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REVERSE LOGISTICS NETWORK DESIGN WITH UNCERTAINTY

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I also want to express my appreciation to my parents who always give their instrumental support.

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Mohammed F. N ALAMASSI

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LIST OF SYMBOLS

P Set of products

I Fixed set of points for customer zones.
J Set of the candidate points for collection/inspection centers.
K Fixed set of the candidate points for recovery centers.
L Fixed set of points for disposal center.
V Set of transportation mode (truck/train).
V_1 Set of less than truck load (LTL) transportation modes.
V_2 Set of full truck load (FTL) transportation modes.
V_3 Set of rail transportation mode.
V_{1i} Set of V_1 transportation modes used from any entity i.
V_{2i} Set of V_2 transportation modes used from any entity i.
V_{3i} Set of V_3 transportation modes used from any entity i.
V_i Type transportation modes used from any entity i.
S Set of Scenario s.
r_{ps} Average fraction of each disposed product (percent) for each scenario *s*.
M_{ps} Amount of each product quantity from customer zones for each scenario s.
f_j Fixed cost to set up collection/inspection center j.
f_k Fixed cost to set up recovery center k.
C_p^v Transportation cost for a ton of product p by the mean of transport v.
C_f^v Transportation cost for a full load means of transport v.
Cp_{pk} Collection and Inspection cost for a ton of disposal products p at collection/inspection center j.

CC_{pi} Processing cost per ton for product p at recovery center k.
Cd_{pl} Disposal cost per ton for product p at disposal center l.
D_{ij} Transportation distance from customer zone I to collection/inspection center j.
D_{jk} Transportationdistancefromcollection/inspection*j*centertorecoverycenter*k*.
D_{jl} Transportation distance from collection/inspection center j to disposal center l.
$SMAX_{pj}$ Maximum capacity of the collection/inspection center j for each product p.
$SMAX_{pk}$ Maximum capacity of the recovery center for product p .
cap_v Capacity in ton of mean of transport v.
$Nmin_j$ Minimum number of collection/inspection center j.
$Nmin_k$ Minimum number of recovery center k.
$Nmax_j$ Maximum number of collection/inspection center j.
$Nmax_k$ Maximum number of recovery center k.

G Very huge number

π_s Probability of scenarios.

X^v_{pijs} Amount of returned products transferred from customer zone *i* to collection/inspection center *j* for each product *p* for each scenario *s*.

X^v_{pjks} Amount of scrapped products transferred from collection/inspection center to disposal center for product *p* for each scenario *s*.

X^v_{pjls} Amount of recoverable products transferred from collection/inspection center to recovery center *l* for product *p* for each scenario *s*.

V^v_{pijs} Integer variable express the number of full load means of transport *v* used between the entities *i* and *j* for product *p* for each scenario *s*.

V^v_{pjks} Integer variable express the number of full load means of transport *v* used between the entities *j* and *k* for product *p* for each scenario *s*.

V^v_{pjls} Integer variable express the number of full load means of transport *v* used between the entities *j* and *l for* product *p* for each scenarios.

Y_j Binary variable equal to 1 if a collection\inspection center is open at location *j* ; 0 otherwise

Y_k Binary variable equal to 1 if a recovery center is open at location *k;* 0 otherwise

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ANN	Artificial Neural Network
BOM	Bill of Material
CLSC	Close Loop Supply Chain
CPU	Central Processing Unite
EEE	Electrical and Electronic Equipment
EOL	End-of-life
ELV	End-of-Life Vehicles
GAMS	General Algebraic Modeling System
ILP	Integer Linear Programming
LCA	Life Cycle Analysis
LP	Linear Programming
MIP	Mixed Integer Programming
MIGP	Mixed Integer Goal Programming
MILP	Mixed Integer Linear Programming
MILP	Mixed Integer Non-Linear Programming
MOO	Multi Objective Optimization
RL	Reverse Logistic
RLND	Reverse Logistic Network Design
RNM	Recovery Network Model
SA	Simulated Annealing
SAA	Sample Average Approximation
SBSM	Scenario Base Stochastic Method
SP	Stochastic Programming
SMIP	Stochastic Mixed Integer Programming
SMILP	Stochastic Mixed Integer Linear Programming
VAM	Vogel's Approximation Method–Total Opportunity Cost
WEEE	Waste Electrical and Electronic Equipment

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ABSTRACT

REVERSE LOGISTICS NETWORK DESIGN WITH UNCERTAINTY

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MSc. Thesis

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Over the past few years, recovery of used products has become increasingly important due to economic reasons and growing environmental or legislative concern. Meanwhile, an efficient reverse logistics network is required to process used products returns so as to recover value by reprocessing them and redistributing them in the market.

Uncertainty is one of the main challenges face the planning and designing processes of reverse logistics network, the high degree of uncertainty in terms of time, quantity and quality of returned products, and the capacities of different facilities inside the network increase the complexity of reverse network designing problems. With consideration of the factors noted above, this thesis proposes a comprehensive model for reverse logistics planning where many real-world features are considered such as the existence of multi objectives, multi echelons, and multiple commodities reverse logistics network system under uncertainty in terms of product return quantity.

In this research, bi-objective two-stage stochastic mixed-integer linear programming model is proposed for designing multi-echelons, multi-commodities, single period reverse logistic network. The proposed bi-objective model includes: (1) minimizing total costs including the sum of fixed, transportation, relocation, collection, inspection, recovery, and disposal costs; (2) minimizing of CO_2 emissions from transportation modes inside the network. The problem was formulated in two stage stochastic model in order to find the set of optimal network configurations which achieve the mains goals of the research.

The proposed model takes into consideration the quantity of returned product uncertainty, where the inherent risk is modeled by scenarios. To find the set of non-dominated solutions, ε-constraint method is used to obtain a list of Pareto-optimal solutions for the proposed model.

Key words: Reverse Logistic Network Design, Two-Stage Stochastic Programming, Multi-Objective Optimization, Augmented E-Constraint Method

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ÖZET

TERS LOJİSTİK AĞ TASARIMI BELİRSİZLİK İLE

Mohammed ALAMASSI

Endüstri Mühendisliği Anabilim Dalı

Yüksek Lisans Tezi

Tez Danışmanı: Doç. Dr. Selin SONER KARA

Birkaç yılı aşkın bir süredir, kullanılmış ürünlerin geri dönüşümü ekonomik sebeplerden ve artan çevresel yada yaşama endişesinden dolayı büyük oranda artmıştır. Aynı zamanda etkili bir tersine lojistik ağı, kullanılan ürünlerin yeniden işlemesi ve pazara yeniden dağıtarak değerini koruması için gereklidir.

