned product from customer zone m, $m \in Z$

- HC_n handling cost per unit at collection center n, n ∈ C
- PC_n^i processing cost of product, component or material per unit at facility n, where n∈R, D, L and I ∈ EU, EL, RC, RT
- U_i unit cost of disposal of material i, where i∈ DI
- d_{mn} distance between facilities m and n, where m, n ∈Z × C, C ×R, C ×D, R× S, RT x S, D × L, D × K, L ×M
- t_{ci} Transportation cost per unit product/ component/material i
- f_n fixed cost of facility n, where n∈ C, R, D, L
- Cap_n^i capacity of facility n, for product/ component/material i
- ∝ maximum flow rate of the collected products to the remanufacturing centers
- β number of recyclable components produced from the product at disassembly center
- γ number of retreaded tires produced from products at disassembly center

4.3.2 Decision variables

- $X^i_{m;n}$ quantity of product/component/ material i shipped from facility m to facility n, where m, n ∈ Z× C, C× R, C× D, R× S, RT X S, D × L, D × K, L ×M and i∈ P, EU, EL, RC, RT, DI, RM, RP
- Y_C 0-1 variable, Y_C=1 if collection center C is used else Y_C=0
- Y_R 0-1 variable, Y_R =1 if remanufacturing center R is used else Y_R =0
- Y_{Rt} 0-1 variable, Y_{Rt} =1 if retreading center R is used else Y_R =0
- Y_D 0-1 variable, Y_D =1 if disassembly center D is used else Y_D =0
- Y_L 0-1 variable, Y_L =1 if recycling center L is used else Y_L =0

4.3.3 Objective function:

The objective for the reverse logistics network is to minimize the total cost of the multi-stage reverse supply chain. We consider inter-facility transportation cost, processing costs at different facilities (operating and establishment costs).

Minimise:

$$\sum m \in Z \sum_{n \in C} \sum_{i \in P} X^i_{mn} + (tc_i \text{ x } d_{mn} + HC_n) + \sum_{m \in C} \sum_{n \in R} \sum_{i \in EU} X^i_{mn} \text{ x } (tc_i \text{ x } d_{mn} + PC^i_n) +$$

$$\sum_{m \in C} \sum_{n \in D} \sum_{i \in EL} X^i_{mn} \text{ x } (tc_i \text{ x } d_{mn} + PC^i_n) + \sum_{m \in R} \sum_{n \in S} \sum_{i \in RP} X^i_{mn} \text{ x } (tc_i \text{ x } d_{mn}) +$$

$$\sum_{m \in D}\sum_{n \in L}\sum_{i \in RC} X_{mn}^{i} \text{ x } (\mathrm{tc_i} \text{ x } \mathrm{d_{mn}} + PC_n^i) + \sum_{m \in D}\sum_{n \in K}\sum_{i \in DI} X_{mn}^{i} \text{ x } (\mathrm{tc_i} \text{ x } \mathrm{d_{mn}} + \mathrm{U_i}) +$$

$$\sum_{m \in D}\sum_{n \in K}\sum_{i \in DI} X_{mn}^{i} \text{ x } (\mathrm{tc_i} \text{ x } \mathrm{d_{mn}} + \mathrm{U_i}) + \sum_{m \in C}\sum_{n \in R}\sum_{i \in EU} X_{mn}^{i} \text{ x } (\mathrm{tc_i} \text{ x } \mathrm{d_{mn}})_{+})$$

$$+ \sum_{m \in C} f_m \text{ x } Y_m + \sum_{m \in R} f_m \text{ x } Y_m + \sum_{m \in D} f_m \text{ x } Y_m + \sum_{m \in L} f_m \text{ x } Y_m \ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Subject to constraints as described below:

- Collection of returns through collection centers:

$$\sum_{n \in C} X_{mn}^{i} = PR_m, \forall m \in Z, \forall i \in P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

- That the returns earmarked as end-of-life go directly to disassembly centers:

$$\sum_{m \in Z}\sum_{i \in P} X_{mn}^{i} \text{ x } (1-\propto) \leq \sum_{m \in D} X_{mn}^{j} \ \forall n \in C, \ \forall j \in EL \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

- Constraint for conservation of returns' flow at collection centers

$$\sum_{m \in Z}\sum_{i \in P} X_{mn}^{i} = \sum_{m \in R} X_{nm}^{j} + \sum_{m \in D} X_{nm}^{j} \ \forall n \in C, \forall j \in EL \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots....(4)$$

- Constraint for conservation of flow at remanufacturing centers.

$$\sum_{m \in C}\sum_{i \in EU} X_{mn}^{i} = \sum_{m \in R} X_{nm}^{j} \ \forall n \in R, \forall j \in RP \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(5)$$

- Constraint limiting total number of returns at disassembly center as number of recyclable components times total number of incoming returns

$$\sum_{m \in C}\sum_{i \in EU} X_{mn}^{i} = \sum_{m \in R} X_{nm}^{j} \ \forall n \in R, \forall j \in RP \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(6)$$

- Constraint to conserve flow at disposal centers

$$\sum_{m \in C}\sum_{i \in EL} X_{mn}^{i} = \sum_{m \in K} X_{nm}^{j} \ \forall n \in D, \forall j \in DI \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(7)$$

- Constraint to conserve flow at recycling centers

$$\sum_{m \in D} \sum_{i \in RC} X_{mn}^{i} = \sum_{m \in K} X_{nm}^{j} \;\; \forall n \in L, \forall j \in RM \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

- Constraint to conserve flow at retreading centers

$$\sum_{m \in D} \sum_{i \in RT} X_{mn}^{i} = \sum_{m \in K} X_{nm}^{j} \;\; \forall n \in L, \forall j \in RM \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

- Processing capacity constraint at collection centers

$$\sum_{m \in Z} X_{mn}^{i} \leq Cap_{n}^{i} \text{ x Yn}, \forall n \in C, \forall i \in P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

- Processing capacity constraint at remanufacturing centers

$$\sum_{m \in C} X_{mn}^{i} \leq Cap_{n}^{i} \text{ x Yn}, \forall n \in R, \forall i \in EU \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

- Processing capacity constraint at remanufacturing centers

$$\sum_{m \in Z} X_{mn}^{i} \leq Cap_{n}^{i} \text{ x Yn}, \forall n \in D, \forall i \in EL \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

- Processing capacity constraint at recycling centers (for recyclable components)

$$\sum_{m \in Z} X_{mn}^{i} \leq Cap_{n}^{i} \text{ x Yn}, \forall n \in L, \forall i \in RC \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Y_n is binary, $\forall n \in C, R, D, L, RT$ ………………………………………………………… (13)

$X_{mn}^{i} \geq 0$ and integer in product flow $\forall m, n$ and i ……………………………… ..….. (14)

- Constraint (13) represents the binary variables.
- Constraint (14) ensures the non-negative flow of products, components and materials.

Also, understandably, the variables are restricted to an integer value, when the flow is in product level.

Tire recovery can be done by three ways: tire retreading, recycling or combustion in cement facilities for energy recovery. In the existing logistics network framework of the company, the company wishes to investigate profitability of launching retreading facility embedded in to the existing facility created for recycling. The model can be solved for different volumes of retreadable tires. Also, tires collected back from customers are directly sent to either recycling facility or cement facility without controlling whether the incoming tires are retreadable. After recycling, the main products obtained are granule and steel wire at respective rates of 65% and 25%.

This formulated model for optimization is subjected to optimization modelling using Lingo R1 in the next chapter, for the existing scenario of arrangement of facilities and inter-entity returns' flow, the inter-facility distance and transportation costs. We also incorporate the fixed facility costs and unit processing costs at different entities. We optimize the model to find optimized cost and locational decision support for the different entities in the reverse logistics network of a rubber and tire manufacturing organization in Delhi NCR and Gurugram region in India.

CHAPTER 5.

Optimization through Lingo and analysis of results

5.1 Introduction and key research questions addressed by the chapter

In the previous chapter we discussed mathematical formulation for network that involved eight entities present in an existing reverse logistics network. The key take-away from the research exercise involve 1). Optimizing a network for a specific industry sector, and 2). Returning a decision support for locational and facility-opening decisions.

In this chapter, we begin with setting the scene for an existing network for a tire manufacturing organization, by first introducing the background and prevalent scenario of the tire manufacturing sector, describe the entities being modelled in terms of their present geography, input the actual flow and cost data values for the software code of the Lingo optimization software, and obtain the optimized results along with flow and locational decision support. We further test the results obtained for sensitivity to percentage increase in the returns-inflow to process, and see how the location-opening decisions are affected by this percentage rise.

5.2 Background of the prevalent scenario for the tire manufacturing organization

Managing the products at the end of its intended use and recovery of tire and rubber products for the associated material from the market is gaining significant importance these days due to global environmental concerns, resource reduction, government regulations and economic factors. Reverse logistics networks serve the same [208].

Today global tire markets, especially the developed ones, are being majorly driven by tightening legislations and growing consumers' demand for sustainable lifestyle. Despite lack of legislations, tire makers in India too are gearing up for the green tires. However, penetrating the price-sensitive Indian market will be a challenge for tire companies as green tires are costlier than conventional tires. Indian cities like Delhi and NCR are among the most polluted cities in the world. However, India is targeting to reduce CO_2 emissions by 20-25% by year 2020.

As per Director General of Automotive Tire Manufacturers Association (ATMA), India, (http://rubberasia.com/2017/02/13/indian-tyre-industry-formidable-growth/ accessed on 28 Mar 2017), tire manufacturers in India have been actively involved in the R&D that reconciles the imperatives of the latest technology and the unique ground realities existing in India. From a tire manufacturer's point of view, India represents a challenging country for the sheer diversity of road profiles and weather conditions. In the course of one journey, a vehicle may pass through mountainous tracks to plains, from expressways to potholed un-metaled roads, from rains to hot tropical conditions. As a result, international OEMs are rolling out their vehicles on India-made tires.

Anticipating the future requirements of green tires, many tire manufacturing companies have already introduced eco-friendly tires to the Indian market. The current Indian market is keen on adopting the latest advances in technology and investing in green tires as a long-term strategy. Due to the increasing number of heavy vehicles in the country like India, large quantities of used tires are generated every year, and proper disposal of these used tires creates problem in the day-to-day life. Hence recover the value from these used tires in the form of material recovery is gaining importance. The implementation of such recycling system usually requires an appropriate reverse logistics network for choosing the physical locations, facilities, and transportation links to convey the used products from the end customers to the recycling facility.

Our work studied existent reverse logistics networks involved in the used tires focusing on retention of economy with a target to flow and cost optimization.

It is appropriate here, that we address the total scope of whole mechanism of returns' management of the tire products. We shall, however, limit our focus on a single manufacturing organization operating in Delhi NCR and UP, for our work and optimization modelling of the particular organization.

The tire returns are classified in to emanating from five different modalities:

- **Manufacturers:** These agents are in charge of the direct logistics flows in which raw materials are transformed in the final finished product of rubber tire. Some waste is generated during the production process and some non-conformities can be recovered during product inspections. Also, some commercial returns are obtained. These reserve logistics activities are mapped in Figure 4.2.

