CHAPTER 2

LITERATURE REVIEW

The importance and the evolution of RL, particularly in the preservation of environment, have played a major role in creating the research interest among academicians and practitioners towards it and also for the recent number of increased publications in this field.

This chapter is divided into five sections. In each section, some of the researches in defined problems is highlighted. The first section introduces the review methodology used. In the second section, the research on RL network design is carried out in detail as per the derived framework. The third section discusses location routing problems along with the solution methods by using the developed classification scheme. The fourth section summarizes the review of RL network design and LRP. Research findings and gaps are provided in the fifth section.

2.1 REVIEW METHODOLOGY

The main goals of this review are:

- To analyse the impact of various issues on RL network design and LRP
- To identify the research gaps available in current literature on combined LRP application in RL network design
• To analyse the various LRP solution methods for effective implementation

• To provide future insights in designing an efficient integrated RL network suitable for different real life scenarios

To conduct the search, a number of key words within each area of interest was initially identified, and, the following keywords were selected:

Reverse Logistics, Reverse Supply Chain, Green Logistics, Green Supply Chain, Closed loop supply chain, Sustainable Logistics, Sustainable supply chain, Location Routing Problem, Combined Location Routing Problem, LRP in Reverse Logistics.

Sciencedirect, ingenta connect and emerald insight data bases were considered for collecting relevant literature with respect to the keywords selected. Prestigious scientific journals were focused in the various categories such as OR and its applications, production and operations management as well as environment protection issues and their applications which were related to reverse logistics. Some books, renowned conference proceedings and scientific reports were also referred for obtaining the conceptual issues of reverse logistics and location routing problem.

2.2 REVIEW ON REVERSE LOGISTICS

Growing interest in environmental protection is visualised through availability of abundant literature on reverse or green logistics. Several comprehensive reviews of the reverse and closed loop supply chain research were published by a number of authors (Gungor and Gupta 1999; Dowlatshahi 2000; Guide, 2000; Fleischmann, 2001; Fleischmann 2003; Prahinski and Kocabasoglu 2006; Rubio et al 2006; Srivastava 2007; Mead et al 2007; Srivastava 2008a; Pochampally et al 2009; Pokharel and Mutha 2009;
Setaputra and Mukthopadhyay (2010) which surveyed and chronicled the past literature on reverse or green logistics.

This review is different from the above articles in such a way that here, the effect of various issues on RL network design have been discussed in a detailed manner.

To the best of knowledge, none of the earlier or previous studies dealt with the effect of various issues on the RL network design in detail. In this review, focus has been intensified to those articles that deal with different aspects of the RL network design particularly recovery strategy as well as network design and capacity for efficient RL collection process. The main motive behind this review is as follows. The collection cost is the highest among the RL costs and the existence of a less standardized RL collection network necessitates the design of the successful collection network for returned products and to maximize the use of resources (Rogers and Tibben-Lembke 1999). As reported by the Reverse Logistics Executive Council, US firms have already lost billions of dollars on account of the inefficient handling of return flows. Rubio et al (2006) have described in their review article that there were fewer articles in the area of the management of the recovery and distribution of end-of-life products. Pokharel and Mutha (2009) also stressed in their article that more concentration has to be given to the management of collection centers. These form the basis for our review analysis.

Based on the published articles, those articles that are related to our focus were sorted out. During the sort-out process, articles that deal with inventory related costs and its corresponding aspects were omitted in order to limit the number of articles. Then in-depth review analysis has been carried out on the selected articles as per the framework designed by Pishvaee et al (2010) which is shown in Figure 2.1.
Figure 2.1 Reverse logistics framework

This section explicitly reviews the research work carried out in reverse logistics as per the framework provided in Figure 2.1. Each subsection provides a detailed classification of the various issues and discusses in detail its effect on the RL network design.

2.2.1 Reverse Logistics Network Stages

It is evident from the collected articles, that the open loop system (Barros et al 1998; Marin and Pelegrin; 1998; Louwers et al 1999; Krikke et al 1999; Jayaraman et al 2003; Le Blanc et al 2004; Lieckens and Vandaele 2007; Aras and Aksen 2008a, 2008b; De Figueiredo and Mayerle 2008; Demirel and Gokcen 2008; Du and Evans 2008; Srivastava 2008a; Aksen et al 2009; Grunow and Gobbi 2009; Qin and Ji 2010) was more focused rather than the closed loop system in earlier days. Recent research articles on integrated forward/reverse logistics characteristics replicate real life application and emphasizes the importance of the closed loop system (Jayaraman et al 1999; Fleischmann et al 2001; Shih 2001; Scultzmann et al 2003;
Logozar et al 2006; Min et al 2006a; 2006b; Salema et al 2006; Ko and Evans 2007; Lu and Bostel 2007; Salema et al 2007; Uster et al 2007; Lee and Dong 2008; Min and Ko 2008; Neto et al 2008; Rivera and Ertel 2009; Kara and Onut 2010; Xanthopoulos and Iakovou 2010; Wang and Hsu 2010). Researchers started focusing real issues in the network design rather than the hypothetical cases.

