CHAPTER 2

LITERATURE REVIEW

A supply chain is a system of facilities and activities that functions to procure, produce, and distribute goods to customers. The efficient and effective movement of goods from raw material sites to processing facilities, component fabrication plants, finished goods assembly plants, distribution centers, retailers and customers is critical in today’s competitive environment. Approximately 10% of the gross domestic product is devoted to supply chain related activities (Simchi-Levi, Kaminsky and Simchi-Levi 2003)

Location decisions may be the most critical and most difficult of the decisions needed to realize an efficient supply chain. Facility location decisions are often fixed and difficult to change even in the intermediate term. Modern distribution centers with million of dollars of material handling equipment are also difficult, if not impossible, to relocate except in the long term. Inefficient locations for production and assembly plants as well as distribution centers will result in excess costs being incurred throughout the lifetime of the facilities, no matter how well the production plans, transportation options, inventory management, and information sharing decisions are optimized in response to changing conditions.

The physical structure of a supply chain clearly will influence its performance, and it is very important to design an efficient supply chain to facilitate the movement of goods. Some major supply chain network decisions include: What suppliers should we use? How many factories and warehouses
should we have and where should we locate them? How do we set the
capacity at each location? What products should each factory produce?
Which factory will supply to which warehouses? How much of the market
demand are allocated to each distribution centers? Given locations and
capacities, the supply chain decisions will then try to answer questions such
as the following: what quantities should we produce and store at these
locations? What quantities should be moved from location to location and at
what time?

Klose and Drexl (2004) presented a classification of facility
network location models such as capacitated Vs uncapacitated models, single
product Vs multiple product models, single stage models Vs multi-staged
models, single period or static Vs multi-period or dynamic models,
deterministic Vs probabilistic models, single objective Vs multi-objective
models, and based on topography-network location models, discrete location
models and plane models.

Based on physical flow of materials in the supply chain networks, it
is possible to divide the SCNs into three categories namely forward supply
chain networks, reverse supply chain networks and bi-directional integrated
networks. The literature related to the design of these networks is presented
here.

2.1 REVIEW ON FORWARD SUPPLY CHAIN NETWORKS

The work done in the area of forward supply chain networks by
earlier researchers is given in this section.
2.1.1 General Models

The forward supply chain network consists of facilities for production and facilities for storage. The elements are supplier’s plants, supplier’s warehouses, manufacturer’s plants, manufacturer’s warehouses, and finally retailer’s warehouses. The major decisions are location of the facility, allocation of supply to facilities and allocation of demand to facilities. A detailed review of the forward network design is given here.

Cohen and Lee (1989) present a deterministic, mixed integer, non-linear mathematical programming model, based on economic order quantity (EOQ) techniques, to develop what the authors refer to as a global resource deployment policy. More specifically, the objective function used in their model maximizes total after-tax profit for the manufacturing facilities and distribution centers. This objective function is subject to a number of constraints, including managerial constraints and logical constraints.

Cohen and Moon (1990) extend Cohen and Lee (1989) by developing a constrained optimization model, called PILOT, to investigate the effects of various parameters on supply chain cost and consider the additional problem of determining which manufacturing facilities and distribution centers should be open. The objective function of the PILOT model is a cost function, consisting of fixed and variable production and transportation costs, subject to supply, capacity, assignment, demand, and raw material requirement constraints. The authors conclude that there are a number of factors that may dominate supply chain costs under a variety of situations, and that transportation costs play a significant role in the overall costs of supply chain operations.
Arntzen et al (1995) develop a mixed integer programming model called GSCM (Global Supply Chain Model), that can accommodate multiple products, facilities, stages, time periods, and transportation modes. More specifically, the GSCM minimizes a composite function of activity days, total cost of production, inventory, material handling, overhead and transportation. The result of this model consists of the number and location of distribution centers and market allocation.

Camm et al (1997) develops an integer linear programming model, based on an uncapacitated facility location formulation, for Procter and Gamble Company. This model determines the location of distribution centers and assignment of customer zones to centers.

Yan and Yu (1998) present a MILP model for supply chain design by including consideration of the product structure, in the form of the Bill of Materials.

Sankaran and Raghavan (1997) deals with optimal design of two level distribution system for LPG distribution in India. They used integer programming to locate the bottling plants and allocation of dealers to the plant.

Starting with a given set of potential facility sites many location problems can be modeled as mixed integer programming models. Two or multi-level facility location models cover complete distribution systems. By integrating production stage with distribution planning is referred as strategic supply chain management (Chandra and Fisher 1994; Pooley 1994; Erenguc et al 1999). Two-level (hierarchical) capacitated facility location models are referred in Geoffrion and Graves (1974), Hindi and Basta (1994), Hindi et al. (1998), Pirkul and Jayaraman (1996, 1998), Tragantalerngsak et al. (1997),

2.1.2 Global Supply Chain Models

A significant number of works available in the area of global supply chain design approaches and these are given in this section. Hodder and Dincer (1986) studied the international plant location problem and developed a single-period model to determine the best locations, material flows and financing patterns. The model identifies the best sourcing plan given multiple possible production sites for a product to be sold in multiple markets. The authors used a function of after-tax profit as the objective, computed as the difference between net revenue, fixed cost for having a plant open, and a cost for financing that allows borrowing in multiple currencies. The cost of financing a plant is managed in the objective function as a single period outlay that represents the sum of the acquisition and interest rate costs, in the numeraire currency (i.e., of the firm’s home country), adjusted using the appropriate currency exchange rate.

Breitman and Lucas (1987) described the PLANETS model, developed at General Motors to assist in making decisions concerning facility location, capacity planning, material sourcing, product allocation, and new product introduction. PLANETS is a tool for building mixed integer programming models that are reportedly capable of providing optimal solutions to difficult global sourcing problems.
Cohen et al. (1989) developed a global supply chain model to address the manufacturing decisions faced by companies that produce and source globally. The model is a multi-period, production-distribution model with time-varying parameters that solves for both location and material shipment quantities over time. The objective maximizes after tax profits subject to material flow constraints, plant capacity, market penetration strategies and local content rules.