Tersine lojistik ağının ana sorunlarından birisi başka bir sorunun karmaşıklığını güçlendiren belirsizliktir. Tersine lojistik parametrelerinde kapasite koşulları, talep ve ürün miktarı açısından belirsizlik dereceleri bulunmaktadır. Yukarıda belirtilen faktörler dikkate alınarak bu tez, birçok gerçek dünya özellikleri gibi lojistik planlama için kapsamlı bir model önermektedir.

Bu araştırmada, iki objektif iki aşamalı stokastik karışık tamsayı doğrusal programlama modeli ters lojistik ağının çoklu kademelerinde, tek bir dönem için çoklu mal tasarımı amaçlanarak önerilmiştir. Önerilen iki amaç doğrultusunda (1); sabit maliyet, ulaşım, yer değiştirme, toplama, denetim, geri kazanım ve bertaraf maliyetleri toplamı dahil, toplam maliyetleri en aza indirmek, (2); ağ içindeki ulaşım modlarının CO_2 emisyonlarını en aza indirmesi hedeflenir. Sorun aynı zamanda, toplam maliyet ve CO_2 emisyonlarını en aza indirmek için en uygun ağ yapılandırması ve ulaşım modları ve

ilgili akışların atanması için formüle edilmiştir. Stokastik optimizasyon modeli bünyesel risk senaryoları ile modellenmiş ve iade edilen ürün belirsizliğinin miktarının altında geliştirilmiştir.

Non-dominated çözümü bulmamız için ε- kısıt yöntemini takip ederek önerilen model için Pareto-optimal çözümleri elde ederiz.

Anahtar Kelimeler: Tersine Lojistik Ağ Tasarımı, İki Aşamalı Stokastik Programlama, Çok Aşamalı Optimizasyon, Augmented ε -Kısıtlama Yöntemi.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Pressing global challenges such as climate change, resources depletion, or the loss of biodiversity demonstrate the imperative for structural change of our economic and societal systems towards the recovery of used products. The management of used product returns is in the scope of Reverse Logistics (RL). Reverse Logistics comprises all operations related to the reuse of products and materials, and it is consider as a part of close loop supply chain. The success of close loop supply chain depends on the success of relations of both manufactures and customers. The new business strategies go through the rationalization of manufacturing operations and production, as well as by efforts to serve new markets with new products and new ecological concepts. The manufactures try to produce products easy to disassembly and friendly to the environment; beside to increase the levels of protection of environments to avoids the government's rules. And the customer try to help the manufactures by sending used products to collection points [1]. Previous studies showed the total cost of reverse logistics activities is huge relative to recovery and recycle industry, in order to avoid this many studies discussed different way to increase the total cost of reverse logistic activities through high utilization rate of collection points, selecting appropriate locations for collection points is critical issues in reverse logistics [2].

The emission of greenhouse gases like (CO_2, NO_2,…est.) has increased over the last years due to the growth of international transport, and should be taken into account in reverse chain design for their negative influence on the environment. Environmentally friendlier transportation has been promoted by governmental initiatives such as the Kyoto protocol and European Union action plans including Freight Transport

Logistics Action Plan (2007) [3], Greening Transport (2008) [4], Strategy for the internalization of external costs (2008) [5], and A sustainable future for transport: Towards an integrated, technology led and user friendly system (2009) [6]. Therefore, optimization of supply chains nowadays also has to consider, besides the cost, the environmental aspects such as the emission of carbon dioxide (CO_2) and particulate matters (PM, also known as fine dust).

According to the above The high degree of uncertainty, and large-scale businesses networks are concerned with the optimization of the location and the capacity of their facilities; have become as one of the challenging issues in the recently emerged field of reverse logistics. These challenges increase the concern of evaluation an efficient design of a product recovery network in general and RLND problems specifically. Moreover, current deterministic facility locations models lack the ability to incorporate inventory related costs, as well as a product's lead time through the network. Nevertheless, the time that returned products spend in the system is an important issue because the costs of obsolescence may be significant.

1.2 Scope of the Thesis

Research motivation of this thesis depends on the need of a comprehensive model for reverse logistics planning which have to consider many real-world features such as the existence of several facility echelons, multiple commodities, and different transportation modes with uncertainty associated with the quantity and the quality of returned products. Since the reverse logistic (RL) networks are surrounded with uncertainty of products return quantity, we developed a two-stage stochastic bi-objective mixed-integer programming (MILP) formulation, and where a deterministic model is proposed extended later by applied the uncertainties in terms of quantity and quality. Definition and detail explanations related to this model can be stated as follows:

Model: Bi-objective optimization model for strategic reverse logistics planning problem with uncertainty of product return quantity.

Goals:

1. Minimization of total reverse logistic network costs.

2. Minimization of the total CO2 emissions.

Given:

- Cost parameters such as fixed set-up, transportation, collection and inspection, recovery, and disposal costs.
- Demand data and corresponding return products,
- Recycling and disposal rates,
- Distances between each stage,
- Collection/ inspection, recovery, and disposal facilities capacities,
- Transportation modes capacities.

Determine:

- Locations of opened regional collection/ inspection centers, and licensed recovery facilities,
- The quantities of each product can be recovered (recycled) in recovery centers; and the quantities will be disposed in disposal centers in different scenarios.

Case study: This model is tested with a case study based on some data from a WEEE reverse logistic network in Turkey.

Used methodologies:

- Mixed integer linear programming,
- Two- stage stochastic programming,
- ε- Constraint Method.

1.3 Research Goals and Motivations

The main purpose of this thesis is to develop a new quantitative model for design a complex reverse logistic network via mathematical modeling approach and to solve them under uncertainty of the quantity of returned products. This complexity comes from the more applicable and realistic issues such as multi-objective nature, availability of multiple recovery options for a reverse logistics system, dynamic design decisions, group decision making environment, uncertain data structure etc. in real world problems. The main objective of this research is the answer of the following question:

“Where to open the collection/ inspection centers and recovery centers in the reverse logistic network that satisfy the optimal cost and minimum CO2 emissions amount with uncertainty of retuned products quantities?”

Beside the main objective of this research there are sub-objectives can be as follows:

- Present a detail overview on definitions of reverse logistics (RL) and close-loop supply chain (CLSC) management, main concepts in RL & CLSC management, categories of RL flows, and other issues such as environmentally conscious manufacturing.
- Present a literature review on RL network design problem and main modeling characteristics in RL network design.
- Develop a multi-objective, multi-echelon and multi-product strategic planning model for reverse logistic network.
- Present an application of two stage stochastic programming approach with different importance.
- Develop a stochastic bi-objective model and considers a multi-mode transportation.

1.4 Thesis Outline

This thesis is divided into six chapters. Followed by the introduction in chapter one, chapter two provides a summary on the characteristics of reverse and closed-loop supply chains, while chapter three provides a literature review on reverse logistics network design. Chapter four describes the applied approaches for estimating the Pareto front for a multi-objective optimization model: secularization methods and two stage-stochastic programming. Chapter five presents the problem description and model formulation, as well as the solution approach. In chapter six, numerical examples are presented and the results are analyzed. Chapter seven presents conclusion, as well as future avenues of research.