It is also evident from the analysis that very few articles (Beamon and Fernandes 2004; Lee et al 2009; El-sayed et al 2010; Salema et al 2010) considered the multiple number of stages required for the real implementation of the closed loop system. The consideration of the multiple number of stages and the flows between them surely reflect original characteristics of the closed loop system.

2.2.2 Problem Definition

Numerous issues have been considered while modeling the RL network, all those issues are classified in a detailed form in this section which is depicted in Figure 2.2. Each subsection gives the description of the effect of each issue on the RL network design.

2.2.2.1 Effect of Facility Capacity

In the RL problems, if the facilities available have a certain capacity to accommodate or carry the flowing products/materials, then the facility is termed Capacitated (Ca) if there is no restriction limit for capacity then it is termed Uncapacitated (UC). Uncapacitated facility type is suitable for the dynamic RL environment, where it is very hard to predict the supply of the returned products and very difficult to accommodate the returned products in the available capacitated type facilities. Similarly the capacitated facility type is more suitable for the static RL environment, where the supply
of the returned products can be predicted and under utilization of the available
uncapacitated type facilities that will increase the total cost can be avoided.
While analyzing the articles selected for review, it has been found that most
of them belong to the capacitated (Ca) type. Very few articles deals with the
Uncapacitated (UC) type facility (Marin and Pelegrin 1998; Krikke et al
1999; Fleischmann et al 2001; Lu and Bostel 2007; Uster et al 2007; Aras and
Aksen 2008a; 2008b; Aksen et al 2009; Rivera and Ertel 2009). The
uncapacitated facility location problem can also be treated as a Fixed Charge
Facility Location Problem (FCFLP) and in an article it was defined as the
Uncapacitated Fixed Charge Facility Location Problem (UFCFLP) (Rivera
and Ertel (2009)).

2.2.2.2 Effect of Demand

Reverse logistics is characterized by one major constraint with
respect to supply of returned products which is considered as demand in RL
networks. Supply in recovery networks is an uncertain and hard to forecast
variable as collectors, remanufacturers and recyclers can hardly predict the
quantity as well as the quality of the products that will be returned. Both these
uncertainties (quantity and quality) are essential elements to take into
consideration when implementing the reverse network. For example, a high
quality product might require better transportation which can lead to higher
transportation costs, whereas lower quality products might require more
extensive remanufacturing which could increase the processes’ costs
(Fleischmann et al 1997).
Figure 2.2 Classification of issues in problem definition
In addition, the uncertainty regarding the number of returned products creates complications when it comes to scheduling the different processes and planning efficiently the transportation required. In reverse logistics, where the products are pushed back into the supply chain, the forecasting tasks can be hard to accomplish (Kumar and Yamaoka 2007). If the returns are greater than expected, one might not have sufficient storage space or sufficient equipment to process all the products quickly. The opposite situation can occur where too few products are returned. Therefore, the success of an efficient reverse network is “highly dependent on ensuring sufficient volumes of input materials” (Knemeyer et al 2002).

Some companies have explained to researchers how they cope and deal with supply uncertainties. For example, Kodak recycles its single-used cameras and creates new ones with the returned ones. The challenge for Kodak is to forecast the supply in order to create the appropriate balance between new parts and remanufactured parts when making new single use cameras. Kodak’s forecasting technique is to estimate the future return products based on sale information and the average life-expectancy of the product. This technique has been employed for some years and has greatly reduced their inventory costs.

It has been shown, through other researches, that most companies will use the same technique as Kodak, based on sales and lifecycle variables, to forecast the possible returns. In addition, different authors have also created theoretical models to forecast supplies based on those variables.

Demand is known to be deterministic if it is predictable for any situation, and is termed stochastic if it is unpredictable one. Deterministic (D) demand has been assumed as a type of demand in most of the literature. The stochastic (S) demand reflects the real scenario of any situation which has been focused in very few articles.
For the studies of the logistics network planning problem under uncertainty, Lee et al (2009) developed a hybrid simulation optimization method for production planning of dedicated remanufacturing under uncertainty.

### 2.2.2.3 Effect of Flow Capacity

In any RL network, if there are flow conservation constraints or there is any restriction to the capacity of flow of materials/products between facilities then it belongs to capacitated flow (CF) and if there is no flow capacity constraints, then it is termed as uncapacitated flow (UCF). Even though the capacitated flow (CF) type appeared in very few articles, it will increase the utilization rate of any facility as well as reduce the idleness or overload of any facility by means of balanced allocation of available resources.