Haug (1992) developed an international location model to study the global sourcing problem in high technology firms. The model identifies the best sourcing plan given a set of possible production sites for a product to be sold in multiple markets. The model is distinct in that it explicitly recognizes learning-curve effects on both material and labor costs, and allows for production to be transferred from site to site in response to improved input costs or exchange rates. The model includes variable costs that are typically considered in location models, such as material, labour, transportation, and utilities. The output of the model is allocation sequence.

Kogut and Kulatilaka (1994) developed a stochastic, dynamic programming model to study the value of production switching in conditions where currency exchange rates are uncertain. The decision to stay to a production facility with unfavourable exchange rates versus shifting production to a facility with more favorable rates is complicated by switching costs-shutdown and startup costs, labor related costs, and managerial time commitments.

Canel and Khumawala (1996) developed un-capacitated and capacitated versions of a mixed integer-programming model to solve an international facility location problem. The objective maximizes after-tax profits, including costs for investment, fixed, transportation, shortage, and
inventory holding. The model selects multiple production sources for end-product manufacturing but not the supply segments.

Canel and Khumawala (1997) extended the above model by including multiple periods so that timing of location changes can be more carefully evaluated.

In Rosenfield (1996), the author developed a model to describe production and distribution costs for an international location problem and then explored its structural properties to draw insights on location and capacity strategies when exchange rates are uncertain.

Vidal and Goetschalckx (2001) developed a global supply chain model to address design problems relating to a multinational corporation that outsource some but not all of its production to supplier facilities. This model simultaneously selects facility locations, computes flows between facilities, sets transfer prices and allocates transportation costs to either the shipper or the receiver to maximize after-tax profits across multiple tiers in the supply chain.

2.1.3 Location-routing models (LR models)

Most of the early studies on LR models focus on heuristic methods, which generally decompose the problem into three sub-problems on facility location, demand allocation, and vehicle routing. Laporte (1988) provides a survey of earlier heuristics for LR problems. Nagy and Salhi (1996) apply a nested heuristic method and a Tabu search to LR problems. A two-phase Tabu search approach is recently proposed by Tuzun and Burke (1999). Wu, Low, and Bai (2002) decompose the LR problem into a location-allocation problem and a vehicle routing problem, and simulated annealing was used for
search methods. Laborte and Nobert (1987) classify the exact algorithms into three categories namely direct tree search, dynamic programming, and integer programming algorithms. Berman, Jaillet and Simchi-Levi (1995) address LP problems in which the decision maker does not know exactly the number and locations of retailers, instead, the only information available is the relative probability distributions. A recent study is from Chan, Carter, and Burnes (2001) in which they apply the three-dimensional space-filling curve and the modified Clarke-Wright heuristic to solve the problem. Balakrishnan, Ward, and Wong (1987) and Min, Jayaraman and Srivastava (1998) provide a good survey of LR problems.

2.1.4 Location-inventory problems (LI Models)

Erlebacher and Meller (2000) formulate a highly non-linear integer location/inventory model. They solve the problem by using a continuous approximation as well as a number of constructions and bounding heuristics. Daskin, Coullard and Shen (2001) propose a joint location/inventory model in which location, shipment and nonlinear safety stock inventory costs are included in the same model. Shen (2000) and Shen, Coullard and Daskin (2003) introduced a location model with risk pooling (LMRP).

2.1.5 Summary

The review under section 2.2 provides a wide variety of tools used to solve facility location problems in supply chains. The MILP is widely used and most of the problems are treated as deterministic. It is also noted that there were integrated models, which combines location problem with inventory and routing problems. On this above review, we have not come across any work related to BDOLSCN.
2.2 REVERSE SUPPLY CHAIN NETWORKS

The reverse supply chain is one of the emerging areas of interest in the field of supply chain management. The reverse supply chain consists of a list of activities involved in recovering used products for the purpose of recycling, remanufacturing and proper disposal by a manufacturer. Reverse supply chain or reverse logistics is the series of activities required to retrieve a used product from a customer and dispose of it properly or reuse after processing (Guide and Wassenhove 2002). The chain connects end users with manufacturer in reverse direction. Reuse and remanufacturing of products and materials are not new in the industry. Wastepaper recycling, metal scrap brokers and soft drink industry are all examples that have been around for a long time. In these cases, recovery of the used products is economically more attractive than disposal. But, in the recent past, there is a growing interest in reuse and remanufacturing among industries and that lead to more studies in the area of reverse logistics. The major forces behind this development are:

1. Environmental legislation related to disposal
2. Opportunity to recover some of the value from old products. e.g. Computer components
3. Opportunity to remanufacture old products and to serve secondary markets
4. Opportunity to become an environment friendly organization.

The retail returns and returns from customers also come under reverse logistics with the objective to minimize overall returns. These supply chains are loosely linked and totally controlled by unorganized sectors. In Europe and U.S.A., companies use reverse logistic network to get back products like Refrigerators, Cameras, Televisions, Cars, Cellular phones and Industrial equipments. In India, not much initiative has been taken by
industries. The environmental legislation will also come into force in India, and Indian companies should be proactive in implementing reverse logistic in their industries. Not only these companies do less damage to environment but they also gain competitive advantage by means of remanufacturing and recycling.

There are many issues related to management of the reverse supply chain. They are forecasting returns, design of reverse logistics network, inventory management of returns, role of outsourcing, integration using information technology and role of customers in returns. The reverse supply chain process is complicated further by following unique dimensions.

- The reverse flow is supply driven and not demand driven. The end user must be willing to return the used products.
- The timing of return is unpredictable
- The nature of products returned differs widely and hence, the type of network also differs.

2.2.1 Design of Reverse Logistic Network

The design of reverse logistic network deals with issues related to location of various activities of supply chain. It also deals with how to design the corresponding transportation links. (Fleischmann, 2001) The companies need to consider the following points, while designing reverse supply network.

(a) How to collect recoverable products from the former user?
(b) Where to inspect and grade collected products?
(c) Where to locate re-processing facility?
(d) Whether to use existing facility or need new facility?
(e) Whether to outsource re-processing or do it self?