CHAPTER 2

REVERSE LOGISTIC FRAMEWORK

The dynamics of globalization have guided the companies to reconsider a number of issues related to competitiveness, productivity, quality, equity and sustainability and integrate these terms into their discourse. Besides, companies devise and implement strategies through the improvement of their operations to secure their survival in a growing competitive market. Due to modern environmental regulations, many manufacturers tend to produce products capable of recycling.

Reverse Logistics (RL) is one of the issues emerging from the rising pressure made by the competitive forces like the government who constantly interfere in manufacturing process for the purpose of environment protection. For example, many of the EU leaders have embraced and engaged in several programs that would conserve the natural resources of their own countries.

Twenty years ago, “Reverse Logistics” (RL) was practically an unknown term in the circles of academics and companies. Traditionally, a product was developed to be manufactured and then go through the supply chain (e.g. manufacturer-wholesaler-retailer) to be sold to a customer. However, supplies chains steadily integrate activities that exceed supply to include service and product recovery.

Recently, the concept of “Reverse Logistics” (RL) has drawn great attention from both the academic and industrial fields. This can be attributed to a number of crucial reasons. Due to the huge cost spend on RL activities, selection the approicate location for different facilities in RL network will help in minimizing the total cost spend on RL activities.

Rogers and Tibben- Lembke point to the total logistics cost that amounted to $862 billion in 1997 and the total cost spent in reverse logistics that sharply increased to by almost $35 billion. This figure shows a significant increase of around 4% in the total logistics cost in the same year [7].

In 2002, the Equipment Leasing Association estimated that of the total investment in business equipment would be financed by leasing companies, at nearly one-third or $204 billion. A key portion of the logistics cost for the leasing industry, the transportation costs, is approximately 1.5% of total costs or approximately $3 billion for 2002. This suggests that logistics decisions greatly impact asset management problems faced by equipment leasing companies [8].

As a sequence of growing concerns with environment factors like climate changes, air pollutions, ground and water pollution from industrial activities have significantly expanded the interaction between environmental management and operations, leading to “Reverse Logistics” [9], where the current threatening level of environmental problems, along with related customer pressure and governmental regulations, motivates corporations to undertake environmentally-conscious initiatives [10], [11].

Due to the governmental regulations and consumer concerns regarding these environmental issues, an increasing number of companies have focused on reduction efforts in the amount of waste stream, diversion of the discarded products from landfills and disposition of the retired products properly. Increasing environmental problems enforce companies to be more environmental responsible [12].

To facilitate the reverse flow of used products from consumers to manufacturers in an efficient manner, the most appropriate approach is to create a reverse supply chain network [13], On the other hand, recovery of used products will help in the sustainability for raw resources and save money in terms of both purchasing fewer raw materials and producing fewer disposals. There has been a significant growing interest in the subject of reverse logistics [14],[15].

This chapter aims to explore the main literature about RL and CLSC, and the different existent definitions of RL. It will also present the reverse logistics steps; discuss the major dimensions of the Reverse Logistics context, namely drivers, actors, depositing options, and cycle times. In this chapter, the flow categories of RL will be addressed and the types of RL networks and its objectives will be described. It will draw a comparison between the “forward” and “reverse” logistics process and provide a literature review of the main publications made in the RL area. Finally, we state some of RL challenges encountered in research and business applications.

2.1Reverse Logistics Definition

Usually the term“logistics”calls to mind the flow and transportation of goods from the company en route to the customer. The Council of Logistics Management (1998) identifies logistics 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”.“Reverse Logistics” also handles issues such as remanufacturing, refurbishing, recycling or disposal to use resources effectively[15].

In research field, several terms are used to refer to RL such as “reversed logistics, return logistics, retro logistics, and reverse distribution” might be encountered [16]. This new concept mostly has been associated with recovery but it differs in most ways such as the way, the time and the structure of product flow. The reuse of products has been practiced for many years because of their economic benefits. Fleischmann cites waste reduction as another reason for the recovery of materials[17].

Our purpose in this section is not to develop new concepts or theories about Reverse Logistics, but to provide a brief summary of the principal statements found in the literature. Definitions of reverse logistics (RL) have been proposed by various authors indicated as follow. In the early nineties, in one of the first publications referring to this term, a White Paper published by the Council of Logistics Management (CLM), Reverse Logistics is introduced as [18]:

“...the term often used to refer to the role of logistics in recycling, waste disposal, and management of hazardous materials; a broader perspective includes all issues relating to logistics activities to be carried out in source reduction, recycling, substitution, reuse of materials and disposal.”

A similar characterization is given by Kopicki et al. (1993) [19]. In yet another early paper Pohlen and Farri define reverse logistics as:

"…the movement of goods from a consumer towards a producer in a channel of distribution." [20].

According to Fleischmann , RL includes logistics activities which ensure providing the markets again with products to use from used products no longer required by the user[15]. Kroon et al. mentioned that reverse logistics refer to the logistics management skills and activities involved in reducing, managing and disposing packages or products [15].

In 1998, Stock defined reverse logistics as the processes associated with the flows of product returns, source reduction, recycling, material substitution, material reuse, waste disposal, material refurbishment, repair, and remanufacturing. More recently, Rogers and Tibben-Lembke have alluded to the CLM's definition of logistics by defining Reverse Logistics 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." [7].

In other words, reverse logistics is the management of any type of returns from any customer with specific purpose, products can be returned from any player within the supply chain or from any end user for different reasons, raw material, work in process or finished goods can be returned, when there are one surplus or left over during the customer's production in manufacturing plan.

Since Reverse Logistics is a relatively new research and empirical area, to avoid encountering with any other literature terms, like reversed logistics, return logistics and retro logistics or reverse distribution, sometimes referring roughly to the same? In fact, the diversity of definitions with respect to recovery practices is a well-recognized source of misunderstandings both in research as in practice [16]. Basically, we can distinguish among three approaches to reverse logistics [21]: Reverse Logistics is almost synonym for material recycling and waste management in effort to minimize cost, retrieve value from reverse flows and fulfill legislative and environmental requirements.

Thus, it is worth making a distinction between “reverse logistics” and “waste management”, as the latter mainly refers to collecting and processing waste (products for which there is no new use) efficiently and effectively. Herein, the meaning of waste is the crux of this matter. This is a major issue, as the term has severe legal consequences reflected in the prohibition of importing waste.

Reverse Logistics concentrates on those streams where there is some value to be recovered and the outcome enters a (new) supply chain, also the terms Green Logistics and Reverse Logistics being likened perhaps without a sound basis. Green logistics considers environmental aspects to all logistics activities and it has been focused specifically on forward logistic, i.e. from producer to customer . The prominent environmental issues pertaining to logistics are consumption of nonrenewable natural resources, air emissions, congestion and road usage, noise pollution, and both hazardous and non-hazardous waste disposal [15].