Flow balance between incoming flow and outgoing flow of an initial collection point has been formulated (Min et al 2006a; 2006b). Lee and Dong (2008) and Wang and Hsu (2010) formulated the flow conservation constraints for the flow of forward products and EOL returned products between different stages. Capacity balance between rework centres has been specified as a flow conservation constraint by Srivastava (2008a). Maximum and minimum limits for the flow of products between different stages were established by Salema et al (2010).

### 2.2.2.4 Effect of Time Horizon

In most of the articles, the time horizon has been assumed as a single period. Considering all the variables or parameters in single period may result in static RL environment in which a used parameter or variable will
have a single value with respect to time. But a multi-period horizon may result in a dynamic RL environment in which a used parameter or variable will have multiple values with respect to time that ultimately project a real time life scenario. It has been considered in fewer articles compared to a single period. Beamon and Fernandes (2004) formulated a strategic level problem in which multiple periods were used uniquely for the purpose of considering the time value of money.

Ko and Evans (2007) assumed that products and product returns are known over the planning time horizon during executing their contracts such as a month, half a year, one year and so on.

Different collection periods were fixed for different collection points by Min et al (2006a). Then, Min et al (2006b) assumed the volume of returned products as well as all decision variables in multiple periods. Later, all model parameters and decision variables were considered in multiple periods by Min et al (2008). A bi-level optimization model was developed to determine the disposition decision for refrigerators, washing machines and passenger cars in the Indian context using data for product returns from literature by Srivastava (2008b). Various decisions such as the disposition decisions, the sites to be opened, the capacity additions at any period of time as well as the number of products of a particular grade that are to be processed or sold during a particular period of time were decided by the model. Then the same model with some variations was solved by Srivastava (2008a) using decomposition method.

2.2.2.5 Effect of Number of Facilities to be Opened

In some cases, the total number of facilities to be opened may have been fixed before solving the model, which is referred as the exogenous
(determined) type. But in most cases, the number of facilities to be opened may have not been fixed and by solving the model it will be determined, which is known as the endogenous (Undetermined). Although the exogenous type of facility may have certain advantages, it may lead to under utilization or over utilization or idleness of any facility, unbalanced allocation of available resources, excessive workload to labour which ultimately increases the total cost and reduces the overall performance of any RL network. Contrary to the above, the endogenous type of facility may avoid these limitations and may project the actual requirement of the number of facilities to be opened by solving the proposed model.

The number of the collection centres to be opened for the returned product collection network is fixed (Aras and Aksen 2008a; 2008b; Aksen et al 2009). Three locations were fixed for processes preparation and reassembly of returned copiers by Krikke et al (1999). Lee and Dong (2008) assumed that the number of the hybrid processing facilities to be built up for EOL computers recovery was known in advance. Wang and Hsu (2010) formulated a constraint that the total number of facilities to be opened is limited for a proposed closed supply chain network.

2.2.2.6 Effect of Product

The types of products that are involved in the RL network also have an influence over its performance. Single product type will reduce the problem complexity. Multi-product type will reflect the real life RL characteristic but it will increase the problem complexity. Recent publications reveal that the multi-product type is chosen for obtaining the real characteristic of RL network.
In earlier days, the single commodity/product RL problems dominated the literature. However, real-world reverse logistics rarely involves a single product. To reflect this reality, Min et al (2005) proposed a non-linear mixed-integer programming model and a Lagrangian relaxation heuristics for solving the multiple product return problem within both the forward and the reverse logistics frameworks. Similarly, Salema et al (2006) extended a single product model to a multiple-product, capacitated recovery network model for performance comparison. Then, Salema et al (2007) adopted the same multiple-product concept to a capacitated RL model with uncertainty. Later, Salema et al (2010) made further refinement of their earlier models by simultaneously designing and planning the supply chains with reverse flows. In the meantime, Min et al (2006a) proposed a mixed-integer, nonlinear programming model (MINLP) and a genetic algorithm that can solve the reverse logistics problem involving both spatial and temporal consolidation of returned products of multiple varieties. By the same token, Min et al (2006b) used the same type of algorithm for determining the number and location of centralized return centers involving multiple product returns from online and retail sales. Min and Ko (2008) solved the multiple-product RL problem involving the location and allocation of repair facilities for 3PLs. Similar efforts to consider multiple-product varieties within the reverse logistics network have continued as illustrated by other published studies (Shih 2001; Ko and Evans 2007; Srivastava 2008a; 2008b; Lee et al 2009; Grunow and Gobbi 2009).