(i) **Product Acquisition**

The collection of used products potentially accounts for a significant part of the total cost, which can be compared with the last mile issue in distribution of products in the forward supply chain. The collection may occur by door to door, through service centre, through sales centre and sometimes by customers. In the case of paper and plastic, people go to individual houses and collect paper products. In the case of batteries, the point of purchase acts as collection centre (retailers). In the case of tyre re-treading, customer brings old tyres to re-treading centers.

Canon used to collect empty cartridges used in their printer through collection boxes kept at different places. Customers can deposit their used cartridges in these boxes and a courier company can send this to refilling.

Dupont operates several facilities for recycling nylon from using carpeting material. Carpet dealers collect the carpet waste.

(ii) **Testing / Grading**

The location of the test and grade operation should be near to collection centers. Early testing might save transportation of useless products. On the other hand, sophisticated testing might involve expensive equipments, which can only be afforded at a few locations. The economy of operating a test center also should be considered while designing the network.
Companies like Bosch which produces Power tools, used to fix sensors so that it will give an idea that whether the motors inside the tool are worth remanufacturing or not. This idea definitely helps the company to reduce costs.

(iii) Reprocessing

Often, the reprocessing stage requires the highest investments within reverse logistics network. The process involves disassembly, repair work, reuse in new products and re-assembly. The critical issues involved are how to reduce the uncertainty in the supply of products to be manufactured, how to ensure a sustainable volume of products to be manufactured and whether to outsource remanufacturing (open-loop system) (Figure 2.2) or to integrate with existing operation (closed-loop system) (Figure 2.1)

![Diagram of Closed loop system](image)

**Figure 2.1 Closed loop system**
(iv) **Role of forward supply chain in collection:**

Recycling can often be described as an open loop system, i.e. the products do not return to the original manufacturer but it will be used in other industries. In this case possibility of integration of forward and reverse network is scant as the actors differ in both channels. (e.g. Paper recycling). Remanufacturing and reuse often leads to closed-loop system. Here the used products are returned to original producers. The remanufacturing or recycling operation is completed and components and products are again reused. (e.g. Kodak single use Cameras).

Reverse logistics may either take place through the original network directly using traditional middleman or through specialized logistical providers. Even if the same actors are involved, integration of forward and reverse distribution may be difficult; at the routing level, since collection and delivery may require different handling. (Fleischmann et al., 1997)

There is high degree of uncertainty in supply both in terms of quality and quantity of used products, returned by consumers. High quality products may justify higher transportation costs and thus more centralized network structure whereas extensive transportation of low value products is uneconomical.
Toktay et al (2000) addressed the issue of procurement of new components for recyclable products in the context of Kodak’s single use cameras. Customers take the used cameras to a photo-finishing laboratory, where the film is taken out and processed. The laboratories receive a rebate for each used camera they subsequently return to Kodak. The reusable parts (the circuit board, plastic body and lens aperture) of the returned cameras are put back into production after inspection. Since, there is an uncertainty involved in return of cameras, the authors developed a closed loop queuing network to find an ordering policy for the procurement of new components that minimizes the total expected procurement, inventory holding and lost sales cost.

(v) A framework for Networks and products

Based on case studies and comparing network ownership and type of products, a framework was developed. Some companies follow their own network to get back the old products. Some use external parties to get back products. The products are classified into industrial and consumer products and networks are classified as independent and OEM network. The framework is presented in Figure 2.3.

<table>
<thead>
<tr>
<th>INDUSTRIAL PRODUCTS</th>
<th>OEM Network</th>
<th>Independent Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries</td>
<td>Paper</td>
<td></td>
</tr>
<tr>
<td>Machine Tools</td>
<td>Plastic</td>
<td></td>
</tr>
<tr>
<td>CONSUMER PRODUCTS</td>
<td>Cameras</td>
<td>Printer Cartridges</td>
</tr>
<tr>
<td>Televisions</td>
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<td></td>
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<tr>
<td>Refrigerators</td>
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Figure 2.3 Reverse Logistics Networks and Nature of Products: A framework
2.2.2 Review on Reverse Supply Chain Networks

Work done in the area of reverse supply chain network by earlier researchers is given in this section. Fleischmann et al (1997) provides a comprehensive survey on reverse logistics. The authors have reviewed different quantitative models used in distribution planning, inventory control and production planning areas of reverse logistics. They also describe different dimensions of the reverse logistics, which also includes forms of reuse, and potential actors involved in reverse logistics activities. The actors involved and their respective functions, including collection, testing, reprocessing are another important part of reverse logistics. A major distinction can be made between reuse by the original producer and reuse by a third party. This sets important constraints on the possibility of integrating forward and reverse logistics activities. The authors further quotes that from an original producer’s perspective the selection of the reuse system functions to carry out in-house involves major strategic trade-offs. Currently producers tend to perform remanufacturing in-house because of the specific product knowledge involved. By contrast, specialized companies often carry out recycling. This results in two categories of reverse flows. One comes back to original manufacturer-closed loop structure and another may use forward channels but reaching an outside recycler-bi-directional open loop structure.

Fleischmann et al (1997) also explained about the issues involved in reverse distribution. Reverse distribution is the collection and transportation of used products and packages. Reverse distribution can take place through the original forward channel, through a separate reverse channel or combination of the forward and reverse channel. The authors also describe that recycling lead to open-loop system and remanufacturing lead to closed loop system. The authors explain the relation between the forward network and reverse network, and how the forward network will be used in reverse
collection process. They also reviewed models for the separate reverse logistics networks and models partly using the original forward network for the reverse distribution, both are included in our literature review.

Fleischmann et al (2000) provides characteristics of logistics networks for product recovery on the basis of case studies. They have given the classification of product recovery networks based on degree of centralisation, number of levels, links with other networks, open or closed loop structure and degree of branch co-operation. In a closed loop network sources and sinks coincide so that product flows within the network. An open loop network, on the other hand has a one-way structure in the sense that flows enter at one point and leave at another point. The authors also highlight the importance of potential interaction between forward and reverse channels. Quantitative results on integration of facilities would be helpful for a better understanding of product recovery networks.