Finally, to settle on a specific definition, reverse logistics is an evolution of traditional forward logistics in an environmental-conscious industry or due to other commercial drives. It includes all the logistics activities and management functions necessary for reintroducing valued-objects, "which have finished or are not suitable to perform their primary function any more, into certain recovery systems for either recapturing their value or proper disposal" [22].

As stated earlier "customer service related to a fast and flexible claim and return process and a short claim-to-pay-back period is important and can create both customer loyalty and competitive advantage" [22]. The value can be regained through reparation or refurbishment when returned to the market place, components from product returns can be reused as refurbished components or as spare parts. In Skjott-Larsen et al.[22] they identify five ways that proactive reverse logistics can have a positive impact on profitability:

- Increased revenues realized from secondary sales.
- Offering new products in place of unsold or slow selling stock.
- Shareholder goodwill from acting with social and environmental responsibility.
- Reduced operating costs from reuse of recovered products and components.
- Higher asset turnover due to better management of returns inventory [22].

2.2 Reverse Logistics Processes

Many companies create reverse logistics networks in order to achieve asset recovery. With this end in view, reverse logistics networks are put in place and these systems include many different activities. According to Blackburn et al. depending on strategic goals, the reverse logistics strive to focus either on the cost efficiency or on the speed of response [23]. Blumberg identified key issues that need to be considered when organizing and controlling reverse logistics processes.

After comparing many major reverse logistics authors and studies, one can conclude that most, if not all authors seem to agree on the same basic reverse logistics activities. While the traditional forward logistics process involves material supply, production, distribution and consumption, reverse logistics process consists of the following activities:

- **Collection and transportation;** refere to all activities of collection the returned products from customers and end user to collection centers, and including different transportation means of returned product between the facilities of reverse network.
- **Inspection / separation denote**; referee to the processes of inspection of returned products and separating them into different segments, some of this product will be recovered and the other will be disposed.
- **Re-processing**; refers to transformation process of returned products into a usable product, component, and material again. This process include different features:
    - **Direct reuse;** some types of returned products do not need any transformation process to reuse it, so it can be used directly. Examples of these products are the means of transportation; pallets, containers, bottles or boxes [24].
    - **Repair;** returned products by end user or customer to have it back in working order. The suppliers change the broken parts if necessary or treat it. Repair process normally is need limited effort. Generally the qualities of repaired products are less quality those new products [25],[24].

- **Refurbishing;** referee to the process of improve the returned products specified quality level. Firstly, products are disassembled and inspected after that they fixed or replaced. The process the quality of the returned product is improved substantially [25],[24].
- **Remanufacturing;** in order to improve the quality standards of returned products, they are carefully inspected, disassembled and broken or outdated parts are replaced with new ones. Additionally, repairable parts and modules also can be used after being fixed.
- **Recycling;** refer to process of recycling reused materials in the products which were inspected and cannot be reused directly or remanufactured so it disassembly the products into parts and recycling the material which can be used later in producing new parts, thus the identity of product is lost.
- **Dispose;** when the returned products cannot be re-used for technical or cost reasons at inspection separation level. Disposal may include transportation, land filling and incineration steps.

2.3 Reverse Logistics Framework Dimension

Framework is "a basic concept structure. There are four logistics perspectives that appear similarly important and represent the main dimensions of reverse logistics framework, namely drivers, the return reasons, recovery options, and actors. These perspectives are explained below as well as compared to the reverse logistics flow studies [26]. Figure 2.1 illustrates a framework for reverse logistics.

1. **Driving forces (why-receiving)**

Generally, the companies carry on reverse logistics because of the profit, obligatory forces or social pressure. According to this classification, the drivers are named as:

- Economics; like decreasing the use of raw materials, decreasing waste materials, obtaining valuable spare parts, other financial opportunities like second hand market, marketing objectives, and Competition drivers.
- Legislation; refers to any jurisdiction indicating that a company should recover its products or take them back [27].

- Corporate citizenship; refers to the set of values or principles that an organization holds to be responsible with RL activities [10].

2. **The return reasons (why-returning)**

   - Manufacturing returns (raw material surplus, quality-control returns and production leftovers);
   - Distribution returns (product recalls, B2B commercial returns, stock adjustments and distribution items/functional returns);
   - (Pos-)Market returns (B2C commercial/reimbursement returns, warranties, service returns/repairs and spare parts, end-of-use, end-of-life returns.

3. **The recovery processes and recovery options (how)**

Options for recovering value from the goods under consideration; in other words, the disposing alternatives may possibly be reused directly without any major reprocessing except for cleaning or minor maintenance. Alternatively, remanufacturing conserves the product identity and seeks to bring the product back into an `as new' condition by carrying out the necessary disassembly, overhaul, and replacement operations. In contrast, the goal of repair is to restore failed products to `working order', though possibly with a loss of quality. Recycling denotes material recovery without conserving any product structures. Finally, returned products may not be reused at all. Therefore, we add disposal, in the form of ladling or incineration, to the list of disposing alternatives.

4. **The actors involved and their roles (who)**

Many players are involved in reverse logistics networks. First of all, consumers play a key role as the incoming supply depends on them. That being said, other actors play key roles in the creation of reverse logistics networks such as the forward supply chain actors – suppliers, manufacturers, distributors, retailers est. [26].

Finally, we had to mention that some studies like [15] had pay attention to Cycle Time as another dimension in reverse logistic process as the time period a product stays with its owner before entering a `reverse' flow. Cycle Time has a direct impact on feasible disposition options: in many cases the economic value of a good that is returned quickly may be expected to be higher than of a product that has stayed in the market for a long time. Furthermore, the cycle time largely influences logistics planning, namely appropriate forecasting approaches and opportunities for integrating 'forward' and 'reverse' flows.