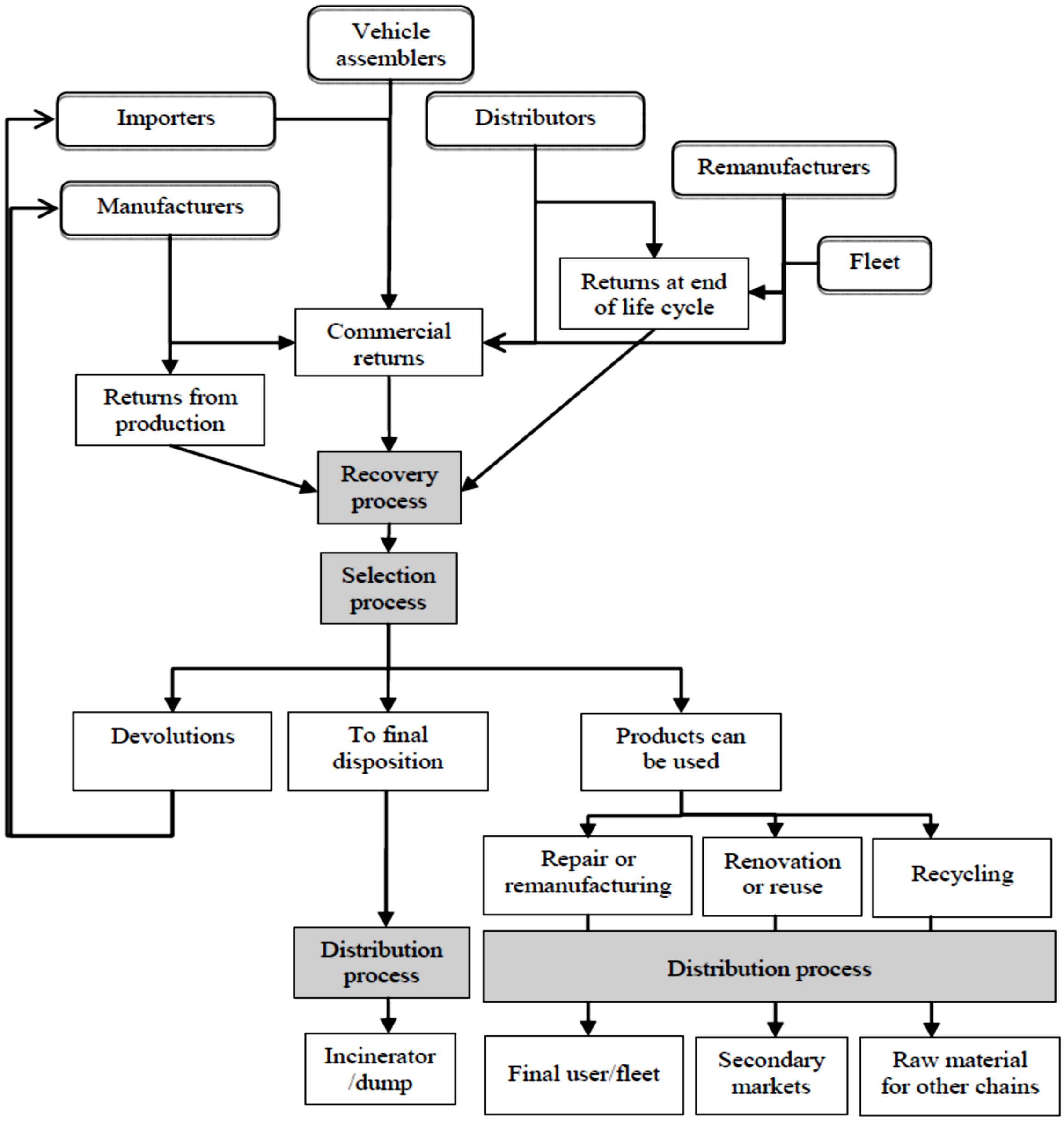

Figure 5.1 Aggregated supply chain of recycled tires

- **Importers:** These agents are in charge of buying tires from foreign manufacturers and they also carry out the commercial process in the country. In terms of RL processes, they only manage commercial returns and the corresponding delivery to the appropriate manufacturer.

- **Distributors:** These actors buy tires to manufacturers and/or importers and sell them to the final customer. Their RL activities concern the following activities: collection of tires at the end of their life cycle, collection of commercial returns; their classification for final disposition according to product quality conditions; and distribution.

- **Assemblers (automotive industry)**: These actors use to buy tires to manufacturers, importers and distributors for their own purpose of assembly vehicles. Their reverse logistics practices are limited to collection of commercial returns and delivery to the corresponding supplier.

- **Fleet:** This actor in the supply chain is in charge of buying tires to manufacturers, importers, distributors or assemblers. Their reverse logistics practices mainly concern tire collection at the end of their life cycle, classification depending on quality standards and distribution (for either remanufacturing or final disposition).

- **Remanufacturers:** These actors receive and/or buy recycled tires. Their practices regarding RL concern the collection of both commercial returns and tires at the end of their life cycle, the selection of those that can be used for remanufacturing or as raw material for new tires, and the distribution of final products.

5.3 Description of modelled entities:

We showcase and optimize a reverse supply chain for the manufacturing organization, which is a global player in tire manufacturing. The manufacturer has two manufacturing plants in India, and we limit our scope of study to the returns' management practices for its Ballabgarh plant in the district Faridabad in the state of Haryana. **Faridabad** is a leading industrial center and situated in the National Capital Region bordering the Indian capital New Delhi.

The manufacturer is engaged in the manufacturing and trading of tires, tubes and flaps, supplying tires to a range of original equipment manufacturers (OEMs). The Company manufactures automotive bias tires, farm tires and commercial truck tires at its Ballabgarh plant. The Company also trades in radial passenger tires (consumer) and off the road (OTR) bias tires, and tubeless radial tires. With cumulative plant capacity of over 38000 tires a day, the manufacturer is one of the largest player in tire manufacturing, rebuilding, and recycling.

The manufacturer has exclusive arrangement for the returns' management. They have categorized returns coming from five market zones in Noida, Faridabad, Ghaziabad, Gurugram, and Sonipat.

The manufacturer has seven returns collection centers located at:

- Noida Phase-II
- Ajronda, in district Faridabad.
- Dasna in district Ghaziabad
- Manesar in Gurugram
- Dhankot in Gurugram
- Murthal in Sonipat, and
- Kakroi in Sonipat, Haryana

The manufacturer has facilities for sorting and pre-processing facilities at four locations, namely, Ajronda, Manesar, near Greater Noida, and near Dasna. From here, the returns head to either remanufacture/repair, recycle or disposal, as per the sorting scrutiny.

Three remanufacturing and repair facilities are located at the plant at Ballabgarh, Moradabad, and Bahadurgarh. Three recycling plants are located in the vicinity of Bulandshahar, Chhaprola, and in Yadavnagar in Ghaziabad. The company is contemplating provisions to install retreading facilities in their existent recycling facility locations. The company has disposal plant near Jewar.

Major chunk of its recycled tires go to primary markets in Gurugram and Ghaziabad, from where they are distributed for the primary market. Also, the repaired or remanufactured tires move to secondary market retail centers in Gurugram and Faridabad.

We use Google maps for mapping locations for different entities. The latitude and longitude of the facility location has been found-out using the combo of Google maps and web-portal www. mapcoordinates.net/en.

Fig. 5.2 shows the topography of the reverse logistics network for the problem in consideration.

