CHAPTER 1

INTRODUCTION

Growing awareness of the limited availability of natural resources, such as fossil fuels, leads to a more careful use of resources. Simultaneously, the demand for natural resources is increasing, due to industrial development in Asia, especially China and India. Hence sustainable development and green marketing have been placed on the strategic agenda of many companies. Sustainability is generally understood as a development approach that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED 1987).

1.1 SIGNIFICANCE OF REVERSE LOGISTICS

The primary output of today's production processes is waste. Across all industries, less than 10 percent of everything that is extracted from the earth (by weight) becomes usable products. The remaining 90 percent becomes waste from production (Kirstie 2007). Taking the electronic industry of China as an example, more than 4 million television (TV) sets, 5 million washing machines, 5 million refrigerators, 6 million personal computers, and 30 million mobile phones were trashed in 2003 without recycling (Wang 2005). Reverse logistics (RL) can reduce costs by reusing products, components and materials instead of simply disposing of them into landfills which negatively impacts the environment.

Typically, a product return involves the collection of returned products at designated regional distribution centers or retail outlets, transfer
and consolidation of the returned products at centralized return centers, asset recovery of the returned products through repair, refurbishing, and remanufacturing, and the efficient disposal of returned products with no commercial value (Min et al 2006). An example is that IBM, through its IBM global financing organization, presently handles approximately 112000 units of used IT equipments worldwide each month. This equates to 3 million kg/month of used products being processed by IBM globally, and an annual total amounting to almost 40000 tons/year. These units are recycled, reused, refurbished and resold into the global marketplace (IBM 2005). An institutional agency, called the WEEE-System, is responsible for allocating the WEEE from private households to producers/importers which must be collected from the individual municipalities. Already in 2006, nearly 50,000 tonnes of WEEE were collected in Denmark. The directive sets recovery targets which vary from 50% to 80% depending on the category (Grunow and Gobbi 2009).

The major concern of the companies involved in product recovery is in the used-product or end-of-use product acquisition or collection (Guide et al 2003). As of 1999, the total value of returned merchandise was $62 billion, representing $10–15 billion in losses to retailers in the United States (US), while the cost of handling these product returns was estimated to be $43 billion a year (ReturnBuy 2000). Indeed, the cost of handling product returns usually comprises 4.5% of all logistics cost in the US (Min et al 2005). As reported by the Reverse Logistics Executive Council (Rogers and Tibben-Lembke 1999), US firms have already lost billions of dollars on account of inefficient handling of return flows. Thus, handling return flows has become an important decision in logistics management.

In the wake of deregulation and globalization, many logistics managers are faced with tough location, allocation, and transportation
problems. As the managers wrestle with these problems, management scientists develop more efficient problem solving techniques using the concept of integrated logistics systems. The crux of such techniques is the combined location-routing model (Min et al 1998). In general terms, the combined location-routing model solves the joint problem of determining the optimal number, capacity and location of facilities (domiciles) serving more than one customer/supplier, and finding the optimal set of vehicle schedules and routes. Its major aim is to capitalize on distribution efficiency resulting from a series of coordinated, non-fragmented movements and transfer of goods.

Hence this thesis mainly focuses on the analysis of combined location-routing problem (LRP) s in designing an efficient Reverse Logistics (RL) network.

1.2 DEFINITIONS OF REVERSE LOGISTICS

Logistics is defined by The Council of Logistics Management as:

The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements (Rogers and Tibben-Lembke 1999).

Reverse logistics includes all of the activities that are mentioned in the definition above. The difference is that reverse logistics encompasses all of these activities as they operate in reverse. Definitions of reverse logistics (RL) have been proposed by various authors.
At the end of the nineties, the American Reverse Logistics Executive Council (Rogers and Tibben-Lembke 1999) defined RL as:

The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal.

More precisely, reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal.

1.2.1 Differences between Forward Logistics and Reverse Logistics

It is often assumed that reverse logistics programs can be successfully implemented by simply reversing the forward supply lines. On the contrary, reverse logistics activities have very different and often more complex issues that affect program performance. Table 1.1, developed by Tibben-Lembke and Rogers (2000) details the key differences between forward and reverse logistics operations.