2.2.2.7 Effect of Incentive on Returns

To motivate the consumers to recycle their used products, some firms and governments began to offer incentive payments as “carrots.” For example, the Massachusetts Department of Environmental Protection (DEP)
provided per ton incentive payments to qualifying municipalities for each ton of recycled materials. Boyaci et al (2006) is one of the first to incorporate the incentive-based collection of returned products into their modelling effort. Following suit, Aras and Aksen (2008a) analyzed an uncapacitated Collection Center Location Problem (CCLP) for incentive-and distance-dependent returns. Later, Aras and Aksen (2008b) developed a p-median model for solving the CCLP under a pick-up policy in which vehicles of limited capacity depart from the CCs to collect the used or returned products from the customers. Aksen et al (2009) presented two bi-level programming models to take into account the subsidization agreement between the government and a company engaged in the collection and recovery operations. Ge et al (2009) also proposed a three-stage, mixed-integer nonlinear programming model for solving a reverse logistics network problem with incentive payment that was concerned with the optimal number and locations of the collection and reprocessing facilities.

The return in which the effect of incentive is also taken into account is termed as Incentive Dependent (ID) return and that in which it is not considered can be termed as Incentive Independent (IID) return. As per the analysis, it is evident that Incentive Dependent (ID) return has been considered in very few articles.

2.2.2.8 Effect of Outsourcing

Recently, more and more companies are outsourcing most or all of their logistics activities to third party logistics providers especially reverse logistics activities. In general, the 3PLs often perform reverse activities better, and their customers find that using the 3PLs will reduce the administrative hassle of doing it themselves. So the 3PLs have become specialists in
managing the reverse flow, and performing key value-added services, such as remanufacturing and refurbishing.

Outsourcing (OE) by 3 PL for collection and/or processing returns was focused by some authors in their publications. Most of the selected literature reveals that the collection and the processing returns were performed by the companies through their own effort (SE). Ko and Evans (2007) presented a mixed integer nonlinear programming model for the design of a dynamic integrated distribution network for 3PLs and also to consider the integrated aspect of optimizing the forward and return network simultaneously. Min et al (2005) dealt with the design of a distribution network for 3PLs, considering integrated forward and reverse flows. The network for 3PLs consists of client’s facilities, warehouses/distribution centers, collection centers, and market places. They proposed a mixed integer-programming model for the design of an integrated distribution network and then explored potential effects from integrated forward and reverse flows.

The main advantage of outsourcing services to the 3PLs is that the 3PLs allow companies to get into a new business, a new market, or a reverse logistics program without interrupting forward flows; in addition, logistics costs can be greatly reduced (Ko and Evans 2007).

2.2.3 Mathematical Model

A few works related to reverse logistics in context with any type of mathematical model are discussed in this subsection and the types are classified as shown in Figure 2.3.
The nature of the model would be like the Mixed-Integer Linear Programming (MILP) for the most frequent cases (Barros et al 1998; Jayaraman et al 2003; Le Blanc et al 2004; Chandiran and Rao (2008)). MILP will become as Mixed-Integer Non-Linear Programming (MINLP) when additional factors such as incentive price paid to the collecting agents have been considered (De Figueiredo and Mayerle 2008; Aras and Aksen 2008a). MILP will become Stochastic Mixed-Integer Linear Programming (SMILP) when uncertainty in demand is considered, which has been focused to get the dynamic RL environment. Bi-level Programming (BP) is another type of mathematical model in which the problem is solved on two levels. This type of model was focused by Aksen et al (2009) in which the maximization of profit for the collecting agents and the minimization of subsidy paid by the government have been simultaneously considered and solved in a two level manner.

2.2.4 Objectives

Considering the mounting reverse logistics costs that account for about a half percent of the total U.S. Gross Domestic Product (GDP), many
RL studies (Krikke et al 1999; Min et al 2005; Li et al 2006; Salema et al 2006; Salema et al 2007; Ko and Evans 2007; Melacini et al 2010) were primarily concerned with the minimization of the total reverse logistics costs. However, it should be noted that reverse logistics can help the firm increase its profit by generating revenue out of salvaged products with commercial value. Recognizing such a fact, a group of researchers like Shih (2001), Lieckens and Vandaele (2007), and Srivastava (2008a) considered profit maximization as the key objective while Aras and Aksen (2008a) combined profit maximization with cost minimization objective for solving the location-allocation problem. Similarly, De Figueiredo and Mayerle (2008) considered both the cost minimization objective and the incentive price paid to collecting agents in the context of queuing relationships. Most recently, Yang et al. (2009) demonstrated that the reverse logistics model with the pure cost minimization objective yielded smaller throughput and subsequently lower profit than that with the profit maximization objective under the theory of constraints (TOC) principle. Their experiment indicated that the pure cost minimization objective was less effective in reducing the volume of environmentally harmful waste. In some cases, both the cost minimization and the profit maximization objectives were combined. The maximization of customer responsiveness and the minimization of environmental impact are the other objectives which have been adopted in a very few articles. Figure 2.4 shows the classification of objectives.
Figure 2.4 Classification of objectives