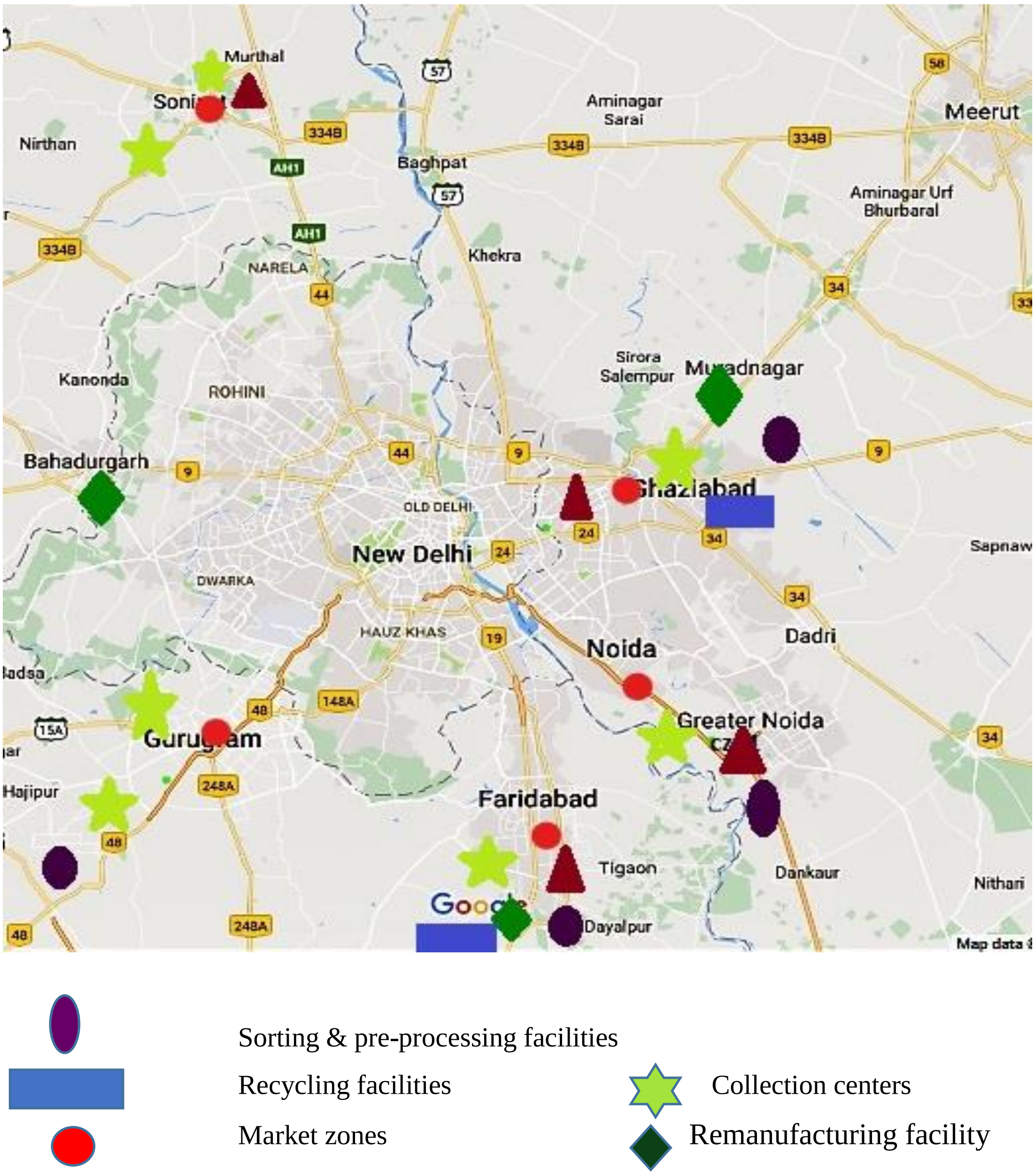

Figure 5.2 Topology of the locations of the existing entities

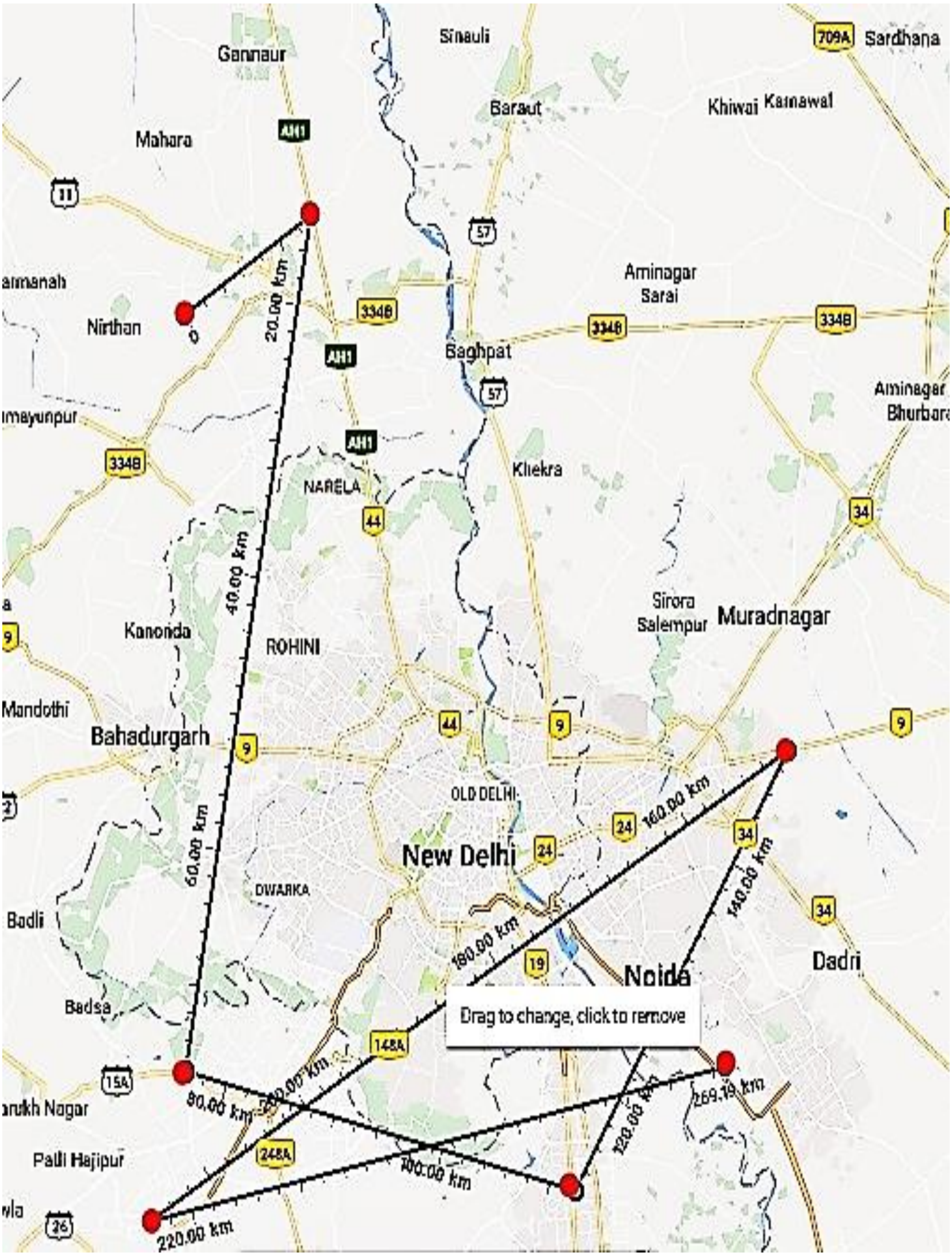

Figure 5.3 Locational map of collection centers

TABLE 5.1 Co-ordinates of different facility locations of returns' management entities

Facility location	Latitude	Longitude
Noida	28.47	77.50
Ghaziabad	28.67	77.45
Faridabad	28.41	77.32
Sonipat	28.99	77.02
Gurugram	28.46	77.03
Ajronda	28.39	77.32
Dasna	28.68	77.52
Dhankot	28.47	76.96
Murthal	29.03	77.07
Kakroi	28.96	76.96
Manesar	28.35	76.94
Ballabgarh	28.34	77.33
Moradabad	28.84	78.77
Bahadurgarh	28.69	76.92

Next, we tabulate the input of quantified numbers of returns, inter-facility distances for different entities of reverse logistics of returns, and other relevant costs of transportation, facility set up, and operations cost at different entities.

5.4 Input data

Table 5.2 shows the number of returns at different market zones (categorized on the basis of geographical locations of original buyer of the products) at an average per day, for farm automobile and passenger automobiles put together.

TABLE 5.2 Number of returns at different market zones

Market zone	MZ-1 Noida	MZ-2 Faridabad	MZ-3 Ghaziabad	MZ-4 Gurugram	MZ-5 Sonipat
Cumulative number of returns (averaged per day)	82	69	99	57	61

Table 5.3 through 5.9 show the distance in kilometers between various existing entities of returns management. These distances have been collected for the exact location of the facilities, and have been mapped as co-ordinates.

TABLE 5.3 Distance matrix for market zone to collection centers

	MZ-1 Noida	MZ-2 Faridabad	MZ-3 Ghaziabad	MZ-4 Gurugram	MZ-5 Sonipat
CC-1 Noida	8	69	105	70	62
CC-2 Ajronda	64	13	64	67	33
CC-3 Dasna	105	57	9	55	52
CC-4 Manesar	32	36	66	37	22
CC-5 Dhankot	62	22	37	34	9
CC-6 Murthal	85	25	38	61	35
CC-7 Kakroi	80	27	26	46	26

TABLE 5.4 Distance matrix for Collection Centers to Pre-processing & sorting centers

	CC-1 Noida	CC-2 Ajronda	CC-3 Dasna	CC-4 Manesar	CC-5 Dhankot	CC-6 Murthal	CC-7 Kakroi
PPR-1 Ajronda	21	85	115	46	75	102	93
PPR-2 Manesar	65	31	49	26	6	30	22
PPR-3 Gurugram	63	42	50	24	11	40	28
PPR-4 Dasna	87	52	26	47	20	33	18

TABLE 5.5 Distance matrix for Collection Centers to remanufacturing centers

	CC-1 Noida	CC-2 Ajronda	CC-3 Dasna	CC-4 Manesar	CC-5 Dhankot	CC-6 Murthal	CC-7 Kakroi
RM-1 Ballabhgarh	88	76	44	54	41	62	46
RM-2 Moradabad	61	75	71	38	46	74	60
RM-3 Bahadurgarh	97	73	30	60	40	54	39

TABLE 5.6 Distance matrix for remanufacturing centers to Secondary (reuse) market

	Secondary Market-1 Gurugram	Secondary market-2 Faridabad
RM-1 Ballabhgarh	51.3	14.6
RM-2 Moradabad	196	171
RM-3 Bahadurgarh	49.6	69

TABLE 5.7 Distance matrix for Pre-processing centers to recycle centers

	RCC-1 Bu’shahar	RCC-2 Chhaprola	RCC-3 Ghaziabad
PPR-1 Ajronda	91.2	30.8	47.4
PPR-2 Manesar	77	57.8	76.4
PPR-3 Greater Noida	46.7	64	37
PPR-4 Dasna	59.6	81.8	17.4

TABLE 5.8 Distance matrix for Pre-processing centers to Disposal center

	Disposal center –Jevar
PPR-1 Ajronda	67.3
PPR-2 Manesar	98.8
PPR-3 Greater Noida	45.5
PPR-4 Dasna	88.4

TABLE 5.9 Distance matrix for Recycle centers to Primary market (Fresh use)

	Primary market-1 Gurugram	**Primary Market -2 Ghaziabad**
RCC-1 Bu'shahr	104	61.8
RCC-2 Chhaprola	49.4	73.4
RC-3 Ghaziabad	64.2	8.6

Also embedded in recycle centers are the potential retreading locations.

Next, we go on to tabulate the transportation costs and disposal costs in Rupees for the product returns.

Transportation costs will be incurred and accounted for the following movements:

- Initial transportation cost for product returns
- Costs for transporting end-of-use tires
- Costs for transporting end-of-life tires
- Costs for transportation of repaired tires
- Costs of transportation for
    - Pre-processing centers to recycling center, and
    - Recycled (and retreaded) returns to secondary market
- Costs for transportation from pre-processing to disposal centers
- Costs for transportation for
    - Pre-processing center to remanufacturing centers, and
    - Remanufacturing centers to primary market

Disposal cost of the end-of-life product returns is extracted to be ₹. 9700 for a unit load of one ton return.

Following Table 5.10 gives transportation and disposal costs for the movements mentioned above:

TABLE 5.10 Transportation costs for inter-entity movement and disposal cost (Rounded-off, in ₹)

	Movement for								
	Product returns	End-of use returns	End-of-life returns	Repair returns	Recycle returns		Returns for disposal	Returns for remanufacture	
Transp. costs (Cost/unit load in Rs.)	594080	107800	56400	185690	103300	42800	42250	44400	11400
Disposal cost (for unit load of 1 ton)							40400		

Next, we consider returns handling capacity and costs for processing returns and facility set up at each of the collection centers:

TABLE 5.11 Processing capacity and costs (Rounded-off, in ₹) at collection centers

	CC-1 Noida	CC-2 Ajronda	CC-3 Dasna	CC-4 Manesar	CC-5 Dhankot	CC-6 Murthal	CC-7 Kakroi
Returns processing capacity at the facility	325	120	145	220	170	140	120
Processing costs for a unit load (₹.)	360	345	360	380	340	320	320
Establishment cost of the facility (₹.)	1250000	1100000	1050000	1200000	1150000	1150000	1100000

Similarly, Tables 5.12 through 5.14 show capacity and costs at recycling, remanufacturing, and disposal facilities.

TABLE 5.12 Processing capacity and costs (Rounded-off, in ₹) at sorting & pre-processing centers

	PPR-1 Ajronda	PPR-2 Manesar	PPR-3 Gurugram	PPR-4 Dasna
Returns processing capacity at the facility	325	445	300	400
Processing costs for a unit load (₹.)	800	425	400	360
Establishment cost of the facility (₹.)	1600000	1760000	1600000	1350000

TABLE 5.13 Processing capacity and costs (Rounded-off, in ₹) at recycling centers

	RCC-1 Bu'shahar	RCC-2 Chhaprola	RCC-3 Ghaziabad
Returns processing capacity at the facility	250	250	325
Processing costs for a unit load (₹.)	11200	18800	9800
Establishment cost of the facility (₹.)	1908000	1780000	180000

TABLE 5.14 Processing capacity and costs (Rounded-off, in ₹) at remanufacturing centers

	RM-1 Ballabhgarh	RM-2 Moradabad	RM-3 Bahadurgarh
Returns processing capacity at the facility	300	450	325
Processing costs for a unit load (₹.)	4800	5300	4800
Establishment cost of the facility (₹.)	350000	980000	1180000

5.5 Considerations for the returns quantity, costs, and distance data

5.5.1 Quantity of returns:

Graphical Evaluation and Review Technique (GERT) has been applied by the manufacturing organization for developing the forecasting model for product returns.

Product returns for their remanufacturing/recycling/repair are stochastic, random and uncertain. GERT addresses the uncertainty, randomness and stochastic nature of product returns. Also, GERT provides the visual picture of the reverse supply chain system and helps in determining the expected time of product returns in a much easier way but it requires probabilities of different flows and product life cycle. Both factors vary over a period, so require data update time to time before implementation.

