2.1 Introduction

Effective management of reverse logistics activities is a key process in today’s business, and a well-designed process can create competitive advantage for a manufacturing firm. The main activity of RL for return process involves the development of a network for returns with the corresponding flow options. The Networking of all RL activities needs effective coordination. Coordination, which means, bringing together, the various logistics activities and it can be, achieved through introduction of all the RL activities for recovering the value of the returns, in a network. This returns network can be referred as Reverse Logistics Network (RL Network).

The RL Network can be designed in such a way that it would deliver its service to satisfy the exact customer requirements. RL Network is an opportunity to generate additional revenue, differentiate market position, and support original product demand. Both retailers and manufacturers have realized these opportunities and RL is becoming an integral component of profitability and competitive position. RL Network allows for the efficient utilization of facilities, minimizing the cost of capacity, while making the service more responsive to customer demands.

The RL Network structure can be divided into two portions. A Convergent Network, in which a portion of the network accumulates the used commodities from individual sources and conveys them to some recovery facilities. Companies can set up dedicated returned commodities collection centers at specific locations or collect the commodities through retailers and distributors.

In a divergent network, the network part links recovery facility to individual customers purchasing reusable commodities. This portion of the network is very much similar to traditional forward supply chain distribution networks and integration with forward supply chain can be done here for maximized optimality.
The different RL networks, which are available in the literature and the possible types of network structures in the RL context, are discussed here.

2.2 Reverse Logistics Networks – A Literature Review

Network structure is generally stated to be of great strategic importance in RL (Cristopher, 1998). RL Network addressed in the literature rely on mixed-integer linear programming and this approach allows for large-scale mathematical optimization. But deriving general insights of impact of various parameters from them is difficult. In order to overcome this difficulty, Daganzo, (1999) followed continuous approximation methodology. Later, authors in RL field formulated RL Network models as a mixed-integer non-linear programming (MINLP). In order to determine when reverse flows should be integrated with forward flows, Fleischmann et al. (2000) simulated the impacts of reverse flows in a logistics network.

When designing RL Network structures, the companies, also need to decide where to locate the various processes and how to design the corresponding transportation links and there is not usually an existing network that can be used Fleischmann et al. (2001), and they proposed a generic RL network model based on a mixed integer linear program and discussed the applications and extensions to the model.

RL Networks need to be constructed with the determination of the number of layers in the network, the number and location of depots or intermediary points, the use of drop points in the collection, the issue of integrating the reverse chain with the forward chain, and finally the financing of the network (Brito and Dekker, 2003). Fleischmann et al. (2003) presented a continuous optimization model for RLN design. Autry, (2005) devised a framework of three typical RL Network structures namely bulk recycling, remanufacturing, and reuse RL networks. To get in-depth knowledge of uncertainties involved in reverse flows, Lieckens and Vandaele, (2007) introduced queueing effects in RL Network design to account for uncertainties and the model was formulated as mixed-integer non-linear programming (MINLP).

RL Network design models may vary from product to product, purpose for which it is intended, the extent, and the size of the operations. The following
materials, taken from various sources and researches conducted elsewhere, through some light on the possible network design that can be considered for the given environment.

**Kroon and Vrijens, (1995)** presented a design of a closed-loop deposit based system for collapsible plastic containers, which can be rented as secondary packaging material. The design involves a central agency - a pool of reusable containers and a logistics service provider - responsible for storing, delivering, and collecting the empty containers, which needs a set of depots. The authors documented how this issue may be addressed by means of a standard warehouse location model. They emphasized that the overall network design problem is characterized by the interaction between the various parties involved and their respective roles. Depot location, pool size, and payment structures all have an important impact on the system’s performance as a whole and its competitiveness with respect to traditional ‘one-way’ packaging.

**Thierry et al. (1995)** presented an integrated supply chain framework to demonstrate the reverse flows and various recovery options such as repair, refurbishing, remanufacturing, recycling, etc. Dawe, (1995) suggested that the shortening of returns cycle time is important for handling returns well.

**Spengler et al. (1997)** examined a single period steel by-products recycling network. During the production process of steel, a substantial volume of residuals generated. For this, they analyzed which recycling processes to install at which locations at which capacity level in order to minimize overall costs. They proposed a modified MILP warehouse location model for an arbitrary number of network levels, corresponding to individual processing steps, and an arbitrary number of end products, linked to alternative processing options. Rogers et al. (1999) argued that the short disposition cycle times related to return product decisions, movement and processing is critical element to successful RL management.

**Barros et al. (1998)** examined sand-recycling network – treating the waste/bye-products from construction works. Sand is to be cleaned before being reused. The cleaning of polluted sand requires an expensive treatment facility.
Regional depots are also to be set up for inspection and storage of the sand. For this purpose the authors developed a tailored multi-level capacitated facility location model. During the analysis, they emphasized that the need for a robust network structure to handle significant uncertainties due to supply and demand. Listes and Dekker, (2005) revisit this case and explicitly taken the uncertainty issue into account in their modeling approach. They proposed a multi-stage stochastic programming model where location decisions need to be taken on the basis of imperfect information on supply and demand while subsequent processing and transportation decisions were based on the actual volumes. The model maximized the expected performance for a set of scenarios with given probabilities. The authors emphasized that the solution needs not be optimal for any individual scenario and hence this approach was more powerful than simple scenario analyses.