Most models neglect the environmental impact, rather than incorporating the environmental aspects of transportation and processing in the analysis. Few researchers adopted multi-criteria models to optimize simultaneously the cost/profits and the environmental impact (Caruso et al. 1993; Bloemhof-Ruwaard et al. 1996; and Krikke et al. 2003)

2.2.5 Outputs

The various types of outputs obtained by solving the RL model can be classified as shown in Figure 2.5.
Figure 2.5 Classification of outputs

Among all the outputs, location became an important and common output for the available RL literature. Transportation Amount (TA), Incentive (I) offered, Number and Load of Vehicles (NLV), Demand Satisfaction (DS) and Vehicle Routes (VR) are the other types of outputs that have been obtained by solving the RL model.

2.2.6 Solution Methodology

Several solution procedures were used by several authors to solve the developed mathematical model as shown in Figure 2.6.

Mathematical methods such as Fibonacci Search were used to obtain solution. Heuristic procedures such as the GA based heuristic, the tabu search (TS) based heuristic, the lagrangian based heuristic, the GRASP heuristic, the modified teitz and bart algorithm, the bisection algorithm and other heuristics also have been used (Ko and Evans 2007; Lu and Bostel
2007; Lee and Dong 2008). The genetic algorithm (GA), the tabu search (TS) and the differential evolution (DE) are some of the meta-heuristics that have been used to solve the problem (Min et al. 2006; Lieckens and Vandaele 2007; Lee et al. 2010; Aras and Aksen 2008a;). In order to solve the complicated model in a very few minutes and to get the good solution optimization solver packages such as the GAMS Suite V.22.0, the CPLEX, the LINDO, the AIMMS algebraic modeling system with CPLEX 7.0 Solver, the CPLEX 8.1 commercial solver, and the GAMS 21.2 with full version of the CPLEX 7.5 Solver (Krikke et al. 1999; Jayaraman et al. 2003; Le Blanc et al. 2004) have been used. Scenario Analysis is another method used for analysis (Shih 2001).

Figure 2.6 Classification of solution methodology
2.2.7 Reverse Logistics Applications

Reverse Logistics (RL) network has been implemented in various fields of applications. In this section, various RL applications among the available RL literature have been consolidated to get a clear insight into it. Figure 2.7 shows the application of RL in various fields.
Figure 2.7 Classification of reverse logistics applications
2.3 REVIEW ON LOCATION-ROUTING PROBLEMS

In many distribution systems, the location of the distribution facilities and the routing of the vehicles from these facilities are interdependent. Although this interdependence has been recognized, attempts to integrate these two decisions have been limited.

2.3.1 Classification of Location-Routing Problem

There are a few LRP surveys in the literature (Madsen 1983 and Laporte 1988; Berman et al 1995; Min et al 1998; Nagy and Salhi 2007). The most recent literature review of the LRP and its extensions is Nagy and Salhi (2007). They proposed a classification scheme for LRP variants and surveyed exact and heuristic algorithms for the LRP. They also pointed out some future research directions for LRP study. Earlier, Min et al (1998) gave a synthesis and survey of the LRP. They defined the location routing model as solving the joint problem of determining the optimal number, capacity and location of facilities serving more than one customer/supplier (demand node), and finding the optimal set of vehicle schedules and routes. The authors stressed that the main difference between the LRP and the classical location/allocation problem is that, once the facility is located, LRP requires a visitation of demand nodes through tours, whereas the latter assumes a straight-line or radial trip from the facility to the clients.

Even though various classification schemes were available to classify location-routing problems, the two-way classification scheme designed by Min et al (1998) is used here to categorize LRP. In one dimension, LRP studies were classified in terms of problem perspective as shown in Figure 2.8. In another dimension, LRP studies were grouped into their algorithmic developments.
2.3.1.1 Problem Perspective

Most sub categories of this classification scheme are somewhat similar to the classification of issues in problem definition of RL network which has been described in detail in this section. The sub categories that are more specific to LRP are briefly discussed in this section.