5.5.2 Transportation costs

Transportation costs have been adopted from the company policy of utilizing a mid-size truck load of 660-1030 kg hired on-contract, and is paid on the basis of ₹ 16.50 per km distance travelled.

5.5.3 Inter-facilities distances

The distances in kilometers have been derived for the exact location of the plants, and for the actually adopted route by road by the transportation contractor. All distances have been verified as per Google maps: www.maps.google.com.

5.6 Optimization results for return flows, costs, and facility location decisions with configuration-decision support

The reverse logistics problem described in the previous section for the tire-manufacturing organization involves a multi-echelon product returns framework. The formulated model was optimized using Lingo 15 optimization platform with the actual flow data, inter-facility distance between different tiers. Also, the cost data for facility establishment, transportation and processing of returns at different facilities was used as input data for the optimization. Further, longitude and latitude of the physical locations of the facilities in different tiers were captured so as locate their optimized locations, with respect to optimized flow and costs for the returns processed.

Following figure displays a snapshot of software coding of the existing system for Lingo optimization software. It is appropriate here to revisit the exercise is carried out with an objective of optimizing the total cost of returns management. The problem formulation also involved optimization of the flow between different echelons and entities of the reverse network.

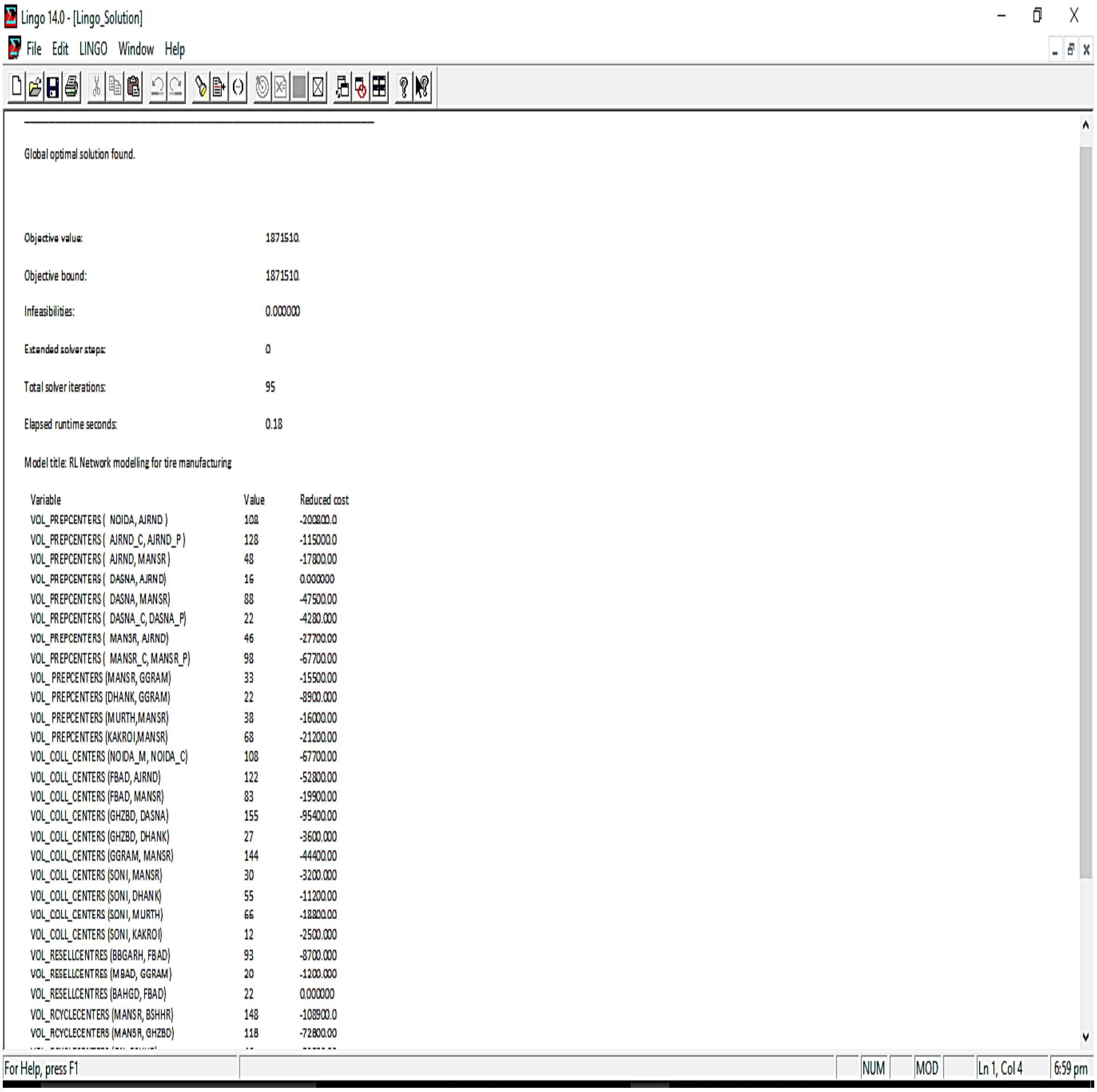

Figure 5.4 LINGO optimization solution

5.7 Results of Inter-entity flow optimization:

Tables 5.15 to 5.17 below shows optimized flow of returns between two successive echelons of the reverse logistics network for the tire-manufacturing organization.

Table 5.15 display the flow of returns from the five market zones of the products towards the collection centers. As is evident from the optimized flow results, maximum flow of returns head to the nearest collection center in the region, as seen from the flow towards Noida, Ajronda and Dasna centers.

Results of Inter-entity flow optimization:

TABLE 5.15 Optimized inter-facility flow: Market zones to Collection centers

	CC-1 Noida	**CC-2 Ajronda**	**CC-3 Dasna**	**CC-4 Manesar**	**CC-5 Dhankot**	**CC-6 Murthal**	**CC-7 Kakroi**
MZ-1 Noida	108	0	0	0	0	0	0
MZ-2 Faridabad	0	122	0	83	0	0	0
MZ-3 Ghaziabad	0	0	155	0	27	0	0
MZ-4 Gurugram	0	0	0	144	0	0	0
MZ-5 Sonipat	0	0	0	30	55	66	12

In Table 5.16, the flow quantity from collection centers to pre-processing centers is shown. Here again, the flow of returns is driven by the proximity factor of the pre-processing facility location. Here, two preprocessing and scrutiny centers are present in Gurugram district: One in Gurugram rural area and another in south-west of the district, in Manesar. The Gurugram sorting and pre-processing facility is equipped with an exclusive facility for the end-of-life returns, hence some of such returns also go to this another pre-processing plant.

It is evident that despite having a pre-processing center closer to Dasna near Ghaziabad, more returns travel to Manesar in Gurugram, as exclusive facility to pre-process farming vehicle tires is present at Manesar. This is also evident from the fixed-facility cost of facility at Manesar.

TABLE 5.16 Optimized inter-facility flow: Collection centers to Pre-processing centers

	PPR-1 Ajronda	**PPR-2 Manesar**	**PPR-3 Gurugram**	**PPR-4 Dasna**
CC-1 Noida	108	0	0	0
CC-2 Ajronda	128	48	0	0
CC-3 Dasna	16	88	0	22
CC-4 Manesar	46	98	33	0
CC-5 Dhankot	0	0	22	0
CC-6 Murthal	0	38	0	0
CC-7 Kakroi	0	68	0	0

In Table 5.17, optimized flow from remanufacturing centers to secondary market is shown. It is logical that the secondary market in Faridabad is where most of the remanufactured returns sell, being closest to Ballabgarh town and tehsil in Faridabad district.

TABLE 5.17 Optimized inter-facility flow: Remanufacturing centers to secondary market

	Secondary Market-1 Gurugram	**Secondary market-2 Faridabad**
RM-1 Ballabhgarh	0	93
RM-2 Moradabad	20	0
RM-3 Bahadurgarh	0	22

Out of three established recycling plants, it is only optimum to have recycling facility established near Bulandshahar town, and another one near Ghaziabad. This is evident from the optimized flow results shown in the Table 5.18. This can be appreciated considering relatively larger cumulative distances of the recycle centers from the pre-processing centers.

Another key consideration could be the higher recycling cost at the Chhaprola recycling center, as evident from processing costs/unit load data, tabulated in earlier chapter.

Further, as tabulated below, the pre-processed and segregated returns are classified in to end-of-use and end-of-life, and have to be processed that was at recycling plants.

It is apt to revisit here that an end-of-life (EOL) product is a product that does not receive continuing support, either because existing marketing, support and other processes are terminated, or it is at the end of its useful life.

TABLE 5.18 Optimized inter-facility flow: Pre-processing center to recycle centers

	RCC-1 Bu'shahar		**RCC-2 Chhaprola**		**RCC-3 Ghaziabad**	
	EoU	EoL	EoU	EoL	EoU	EoL
PPR-2 Manesar	148	155	0	0	118	22
PPR-3 Greater Noida	46	18	0	0	155	128
PPR-4 Dasna	0	0	0	0	46	48

Further, Table 5.19 denotes the optimized flow of pre-processed and classified returns to the disposal center situated at Jewar in Gautam Budhdhanagar district of UP, south-east of Noida and Faridabad districts.

TABLE 5.19 Optimized inter-facility flow: Pre-processing center to disposal center

Pre-processing centers	**Disposal center –Jewar**
PPR-1 Ajronda	47
PPR-2 Manesar	23
PPR-3 Greater Noida	30
PPR-4 Dasna	38

Next, we discuss optimization results for the location decisions for the facilities, signifying optimized numbers of facilities and their locations for processing the returns. We consider three cases for the location decision.

5.8 Optimized facility opening decisions

In the previous chapter, we had described present locations for the four main echelons of the reverse logistics network: Collection centers, Pre-processing centers, Remanufacturing center, and Recycling centers. The network modeling yielded optimized location decisions that incorporated flow optimization and cost optimization criterion in to the resultant locational decision.

The stochastic nature of the returns demands that the facility opening decisions should take stock of a scenario where the returns fluctuate to 20 to 30 % of the averaged forecast returns. Our optimization modeling results into following location decisions for the three situations: Flow rate of returns during the period of study, a situation where the returns exceed by 20%, and thirdly, where the returns exceed by 30 %.

Table 5.20 shows how the facility location and opening decision would be influenced by the add-on load of processing.

a) Locations for Collection centers:

Out of original seven collection centers at Noida, Ajronda, Dasna, Manesar, Dhankot, Murthal and Kakroi, the optimized locations for the present flow, distances and costs turn out to be the first five locations. That is, for the current load situation, only five locations give the optimized flow and cost combination.

When the returns flow exceed by 20%, the location decision doesn’t alter. In the third scenario, when number of returns exceed by 30 %, we observe that locations at Noida, Dasna, Manesar, Dhankot, and Kakroi yield the optimal balance.

b) Pre-processing centers:

Pre-processing is one of the crucial routing stop-over for the returns management, for, they actually contribute to optimization of transportation cost by classifying the returns in to categories of end-of-life, remanufacture/repair, recycle or disposal.

The optimization modeling returns pre-processing center locations as Ajronda and Manesar in Gurugram district for the first two cases of quantum of returns: During the study period, and at 20 % additional capacity. When the returns exceed by 30 %, it would be optimum to have pre-processing facilities at the third location, Greater Noida.