Table 1.1 Differences between forward logistics and reverse logistics

<table>
<thead>
<tr>
<th>Forward</th>
<th>Reverse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecasting relatively straightforward</td>
<td>Forecasting much more difficult</td>
</tr>
<tr>
<td>One-to-many transportation</td>
<td>Many-to-one transportation</td>
</tr>
<tr>
<td>Product quality uniform</td>
<td>Product quality not uniform</td>
</tr>
<tr>
<td>Product packaging uniform</td>
<td>Product packaging often damaged</td>
</tr>
<tr>
<td>Destination and routing clear</td>
<td>Destination and routing unclear</td>
</tr>
<tr>
<td>Standardized channels</td>
<td>Exception driven channels</td>
</tr>
<tr>
<td>Disposition options clear</td>
<td>Disposition not clear</td>
</tr>
<tr>
<td>Pricing relatively uniform</td>
<td>Pricing dependent on many factors</td>
</tr>
<tr>
<td>Importance of speed recognized</td>
<td>Speed often not considered a priority</td>
</tr>
<tr>
<td>Forward distribution costs closely monitored</td>
<td>Reverse costs less visible</td>
</tr>
</tbody>
</table>
Table 1.1 (Contd...)  

<table>
<thead>
<tr>
<th>Inventory management consistent</th>
<th>Inventory management not consistent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product life-cycle manageable</td>
<td>Product life-cycle issues more complex</td>
</tr>
<tr>
<td>Negotiations between parties straightforward</td>
<td>Negotiations complicated by additional factors</td>
</tr>
<tr>
<td>Marketing methods well known</td>
<td>Marketing complicated by many factors</td>
</tr>
<tr>
<td>Real-time tracking information available</td>
<td>Visibility often less transparent</td>
</tr>
</tbody>
</table>

(Source: Tibben-Lembke and Rogers (2000))

Since the behaviours best suited for forward logistics (FL) are not necessarily best suited to reverse logistics, the costs in reverse logistics are not necessarily the same as the costs in forward logistics. Table 1.2 lists some of the ways in which the reverse logistics costs differ from the costs of forward logistics.

Table 1.2 Comparison of forward and reverse logistics costs

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Comparison to Forward Logistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Greater: lower-volume channels</td>
</tr>
<tr>
<td>Inventory holding costs</td>
<td>Lower: lower-value items</td>
</tr>
<tr>
<td>Shrinkage (theft)</td>
<td>Much lower: limited use without repair</td>
</tr>
<tr>
<td>Obsolescence</td>
<td>Obsolescence: may be higher due to delays</td>
</tr>
<tr>
<td>Collection</td>
<td>Much higher: less standardized</td>
</tr>
<tr>
<td>Sorting, quality diagnosis</td>
<td>Much greater: item-by-item</td>
</tr>
<tr>
<td>Handling</td>
<td>Much higher: nonstandard sizes and quantities</td>
</tr>
<tr>
<td>Refurbishment</td>
<td>Significant for RL, nonexistent for forward</td>
</tr>
<tr>
<td>Change from book value</td>
<td>Significant for RL, nonexistent for forward</td>
</tr>
</tbody>
</table>

(Source: Tibben-Lembke and Rogers (2000))
Since the collection cost is much higher and less standardized (Table 1.2), this thesis mainly deals with the minimization of the collection costs.

1.3 REVERSE LOGISTICS SYSTEMS

An RL network can be classified as a closed and an open loop system. The closed loop system incorporates traditional logistics, in a forward flows with logistics channels reversed as shown in Figure 1.1. The flow of materials and products in this system, occurs both from the customer to the supply center (reverse flow), and from the supply center to the customer (forward flow). Since most of the products and materials may be conserved, essentially this forms a closed-loop system (CLS). In this system, new materials are needed to replace only materials which are not recovered by the system and the end-users are the source of input materials as well as customers of the system.

Figure 1.1 Closed loop system (CLS)
The open loop system (OLS) incorporates only reverse flows as shown in Figure 1.2. The flow of materials and products in this system occurs only from the customer to the supply center (reverse flow). The recovered materials and products after processing will be distributed for reuse in any place wherever needed.

The RL system considered in this thesis belongs to the open loop, since the flow of products occurs only from the customer to the processing center.