Figure 2.8 Classification of LRP with regard to its problem perspective

On the basis of the hierarchical level, LRP is categorized as single stage and multi stage LRP. The single stage LRP is primarily concerned with both the location of facilities serving customers and the establishment of the outbound delivery routes around those facilities shown in Figure 2.9. The multi stage LRP considers two layers of the production-distribution network involving both the outbound (delivery) routes and the inbound (pickup) processes.
- Open depot sizes   →   Tours

- Customers

**Figure 2.9 A single-stage location-routing problem**

On the basis of the layers of distribution facilities, LRP is classified as primary facility and secondary facility (Figure 2.10). A primary facility represents either the origin or the destination of a vehicle journey. Some examples of primary facilities are manufacturing plants, hospitals, waste collection centers, airports and landfills. On the other hand, a secondary facility represents an intermediate or a transshipment point such as a military depot, a warehouse, a distribution center, a waste transfer station, a consolidation terminal or a break-bulk terminal.
2.3.1.2 Algorithmic Development

The location-routing problem (LRP), which combines the facility location and the vehicle routing decisions, is NP-hard. The problem complexity of LRP necessitates discussing the solution methods for solving LRPCs with the use of the available literature.
Two distinct types of solution methods have been used for solving LRPCs. These are exact algorithms and heuristics.

Analogous to the vehicle routing problem (VRP) classification scheme suggested by Laporte (1992), the exact algorithms for the LRP can be classified into four categories:

- direct tree search/branch-and-bound,
- dynamic programming,
- integer programming, and
- non-linear programming.

Since location-allocation problems and vehicle routing problems (VRPs) are often NP-hard, LRP which combines those two difficult problems will often prohibit the use of pure exact algorithms.

As such, the multi-phase decomposition solution which can ease the problem complexity is used for solving LRPCs. These procedures may comprise of some combinations:

- location-allocation-first, route-second,
- route-first, location-allocation-second,
- their main insertion, and
- tour improvement/exchange.

Sequential methods first solve the location problem by minimising the sum of depot-to-customer distances (also known as radial distances) and then solve the routing problem based on the depot locations found. The
sequential solution concept does not allow for feedback from the routing phase to the location phase.

Balakrishnan et al (1987, p. 37) point out that “the sequential solution of a classical facility location and a vehicle routing model can lead to a suboptimal design for the distribution system”

This observation was later supported by the empirical investigations of Salhi and Rand (1989) and Salhi and Nagy (1999) for the static and the dynamic cases respectively.

The iterative LRP heuristics decompose the problem into its two constituent subproblems. Then, the methods iteratively solve the subproblems, feeding information from one phase to the other. Clearly, the crux of the problem here is just how information can be compressed from one phase and fed into the other.

Hierarchical heuristics are motivated by the following observations. While iterative methods are clearly an improvement on the sequential methods, they “inherit” some of their drawbacks. They let the location algorithm run until the end and then restart it taking into account new routing information. Thus, if the routing information is not utilised well in the location phase, the method may go astray.

In hierarchical heuristics, the main algorithm is devoted to solving the location problem and refers in each step to a subroutine that solves the routing problem. Hierarchical methods may provide a better model of the real situation and are also likely to give better solutions. These methods sometimes rely on route length estimation.
Christofides and Eilon (1969) were the first to consider the problem of locating a depot from which customers are served by tours rather than individual trips. They proposed an approximation algorithm for the solution of the problem.

Watson–Gandy and Dohrn (1973) proposed an algorithm where the problem is solved by transforming its location part into an ordinary location problem, using the Christofides–Eilon approximation algorithm. The routing part of the algorithm is solved using the Clarke and Wright algorithm.

Jacobsen and Madsen (1980) proposed three algorithms, where the first is called tree-tour heuristic, the second is called Alternate Location Allocation and Saving Method (ALA-SAV) and is a three phase heuristic, wherein the first phase a location–allocation problem is solved and in the second and third phases a Clarke and Wright heuristic is applied for solving the problem. Finally, the third proposed algorithm is called Saving and Drop (SAV-DROP) and is a heuristic algorithm, which combines the Clarke–Wright method and the DROP algorithm.

Perl and Daskin (1985) proposed an IP model modification of the warehouse location-routing problem. The heuristic solution method of the model includes three stages; vehicle dispatch, location-allocation, and multiple dispatch routing allocation problems. The method is initially tested with small-sized problems and a large-scale case study is implemented.

Laporte et al (1988) consider three variants of LRP including, (1) capacity constrained vehicle routing problems, (2) cost constrained vehicle routing problems and (3) cost constrained LRP. The authors examined multi-depot asymmetrical problems and developed an optimal solution procedure that enables them to solve problems with up to 80 nodes.
Min (1996) proposed a three phase clustering-based heuristic procedure to solve small scale problems. Phases start with capacitated clustering and continue by solving the $p$-median problem. At the last step the routing in each cluster is determined by the TSP solution method of Little et al (1963).

Tuzun and Burke (1999) proposed a two-phase tabu search architecture for the solution of the LRP.

Chan et al (2001) solved a multiple-depot, multiple-vehicle, LRP with stochastically processed demands, which are defined as demands that are generated upon completing site-specific service on their predecessors.