TABLE 5.20 Sensitivity of locational decisions for add-on load of 20% and 30%

	Locations of facilities		
	Present plant capacity	**at 20 % excess load**	**at 30 % excess load**
Collection centers	Noida, Ajronda, Dasna, Manesar, Dhankot	Noida, Ajronda, Dasna, Manesar, Dhankot	Noida, Dasna, Manesar, Dhankot, Kakroi
Pre-processing centers	Ajronda, Manesar	Ajronda, Manesar	Ajronda, Manesar, Greater Noida
Remanufacturing centers	Ballabgarh	Ballabgarh	Ballabgarh, Moradabad
Recycling centers	Bulandshahar, Ghaziabad	Bulandshahar, Ghaziabad	Bulandshahar, Chhaprola, Ghaziabad

c) Remanufacturing centers:

Ballabgarh is the location for the original product manufacturer, for the reverse supply chain under study in our work. The original manufacturing facility has adequate additional provision to accommodate processing of returns, as long as the number of returns don't exceed the present processing capacity by additional 20 %. Meaning, at 30 % additional load, it would be optimum for the tire manufacturer to open the remanufacturing facility at another location in Moradabad.

Thus, the optimality conditions prescribe not to operate the facility at Bahadurgarh.

d) Recycling centers:

Going by the industry sector and its' inherent characteristics, returns' management of tire manufacturing has recycling as the highest component, quantity and cost effectiveness wise. It is also evident from the cost figures for facility establishment and processing.

Optimal locations for the recycling centers at normal load and 20 % add-on load remain Bulandshahar and Ghaziabad, whereas, it becomes optimum to operate the third facility at Chhaprola, only when the number of returns exceed by 30 %.

Fig 5.1 show the optimized locations for the facilities on geographical map.

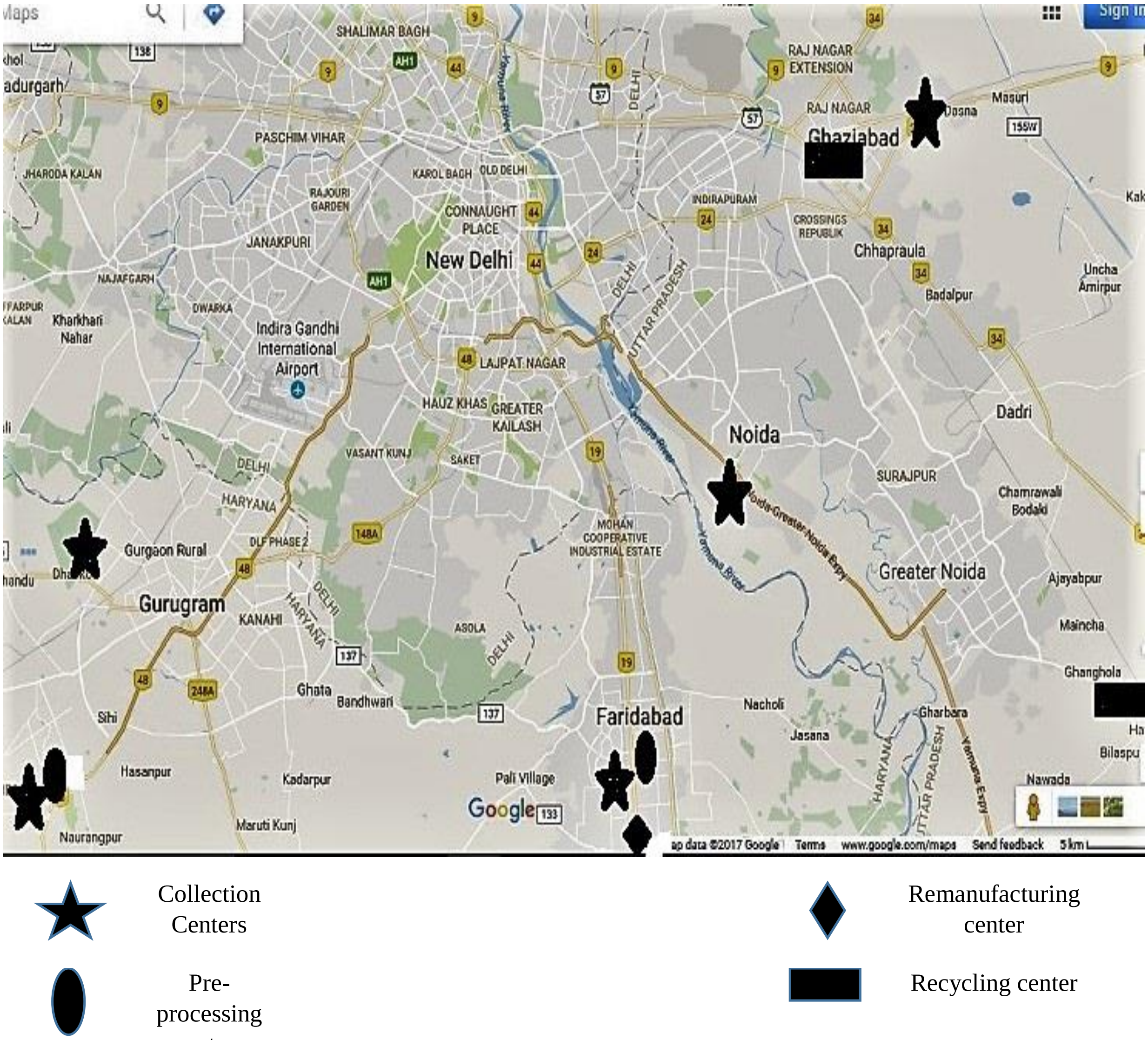

Figure 5.5 Optimized locations of reverse logistics facilities

Finally, we discuss optimized cost components for the composite reverse logistics network of all 7 entities and their location put together.

TABLE 5.21 Sensitivity of different cost components (in ₹) at add-on load of 20% and 30%

Cost component	At present plant capacity	at 20 % excess load	at 30 % excess load
Total composite cost (in ₹)	1871510	2157890	2440000
Cost of transportation (in ₹)	671500	8112670	862600
Establishment cost (in ₹)	10300000	10490000	10670000
Operating costs (in ₹)	2670000	2975000	3020000
Cost for disposal (in ₹)	25100	26020	29600

The results of optimization exercise primarily show evidence of drastic cost savings in terms of reduction of number of facilities under four entities involved in reverse logistics network:

- Out of 7 original collection centers, optimality in terms of processed returns flow quantity and combination of transportation + operating + facility establishment costs, operating only 5 collection centers optimize the objective function. Considering increase of 30 % in the product returns for processing, numbers of collection centers would still remain 5, although the optimized locations would change.

- Out of 3 original pre-processing and scrutiny classification centers, only 2 centers return the optimum solution. In case of 30% increase, it would be optimum to operate from all 3 facilities as per original set up.

For remanufacturing, 3 facilities operate as per the existing arrangement. However, considering the number of returns remanufactured, optimization exercise returns that only one, that is the original facility location of the plant, would be meet the objective function. Even when the returns' quantity rise by 20 %, no additional facility would be required to operate. At 30 % increase, however, 2 facilities would be required to operate.

Tire retreading being the predominant mode of product recovery, it becomes logical and optimal to operate recycle plants at only one out of original two locations.

Also, with rise of additional 30% and above, it becomes optimal to operate with all three recycle facilities.

It would, however be prudent to maintain facilities at all three locations, considering that the industry-domain is recycling dominated, and it is natural to expect a rise in the number of returns.

TABLE 5.22 Optimized locations of key entities

	Locations of facilities		
	Present plant capacity	**at 20 % excess load**	**at 30 % excess load**
Collection centers	Noida, Ajronda, Dasna, Manesar, Dhankot	Noida, Ajronda, Dasna, Manesar, Dhankot	Noida, Dasna, Manesar, Dhankot, Kakroi
Pre-processing centers	Ajronda, Manesar	Ajronda, Manesar	Ajronda, Manesar, Greater Noida

Remanufacturing centers	Ballabgarh	Ballabgarh	Ballabgarh, Moradabad
Recycling centers	Bulandshahar, Ghaziabad	Bulandshahar, Ghaziabad	Bulandshahar, Chhaprola, Ghaziabad
Retreading centers	Bulandshahar	Bulandshahar	Bulandshahar

5.9 Summary and discussion

In this chapter, we built further on network of various entities involved in either 1). Economic recovery or extension for reuse, or 2). Environmentally safe disposal of the returns that have reached end of useful and environmentally-fit life span. We chose the real life industrial case of tire and rubber product returns, which is a real representative sector for the returns' management, for, it involves all key attributes of logistics, repair, remanufacture and also, the crucial environmentally safe disposal. Especially, the environmental importance of this produce, owing to its carbon and metal constituents gains significance in the state of UP, India, that strives and struggles for up keeping clean and pollution-free air.

We started with mixed-integer linear programming formulation for the returns management for this tire manufacturing organization, by considering eight different entities involved in its entire reverse supply chain, like customer zones, collection centers, remanufacturing centers, disassembly centers, recycling centers, Retreading, primary markets, secondary markets and disposal centers.

Further, formulated optimization model for this realistic reverse supply chain was subjected to optimization for the real-life data on costs, flow and locations of the facilities of the tire manufacturing organization, using Lingo 14 software. All exact locational and distances data were collected for the route actually followed for the transport back and forth of the returns. Validated transportation costs were also obtained and were input.

This generic model was then optimized using optimization solver Lingo, considering actual data of returns' quantity between different echelons of the network and inter-facility distance for facilities at different locations, different cost components at each stage, and the actual locational data, for a tire-manufacturing industry operating pan-India. We limited our scope of work to one manufacturing plant (out of total two) operating in geographical region of Delhi NCR and UP.

On the premise of the optimization exercise, we further strengthened this decision support model by considering the sensitivity to fluctuation (rise) in the demand (for increased number of returns to process). We demonstrated sensitivity of the optimization results for two additional scenarios: Rise in number of returns by 20% and 30%, respectively.

In the next chapter, we stage wise summarize the whole work, and present the future scope and recommendations.

CHAPTER 6.

Summary of work, future scope and recommendations

This industry-responses dominated work was set-out to provide a decision support framework to the industrial organizations involved in carrying out reverse logistics activities for managing product returns. In this concluding chapter, we summarize the results obtained during the course of the study (described in chapters 3 and 4) in three logical steps, so as to meet key objectives defined in chapter 1, and also as to what extent the work bridges the present work addresses the research gaps identified in chapter 1 and literature surveyed in chapter 2.

6.1 Summary of the work

We list the stage wise major outcomes of the research process:

6.1.1 Establishment of the network components in reverse logistics activity through validation based on industry survey, and recommend network configurations for key industry-sectors engaged in reverse logistics of product returns.

The base of the work was a multi-sector industry feedback that aimed to identify typical network flows in the returns' management in each of the studied sectors. The feedback also helped in identifying alternatives (regardless of the industry-sector) exercised by the industries for carrying out three principle activity stages of reverse logistics: Collection of returns, Scrutiny classification of returns, and finally, Processing the returns. Two alternatives-each exercised by the industries were identified, resulting in to a matrix of total 8 network configurations.

The industry-survey also involved identifying industry's weighing of two business objectives for reverse logistics and returns' processing, in general: Cost optimization, and Maintenance of customer relations.

These principle business objectives were then classified in to sub-objectives (industry-sector-dependent). Four sub-objectives were categorized under cost optimization objective: No. of recyclable components, costing for scrutiny/test, Transportation costs for scrap handling, and Establishment costs for processing facility.