Fleischmann et al (2001) presented a generic facility location model and discuss differences with traditional logistics settings. This model was used to analyse the impact of product return flows on logistic networks. They have carried out a detailed numerical analysis based on two cases concerning copier remanufacturing and paper recycling. These cases served to illustrate the model and to investigate the impact of different return rates on the network design by means of parametric analysis. They addressed the question whether adding a recovery network to an existing forward network (sequential design) entails substantially higher costs than the simultaneous design of forward and reverse network (integral design). They found different results in both cases: while integral design, in general resulted in a more decentralized network, cost differences were significant only in the paper recycling example. It shows that the influence of product recovery is very much context
dependent. They also conclude that, in general, forward flows dominate the network design.

Flesichmann (2003) also provide a continuous network design model for reverse logistics. He also suggests that there may be synergies in terms of transportation and shared facilities if one uses forward network for reverse collection. He also addresses the compatibility issue between forward network and reverse network. In many cases, reverse logistics networks are not designed from scratch but are added on top of existing logistics network. The author has done a quantitative analysis of this problem and he suggests that there is enough flexibility in the design to successfully exploit potential synergies.

Based on the above review, the following important points emerge out.

- Forward network will have a larger role in reverse logistics.
- The efficiency of integration of both the forward and reverse networks is context dependent
- While integrating, it will have some impact on forward network in terms of capacity and location.
- It is clear that scope for integration of forward and reverse network is high and this can be further explored.
- In the case of recycling, the old products are not returned to manufacturer but sent to specialist recyclers. This leads to formation a bi-directional open-loop network, where manufacturer uses forward channel to collect the old products.
The design of supply chain network with this type of flow of products is not studied in detail by the previous research studies.

To get a clear picture about networks related to remanufacturing and recycling, a two level review of literature was carried out. First review is on separate reverse network designs with respect to old product recovery and remanufacturing, where it was not connected to the forward distribution network. The second one is on integrated networks, where the reverse network uses the forward network facilities for collection, storage and transportation. The second category also termed as closed-loop supply chains in the literature.

2.2.2.1 Review on Separate reverse network designs

Guilinan and Nwokoye (1975) provided one of the first analyses of reverse distribution networks, identifying four major types of reverse channels according to the actors involved. Outsourcing option was not considered in this study.

Caruso et al (1993) describe a solid waste management system, including collection, recycling and disposal. A multi-objective location-allocation model and some heuristics are used to plan the waste management system. The procedure results in the number and location of waste disposal plants, specification of the technology adopted and the amount of waste processed.

Kroon and Vrijens (1995) present a return logistics system for returnable containers, which was developed in a case study for logistics
service organization in the Netherlands. The system is concerned with the transportation, maintenance and storage of empty containers. A classical plant location model is formulated to analyze the number of containers, the number of depots and their locations.

Barros et al (1998) present a network for the recycling of sand from construction waste. Two types of intermediate facilities namely regional depots and treatment facilities have to be located. The model is a multi-level capacitated warehouse location model. Scenario analysis is used to cater for uncertainty in location of the demand points and in the return flows.

A mixed-integer programming model was developed by Spengler et al (1997) for recycling of industrial byproducts, which is applied to the German steel industry. Steel companies need to decide which recycling process or process chains are favorable from an economic point of view. The model is based on the multi-level capacitated warehouse location problem modified for the special problem structure.

Realff et al (2004) discussed about robust reverse production system design for carpet recycling. They developed a robust-mixed-integer linear programming model to support decision-making for reverse production infrastructure design. Their model seeks solutions close to the mathematically optimal solutions for a set of alternative scenarios identified by a decision maker.

Ammons, Realff, and Newton (1997) has developed a mixed integer programming model to support decision making for effective design and operation of a reverse production system associated with carpet recycling. This is a single time period model of the existing carpet recycling network established by DuPont in the USA. The mathematical programming model
maximizes the overall network profits as defined by the value of the final material minus the processing and transport costs and subject to conservation flow, capacity, and upper and lower bounds.

Spengler et al (2003) presented a case study on electronic scrap recovery. In order to consider the interactions between choice of scrap to be recovered (acquisition problem), disassembly and bulk recycling, a mixed-integer programming model for integrating planning of these stages is presented in this case study.

Jayaraman et al (2001) proposes a mathematical programming model and heuristic solution methodology. The solution methodology complements a heuristic concentration procedure, where sub-problems with reduced sets of decision variables are iteratively solved to optimality. Based on the solution from the sub-problems, a final concentration set of potential facility sites is constructed and this problem is solved to optimality. In a working paper of INSEAD on closed loop supply chains for refrigerators (Krikke et al 2000), the authors deal with the product and corresponding supply chain design for refrigerators. It presents a quantitative model to support an optimal design structure of a product, i.e. modularity, reparability, recyclability, as well as the optimal locations and goods flows allocation in the logistics system.

Kai-Ingo Voigt developed linear optimizing model taking the main aspects of industrial reverse logistic system of End-of-life vehicles. (Voigt 2001) He proposes two objective functions, one on cost minimization and another on minimization of environmental impact, which are to be optimized.

In a study on reverse logistic network design for copier remanufacturing (Oce Technologies, Venlo, The Netherlands),
(Krikke et al 1999) optimization involves choosing efficient locations for reverse logistics facilities as well as goods flows between these facilities. A mixed integer linear programming model is developed to optimize total operational costs and it also compares several scenarios. It concerns the installment of remanufacturing processes for one product line, where there is a choice from two locations in Venlo (NL) and one in Prague (Czech Republic).

Marien (1998) explains how businesses perceive reverse logistics as a competitive advantage. He claims that as industry take responsibility for post-consumer waste, they are striving to generate revenue or achieve cost savings-or at a minimum, keep from losing money from regulatory compliance.

Listes and Dekker (2003) presented a stochastic programming based approach by which a deterministic location model for product recovery network design may be extended to explicitly account for the uncertainties. This stochastic model was applied to a representative real case study on recycling sand from construction waste in The Netherlands.