Wu et al (2002) proposed an algorithm, which divides the original problem into two sub problems, i.e., the location–allocation problem, and the general vehicle routing problem, respectively. Each sub problem is then solved in a sequential and iterative manner by the simulated annealing algorithm embedded in the general framework for the problem solving procedure.

Albareda-Sambola et al (2005) modelled a one echelon LRP and presented an upper bound, using a tabu search and a lower bound using a saving/insertion heuristic.

Barreto et al (2006) considers a discrete LRP with two levels: a set of potential capacitated distribution centres (DC) and a set of ordered customers with capacitated vehicles. Also, the problem deals with a homogeneous fleet of vehicles, carrying a single product. Several hierarchical and non-hierarchical clustering techniques with several proximity functions are integrated in a sequential heuristic algorithm to solve the model. Different
clustering techniques and linkage methods are applied and compared in the study. Four phases are proposed for the model including, clustering, determining routes by TSP, improving routes, and assigning DCs to routes.

Nagy and Salhi (2007) analysed the situation of dealing with location-routing problems simultaneously to have better results in a long planning horizon. The significant studies over this issue started with Salhi and Rand (1989) proposing a location, allocation and routing procedure that consider the stages simultaneously.

Most recently, Alumur and Kara (2007) modeled a two-echelon LRP for hazardous material with multiple objectives as a mixed integer programming problem, and solved it via CPLEX.

Ozyurt and Asken (2007) presented a branch and bound scheme based on a tabu search heuristic, Lagrangian relaxation and a minimum spanning forest problem.

Albareda-Sambola et al (2007) considered an LRP with stochastic customers and applied it, using a neighborhood search heuristic and a lower bound, based on decomposition of the objective function to location and m-TSP sub problems.

Schwardt and Fischer (2008) proposed a neural network algorithm, based on self-organizing maps for a single facility LRP in continuous space.

Finally, Ambrosino et al (2009) proposed a two-phase heuristic with a large neighborhood search, based on path and cyclic exchanges of customers among routes, for the single facility LRP.
2.3.2 Location-Routing Problems in Solid Waste Management

Nagy and Salhi (2007) classify the solid waste management problems as transportation-location problems. Hazardous waste management problems are the most studied problems among solid waste problems.

Gottinger (1988) proposed a network flow model for regional solid waste management that minimizes a single objective function of the total costs of transportation, processing, and construction. Some models aim to maximize the average separation distance; some maximize the minimum separation distance, and others minimize the number of people within some critical distance or impact radius.

ReVelle et al (1991) dealt with a problem to determine the location of disposal sites, allocation of types of wastes to particular disposal sites, and defining routes. As the problem is a hazardous waste management type problem, the objective is to reduce the transportation cost, while also reducing the risk of hazardous wastes. The shortest paths for routing, a zero-one mathematical program for site selection, and the weighting method of multi objective programming are used to solve the problem.

Giannikos (1998) proposed a multi-objective model for locating disposal or treatment facilities and transporting hazardous waste. Population centers are considered in this study as hazardous waste generator points. A goal programming model to solve the problem is developed with four objectives. They are related to total operating cost, total perceived risk, distribution of risks among population centres, and the fair usage of disposal centres. There is a real life application where the model is implemented.
2.3.2.1 Clustering

In the past literature, cluster analysis has been often employed as a way to ease the computational complexity of location and routing problems.

‘Cluster be described as connected regions of a multi-dimensional space containing a relatively high density of points, separated from other such regions by a region containing a relatively low density of points’(Jain and Dubes 1988).

This definition of group is an excellent reason to use cluster analysis in the resolution of LRPCs. Recognizing groups of customers can be a good start to obtain good LRP solutions.

Concerning location problems, Kuehn and Hamburger (1963), also recognized the benefits of grouping (nearby customers) when they say that ‘In many cases a prior judgement can be made that customers in certain geographical regions will not be serviced from potential warehouses in other regions. Customers can frequently be aggregated into concentrations of demand (for example, metropolitan chain grocery and wholesaler warehouses) because of geographical proximity’.

This is probably one of the first explicit references to the interest of grouping customers.

Clustering-based methods begin by partitioning the customer set into clusters: one cluster per potential depot or one per vehicle route.
Then, they may proceed in two different ways:

- Locating a depot in each cluster and then solving a VRP (or TSP) for each cluster;

- Solving a TSP for each cluster and then locating the depots;

However, clustering is based on some “skeleton” of a routing plan (such as a minimal spanning tree of all customers), so this is a better attempt at integrating location and routing decisions (Nagy and Salhi 2007).