1.3.1 **An Overview of RL Processes**

The various processes involved in the reverse logistics (Fleischmann et al 2000) are described as follows.

1.3.1.1 **Collection**

It refers to all activities rendering used products available and physically moving them to some point for further treatment. Collection may include purchasing, transportation and storage activities.
1.3.1.2 Inspection/Separation

It denotes all operations determining whether a given product is in fact reusable and in what way. Thus, inspection and separation result in splitting the flow of used products according to the re-use (and disposal) options. Inspection and separation may encompass disassembly, shredding, testing, sorting and storage steps.

1.3.1.3 Re-Processing

It means the actual transformation of a used product into a usable product/ component/material again. This transformation may take different forms including recycling, repair and remanufacturing. In addition, activities such as cleaning, replacement and re-assembly may be involved.

1.3.1.4 Disposal

It is required for products that cannot be re-used for technical or cost reasons. This applies, e.g., to product rejected at the separation level due to excessive repair requirements but also to products without satisfactory market potential, e.g., due to obsolescence. Disposal may include transportation, land filling and incineration steps.

1.3.1.5 Re-Distribution

It refers to directing re-usable products to a potential market and to physically moving them to future users. This may include sales, transportation and storage activities.

Since the major concern of the companies is in the used product or end-of-use product collection or acquisition as mentioned in Section 1.1, this thesis mainly deals with the three processes namely collection,
inspection/separation and re-processing in order to get an insight on the handling of return flows.

1.3.2 Types of Recovery Activities

De Brito and Dekker (De Brito and Dekker 2002) proposed recovery activities which are related to re-processing, disposal and re-distribution processes above, as:

1.3.2.1 Product Recovery

Product may be recycled directly into the original market or into secondary market, or repaired and sent back to the user under conditions of warranty.

1.3.2.2 Component Recovery

Products are dismantled and parts can be remanufactured into the same kind of product or different products.

1.3.2.3 Material Recovery

Materials are recuperated and recycled into raw materials like metal, paper or glass.

1.3.2.4 Energy Recovery

Products are incinerated to generate energy.

Among the various types of recovery activities, this thesis focuses only on product recovery activity.
1.3.3 Types of Return Flows

Products, components, packages, carriers, refillable units are returned at different points in the product life cycle, resulting in different types of returns (Fleischmann (2001)). Based on the literature, six types of returns have been distinguished as follows:

1.3.3.1 By-Products and Scrap

These include materials or products resulting from the production process, that are unavoidable in a blending or cutting process or do not fulfill the quality requirements. Some products can be reworked to meet the quality requirements, while the excess products need to be disposed of or recycled to reduce costs and the environmental impact.

1.3.3.2 Commercial Returns

These are product returns that occur during or shortly after the sales process. Among the reasons for commercial returns are customer dissatisfaction, customer tests, overstocking at retailers and promotional actions. For catalogue or internet sellers, accepting returns is critical in establishing and maintaining the customer relationship. Returned products for commercial reasons typically have immediate markets in another location or segment.

1.3.3.3 Warranty, Repairs and Product Recalls

These are returns of products or components that are suspect or the defect. The customer is entitled to have the same or similar product (function) back. The initiative for returning a product for warranty and repairs lies with the user, while for product recalls the manufacturer actively recalls the products to return. The latter occurs typically with complicated products,
where the manufacturer detects potential failures or safety risks the customer is not aware of.

1.3.3.4 Reusable Items

These returns are related to consumption, use or distribution of the main product. This type concerns many different items, e.g. reusable containers and pallets, refillable cartridges, bottles, and “one-way” cameras. The common characteristic is that they are not part of the product itself, but contain and/or carry the actual product. Many examples can be found in society, for example, reusable trays for food in the retirement homes, crates, deposit bottles and containers.

1.3.3.5 End-of-use Returns

These are products returned after some period of use due to end of lease, trade-in or replacement. Depending on the status of the return, the product is refurbished or repaired and sold through an alternative channel, or remanufactured into new goods. Alternative markets for products can easily be targeted using electronic market places such as eBay, for example. Copier machines that are remanufactured are sold in the same market in another segment, while remanufactured or refurbished cellular phones are sold on geographically different markets.