Jayaraman et al. (1999) analyzed a RL Network design of an electronic equipment remanufacturing company. The network includes the activities of the core collection, remanufacturing, and distribution of remanufactured products (there is no coincidence of delivery and demand). With this setting, they analyzed about the optimal number and locations of remanufacturing facilities and the number of cores collected with consideration of the investment, transportation, processing, and storage costs. And they showed that the network design problem could be modeled as a standard multi-product capacitated warehouse location MILP. Finally they emphasized that managing the capacity was crucial for the performance system and it required different approaches than in a traditional production-distribution network.

Realff et al. (1999) provided a first step in the strategic transition of multi-period network design models from a stationary, single-period perspective. Few models explicitly incorporate uncertainty other than scenario analyses. Besides the stochastic programming model Listes and Dekker, 2001, Newton et al. (1999) made a robust network design model for carpet recycling. This approach resulted in different network structures when compared with scenario analysis. The cost advantages turn out to be limited in many cases.

Fleischmann et al. (2000) focused on the consequences for OEMs of adding product recovery operations to an existing production-distribution network. They
presented a general MILP facility location model, which encompasses both forward and reverse product flows. The authors concluded that, based on numerical study, the overall network structure was fairly robust with respect to variations in the recovery volume and the RL networks can efficiently be integrated in existing logistics structures in many cases. They illustrated this case with an example of OEM copier remanufacturing and paper industry.

**Brito and Dekker, (2004)** provided a RL framework to take decisions in terms of strategic, tactical and operational aspects of the problem. Some researchers put forward the strategic factors, like costs, which are in need to be considered when designing a RL Network. Minimizing strategic costs is essential for a successful RL system *(Chang and Wei, 2000; Guide et al. 2003)* and *(Ginter and Starling, 1978)*. Few companies outsource their RL operation to third-party providers for the benefits of cost reduction, improved expertise and easy access to data, improved operation and customer services, and the ability to focus on core competencies and flexibility *(Castillo and Cochran, 1996)* and *(Fleischmann, 2004)*. *Lu and Bostel, (2007)* gave a brief introduction to the basic concepts of RL with a two-level location problem with three types of facilities to be located in a specific RL system, with both forward and reverse flows and their mutual interactions.

**Min et al. (2006)** proposed a minimum-cost solution RL Network model with nonlinear mixed-integer programming to solve the RL problem involving product returns which include: defects, in-transit damage, trade-ins, product upgrades, exchanges for other products, refunds, repair, recalls, and order errors. The proposed model and solution procedure considered explicitly, the trade-offs between freight rate discounts and inventory cost savings due to consolidation and transshipment. The model and solution procedure may enable the reverse logisticians to determine the exact length of holding time for consolidation at the initial collection points and total RL costs associated with product returns. *Jeung Ko and Evans, (2007)* presented a mixed integer nonlinear programming model, a multi-period, two-echelon, multi-commodity, capacitated network design problem, considering both forward and reverse flows simultaneously.
Salema et al. (2007) proposed a generalized model for the design of RL Network. This model is based on the recovery network model (RNM) proposed by (Fleischmann et al. 2001). This work extended the RNM model and developed a capacitated multi-product RL network model with uncertainty. The capacity constraints were imposed on total production/storage capacity of the facilities, which might be factories, warehouses or distribution centers. The model formulation allows any number of products, establishing a network for each product while guaranteeing total capacities for each facility at a minimum cost. They studied the network model in the context of uncertainty in both product demands and returns, through the use of a multi-scenario approach. This model attempts to overcome the limitation of generality in reverse distribution network model. This establishes a network for each product with minimum cost.

Listes, (2005) examined the design of networks comprising both supply and return channels, organized in a closed loop system for manufacturing/re-manufacturing type of systems with a decomposition approach. This approach can effectively exploit certain problem features, such as the flexibility offered by multiple capacity levels or by economies of scale. His findings on an overall analysis led to the main conclusion that volume was a powerful driver in integral networks with re-manufacturing options and the processes which can adjust as accurate as possible to the overall requirements generally enjoy a natural advantage, provided that their investment costs were not prohibitive.

Lieckens and Vandaele, (2007) examined a RL Network design using an extended version of models to determine which facilities to open that minimize the total cost. Finally, the authors showed that, the constraint could be improved when they were combined with a queueing model because it enables to account for some dynamic aspects like lead time and inventory positions, and the higher degree of uncertainty inherent to RL.

Lu and Bostel, (2007) gave a brief introduction to the basic concepts of RL with a two-level location problem with three types of facility to be located in a specific RL system, with both forward and reverse flows and their mutual interactions, named a Remanufacturing Network. This model was formulated as a 0–1
mixed integer programming. They demonstrated that reverse flows influence the
decisions about location and allocation and the influence varied with the magnitude of
the reverse flows, their distribution at demand sites and their correlation with forward
flows.