Fernandez et al (2006) deals with the study of the design of a recycling chain for a certain type of WEEE, the mobile phones. The goal is to analyze the optimal design of the logistic network required to guarantee that the amount of wasted mobile phones obtained at the generation points is collected, managed and transported in an appropriate way to the destination points constituted by recycling companies. The problem falls into the category of the location and routing problem (LRP). The facilities considered in this study are recycling centers, intermediate consolidation points and collection centers.
A Genetic algorithm approach was used in their study (Min et al., 2006) on developing the multi-echelon reverse logistics network for product returns. This paper proposes a non-linear mixed integer programming model and genetic algorithm which aim to provide a minimum-cost solution for the reverse logistics network design problem involving product returns. This model considers explicitly, trade-offs between freight rate discounts and inventory cost savings due to consolidation and transshipment. The model and solution procedure enables reverse logisticians to determine the exact length of holding time for consolidation at the initial collection points and total reverse logistics costs associated with product returns. It also produced the multi-echelon reverse logistics configuration that considers the interplays between initial collection points and centralized return centers.

Motivated by the risk of re-processing used products in facilities of insufficient potentiality, this study proposes a method to identify potential facilities in a set of candidate recovery facilities operating in a region where a reverse supply chain is to be established (Pochampally et al 2003). In this study, the problem is solved using a method called physical programming. The most significant advantage of using physical programming is that it allows a decision maker to express his preferences for values of criteria (for comparing the alternatives), not in the traditional weights but in terms of ranges of different degrees of desirability, such as ideal range, desirable range, highly desirable range, undesirable range and unacceptable range.

**Summary**

Based on the review under section 2.3.2.1, in many cases separate independent networks are designed to collect and recycle old products without considering the existing facilities. The products are mostly of commodity character like construction waste, electronic scrap, industrial byproducts, and
bulk products like cars, copiers, and containers. The role of forward network facilities was very small in these networks. The question of BDOLSCN does not arise here, because the reverse flow is not happening through the forward existing network. These studies are pertaining to cases where, the reuse of components and reselling of refurbished products are not common. The other major observations are.

(a) Separate reverse supply chain networks are used mainly for bulk commodities like construction waste, steel, electrical and electronic scrap and carpet.

(b) Industry wide collection networks are fall under this category. The network mostly involves location of collection centers, inspection facility and recycling facilities.

(c) Some enterprises also design their own collection network separately. Most of the networks discussed are result of environmental legislation in that country.

(d) Some of these networks use external recycling facility for recycling and many OEM just sold the collected products to external recyclers.

(d) The mathematical tools used are MILP, heuristics, non-linear programming and stochastic programming.

2.2.2.2 Review on integrated reverse and forward supply chain networks (Closed-loop supply chain networks)

Fleischmann et al (1997) reviewed about reverse distribution and they provided some insight about actors involved in reverse logistics. Actors may be members of the forward channel, (e.g. Traditional manufacturers, retailers and logistics service providers) or specialized parties (e.g. secondary
material dealers and material recovery facilities). These distinctions set important constraints on the potential integration of forward and reverse distributing. While the forward supply chain in distribution management is a well-researched topic, the reverse supply chain has received scant attention.

There are at least three characteristics that differentiate a reverse logistics system from a traditional forward supply chain: (Jayaraman Guide and Srivastava 1999).

a. Most logistics systems are not equipped to handle product movement in reverse.

b. Returned goods cannot be transported, stored or handled in the same manner as in regular channel.

c. Reverse distribution costs may be several times higher than moving the original product from the manufacturing site to the consumer.

The authors also provide a closed loop logistics model for remanufacturing. They presented a 0-1 mixed integer programming model that simultaneously solves for the location of remanufacturing/distribution facilities, the transshipment production, and stocking of the optimal quantities of remanufactured products and cores (returned materials).

In a review of case studies, the authors (Britto et al 2003) reviewed 24 case studies on reverse logistics network structures. Their observations include,

1. Critical issues of remanufacturing are the location of the remanufacturing facility, how to ensure a sustainable volume
of products to be remanufactured and finally, how to reduce the uncertainty in the supply of cores (products to be remanufactured).

2. Both private and public networks exist, although several private ones were not successful. The public networks were created out of government interferences in order to reduce waste.

3. Recycling often requires expensive facilities and therefore is likely to be centralized. In order to be economically viable, sufficient volumes should be realized.

4. Product acquisition and collection network efficiency are major bottlenecks in the economics for private recycling networks.

The author described about reverse logistics network structures and design in detail (Flesichmann 2003). The author provided some insights about collection part of the closed loop supply chain. Analogous with the ‘last mile’ issue in distribution, transportation of a large number of low volume flows tends to render collection an expensive operation. Companies have explored several options for reducing transportation costs of the ‘first mile’. Rather than collecting goods, a company may install some drop-points where customers can hand over used products. For example, think of public glass or paper collection boxes and of consumer electronics handed in at retail outlets. While this strategy reduces transportation, additional storage space is required and this approach may be limited to relatively small, low value consumer products.

Flesichmann (2003) also provide a continuous network design model for reverse logistics. He also suggests that there may be synergies in
terms of transportation and shared facilities if one uses forward network for reverse collection.

Fleischmann et al (2001) focus on the consequences for original equipment manufacturers of adding product recovery operations to an existing production-distribution network. A fairly general mixed integer linear programming facility location model is presented that corresponds with the network of both forward and reverse flows.

IBM’s business activities involve several closed-loop chains, concerning end-of-lease product returns, buy-back offers, environmental take-back, and production scrap. IBM considers a hierarchy of reuses options on a product, part, and material level. In this way, product recovery accounts for an annual financial benefit of several hundred million US$ and at the same time reduces land filling and incineration to less than four per cent of the volume processed (IBM 2000).

In the Netherlands manufacturers and importers of electric and electronic equipments are legally obliged since 1999 to take-back and recover their products after use. In response, the manufacturers have set up a joint collection and recycling network managed by the branch organization NVMP. The system includes a network of regional storage centers where products that are collected via municipalities and retailers are sorted and consolidated and then shipped to some recycling subcontractors (NVMP 2001).

DuPont operates several facilities for recycling nylon from used carpeting material. A large-scale plant in Tennessee (USA) processes carpet waste collected from carpet dealerships in major US metropolitan areas. Reusable content is separated from waste and is recycled for several
applications, including new carpet fibers and automotive parts (DuPont, 2001).