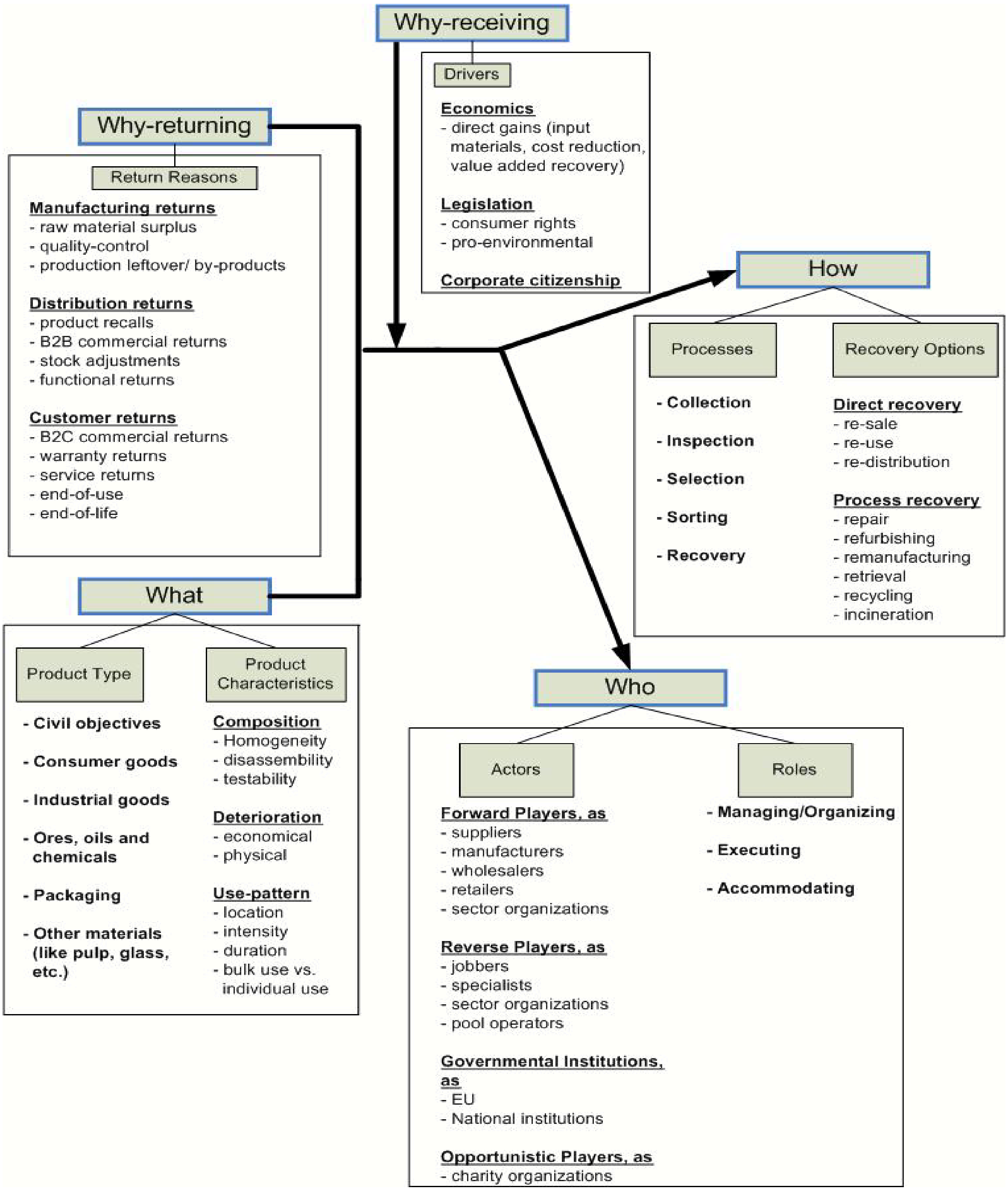

Figure 2.1 Framework for reverse logistics (Adapted from De Brito 2003)

2.4 Reverse Logistic Flow Categories

Five different reverse logistic flows can be categorized and explained as follows:

1. End of use returns

Products those have been completely used and should be disposed or that have not yet reach the end of their technical or economic life and still have recovery options like remanufacturing or recycling.

2. Commercial returns

The buyer returns products to the original sender against refunding. This is above all relevant for products involving a high risk of obsolescence, for example due to seasonality or short product lifecycles.

3. Warranty returns

These kinds of returns refer to products failed during use or damaged during delivery that are returned to the original sender. Product recalls also belong to this category.

4. Production scrap and by products

This category is about excess material resulting for example from cutting reintroduced in the production process.

5. Packaging

Crates, refillable, bottles, pallets, or reusable boxes are common kinds of packaging moved in reverse logistics flows. The main advantage is that they can often be reused directly without major reprocessing, except for cleaning. There are two possibilities how this packaging can be handled. Either it is returned to the original sender or it is transferred to alternative parties such logistics services Provides who recollect reusable packaging.

2.5 General Characteristics of RL Networks

RL networks have several characteristics that differentiate them from the typical supply chain. There are three main managerial issues that distinguish the design of reverse logistics networks from traditional distribution networks, which is shown in Figure 2.2.

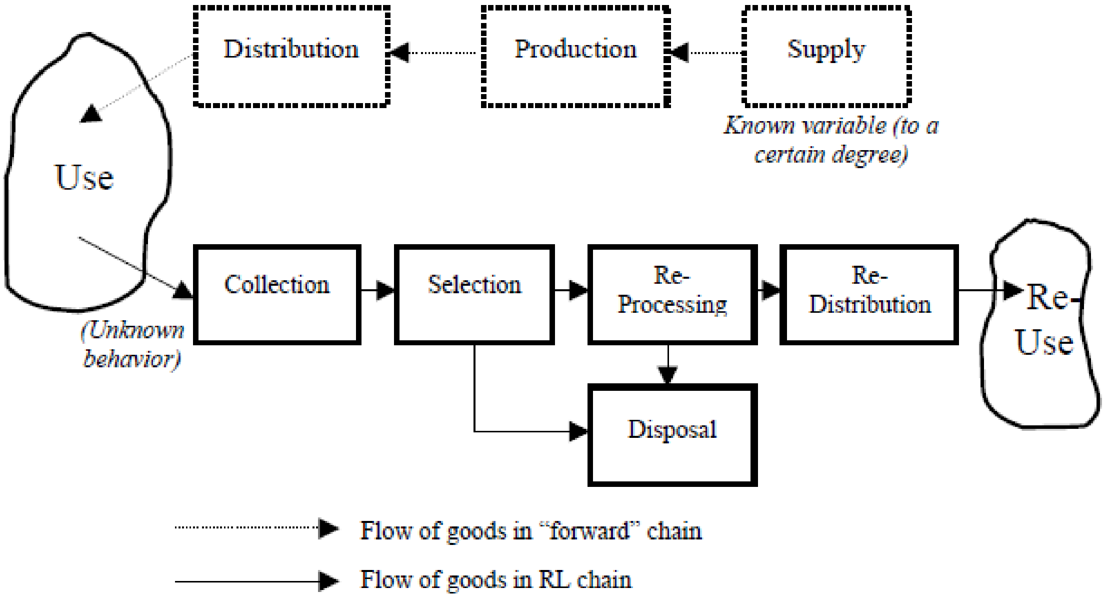

Figure 2.2 Reverse logistic Network (Fleischmann, 2001)

1. Centralization of testing and grading

We have seen that the location of the test and grade operations has major consequences for the product flows in a closed- loop supply chain. What is special about this situation is the fact that product destinations can only be assigned after the test stage. In a traditional distribution environment product routings are, in principal, known beforehand. While there may be exceptions, e.g., for by-products or rework, this is not a major focus of conventional production-distribution networks.