1.3.3.6 End-of-Life Returns

These are the returns of products that are worn out and no longer useful. Examples are car wrecks, white and brown goods and carpets (Louwers et al 1999). The time that elapses before products are at the end-of-life stage is long and quite uncertain, since customers determine when they regard their product as worn out. The products are taken back from the market to avoid negative externalities (environmental or even commercial damage).
Among the various types of return flows, this thesis deals with the end-of-use returns.

1.4 REVERSE LOGISTICS NETWORKS

Reverse logistics systems can be classified into four major categories considering the types of return items (Fleischmann et al 1997) and the main options of recovery. These four classes are directly reusable network (DRN), remanufacturing network (RMN), repair service network (RSN) and recycling network (RN).

Each network has its own characteristics as described below:

1.4.1 Directly Reusable Network (DRN)

This network involves new unopened returned items and reusable containers such as pallets, trays, boxes, and standard containers. They can be directly reused without major operations on them. Only inspection, cleaning and minor maintenance are to be done. Forwards and reverse flows are closely associated. Thus, this system is a closed loop.

1.4.2 Remanufacturing Networks (RMN)

Products (or components) at the end of life or maintenance cycle are returned, and some parts or components are remanufactured to be used like new parts. This network is a closed loop system because remanufacturing is usually performed by the original manufacturer. The examples of this are copy machines and air craft engines.

1.4.3 Repair Service Network (RSN)

Defective products, such as durable goods or electronic equipments, are returned and repaired in service centers. There are a few links between FL and RL, so it is considered an open loop system.
1.4.4 Recycling Network (RN)

Raw materials, for example metal, glass and paper are recycled usually by third party recyclers. This can be considered an open loop system. This type of network also includes waste collection and elimination.

This thesis focuses only on the recycling network among the available RL networks.

1.5 DECISION PROBLEMS IN REVERSE LOGISTICS

1.5.1 Strategic Decision Problems

Strategic decision problems receiving attention in the current literature are long term planning problems associated with the nature and capacity of the recovery processes. Reverse supply chain network design, supply-chain coordination and capacity planning problems as well as planning for green manufacturing, which are manufacturing systems designed with environmental considerations, fall into this category. Other current issues include deciding locations of components of a reverse supply chain to be centralized or decentralized.

1.5.2 Tactical Decision Problems

Tactical decision problems analyzed in the current literature include medium term problems where decisions are associated with the design of the products, returns forecasting, data and information collection designs, product returns handling, warehousing and aggregate production planning in terms of returns recovery.
1.5.3 **Operational Decision Problems**

Operational decision problems are short term problems related with warehousing operations, dynamic control of product recovery operations, dynamic acquisitions, dynamic pricing, disassembly scheduling and lot sizing problems where both quantity and timing decisions are made to run the recovery processes effectively and economically under various constraints and uncertainties.

1.6. **LOCATION ROUTING PROBLEM**

The location routing problem (LRP) is a relatively new field which takes into account two key components of a logistics system, namely the facility location and vehicle routing. Significant productivity gains can be achieved through the design of location routing models as these models can determine true least-cost solutions to a logistic problem taking into account both strategic policy (facility location) and operational decisions (vehicle routing).

1.6.1 **Significance of Location Routing Problem**

The choice of locations for distribution centers (DCs) is among the most critical elements in logistics system design. Both the cost of the system and the level of customer service that can be provided are significantly affected by the number, size, and locations of the DCs and by the decisions on which customers to serve from each DC (customer allocation). Consequently, a great deal of effort has been devoted to the development of analytic models for DC location.

Existing DC location models represent the delivery cost from a DC to any given market in one of two ways: (1) as being directly proportional to
the distance to the market, or (2) by a specific point-to-point freight rate. This representation implicitly assumes that loads are delivered from the DCs to customers on a “straight-and-back” basis. Such a representation may be adequate when the shipments to individual customers constitute Truck Loads (TLs), are done via common carrier. However, the shipping of goods from DCs (delivery) is often done in Less than Truck Load (LTL) quantities using private (or contracted) fleets. In such cases, delivery vehicles commonly operate on routes which include multiple customers. The delivery cost to any given customer may be marginal if the customer can be included on an existing route with insignificant additional travel distances. However, if the delivery vehicle does not have the necessary excess capacity and a special trip is needed, the cost of delivering the same amount may be significant.