Although on the surface it may seem the best strategy to recall products from distributors and customers through existing distribution channels, this may not be wise (Ballou 1992). One danger is the possibility of contamination of the good product flowing in the channel with the recalled product (for example, tainted off-the-shelf pain medicine versus good product). In such cases, the recalling firm may establish a separate channel to specifically handle the recall. In their working paper, the authors (Guide and Wassenhove 2000) described different closed-loop supply chains practiced in different industries like Cellular phones, Copiers, Cameras and Print Cartridges.

Savaskan et al (2004) addresses the problem of choosing the appropriate reverse channel structure for the collection of used products from customers. The options tested are, direct collection by manufacturer, collection through retailer and collection by third party. The collection through retailer was the most effective undertaker of product collection activity for the manufacturer.

Klausner and Hendrickson (2000) provide reverse logistics strategy for product take-back in the case of power tools in Germany. In the take-back program for power tools in Germany, costs exceed revenues for recycling power tools. They developed a model that allows them to determine the optimal unit cost of reverse logistics. The model can be used to select a suitable reverse logistics system for end-of-life products.

Xerox’s environmental strategic goal is to become a waste-free company. This ideal permeates the life cycle of Xerox products: waste-free
products from waste-free factories for waste-free offices. Xerox has witnessed numerous benefits from implementing this strategy; by using design-for-the-environment principles, it has redesigned products and packaging to support product recovery and to reduce resource and energy consumption (Maslennikova and Foley 2000).

In their article, Beamon and Fernandes (2004) described a supply chain configuration for product recovery. In this work, they studied a closed-loop supply chain in which manufacturers produce new products and remanufacture used products. The decisions to be made are: which warehouses and collection centres should be open, which warehouses should have sorting capabilities and how much material should be transported between each pair of sites. The multi-period integer-programming model uses the present worth method to jointly analyze investment and operational costs. Engels et al (2003) have developed a hybrid approach to establishing a closed-loop supply chain for spent batteries that combines an optimization model for planning a reverse supply chain network and a flowing sheet process model that enables a simulation tailored to potential recycling options for spent batteries in the steel making industry. Their result shows that almost complete recycling of spent batteries can be achieved by transforming the current structure into a modified recovery network.

Grave et al (2003) worked on a project exploiting product returns as a source of spare parts in IBM. The major decisions involved are the channel design, what recovery opportunities to use, and coordinating alternative supply sources. The major outcome was cutting down of the procurement cost and recovery channel design.

Wassenhove et al (2003) discussed about the challenges of closed-loop supply chains. The authors said that the closed-loop supply chains
differ significantly from forward supply chains in many aspects and these are not well understood in many contexts. The progress in this field is very slow since closed-loop supply chains are rarely considered as value-creating systems, and much of the focus is on the operational aspects, rather than the larger strategic issues.

Schultmann et al. (2006) provide different design options for a closed-loop supply chains for end-of-life vehicle treatment in Germany with concentration on how reverse material flows can be handled with regard to reintegrate them into their genuine supply chains. Introducing a problem-tailored algorithm, results of several closed-loop supply chain scenarios are discussed.

Kumar and Malegeant (2006) describe the closed-loop supply chain design for Nike and focuses on the collection challenges companies have been facing. They also describe the involvement of a non-profit organisation with Nike in creating value from returns.

Spengler (2003) provides a decision support system for electronic scrap recycling companies. A cost-efficient management of material flows between suppliers, producers, customers, and recycling companies require an integrated information management as well as advanced planning systems.

Daskin et al. (2004) have extended uncapacitated fixed charge location model to include both reverse and forward flows. Two models assume that either reverse sites are a subset of the forward sites (appropriate for products in the beginning of their lifecycle) or that forward sites are subset of reverse sites (for products at the end of their lifecycle). The final model, which is appropriate for products in the middle of the lifecycle, provides economic incentives for co-location of forward and reverse facilities. All
these models were solved using Lagrangian relaxation. This paper provides a clear support for an integrated network for reverse logistics.

The Ministry on Environment and Forests of Government of India has brought a legislation to streamline the process of unauthorized smelting of Lead from used batteries. And as per the Batteries (Management and Handling) Rules, 2001 gazetted under the Environmental Protection Act 1986, lead can be re-cycled only through an eco-friendly process (Business line, 2003). It means every battery manufacturer in India has to take responsibility of taking back the old batteries from customers and recycle it with environmentally friendly process. It involves huge cost and issues like inspection, transportation, warehousing, recycling and usage of recovered lead for further manufacturing.

Summary

The salient features of review under section 2.3.2.2 is given here,

- Closed-loop supply chains are integral networks of both forward and reverse networks.
- Mostly these networks are forward driven
- Most of the cases mentioned in the literature are follows closed loop supply chain networks. All the old products are recovered through the forward network and recycled or remanufactured by the original equipment manufacturer. In this case, the loop is completed.
- In some industry like automotive batteries, the products returned are handled by forward network up to some point and after that it is sent to external recycling or remanufacturing
plants by the manufacturer. Many times, the original manufacturer does not use the recycled materials. In this case, the products are flowing in both directions but the loop is not closed since the products do not reach the manufacturer. These networks are termed as **bi-directional open loop supply chain networks**. The work related to this kind of network is very limited and it needs further investigation.

The design of reverse supply chain network with partial use of forward network facilities along with some new storage facilities and external recycling facilities can be considered as new case. When external recycling is used and the manufacturer does not use or redistribute the recycled materials, then the loop is not completed even though the products flowing through the forward network. In such situations, given the potential location of external recycling plants, it may not be always economical to operate reverse collection process with the existing forward distribution network of facilities. This situation leads to fresh look at the network design and its configurations and the modification of the existing network to suit the external recycling. This may result in changes in the forward network with some addition to number of facilities and the nature of flow of materials.

Even though various alternatives are given in the literature to handle reverse flow of products, the comparative analysis of different network configurations for both forward and reverse logistics is minimal in the literature.

The tools used in the literature related to closed-loop supply chains are mixed integer linear programming, Langrangian relaxation heuristics, extended approximation methods, and some stochastic methods.
2.3 REVIEWS ON PERFORMANCE EVALUATION APPLIED TO SCNS

Performance measurement is defined as the process of quantifying the effectiveness and efficiency of a process (Neely 1995). There are different performance measures used to evaluate a supply chain. The evaluation approaches are many and a detailed review is required to know the use of different approaches.