Similarly, two sub-objectives were categorized under customer relations objective: Protection of product design secrecy, and maintaining interactions with customers.

Further, resultant objective-sub objective matrix was ranked for all eight possible network configurations, to synthesize them into a solution vector through AHP methodology. AHP Excel solver was used to establish the priorities from the industry-responses.

The AHP solver established different network configuration preferences for their reverse logistics activities, as shown in Table 5.1 below**.** In order to reach these recommendations, all pertinent considerations for each configurations were also described and tabulated. These preferences were also aligned with business objective of the organization for the reverse logistics activities for managing product returns.

TABLE 6.1 Network configurations for different industry-sectors engaged in RL

Industry sector	**Network configurations**
Automobile manufacture (Industrial, Passenger, farm)	Produ. managed coll. (P), Central- location s & c (C), and Original facility proc.(O)
Rubber and tire (Butyl, Granules, Liquid Latex)	Produ. managed coll. (P), Central- location s & c (C), Seco. Fac. Proc. (S)
Electronic parts/ Electronic gadgets repair/refurbishment (Incl. Cellphones, Toys, ICs)	Produ. Managed coll. (P), De-Cent. Loc. S & C (D), Original facility proc.(O)
Toner and cartridge, Bottling (LPG, Soft drinks)	Produ. Managed coll. (P), De-Cent. Loc. S & C (D), Seco. Fac. Proc. (S)
Apparel & other on-line merchandize	TP Coll. (T), Central- location s & c (C), and Original facility proc.(O)
Plastic (Polypropylene Terephthalate-PET, PVC, Low density Polyethylene-LDPE, Acrylonitrile butadiene styrene (ABS), Polypropylene)	TP Coll. (T), Central- location s & c (C), Seco. Fac. Proc. (S)
DC Batteries	TP Coll. (T), De-Cent. Loc. S & C (D), Original facility proc.(O)
Paper and packaging, Building material	TP Coll. (T), De-Cent. Loc. S & C (D), Seco. Fac. Proc. (S)

This stage mapped conceptual framework with validation through sector-independent industrial data, whereby different network configurations could be associated with different industry sectors, as tabulated above.

6.1.2 Formulation of a real-life reverse logistics network for existing returns' processing arrangement for the most representative industry-sector

In this stage, we partly adapted a MILP formulation that represented a comprehensive real life eight-entity reverse logistics framework for application in tire manufacturing reverse logistics. Importantly, the chosen industry-domain represents present-day's need-of-the hour, environmental considerations in the geographical area in particular, which is facing severe air pollution problem.

In chapter 4, we described an existing seven stage reverse supply chain for the tire manufacturing organization based in Delhi NCR and Haryana geography in India. The network has different entities such as customer zones, collection centers, remanufacturing centers, disassembly centers, recycling centers that proposes to embed retreading facilities), primary markets, secondary markets and disposal centers. We partially adapted the formulation [183] to minimize the total cost of the multi- stage reverse supply chain for the tire manufacturing organization.

We went on to optimize this formulation considering actual return flows at different entities, costs of inter-entity transport and obtained figures for facility establishment and return processing costs in ₹.

6.1.3 Application and configuration-decision support for the selected real-life industry sector, through optimization of return flows, costs, and facility location decisions.

We used optimization software to yield optimization results for the exercise. The MILP formulation generic model that represented an eight-echelon reverse logistics network was then optimized using optimization solver Lingo, considering actual data of returns' quantity between different echelons of the network and inter-facility distance for facilities at different locations, different cost components at each stage, and the actual locational data, for the chosen tire-manufacturing industry operating pan-India. We limited our scope of work to one manufacturing plant (out of total two) operating in geographical region of Delhi NCR and UP.

On the premise of the optimization exercise, we further strengthened this decision support model by considering the sensitivity to fluctuation (rise) in the demand (for increased number of returns to process). We demonstrated sensitivity of the optimization results for two additional scenarios: Rise in number of returns by 20% and 30%, respectively.

All in all, the work constructed and demonstrated a decision support mechanism for optimization of reverse logistics network, primarily in present Indian context, and replicable for different industry-sectors with similar scope and scene.

6.2 Future scope and recommendations

Network design is the most critical area of reverse logistics that is assuming greater importance and interest of industry and researchers day by day. The present study has significant theoretical and practical implications in terms of the profitability of efforts, processes, environmental obligations, and economy of returns. The problem is solved for a realistic situation and a comparison of the solution under three different instances is also done. The results show the importance of the proper modelling and analysis of network design decisions.

The optimum solution obtained in one case may not be optimal in another situation with a tweak in terms of modality and capacity. The changes in the forecasted values of product return are inevitable. Hence, it is recommended that the decision makers should analyze the problem environment and its possible changes before taking a decision regarding the network design. The proposed model is a general one and with the proper analysis of the results obtained, it helps to analyze the long-term operation of a reverse supply chain. It can aid managers in taking better decisions for the network design of a reverse supply chain.

The model could be further extended for investigations under various scenarios and new emerging domains, like food processing and pharmaceutical returns, where the economy-loss would be staggering.

In this study, we considered only a single product, single-period situation and it could be further extended by considering a multi-product, multi-period situation. The uncertainty in data can also be incorporated into the study as a future research.

Moreover, inconsistencies in terms of re-manufacturability and quality assurance for re-manufactured products, especially in to booming sector like passenger automobiles, can be addressed by seeking solution through more formal and quantifiable routing and re-marketing problem. Researchers can build on the methodology adopted in this work, with necessary customization. The economic advantage achieved could be large.

It is, however, imperative to note here that the reverse logistics product return management is perennially considered a NP-Hard problem, and stochastic nature of the returns could affect and vary the expected outcomes. Different mathematical methods have been tried and tested by researchers to aid the network design decision makers, but the solutions advocated have still remained limited shelf-life solutions, and have been prone to turning pseudo-optimal or even non-optimal solutions.

Researchers have been moderately successful in proposing amicable solutions on optimal design of reverse logistics network configurations for specific product-ranges. However, future researchers can base their work on findings of this multi-sector industry study, and take it on from there to bring finesse and refinement in solution for specific sector they study. Also, it would be apt to stretch the solution-umbrella to similar and related products in the same industry-sector.

While the efforts have been made to include active industry-sectors into the scope of the study, still, our work only makes use of a few industries to ascertain its robustness of solution. Future research could study more industries to verify and further improve on the framework.

Finally, environment abiding disposal means and optimization of transportation -especially for the tire-manufacturing industry-sector discussed in the study- could help achieving the green supply chain in right vein. Researchers can base their future work on the present study and extend to other similar product returns having high environment impact.

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List of Publications

1. Chhaya UK, Dr. M.B. Patel; "*Validation of research design for multi-criteria decision support mechanism for reverse logistics networks*", 2012, International Journal of Scientific Computing Vol. 6; No. 2; 2012: ISSN: 0973-578X
2. Uday K. Chhaya, Dr. M.B. Patel ; "*Formulation and Validation of multi-objective decision support mechanism for reverse logistics networks";* Brown walker press Inc., USA, *2013,* ISBN-10: 1612336248, ISBN-13: 9781612336244
3. Uday K. Chhaya; "Configuration of reverse logistics facilities networks for rubber and PET products: An industrial case study"; Sage Publications, Cogent Engineering OA journals, Taylor & Fransis; 2017; Under review
4. Uday K. Chhaya, Dr. M.B. Patel; "Network Configuration for Reverse logistics of product returns: An industrial case study"; International e-publication for International Science Community Association (Ministry of Corporate Affairs, Government of India) (www.isca.co.in); (ISBN number: **978-93-84659-77-6**)

Reviewed Conference publications:

1. Chhaya UK, Mankad AJ; "IT architecture for reverse logistics networks", International conference on Logistics & Supply Chain Management, Aug 3-5, 2004, Coimbatore

2. Chhaya UK, Mankad AJ; "*Virtual Networks for IT- Enabled Reverse Logistics Involving Decision Support for Supply Chain Management*"; International conference on Asia Pacific Industrial Engineering & Management System, Bangkok, Thailand; Dec 17-20, 2006, ISBN 974-8257-26-6

3. Chhaya UK,; "*Virtual networks in reverse supply chain & Logistics management: An IT architecture*"; International Conference on Advances in Manufacturing and Technology Management (ICAMTM 2007) Mumbai, India, January 2007

4. Chhaya UK, Mankad, AJ; "*Meta-Heuristics based model for decision support application of a reverse supply chain";* International conference on advances in Mechanical Engineering; SVNIT, Surat; Dec 15-17, 2008

5. Chhaya UK, Dr. M.B. Patel; "*Formulation and Validation of multi-objective decision support mechanism for reverse logistics networks";* International conference on Emerging Trends in Mechanical Engineering*";* Vallabh vidyanagar, 2013, ISBN: 978-1-61233-6244

6. Chhaya UK; Dr. M.B. Patel; "*Configuration of reverse logistics networks for rubber and PET products' supply chain: An industrial case study"*; International conference on best practises in Supply chain management, Trivandrum, Dec 22-23, 2016

APPENDIX -1
Industry survey form

Reverse logistics practices: Industry Feedback form

I introduce myself as a research fellow (Doctoral student) of Mechanical Engineering at Gujarat Technological University, Ahmedabad, Gujarat. I am pursuing my doctoral work in broad domain of supply chain management, and in particular, design of reverse logistics networks.

My work seeks to identify preferences for managing the returns' management (through the returns collection methods, scrutiny-classification and routing of the returns, and actual processing of returns) in order to synthesize them in to explicit priority for managing the returns. I wish to make a multi-sector industry survey that gives a holistic perspective about the preference for adopting particular way of managing the product returns. I am predominantly focusing on manufacturers who employ reverse logistics practices in different ways and capacities.

I wish to request you to spare your/ authorized respondent's valuable time to respond to the questions compiled in this questionnaire. I wish to ensure you of keeping the secrecy of the data and using it only for academic purposes for my doctoral thesis. Your feedback will only be visible to me and my work supervisor, Dr. M.B. Patel.

In case of any clarifications/query/suggestions, kindly use my email id: profudaykchhaya@gmail.com, and my cell number: +919825700962.

With profuse thanks for your anticipated contribution in making of this work realistically appropriate and usable for academic and industrial purposes.

Uday K. Chhaya

* Required

1. **Name of your industry** *

2. **Postal address** *

3. **Email** *

4. **Contact number** *

5. **Type of organization** *
Check all that apply.

- [ ] Manufacturing organization
- [ ] Multi-product retail
- [ ] Exclusive logistic services
- [ ] Remanufacture/Repair
- [ ] Recycle
- [ ] Disposal processing

6. **Forecasted/ averaged number of product returns processed per month** *
Mark only one oval.

- ◯ 50-150
- ◯ 150-300
- ◯ 300-500
- ◯ More than 500

7. **Primary mode of transport of unprocessed/processed product returns** *
Mark only one oval.