2. Uncertainty and lack of supply control

It has often been claimed that reverse logistics environments are characterized by a high level of uncertainty [25]. While in traditional supply chains demand is typically perceived as the main unknown factor, it is the supply side that significantly contributes to additional uncertainty here. Used products are a much less homogenous input resource than conventional 'virgin' raw materials in that timing, quantity, and quality may be uncertain and difficult to influence. Effectively matching demand and supply therefore is a major challenge in closed-loop supply chains. Consequently, robustness of the logistics network design with respect to variations in flow volumes and composition appears to be particularly important in this context.

3. Integration of forward and reverse flows

As discussed above, logistics implementation of closed-loop supply chains may offer several opportunities for exploiting synergies between different product flows. While traditional distribution networks are typically perceived as ‘one-way’ objects, closed-loop chains naturally involve multiple inbound and outbound flows of different ‘orientation’. Hence, there may be room for integration both in transportation and facilities. At the same time, these opportunities raise a compatibility issue. In many cases, reverse logistics networks are not designed ‘from scratch’ but are added on top of existing logistics structures. One may wonder whether this sequential approach allows for efficient solutions or whether an integral redesign of the entire closed- loop network offers tangible benefits.

Before addressing these issues in a quantitative analysis we discuss their relative importance in different supply chain contexts in some more detail. To this end, the next section takes a closer look at different types of reverse supply chain networks.

2.6 Difference between Reverse Logistics and Forward Logistics

Reverse logistics is quite different from the traditional logistics, or forward logistics, activities [7]. The border between forward logistics (from raw materials to end user) and reverse logistics (from end user to recovery or to a new user) is not strictly defined as one can wonder about what ‘raw materials’ are, or who the ’end user’ is, in modern supply chains. Figure 2.3 is adopted from Rogers & Tibben-Lembke [7], it shows the information flow from a typical retail forward logistics process.

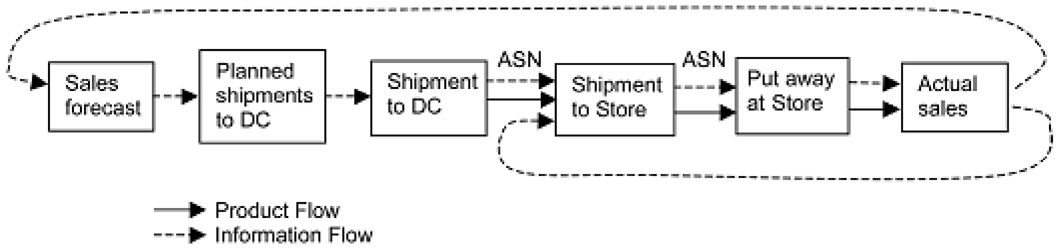

Figure 2.3 Forward Logistics Flow (Rogers & Tibben-Lembke (2002)).

Sales forecast is used to project sale requirement, when certain amount product is required, they will be shipped to the DC (distribution center) and then shipped to the retail stores from DC. At every single level of the supply chain, ASNs (Advanced Shipping Notices) will be assisting the useful information as the products flow.

Reverse logistics flow, on contrast, is a different story. Firms generally do not initiate reverse logistics activity as a result of planning and decision making on the part of the firm, but in response to actions by consumers or downstream channel members [7]. Figure 2.4 below gives this process a clear depiction:

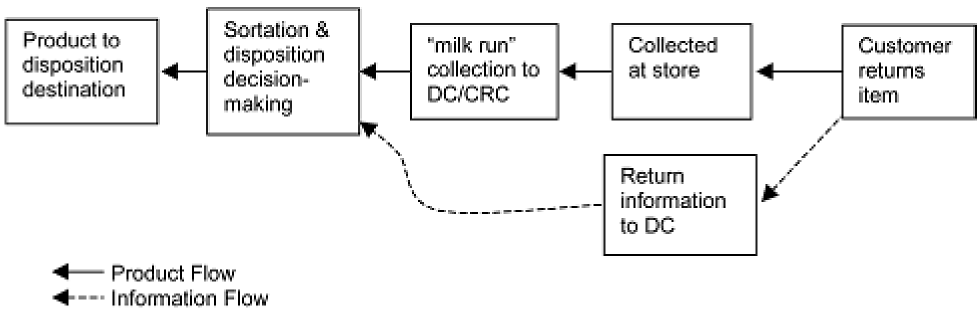

Figure 2.4Reverse Logistics Flow (Rogers & Tibben-Lembke (2002)).

Above figure is a common information flow of reverse logistics, when a return occurs, the returned product will be collected (in many different ways) and sent to the distribution center. At the same time the relevant information about the return, e.g. item description, condition at return, customer information etc., will be transferred to the return processing center, but unfortunately, given the current state of the reverse logistics status quo [28] , this information capture process rarely occurs, or occurs with less inaccuracy.

Min, Ko et al. [28] has summarized differences between reverse and forward logistics as in the Table 2.1.

Table 2.1 Differences between Reverse and Forward Logistics.

	Reverse logistics	Forward logistics
Forecasting	Relatively straightforward	More difficult
Quality	Product quality uniform	Product quality not uniform
Packaging	Product packaging uniform	Product packaging often damaged
Inventory management	Inventory management consistent	Inventory management not consistent
Quantity	Small quantities	Large quantities of standardized items
Information tracking	Combination of automated and manual information systems used to track items.	Automated information systems used to track items
Order cycle time	Medium to long order cycle time	Short order cycle time
Product value	Moderate to low product value	High product value
Inventory control	Not focused	Focused
Priority	Low	High
Cost elements	More hidden	More transparent
Product flow	Two way ("push and pull")	One way ("pull")

Channel	More complex and diverse (multi-echelon)	Less complex (single or multi-echelon)

2.7 Reverse Logistic Network Design

To be able to capture additional value from returns processes it is necessary to design and control reverse supply chain carefully. The design of product recovery networks is one of the challenging and actual reverse logistics problems. Stimulated by environmental, legislative and economical reasons several recovery networks have been set up in the last decade. Several researchers have focused on issues of reverse logistics will be discussed in chapter 3. The efficient design of RL network is one of the challenging due to uncertainty and the large scale of business. Due to the high number of processing activities involved and the high variability in the value of the components, this location-allocation problem is particularly relevant in a reverse logistics context. However, the high level of uncertainty in this field also applies to network design. In particular, compared to the traditional forward chain, it is more difficult to control for the timing, quantity and quality of the supply, while in addition the processing activities are highly variable.

Furthermore, current deterministic facility locations models lack the ability to incorporate inventory related costs, as well as a product's lead time through the network. Nevertheless, the time that returned products spend in the system is an important issue because the costs of obsolescence may be significant.