Thus, when LTL shipments are prevalent and deliveries are carried out by a private (or contracted fleet), estimating the delivery cost in the analysis of DC location requires knowledge of vehicle routing, while the design of delivery routes depends on the location of the DC. Therefore interdependence exists between DC location and vehicle routing.

1.6.2 Definition of Location Routing Problem

The phrase ‘location-routing problem’ is misleading, as location-routing is not a single well defined problem like the Weber problem or the travelling salesman problem. It can be thought of as a set of problems within the location theory.

Thus, Nagy and Salhi (2007) defined location-routing as,

‘Location planning with tour planning aspects taken into account’
1.6.3 Differences between LAP and LRP

The main difference between the location-routing problem (LRP) and the classical location-allocation problem is that, once the facility is located, the former requires a visitation of customers/suppliers through tours, whereas the latter assumes the straight-line or radial trip from the facility to the customer/supplier. Therefore, the classical location-allocation problem ignores tours when locating facilities and subsequently may lead to increased distribution cost (Salhi and Rand 1989). In contrast with the classical location-allocation problem, LRP consider tours and then seeks the optimal facility location and route design simultaneously so that it can interrelate those two decisions (Figure 1.3).

The LRP differs from the classical vehicle routing problem because the optimal depot location and optimal vehicle routes must be determined simultaneously.
1.6.4 Decisions in Location Routing Problem

In most location models, it is assumed that the customers are served directly from the facilities being located. Each customer is served on his or her own route. In many cases, however, customers are not served individually from the facilities. Rather, customers are consolidated into routes that may contain many customers. One of the reasons for the added difficulty in solving these problems is that there are far more decisions that need to be made by the model.

These decisions include:

- how many facilities to locate,
- where the facilities should be,
- which depot to be assigned to which customer,
- which customers to be assigned to which routes,
- in what order customers should be served on each route.

In the LRP, a number of facilities is located among candidate sites, and delivery routes are established to a set of users in such a way that the total system cost is minimized.

As Perl and Daskin (1985) pointed out, the LRP involves three inter-related, fundamental decisions:

- where to locate the facilities,
- how to allocate customers to facilities and
- how to route the vehicles to serve customers.
1.6.5 Applications of Location Routing Problem

The LRP is really applicable in practice and is not a purely academic construct. It can be applied in all fields such as food and drink distribution, consumer goods distribution, newspaper distribution, blood bank location, postbox location, military equipment location, parcel delivery, telecom network design, optical network design, shipping industry and waste collection.

1.7 RESEARCH MOTIVATION

With the growing awareness of carbon footprints and their impact on environmental degradation, many firms hope to streamline their reverse logistics operations involving end-of-use products. However, managing end-of-use products can be extremely challenging due to the inherent complexity in collection, sorting, transshipment, and processing these products. Despite numerous challenges, the efficient handling of these products can be a source of competitive advantages. This necessitates the adoption of the integrated logistics systems concept in the RL context.

Since the integrated logistics systems play a vital role in today’s managerial decisions, this thesis attempts to develop an integrated model and methodology to solve combined location routing problem in the RL context. The performance of the proposed model and methodology has to be tested by using the data collected from a plastic recycling company located in Southern India. The proposed methodology is to be subjected for comparative analysis and sensitive analysis to validate its performance.
1.8 ORGANIZATION OF THESIS

This section summarizes the significance, definition, types of networks, decisions, applications of reverse logistics and location routing problem along with the motivation of the thesis.

The rest of the thesis is organized as follows:

Chapter 2 reviews the literature on reverse logistics and location routing problem in detail and by considering their interdependence, highlights the need for this proposed work.

Chapter 3 explains the model formulation of CRAB-SP along with objective function, costs involved, assumptions, constraints and decomposed methodology for the single product RL network.

Chapter 4 details the model formulation of CRAB-SP along with the integrated methodology for implementing it in a single product RL network.

Chapter 5 proposes the model of CRAB-MP and explains the integrated methodology for solving it in detail with the use of a case illustration.

Chapter 6 discusses the result obtained by solving various case instances with the use of the proposed methodology and analyzes the impact of various issues on combined LRP in RL application by conducting sensitivity analysis.

Chapter 7 concludes the research findings and suggests future direction of research.