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 backbone 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

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

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

Bizzztor 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/](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.

![Per cent transport mode adopted for logistics activity in India](image)

**Figure 1.2 Break-up of transport modes 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/](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”.

![Logistics cost compare](image.png)

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

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

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 into 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>
<thead>
<tr>
<th>Sr. No.</th>
<th>Author</th>
<th>Key contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>[18]</td>
<td>Tradeoff considerations for returns collection mode, network design, transportation modes, etc.</td>
</tr>
<tr>
<td>2.</td>
<td>[19]</td>
<td>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</td>
</tr>
<tr>
<td>3.</td>
<td>[20]</td>
<td>Descriptive conceptual model that distinguishes among network types based on product function like recycling, remanufacturing, or reusing to propose specific network design considerations</td>
</tr>
<tr>
<td>4.</td>
<td>[21]</td>
<td>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.</td>
</tr>
<tr>
<td>5.</td>
<td>[22]</td>
<td>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</td>
</tr>
<tr>
<td>6.</td>
<td>[23]</td>
<td>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)</td>
</tr>
<tr>
<td>7.</td>
<td>[24]</td>
<td>need for new research into strategic aspects and organizational frameworks for reverse logistics</td>
</tr>
<tr>
<td>8.</td>
<td>[25]</td>
<td>Described need for grounding framework for retail reverse logistics</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Sr. No.</th>
<th>Author</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>[26]</td>
<td>Discussed two phases of the method as the prioritization of supply chain objectives; and the selection of risk indicators</td>
</tr>
<tr>
<td>2.</td>
<td>[27]</td>
<td>Discussed vagueness and need for a holistic approach for selecting a TPL service provider</td>
</tr>
<tr>
<td>3.</td>
<td>[28]</td>
<td>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</td>
</tr>
<tr>
<td>4.</td>
<td>[29]</td>
<td>Prioritization of objectives for the producer’s cost (Prcost) and the Informal Waste Sector (IWS) Profit for Electrical and electronic equipment companies</td>
</tr>
<tr>
<td>5.</td>
<td>[30]</td>
<td>ANP technique to address the interaction issues between indicators when applying the Balance Score Card for performance measurements amongst objectives</td>
</tr>
</tbody>
</table>

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

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

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.
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 crossover 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.