Reverse logistics systems can be classified into four major categories considering types of return items [17] and the main options of recovery [25] these four classes are directly reusable network (DRN), remanufacturing network (RMN), repair service network (RSN) and recycling network (RN). Each network has own characteristic as described below:

- **Directly reusable network (DRN):** This type of RL network include activities like inspection and cleaning and send direct to market again like reusable pallets, trays, boxes, and standard containers; and it consider as closed loop network.
- **Remanufacturing networks (RMN):** Used products or parts at the end of life cycle are returned, some of these parts manufactured and return again to the markets. This Type of network is a closed loop system because remanufacturing is usually performed by the original manufacturer.
- **Repair service network (RSN):** defective products or part changed and returned again to customer, such as electronics equipment, are returned and

repaired in service centers. Because there are a few links between FL and RL, so it is considered an opened-loop system.

- **Recycling network (RN):** Raw materials like metal, paper and glasses, which produced by disassembly or used products are recycled. This type of RL network can be considered an opened-loop system and also includes waste collection and elimination [29].

2.8 Reverse Logistics Challenges

The goal of this section is to identify the possible different challenges arising from working with Reverse Logistics and how these challenges can be handled along with examples based on theoretical models. Regardless of the purpose of making Reverse Logistics system, it is important to understand the difficulties arise from operating a reverse logistics network.

According to Rogers and Tibben-Lembke [7], in order to increase competitiveness and gain additional value of product returns, companies must possess a strategic vision of managing reverse flows. However, "reverse flows" encounter specific challenges that differ from those of "forward flows" [22]. In the literature of the reverse supply chain, researchers identify a number of challenges that influence reverse flows management and reverse supply chain strategy. These challenges are:

1. Lack of formal operating procedures

Products retrieved from the market may be unpacked or not have product identification such as bar-coding or labeling. This can cause difficulties with the validation of information systems and standardizing procedures. A lack of formal operating procedures causes a waste of time and requires additional resources [22]; [30].

2. Differences in quality, quantity and timing

Great differences in value, quality, quantity and timing of returns lead to difficulties in making early forecast and planning requirements and resources needed for product return processing through the reverse chains [23];[17].

3. Decreasing market value due to time delays

It is true that late returns differentiation (e.g. in centralized return centers) can save cost and resources; however, due to time delay, it can also decrease market value that is essentially important for returns with high marginal time value. Thus, the differentiation, in the reverse chain, should be carried out as early as possible. However, the complexity of the characteristics of product returns, the required resources and coordination issues between parties can also be major obstacles to implementing early differentiation [23];[22].

4. Retailer-Manufacturer conflict

According to Rogers and Tibben-Lembke, conflicting objectives between retailers and manufacturers may cause inefficiencies that lengthen the processing time and generate conflicts arising from disagreement on value and condition of returned items and the time of response[7].

5. Lack of local competence

According to Skjott-Larsen et al., reverse supply chain processes such as the inspection, testing and the evaluation require a high level of competence. A lack of local competence (e.g. lack of competence at retailer's store) in these processes can decrease the speed of reverse flows and cause errors (e.g. by choosing appropriate disposition alternative) [22].

6. Lack of performance measurement

According to Pochampally et al. , the performance of measurement techniques used in a forward supply chain cannot be applied to the reverse supply chain due to the differences in various aspects. Furthermore, Skjott-Larsen et al. have found out that companies rarely measure the efficiency their returns processes in a systematic way [30]. However, in order to boost the performance of reverse supply chain, it is important to set up performance measures such as "time from customer's complain to replacement of new product/repaired defect product at the customer premise, quantity and quality of returns, causes of return, cost involved in returns" [22].

CHAPTER 3

LITERATURE REVIEW

Over the last six decades researches on reverse logistics (RL) have been flourished along with increasing publications on strategies and models on RL come to the fore. However, there are limited efforts to synthesize the research in an integrated broad-based body of knowledge as most research has been restricted to a small area of RL systems related to network design, production planning or environmental issues. After reviewing the reverse logistics literature, we have found some topics that are commonly studied by researchers which are worth reviewing in order to know what has been included and excluded. We will look closely at these research topics in this chapter. Early reverse logistics researchers focus attention on the large-scale view of reverse logistics in which most of their work went into the whole process of reverse flow. For example, Thierry et al. [25] presented an integrated supply chain framework to demonstrate the reverse flows and various recovery options such as repair, refurbishing, remanufacturing, recycling, etc. Lately, the emphasis has been shifting towards recovery in the light of the high costs and environmental burdens of disposal. More than ever firms take responsibility for collecting, dismantling and upgrading of used products and packaging materials [15].

Some literature addressed the focus on reverse logistics concerning product handling, e.g. transportation, inventory management, and distribution [20]. They investigated the reverse distribution channel structure in plastics recycling and analyzed the compaction and routing issues related to transportation in the RL process. Some researcher put reverse logistics practice into quantitative models. For instance, reverse logistics network addressed in the literature rely on mixed-integer linear programming giving the scope for large-scale mathematical optimization. Fleischman [15] noted that for most of the reverse logistics network models, facility location models based on mixed integer linear programming (MILP) have become a standard approach.

There are models from simple un-capacitated plant location models to more complex capacitated multi-level multi-commodity models. A variety of solution algorithms proposed relies on combinatorial optimization theory.

Some quantitative papers have been made on production scheduling, inventory control and remanufacturing. Van der Laan studied the production planning and inventory control in systems where manufacturing and remanufacturing operations occur simultaneously. They consider a relatively simple hybrid system related to a single component durable product. They present a methodology to analyze a push control strategy (all returned products are remanufactured as early as possible) and a pull control strategy (where all returned products are remanufactured as late as it is convenient). They derive some managerial insights into the inventory-related effects of remanufacturing.

In addition to the previous examples, there are many other quantitative models contributed by various researchers [17]. These models can be used to improve numerous dimensions of reverse logistics practices, such as, extending product life cycles, protecting product failures, etc.

Fleischman concluded that current models for reverse logistics network design are quite similar to traditional facility location-allocation models, especially to the multi-level warehouse location models. The main differences are additional flow constraints reflecting supply restrictions concerning the disposer market. The models include supply-push constraints rather than entirely demand-pull driven. Other modifications include multiple return flow disposition and possible interaction between forward and reverse channel. As a result, most of the models have characteristics of multi-commodity flow. All models are deterministic and only treat uncertainty in a conventional way by using scenario and parametric analysis [21].

3.2 Reverse Logistic Network Design Models

In this chapter, we will explore some research works mainly concerned with the reverse logistic network design (RLND) problems. The literature fordesigning the reverse logistics network contains two approaches. The first one is to consider the forward and reverse networks as separate entities and design them sequentially. The other approach is to integrate both flow types into the design process. These studies can be classified according to model type into two main categories: deterministic models and stochastic models based on the certainty of information available about the quantity, quality, and timing of returned products. If the number of facilities or nodes of network, their locations and demands are known with certainty, the model is called deterministic. When the customer demands are modeled into the use of probability distributions, these models are termed stochastic. Some of these studies are briefly explained as follows: the research in reverse logistics and its impact on forward supply chain functioning. Overall, the reviewed papers applied models such as linear programming, non-linear programming, MILP, MILNP, network equilibrium model, stochastic model and simulation model to deal with the above research issues.