Rico Wojanowski et al. (2007) presented a continuous modeling framework
for designing a drop-off facility network and determining the sales price that
maximize the firm’s profit under a given deposit–refund. Their analysis on an
illustrative example showed that the returned product value was a key factor that
determines the nature of collection in an industry. Products with high return value, the
deposit refund voluntarily offered by the firms could be sufficient to achieve high
collection rates.

The overall status of the literature on RL Network design shows that RL
networks have close analogies with conventional production-distribution networks.
From the mathematical perspective, the models that have been proposed differed
fairly little from traditional MILP facility location models. Some special features
reflect the particular role of testing and grading and alternative market conditions on
the demand and supply side. One important aspect is the issue of uncertainty in
supply. Very few models, in RL network, only incorporate uncertainty other than the
scenario analyses. These approaches result in different network structures. Now
closed-loop supply chains are in an emerging state and we can see that companies are
gradually extending their operations from moderate pilot-study to full-scale business
processes, in order to get competitive advantage.

The network structures constructed, formulated and discussed in literature
resulted the availability of different types of Network structure since the flow of
commodities/products in different levels categorizes the different patterns of flow.

2.3 Different Reverse Logistics Network Structures

Manufacturers in worldwide are increasingly facing the problem of assuming
responsibility for their products at end of life and must provide for collection and
product recovery or proper disposal (Klausner et al. 2000). To satisfy the high
expectations of customers, all manufacturing industries are in need to make very thriving process. Especially, with the rapid increase in the introduction of new and advanced technologies, the manufacturing industries increased their focus on Networks, which involves Reverse Logistics and Repair Services (RLRS).

Basically, there can be four different possibilities of commodity flow exists in RL. They can be given as,

- Single Level Single Commodity Flow (SLSCF)
- Single Level Multi Commodities Flow (SLMCF)
- Multi Level Single Commodity Flow (MLSCF) and
- Multi Level Multi Commodities Flow (MLMCF)

The figure 2.1 shows the different possibilities of the flow pattern of different commodities in different levels in a Reverse Logistics Network (RL Network).

![Flow Pattern Diagram](image)

**Figure 2.1 Possibilities of flow of commodities in Reverse Logistics Network**

In this investigation, the flow of multi-commodities, which flows through multiple repair service facilities situated at single level and also at multi-levels are considered for the analysis.
2.3.1 Single commodity flow/ Flow of single commodities in a RL Network

There are different types/varieties of commodities in different numbers flows in a RL Network. If only a particular variety of commodity flow exists in an RL network, then it is called as single commodity flow.

- Example: Flow of Refrigerators (single commodity) in a RL Network.

2.3.2 Multi commodity flow/ Flow of Multi commodities in a RL Network

If the flow of more than one type/variety of commodities exists in an RL Network, then it is called as a multi-commodity flow.

- Example: Flow of washing machines in addition to refrigerators (multi-commodities) in a RL Network.

2.3.3 Single Level RL Networking/ Single level Repair Servicing in a RL Network

The commodities, in reverse flows need some repair service work to be done to recover its value. The repair service may be carried out in a single facility or in number of facilities, which are situated at different locations, depending on the status or the condition of the commodities returned.

If the entire repair service work of a particular commodity is carried out in a particular repair service facility without sending it to any other service facility, then the type of the repair service performed in that repair service facility is known as single level servicing in a RL network.

To put in other words, if the repair service of a particular commodity, to recover its value is made specifically in a single repair service facility only, then it is called as Single level servicing and their corresponding flow is referred as a Single level RL Networking.
• Example: If the entire repair service work needed to recover the value of a refrigerator is performed only (by the servers) in a single repair service facility of the manufacture.

2.3.4 Multi Level RL Networking/ Multi level Repair servicing in a RL Network

In some situation, the returned commodities/products need some additional work to be done (any specialized work) due to the reason of unavailability of tools/equipments, spares, expertise, etc., to recover its full value, in addition to the work performed in the first level service facility.

In that situation they are sent to some other service facilities, which is, situated in different locations (may be the manufacturing plant-second level) to perform additional or specialized works. This type of service performed is known as multi-level servicing in a RL Network.

To put in other words, the repair service work of a commodity is carried out in more than one repair service facilities, which are located at different levels or locations is known as Multi level Servicing and their corresponding flow is referred as a Multi level RL Networking.

• Example: Entire repair service work needed to recover the value of a refrigerator is carried out in more than one repair service facility, which is situated in different levels.

2.4 Conclusion

Reverse Logistics Network review shows that, different types of network are analyzed with different recovery options/methods. The main recovery options followed can be listed as, recycling, remanufacturing, refurbishing/repair service, reuse, and disposal. The maximum works on RL networks found, are dealt with single commodity flow only. This paves the way to analyze the problems regarding the flow of multi-commodities in RL networks.
The possibilities of different network structure with commodities/products flows are also studied in this chapter. There are four different possibilities of RL Network. These are mentioned and explained. In this current research work, the flow of multi-commodities in both single and multi-levels are considered.