- ◯ Road
- ◯ Rail
- ◯ Road-Rail combo
- ◯ Others

Classification of returns processed in a month in to different categories as a per cent of total no. of returns

In this section, we categorize the proportion of the total number of returns processed as % re-manufactured or repaired, % Recycled, % Disposed as scrap, and % sold to secondary market fter minor processing

8. **% of remanufactured or repaired returns out of total no. of returns processed by the organization**

____

9. **% of recycled returns out of total no. of returns processed by the organization**

____

10. **% of returns that are scrapped/disposed off out of total no. of returns processed by the organization**

____

11. **% of returns that are sold to secondary market after minimal processing, out of total no. of returns processed by the organization**

____

Business objectives at your organization and their weights

In this section, we seek your inputs on two main business objectives for the reverse logistics activity management: Cost optimization, and Customer relations. We seek the measure of weight the organization attaches two these two business objectives. In subsequent questions, we also sub-categorise each objective into multiple sub-objectives, and seek weight company attaches to each of them.

12. **Key business objectives of organization (Check the appropriate box, you may check more than one boxes) ***

    Check all that apply.

    - [ ] Cost optimization of the reverse logistics processes
    - [ ] Maintaining customer relations while reverse logistics activity

13. **Weight attached to cost optimization objective by your organization ***

    Mark only one oval.

	1	2	3	4	5	
Less Important	◯	◯	◯	◯	◯	Most Important

14. **Weight attached to objective of customer relations by your organization ***

    Mark only one oval.

	1	2	3	4	5	
Less Important	◯	◯	◯	◯	◯	Most Important

Ranking of sub-objectives identified under objective of cost optimization

In the following questions, please rank the sub-objectives under cost optimization on a scale of 1 to 9 (Saaty's scale of ranking of objectives, wherein rankings 1,3,5,7,9 indicate intensity of importance, and 2,4,6,8 indicate intermediate intensity.)

15. **Please rank the sub-objective of 'Number of recyclable components in product returns' on to Saaty's linear scale of 1 to 9 (Pl. refer to the description above) ***

    Mark only one oval.

	1	2	3	4	5	6	7	8	9	
Least Important, if no. of recyclable components are fewer in product returns	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most important, if no. of recyclable components are higher in product returns

16. **Please rank the sub-objective of 'cost of scrutiny/segregation/condition assessment of product returns' on to Saaty's linear scale of 1 to 9 (Pl. refer to the description above) ***

Mark only one oval.

	1	2	3	4	5	6	7	8	9	
Least Important, if scrutiny/condition assessment doesn't require specialised equipment or testing methods	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most important, if scrutiny/condition assessment requires specialised equipment or testing methods

17. **Please rank the sub-objective of 'transportation costs for scrap handling for product returns' on to Saaty's linear scale of 1 to 9 (Pl. refer to the description above) ***

Mark only one oval.

	1	2	3	4	5	6	7	8	9	
Least Important, if returns have less scrap content to be transported	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most important, if product returns has high scrap content to be shipped

18. **Please rank the sub-objective of 'return processing facility establishment cost' on to Saaty's linear scale of 1 to 9 (Pl. refer to the description above) ***

Mark only one oval.

	1	2	3	4	5	6	7	8	9	
Least Important, if the processing center has to be established at other location, giving less opportunity to optimize cost	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most important, if existing manufacturing facility can be utilized, to optimize cost

19. **Please rank the sub-objective of 'return processing facility establishment cost' on to Saaty's linear scale of 1 to 9 (Pl. refer to the description above) ***

Mark only one oval.

	1	2	3	4	5	6	7	8	9	
Least Important, if the processing center has to be established at other location, giving less opportunity to optimize cost	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most important, if existing manufacturing facility can be utilized, to optimize cost

20. **Ranking of sub-objectives identified under objective of maintenance of customer relations**

In the following questions, please rank the sub-objectives under customer relations on a scale of 1 to 9 (Saaty's scale of ranking of objectives, wherein rankings 1,3,5,7,9 indicate intensity of importance, and 2,4,6,8 indicate intermediate intensity.)

21. **Please rank the sub-objective of 'protection of product design secrecy' on to Saaty's linear scale of 1 to 9 (Pl. refer to the description above) ***

Mark only one oval.

	1	2	3	4	5	6	7	8	9	
Least important, if organization doesn't attach huge importance to protect design secrecy	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most Important, if organization preferes to protect design secrecy

22. **Please rank the sub-objective of 'maintaining interactions with customers ' on to Saaty's linear scale of 1 to 9 (Pl. refer to the description above) ***

Mark only one oval.

	1	2	3	4	5	6	7	8	9	
Least important, if organization doesn't attach huge importance to protect design secrecy	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most Important, if organization preferes to protect design secrecy

23. **Please rank the sub-objective of 'maintaining interactions with customers ' on to Saaty's linear scale of 1 to 9 (Pl. refer to the description above) ***

Mark only one oval.

	1	2	3	4	5	6	7	8	9	
Least important, if organization doesn't feel necessity for frequent visits/interactions at customer's locationfor services/maintanance	◯	◯	◯	◯	◯	◯	◯	◯	◯	Most Important, if organization prefers to pay frequent visits/interactions at customer's location for services/maintanance

Organization's preference for different modes of returns management framework

In this section, we seek organization's preference for three principle returns' management activities: Method of returns' collection, mechanism for scrutiny, segregation, and classification of returns, and thirdly, location where the returns are processed.

24. **How does the organization collect the returns?**

Mark only one oval.

◯ Proprietary collection arrangement, wherein industry collect their product returns by a dedicated collection arrangement

◯ Third-party returns' collection arrangement, wherein similar/dissimilar returns from multiple manufacturers are collected by third-party collector

25. **Where your organization prefers to scrutiny-sort and classify returns?**

Mark only one oval.

◯ Centralized location, strategically located by the manufacturing organization

◯ Decentralized location, where company sub-lets scrutiny testing

26. **Where your organization prefers to process the returns?**

Mark only one oval.

◯ At original location of the manufacturing organization

◯ At secondary/inexclusive facility available in the geographical zone

APPENDIX -2
Mathematics of calculation of priorities: AHP methodology

Notations:

- Objectives: **O** (1 through 2)
- Sub-Objectives: **S** (1 through 4 for Cost optimization objective, 5 through 6 for maintenance of customer relations)
- **i**: Counter for framework alternatives (1 for PCO, 2 for PCS, 3 for PDO, …, 8 for TDS)
- **m**: Counter for 6 sub-objectives for alternatives comparison frameworks (1 through 4 for sub-objectives under Cost optimization objective, 5 through 6 for sub-objectives under maintenance of customer relations objective)

Table A-2.6.1 Pairwise comparison matrix for principle objectives

Objectives	**Cost Optimization O_1**	**Customer relations O_2**	**Percent ratio scale of priorities V^O**
Cost Optimization O_1	1	O_1/O_2	$O_1/ (O_1 + O_2) \times 100$
Customer relations O_2	O_2 / O_1	1	$O_2 / (O_1 + O_2) \times 100$

Table A-2.1.2 Pairwise comparison matrix for cost optimization sub objective

Cost savings	**No. of recyclable components S_1**	**Costing for scrutiny/test S_2**	**Transportation costs for scrap handling S_3**	**Establishment costs for processing facility S_4**	**Percent ratio scale of priorities V^C**
No. of recyclable components s_1	1	S_1/S_2	S_1/S_3	S_1/S_4	$S_1/\sum_{i=1}^{4} S_i \times 100$
Costing for scrutiny/test S_2	S_2/S_1	1	S_2/S_3	S_2/S_4	$S_2/\sum_{i=1}^{4} S_i \times 100$
Transportation costs for scrap handling S_3	S_3/S_1	S_3/S_2	1	S_3/S_4	$S_3/\sum_{i=1}^{4} S_i \times 100$
Establishment costs for processing facility S_4	S_4/S_1	S_4/S_2	S_4/S_3	1	$S_4/\sum_{i=1}^{4} S_i \times 100$
	$(\sum_{i=1}^{4} S_i)/ S_1$	$(\sum_{i=1}^{4} S_i)/ S_2$	$(\sum_{i=1}^{4} S_i)/ S_3$	$(\sum_{i=1}^{4} S_i)/ S_4$	

Table A-2.1.3 Pair wise comparison matrix for customer relations sub objective

Customer relations	Protection of product design secrecy S5	Maintaining interactions with customers S_6	Percent ratio scale of priorities V^R
Protection of product design secrecy S_5	1	S_5/S_6	$S_5/(S_5 + S_6) \times 100$
Maintaining interactions with customers S_6	S_6/S_5	1	$S_6/(S_5 + S_6) \times 100$
	$(S_5 + S_6)/S_5$	$(S_5 + S_6)/S_6$	

Table A-2.1.4 Pair wise comparison matrix for alternative configurations (a) relative to sub objectives S= 1,…, 6 for 8 network configurations

Sub objectives S	(P,C,O) a_1^S	(P,C,S) a_2^S	…	(T,D,S) a_8^S	Priority Vector $w^A m$
(P,C,O) a_1^S	1	a_1^S/a_2^S	…	a_1^S/a_8^S	$a_1^S/\sum_{I=1}^{8} a_1^S$
(P,C,S) a_2^S	a_2^S/a_1^S	1	…	a_2^S/a_8^S	$a_2^m/\sum_{I=1}^{8} a_1^S$
. . .	. . .	. . .	…	. . .	. . .
(T,D,S) a_8^S	a_8^S/a_1^S	a_8^S/a_1^S	…		$a_8^S/\sum_{I=1}^{8} a_1^S$
	$(\sum_{i=1}^{S} a_1^S)/a_1^S$	$(\sum_{i=1}^{S} a_1^S)/a_2^S$	$(\sum_{i=1}^{S} a_3^S)/a_1^m$	$(\sum_{i=1}^{S} a_1^S)/a_4^S$	

Priority vector for cost optimization sub-objective:

$P^C = [W_A^1 W_A^2 W_A^3 W_A^4] [V^C]$……………………………………………………(A-2.1)

Priority vector for customer relations sub-objective:

$P^R = [W_A^5 W_A^6] [V^R]$ ………………………………………………………(A-2.2)

Priority vector for over-all business objective

$P^O = [U_C \ U_R] V^O]$………………………… ………………………………(A-2.3)

Using equations (A-2.1), (A-2.2), and (A-2.3), the priority vector P^O can be written in terms of the relative rankings O_1, O_2, S_1, S_2, S_3, S_4, S_5, and S_6.

i[th] element of priority vector P^O has the form

$u_i^O = \frac{O_1}{O_1+O_2} (\frac{1}{\sum_{k=1}^{4} S_k})) (S_1 a_i^1/\sum_{k=1}^{8} a_k^1 + S_2 a_i^2/\sum_{k=1}^{8} a_k^2 + S_3 a_i^3/\sum_{k=1}^{8} a_k^3 + S_4 a_i^4/\sum_{k=1}^{8} a_k^4) + \frac{O_1}{O_1+O_2} (\frac{1}{S_5+S_6}) (S_5 a_i^5/\sum_{k=1}^{8} a_k^5 + S_6 a_i^6/\sum_{k=1}^{8} a_k^6)$………………………………… **(A-2.4)**

The solution vector U^o contains the overall preferences for all eight network configurations, that is, if $u_i^O > u_j^O$ then the i[th] alternative is preferred over the j[th] alternative. The highest value in the solution vector corresponds to the most preferred network configuration.

We can analyze how relative rankings change using Eq. (A 2.1), and can be used to show sensitivity of prioritization to the relative rankings.