In his paper, Chan (2003) presented the formalization of both quantitative and qualitative performance measures for easy representation and understanding. Under quantitative measures he has given cost and resource utilization as major measure of performance. Labour, machine, capacity and energy utilization are measured for supply chain. Under qualitative measures, quality, flexibility, visibility, trust and innovativeness are used. The quality is measured in terms of customer satisfaction, customer response time, lead-time, on-time delivery, fill rate, stock out probability and accuracy of products. The flexibility is measured in terms of labour flexibility, machine flexibility, material handling flexibility, routing flexibility, and operation flexibility, flexibility in volume, delivery, mix, and expansion. Visibility for a supply chain is important for accurate and fast delivery of information. It is clear that measurement of visibility is the time and accuracy of information transfer. Trust is measured in terms of consistency and variability. Innovativeness is measured in terms of successful launching of new products and use of new technology in supply chain.

An overview and evaluation of the performance measures used in supply chain models are presented and a framework for the selection of performance measurement systems for manufacturing supply chains also given here (Beamon 1999). She has given three types of performance
measure type-Resources, Output and Flexibility. Under resources, the measures are total cost, distribution costs, manufacturing cost, Inventory and return on investment. Under output, sales, profit, fill rate, on-time deliveries, stock-out probabilities, customer response time, manufacturing lead-time, shipping errors and customer complaints are used for measurement. Flexibility is measured in terms of volume, delivery, mix and new product.

Beamon (1996) presents a number of characteristics that are found in effective performance measurement system and these are inclusiveness, universality and consistency. Besides analyzing the measures based on their effectiveness, benchmarking is another important method that is used in performance evaluation.

The use of a single performance measure is attractive because of its simplicity. However, one must ensure that if a single performance measure is utilized, this measure adequately describes the system performance. Beamon (1996) identified and evaluated various individual supply chain performance measures. The author concluded that significant weakness were present in each of the measures evaluated, based on such criteria as inclusiveness, universality, measurability and consistency.

In order to study the large number of performance measures available, researchers have categorized them. Neely et al. (1995) presents a few of the categories in the literature, including: quality, time, flexibility, and cost.

Supply chain models have predominantly utilized two different performance measures; (1) Cost and (2) a combination of cost and customer responsiveness. Cost may include inventory costs and operating costs. Customer responsiveness measure includes lead-time, stock-out probability,
and fill rate. Table 2.1 below summarizes the supply chain models and their respective performance measures used.

**Table 2.1 Supply chain models and performance measures**

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<th>Measure</th>
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<td>Customer responsiveness</td>
<td>Lee and Billington (1993)</td>
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<td>Flexibility</td>
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Beamon and Chen (2001) provide five performance measures used to study the performance of various operational factors on conjoined supply chains. The study is accomplished via experimental design and simulation analysis.

Raghavan and Viswanadham (1999) have investigated dynamic modeling techniques for analyzing supply chain networks using generalized
stochastic Petri nets (GSPN). The modeling method accounts for both the logistics process as well as the interface processes that exist between any two members of the supply chain. The customer order arrival is assumed to be Poisson and the service processes at various facilities of the supply chain are assumed to be exponential.

Raghavan and Viswanadham (2001) have described how queuing networks can be used to model the performance of supply chain networks. They presented analytical models for evaluating the average lead times of make-to-order supply chains. They explained the use of fork-join queuing networks to compute the mean and variance of the lead-time.

Raghavan and Viswanadham (2002) investigate use of stochastic network modeling techniques for analyzing supply chain networks. This paper describes stochastic network models for computing the average lead times for make-to-order supply chains. The authors provide the analytical methods for supply chain network modeling, which includes series-parallel graphs, Markov chains, queuing networks, Petri nets and system dynamics models. The authors have used serial-parallel graph models for analyzing supply chain networks.

Raghavan et al (2003) have presented how queuing models can be used for conducting performance analysis of supply chains. They have presented how discrete time queueing models, continuous time bulk queueing models and simple Markovian models can be used to model complex decisions in determining the optimal inventory levels in CONWIP based supply chains.

Kamath (2003) explained the use of parametric decomposition approach to analyze supply chain networks. He has suggested the use of
queueing and production-inventory models based on the PD approach as the mathematical basis for such rapid analysis tools.

Biehl et al (2007) provide a simulation of carpet reverse logistics supply chain and they used a designed experiment to analyse the impact of the system design factors as well as environmental factors impacting the operational performance of Reverse logistics system.

Dong and Chen (2004) have developed a network of inventory-queue models for the performance modeling and analysis of an integrated logistic network. The authors have developed an analytical modeling framework where the interdependencies between model components are captured. Later a network of inventory-queue models for performance analysis was developed. The results from the analytical performance evaluation model and those obtained from the simulation are compared.

Kara et al (2007) presented a simulation model of a reverse logistic network for collecting end-of-life appliances in the Sydney Metropolitan area. The model calculates collection costs in a predictable manner. Moreover, it provides a tool to understand how the system behaves by carrying out what-if analysis.

**Summary**

Based on the review under section 2.4 an array of methods is used in the literature for modeling the networks for performance evaluation. Queuing networks, systems dynamic modeling and simulation modeling are the widely used methods for performance modeling. (Raghavan and Viswanadham, 2001, Jain, 2002, Raghavan, 1998, Chang and Makatsoris,
Queuing networks is used extensively to model the supply chain for its evaluation.

Solving a network of queues for determining the steady state average waiting times and mean queue lengths are well researched area. If the arrivals are Poisson and service times are exponentially distributed, then we use either Jackson’s results or Gordon-Newell’s results, depending on whether the networks are open or closed, respectively. These approaches are called as product-form approach, (Viswanadham and Narahari 1992). On the other hand, if the arrivals and service times are non-exponential, and are generally distributed with given mean and variance, then seeking exact analytical expressions for computing the performance measures of interest is a futile exercise unless the distributions have certain nice features. In general, one resort to approximate methods of analyzing the queuing networks. A fundamental change occurred in mid eighties where there was a paradigm shift from exact analysis of an approximate model to approximate analysis of a more exact model (Whitt 1983). Whitt proposed a queuing network analyzer (QNA), a decomposition based approach. An analysis method known as parametric decomposition method based on two-moment queuing approximations becomes popular.