In particular, the group average proximity measure (Min 1989), and the single linkage or complete linkage measure (Romeshburg 1984) have been used for clustering customer nodes in LRP. In addition, the ward measure of proximity has been used because of its effectiveness in forming groups of equal dimensions and promising results reported in some vehicle routing studies (Min et al 1992). For instance, Barreto et al (2007) used a cluster analysis to aggregate customers in LRP and obtained good approximate LRP solutions. As such, a cluster analysis can be useful for grouping the customers and then assigning the customer clusters to different ICPs in the closed-loop supply chain.

2.3.2.2 Balanced Allocation Problem

A considerable amount of research has been conducted to solve the location-allocation problem in RL setting. However, few studies have attempted to consider the Location-Routing Problem (LRP) as well as the Balanced Allocation Problem (BAP) (Min 1998).

The Balanced Allocation Problem (BAP) is primarily concerned with the optimal assignment of product flows between multiple distribution
centers and a set of customers (Zhou et al 2002). The failure to balance the allocation of resources in RL networks may result in under-utilization of resources, leading to higher operational costs and increased workload disparities among workers (Chan and Kumar 2009).

2.4 SUMMARY

This section summarizes the literature review of RL network design and location routing problem separately along with observations.

2.4.1 Literature on Reverse Logistics Network Design

In the recent past, the increased interest of people in RL is mainly due to the various competitive forces. The increasing number of publications indicates that still lots of issues related to RL have to be analyzed thoroughly for implementing it effectively in a real scenario. Reverse logistics, as a part of effective supply chain management, provides a useful context of analyzing models for network design and the proper management of product returns. In this review, the analysis of the RL network design has been carried out by collecting relevant articles from reputed scientific publications. This review mainly focuses on various issues affecting the performance of the RL network. A summary of the above review on the Reverse Logistics network design as per the framework (Figure 2.1) has been given in Table 2.1.
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<td>CIC* (OLS)</td>
<td>UC,D,UCF,MP, Ex, SPr,ID,SE</td>
<td>MINLP</td>
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<td>L,TA,NV,I</td>
<td>Manufacturing Industry</td>
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<td>MILP</td>
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<td>L, TA, DS</td>
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<tr>
<td>Salema et al. (2007)</td>
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<td>L, TA</td>
<td>Product Recovery Networks</td>
<td>Benders decomposition</td>
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</table>

* Facilities to be located in the network
From this review, it has been found that the focus of the closed loop models with due consideration of other factors such as risk and demand uncertainty, multiple period, multiple product, multi-stages have been increasing tremendously to capture a real RL environment. However, still lot of issues are available that have to concentrate on the effectiveness of the RL network, since the handling of return flows is not the same as the usual handling of forward flows coming into the warehouse (Brito and De Koster (2004)). In conclusion, there is still a shortage of quantitative models to support return handling decisions. At the same time, there are many opportunities to extend existent forward models or to initiate new research paradigms.

2.4.2 Literature on Location Routing Problems

From the review on LRP literature, it is clear that more research has to be conducted on LRP with due consideration of other rarely focused factors such as dynamic, stochastic, multiple periods, multiple objectives, and multiple stages in order to gain better insight on the characteristics of LRP.

As mentioned in section 2.3.2.2, various solution methods are available for solving LRP. Each method has its own merits and limitations. The sequential method is easier to solve but it leads to suboptimal design. Even though the iterative type heuristics are better than the sequential method, it has certain drawbacks. If the routing information is not utilised well in the location phase, the method may go astray. It is evident from the review that the hierarchical heuristics outperform the other types of LRP heuristics. While using this heuristic, the main algorithm is devoted to solve the location problem and refers in each step to a subroutine that solves the routing problem.

2.5 REVIEW FINDINGS

- As the above literature review reveals, some of these prior studies considered an overarching nature of the different
logistics decisions featured by many-to-one transportation, unclear routing/destination, less priority for speed, incentive-based payments, and multiple commodities.

- Despite their merits, none or few of these prior studies fully considered the inter-dynamics of location, allocation and routing decisions in the RL context.

- Very few attempts were made to incorporate the incentive-payment effects based on quality aspects and multi-product varieties into the modeling process.

- An integrated location-routing approach may help the firm develop more efficient logistics networks by avoiding sub-optimization (Min, 1996; Min 1998).

- Since the integrated location-allocation-routing model with many realistic aspects would be very challenging to solve, the clustering procedure has to be used as a way to ease the computational complexity which has received little attention in RL context.

- Despite the importance of balanced allocation to the reverse logistics network design, very few attempts have been made to tackle BAP in both forward and reverse logistics networks.

- It is found that the use of a sequential method leads to worse solutions than a combined method that has been focused in very few cases of LRP.

- Simultaneous treatment of location and routing decisions ultimately reveal the real characteristics of any research problem even though it has more computational complexity.

Hence in the remaining chapters of this thesis, both decomposed and integrated methods have been proposed to solve LRP in RL application, followed by comparative and sensitive analysis on them to validate their efficiency.