Part-II Sensitivity analysis

Where i[th] alternative becomes equal to j[th] alternative, i.e. $u_i^O = u_j^O$

$$\frac{O_1}{O_1+O_2}\ (1/\textstyle\sum_{k=1}^{4} S_k)\ (S_1 a_i^1/\sum_{k=1}^{8} a_k^1 + S_2 a_i^2/\sum_{k=1}^{8} a_k^2 + S_3 a_i^3/\sum_{k=1}^{8} a_k^3 + S_4 a_i^4/\sum_{k=1}^{8} a_k^4) + \frac{O_1}{O_1+O_2}\ (\frac{1}{S_5+S_6})\ (S_5 a_i^5/\sum_{k=1}^{8} a_k^5 + S_6 a_i^6/\sum_{k=1}^{8} a_k^6) = \frac{O_1}{O_1+O_2}\ (1/\textstyle\sum_{k=1}^{4} S_k)\ (S_1 a_j^1/\sum_{k=1}^{8} a_k^1 + S_2 a_j^2/\sum_{k=1}^{8} a_k^2 + S_3 a_j^3/\sum_{k=1}^{8} a_k^3 + S_4 a_j^4/\sum_{k=1}^{8} a_k^4) + \frac{O_1}{O_1+O_2}\ (\frac{1}{S_5+S_6})\ (S_5 a_j^5/\sum_{k=1}^{8} a_k^5 + S_6 a_j^6/\sum_{k=1}^{8} a_k^6)$$

Equation used to analyze sensitivity of ordering of alternatives to relative ranking of objectives and sub objectives

$$\left(\frac{O_1}{O_1+O_2}\right)\left[\frac{S_1}{\sum_{k=1}^{4} Sk}\right)\left(\frac{a_i^1-a_j^1}{\sum_{k=1}^{8} a_k^1}\right) + \left[\left(\frac{S_2}{\sum_{k=1}^{4} ck}\right)\left(\frac{a_i^2-a_j^2}{\sum_{k=1}^{8} a_k^2}\right) + \left[\left(\frac{S_3}{\sum_{k=1}^{4} ck}\right)\left(\frac{a_i^3-a_j^3}{\sum_{k=1}^{8} a_k^3}\right) + \left[\left(\frac{S_4}{\sum_{k=1}^{4} S_k}\right)\left(\frac{a_i^4-a_j^4}{\sum_{k=1}^{8} a_k^4}\right)\right] + \left(\frac{O_1}{O_1+O2}\right)\left[\left[\left(\frac{S_5}{S_5+S_6}\right)\left(\frac{a_i^5-a_j^5}{\sum_{k=1}^{8} a_k^5}\right) + \left[\left(\frac{S_6}{S_5+S_6}\right)\left(\frac{a_i^6-a_j^6}{\sum_{k=1}^{8} a_k^6}\right)\right] = 0$$

Appendix- 3
Lingo code

```
MODEL:

TITLE Optimization of Returns Processing entity network for tire manufacturing organization_UK Chhaya;
! Reverse Logistics network Problem;

SETS:
COLL_CENTERS / NOIDA, AJRND, DASNA, MANSR, DHANK, MURTH, KAKROI/:
SUPPLY_PREPCENTERS; !, OPENRET, RETFXD_COST;
PREP_CENTERS / AJRND, MANSR, GGRAM, DASNA /: PREPFXD_CST,
CAP_PREPCENTERS, OPEN1;
ARCS1 (PREP_CENTERS, COLL_CENTER): COST_PREP_CENTERS, VOL_PREPCENTERS;
RMCENTERS / BLRP, DHNR, JAUN/ :
SUPPLY_RMCENTRES;!,OPENRET, RETFXD_COST;
CAP_RMCENTERS, OPEN2;

ARCS2(RMCENTERS, COLL_CENTERS):
COST_RMCENTERS, VOL_RMCENTERS;

RCYCL_CENTERS /BULSHR, CHHPR, GHZBD2/;
SUPPLY_RCYCL_CENTERS; !, OPENRET, RETFXD_COST;
CAP_RCYCL_CENTERS, OPEN3;

ARCS3 (RCYCL_CENTERS, COLL_CENTERS):
COST_RCYCL_MCENTERS, VOL_RCYCL_CENTERS;

SUPPLY_RMCENTERS;!,OPENRET,RETFXD_CST;
DISP_CENTER /JEWAR:
SUPPLY_DISP_CENTER; !, OPENRET, RETFXD_COST;
CAP_DISP_CENTER, OPEN4;
```

```
ARC4 (PREPCENTERS, DISP_CENTER) : COST_DISP_CENTER, VOL_DISP_CENTER;
ENDSETS

!SUBMODEL minimize total cost:

! The objective;

[TTL_COST] MIN = @SUM( ARCS1: COST_COLL_CENTERS * VOL_COLL_CENTERS) +
@SUM( COLL_CENTERS: PREPFXD_COST * OPEN1)+@SUM( ARCS2:
COST_PREP_CENTERS * VOL_PREP_CENTERS) +
@SUM( RMCENTERS: RMCENTERFXD_CST * OPEN2)+@SUM( ARCS3:
COST_RMCENTERS * VOL_RMCENTERS) +

@SUM( RCYCLCENTERS: RCYCLCENTERSFXD_CST * OPEN4)+ @SUM( ARCS5:
COST_DISPCENTER * VOL_DISPCENTER) + @SUM (RTCENTERS:
RTCENTERSFXD_CST * OPEN5) + @SUM(ARC6:COST_RTCENTERS *
VOL_RTCENTERS) +
@SUM( DISPCENTRES: DISP_CENTERFXD_CST * OPEN5);

!Constraints:
! The supply constraints;

@FOR( COLL_CENTERS (J): [SUPPLY1]!,1;
@SUM( PREP_CENTRES(I): VOL_PREPCENTRES( I, J))= SUPPLY_PREPCENTRES(J)
);
@FOR ( PREP_CENTERS( I): [CAPACITY]
@SUM( CZONES2( J): VOL_PREPCENTRES( I, J))<= CAP_PREPCENTRES( I) * OPEN1(
I)
);
@FOR( CZONES3(J): [SUPPLY2]!2;
@SUM( SMARKET(I): VOL_SMARKET( I, J)) = SUPPLY_SMARKET(J)
);
@FOR( SMARKET( I): [CAPACITY2]
```

```
@SUM( CZONE2( J): VOL_SMARKET( I, J)) <= CAP_SMARKET( I) * OPEN2( I)
);
@FOR( COLL_CENTERS (J): [SUPPLY3]!3;
@SUM (RMCENTERS (I): VOL_RMCENTERS ( I, J)) = SUPPLY_RMCENTERS(J)
);
@FOR( RMCENTERS( I): [CAPACITY3]
@SUM( RMCENTERS( J): VOL_RMCENTERS( I, J)) <= CAP_RMCENTERS( I) * OPEN3(
I)
);
@FOR( COLL_CENTERS (J): [SUPPLY4]!4;
@SUM( RCYCLCENTERS(I): VOL_RCYCLCENTERS( I, J)) = SUP_RCYCLCENTERS(J)
);
@FOR( DISP_CENTER ( I): [CAPACITY4]
@SUM( DISP_CENTER( J): VOL_DISP_CENTER( I, J)) <= CAP_RECYCENTRES( I) *
OPEN4( I)
);
);
! Make OPEN binary(0/1);
@FOR( PREP_CENTRES: @BIN(OPEN1)
);
@FOR( COLL_CENTERS: @BIN(OPEN2)
);
@FOR( RMCENTERS: @BIN(OPEN3)
);
@FOR(RCYCLCENTERS: @BIN(OPEN4)
);
@FOR (RTCENTERS:@BIN (OPEN5)
);
@FOR( DISPCENTER: @BIN(OPEN6)
);

DATA:
! Returns' Collection and quantities;
```

SUPPLY_COLL_CENTERS= @OLE ('\LINGO14\SAMPLES\OPENLOOP RETURNS_Q_CC.xlsx);

SUPPLY_PREPCENTERS=@OLE('\LINGO14\Samples\OPENLOOP PREP_Q_PPC.xlsx');

! The Preparation centers, their fixed costs;

PREP_CENTERSFXD_COST = @OLE('\LINGO14\Samples\OPENLOOP PREP_CENTER_COSTS.xlsx');

! The Remanufacturing centers and their Capacities;

CAP_RMCENTRES= @OLE('\LINGO14\Samples\OPENLOOP RMCENTERS_CAPACITY.xlsx');

! The Remanufacturing center to original user cost/unit shipment matrix;

COST_RMCENTERS=@OLE('\LINGO14\Samples\OPENLOOP RMCENTERS_COST.xlsx');

! The Recycle centers & their supply quantities;

SUPPLY_RCYCL_CENTERS=@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx');

! The Retreading centers & their supply quantities;

SUPPLY_RTCENTERS= @OLE ('LINGO14\Samples\OPENLOOP FLOW CHART.xlsx)

! The Recycle centers, their fixed costs;

RCYCLESFXD_CST = @OLE('\LINGO14\Samples\OPENLOOP RCYCL_COST.xlsx');

! The Disposal centers and their Capacities;

CAP_DISP_CENTER= @OLE('\LINGO14\Samples\OPENLOOP DISP_CENTER.xlsx');

! The Pre-processing centers, their fixed costs;

PREP_CENTERFXD_COST = @OLE('\LINGO14\Samples\OPENLOOP PREP_CENTER.xlsx');

! The Remanufacturing centers and their Capacities;

CAP_RMCENTERS= @OLE('\LINGO14\Samples\OPENLOOP RMCENTER_CAPACITY.xlsx');

! Collection center to Preprocessing center cost/unit
shipment matrix;
COST_CC_PPR =@OLE('\LINGO14\Samples\OPENLOOP CC_PPR.xlsx');
! The Collection centers & their supply quantities;
SUPPLY_COLL_CENTERS=@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx');

! The Preprocessing center to remanufacturing cost/unit
Shipment matrix;
COST_RMCENTERS =@OLE('\LINGO14\Samples\OPENLOOP RMCENTERS_COST.xlsx');
! The Recycle centers & their supply quantities;
SUP_RCYCENTER=@OLE('\LINGO14\Samples\OPENLOOP RCYC.xlsx');
! The Recycle centers, their fixed costs;
RCYCL_FXD_COST = @OLE('\LINGO14\Samples\OPENLOOP RCYCFXDCOST.xlsx');
! The Recycle centers and their Capacities;
CAP_RCYCL_CYCENTRES= @OLE('\LINGO14\Samples\OPENLOOP RCYCLECAPACITY.xlsx');
! The Disposal center cost/unit
Shipment matrix;
COST_DISP_CENTERS =@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx');
! Disposal center & its' supply quantities;
SUP_DISPCENTRES=@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx');
! The disposal center and its fixed costs;
DISP_CENTER_FXD_COST = @OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx');
! The Disposal center and its Capacity;
CAP_DISPCENTER= @OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx');
! The Disposal center cost/unit
Shipment matrix;
COST_DISP_CENTERS =@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx');

```
!Export results to excel;
@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx',
'VOL_PREPCENTERS') = VOL_PREPCENTRES;
!Export results to excel;
@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx',
'VOL_COLL_CENTERS') = VOL_COLL_CENTRES;
!Export results to excel;
@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx',
'VOL_RMCENTERS') = VOL_RMCENTERS;
!Export results to excel;
@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx',
'VOL_RECYCENTERS') = VOL_RECYCENTERS;
!Export results to excel;
@OLE('\LINGO14\Samples\OPENLOOP FLOW CHART.xlsx',
'VOL_DISPCENTRES') = VOL_DISPCENTER;
ENDDATA
END
```