Another approach to analyze a queuing network is simulation, which is also an approximation approach. In simulation of a queuing network, the arrival and service times can be modeled exactly as observed in reality and the performance measures can be estimated.

Most of the literature deals with performance analysis of forward supply chains networks only. So there is a need for conducting performance evaluation for reverse networks and also for integrated forward cum reverse network. The performance measures also to be developed specifically for
reverse logistics network. The literature does not provide any specific performance measure except the cost of the network.

2.4 SYSTEM DYNAMICS MODELING APPLICATIONS TO SCN

System Dynamics is a computer-aided approach for analyzing and solving complex problems with a focus on policy analysis and design. Initially called ‘Industrial Dynamics” (Forrester, 1961), the field developed from the work of Jay W. Forrester at the Massachusetts Institute of Technology. This approach uses a perspective based on information feedback and delays to understand the dynamic behavior of complex, physical, biological and social systems. Forrester (1961) defines Industrial Dynamics “the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy”.

Lane (1997) precisely summarizes Forrester’s approach to modeling and understanding management problems, as “Social systems should be modeled as flow rates and accumulations linked by information feedback loops involving delays and non-linear relationships. Computer simulation is then the means of inferring the time evolutionary dynamics endogenously created by such system structures. The purpose is to learn about their modes of behavior and to design policies which improve performance”.

System Dynamics has been applied to a wide range of problem areas. It includes work in corporate planning and policy design (Forrester

Towill et al (1992) have presented an industrial dynamics model of supply chain design. This model deals with demand amplification, and application of JIT on supply chain dynamics.

Vos and Akkermans (1996) use a system dynamic modeling of decision making in a supply chain. It is based on three principles: the identification and design phase of strategic decision making, the active participation of decision makers and an integral chain approach as the underlying conceptual model. It is enhanced by system dynamics modeling to capture the dynamic nature of supply chain.

Spengler and Schroter (2003) have developed tools for information management and spare-parts management in closed-loop supply chains. Using system dynamics, the authors modeled an integrated production and recovery system for supplying spare parts to evaluate possible strategies for meeting spare-parts demand for electronic equipment in the end-of life service period.

Georgiadis and Vlachos (2004) used system dynamics to model reverse logistics. This study compares disposable cost, and remanufacturing cost when there is an increase in returns and increase in capacity of remanufacturing respectively. It also analyzes the flows with respect to change in capacity.
Tan and Kumar (2006) presented a system dynamic model to maximize the profit from reverse logistics operations. The results from the model indicate that part replacements from suppliers are more profitable than refurbished computer parts. In addition, transportation delay and supplier delay in processing returns have significant impact on the viability of the reverse logistic regardless of return volumes.

Summary

Based on the review as per section 2.5, the application of system dynamics in supply chain management is more of policy evaluation. Different policies are tested in the supply chain models and results are given. In the case of reverse networks, cost and profits are used as important measures of performance. This method can also be used to evaluate the integrated reverse and forward network for different policy decisions like inventory, incentive system and facility decisions. In most of the reverse supply chain network, the returns are driven by environmental legislation and economic reasons. It is required to motivate the customers to return the old products. The incentive system and other external factors will play a major role in returns and in reverse supply chain network. The different players in the network may act independently or may act as a team in the collection process. There is a requirement to study the different factors, which affect this integrated forward and reverse network system.

2.5 OVERALL SUMMARY OF LITERATURE REVIEW

The overall literature review is summarized in terms of supply chain type, methods used to design and evaluation of supply chain networks. The summary is presented in Table 2.2.
### Table 2.2 Summary of Literature review and Research gap identification

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FN - Forward network  
RN - Reverse Network  
IN - Integrated Network  
FT - Flow time  
GA - Genetic Algorithm  
PD - Parametric Decomposition  
MINLP - Mixed Integer Non-Linear Programming  
MILP - Mixed Integer Linear Programming
2.5.1 Observations from Table 2.2

From the information compiled in Table 2.2, we observe the following:

(i) The number of research publications in the area of integrated supply chain networks is relatively low when compared to forward and reverse supply chain networks.

(ii) Most of the researchers have used mathematical programming for optimal design of facilities in the networks. Few researchers have attempted queuing networks and simulation for evaluating the performance of supply chain networks.

(iii) From the above limited literature review, it would appear that investigation into mathematical modeling of BDOLSCN types of supply chain networks and related system performance under various configurations is a fruitful area of research.

(iv) The policy issues related to incentive for product returns and its dynamics related to returns in reverse supply chain networks are another opportunity for further investigation to model policy decision making.

Hence it is decided to take this as a research gap and formulate research problem.

To bridge these gaps the following objectives and research framework are proposed.
2.5.2 Objectives of the Research

The objectives of this research work are

(a) To identify and evaluate all possible configurations of BDOLSCN under integrated networks, for optimal location of facilities and allocation of demand.

(b) To evaluate the performance of the selected networks in terms of flow time, and inventory to detect suitable configuration for forward and reverse operations.

(c) To study the impact of incentive system on the volume of used product returns in reverse supply chain networks.

For the above objectives, the proposed research framework is presented in Figure 2.4.
Figure 2.4 The Research Framework
(i) Formulation of Supply chain network configurations for the case study organization

(ii) Development of mathematical programming models for each configuration (MILP) with an objective to minimize total operating cost (transportation, inventory and facility cost) subject to constraints on demand, capacity and supply.

(iii) Solution to the MILP models to find out optimal location of facilities (warehouses, franchisees and smelters) and optimal allocation of demand to the facilities.

(i) Development of queuing network model of forward and reverse supply chain networks

(ii) Simulating the queuing network model to estimate performance of network configurations.

(i) Development of system dynamic model of reverse supply chain network

(ii) Simulating system dynamic model to evaluate policy issues related to incentive pricing for increasing the volume of used products.

(i) Guidelines for organizations who are following forward supply chain network for product distribution and return network for used product collections.

(ii) Summary of research contributions

Figure 2.4 Continued