3.2.1 Deterministic network model

A network model is categorized as a deterministic model when the information on the nodes of the network is known or predefined. This type of model simplifies the problem but can also give a generalized view of the problem. The deterministic model may also represent the real problem if it is analyzed by using different sets of scenarios or through performing sensitivity analysis.

(Spengler et al., 1997) develop a MILP-model for the recycling of industrial byproducts in German steel industry. This model is based on the multi-level warehouse location problem and modified for this case study. This requires identifying store locations and means of transporting flows from the sources through the intermediary facilities to the sinks. This model is multi-stage and multi-product allowing the transfer sub-streams of interim products from one intermediary facility to another in various ways, before delivering it at a sink. A sink can be either a reuse or a disposal location. Facilities can be installed at a set of potential locations and at different capacity levels, with corresponding fixed and variable processing cost. The type of processes to be installed at the intermediary facilities also have to be determined, hence the processing graph is not given in advance. Maximum facility capacities are restricted and transportation costs between locations are linear. While the amounts of waste generated at the sources are fixed, the demand at the sinks is flexible within range. This range is set by the minimal required throughput and the maximum capacity of the sink [31].

(Barros et al., 1998) develop a model to determine an optimal network for the recycling of sand. In this case, sieved sand is coming from construction works, which represent the sources. The sand is delivered at a regional depot, where it is sorted into three quality classes. The first two classes, clean and half clean sand, are stored at the regional depot in order to be reused. The dirty sand is cleaned at a treatment facility, where it is also subsequently stored as clean sand. Both the clean and the half clean sand can be reused in new projects, which represent the sinks. Both supply and demand are fixed for the respectively three and two qualities of sand. It has to be determined at which locations regional and treatment centers must be opened, where locations can be picked from a pre given set of potential locations. Also the capacities of the facilities and the routing through the system have to be determined, where capacities of both facilities are restricted. Opening a facility incurs a fixed and variable linear processing cost, transportation costs are also linear. The model used is a multi-level capacitated warehouse location model, for which heuristic algorithms are developed [32].

(**Kirk, 1999)** identified the design principles of a closed loop supply chain. The authors aimed at optimizing economic, logistic and environmental performance of the closed-loop supply chain. Quantitative modeling was developed to support the optimal design structure of a product. The environmental impacts were measured based on the energy utilized and waste produced during the life cycle while the economic cost was assumed to be linear to volume. Krikke simulated the model by using Deterministic Petri Net and Mixed Integer Linear Programming (MILP), optimizing the process and product parameters. However, the study was conducted in a single period, based on a deterministic situation. The product design parameters were given and the logistic data was generated randomly. The system was a Pull system based on the consumer demands [33].

(Louwers et al., 1999) also developed a mathematical model for reverse logistics networks. The model was applied to a reused carpet network. In their logistics structure, they considered physical locations, capacities, transportation modes, allocation, and facilities. The expenses for building and/or buying facilities were also considered using linear depreciation while the location cost was determined using geometric distance. However, the environmental impacts and uncertainty in time were not addressed in the model [33].

(Shih, 2001) utilized a mixed integer programming model (MILP) to design an optimal collection and recycling system plan for end-of-life(EOL) computers and home appliances. The optimal physical flows of EOL products flowing through collection points, storage sites, recycling plants and final disposition sites are obtained. The developed model amiss to minimize the total cost including transportation cost, operating cost, fixed cost for new facilities, final disposal cost and landfill cost, as well as the sale revenue of reclaimed material. Many scenarios were applied take in consideration different take-back rates and operating conditions, and the model parameters have been estimated due to the absence of historical data for Taiwan [34].

(Jayaraman et al., 2003) presented mathematical models for locating the recycling facilities and proposed heuristics to solve the locationproblem. The author beside proposing an MILP model as a two-echelon capacitated facility location problem with limited collection and refurbishing facilities, in this study there was a combination between heuristic concentration procedures and heuristic expansion components in order to this type of large business problems. The model and solution procedures are still confined to a single period, single product problem and are not designed to deal with the possibility of making tradeoffs between freight rate discounts and inventory cost savings resulting from consolidation of returned products; despite their success in solving large-sized problems [35].

(Du and Evans, 2008) proposed a multi-period, two-echelon, multi-commodity, capacitated location mixed integer nonlinear programming model for the design of a dynamic integrated distribution. The proposed model focused on cost minimization. Returns and demand uncertainty in terms of quantity were addressed. The model is solved by using a genetic algorithm-based heuristic. In order to avoid complexity of the constraints, they solved the problem by dividing it into two sub-problems based on forward and reverse flows, where only the binary and integer decision variables were used to represent a chromosome for both forward and reverse flows simultaneously [36].

(Pati et al., 2008) developed multi objective mixed integer goal programming (MIGP) model to deal with paper recycling logistics problems. The model aimed reduce reverse logistics cost ; increase segregation at the source product quality improvement through; and environmental benefits through increased wastepaper recovery. In order to check the Pareto efficiency of the solutions generated by the

MIGP model, Pareto detection techniques was applied on the model with ‘CNW’ priority structure by using LINDO-32 [37].

(Rivera and Ertel, 2009)described several features of establishing a closed-loop supply chain for the collection of End-of-Life Vehicles (ELV) in Mexico. To address this task, they handled the problem through reverse logistics and modeled it through an uncapacitated facility location problem. The solution of this model is obtained using software SITATION. The main result is the configuration of the collection networks for three different scenarios that consider varied percentage of collection, Regions with high ELVgeneration are identified as well as relevant factors affecting total costs in the reverse supply chain [38].

(Pishvaee et al., 2011) used a robust optimization model to deal with uncertainty of input data in a CLSC network design problem. First, a deterministic MILP model was developed to design CLSC network. Followed by applying robust counter part of the proposed MILP model by using the recent extensions in robust optimization theory. Finally, to assess the robustness of the solutions obtained by the novel robust optimization model, they are compared to those generated by the deterministic MILP model in a number of realizations under different test problems [39].

(Paksoy et al., 2011)modeled and analyzed a multi-product CLSC with an explicit focus on greenhouse gas emissions of the transportation activities, and the costs thereof, as well as product recovery. They used a mathematical model in the form of a linear programming formulation to model the problem, which captures the trade-offs between various costs, including those of emissions and of transporting commodities within the chain. Computational results were presented for a number of scenarios, using a realistic network instance [40].

(Das and Chowdhurry, 2012) developed a mixed integer linear programming model for a CLSC planning with modular design architecture and different quality levels of sold products to the markets with the objective of overall profit maximization. They tried to determine the amounts of recovered modules at recovery service providers, optimal product mixture at different quality levels, production quantity of new modules at plants, purchasing quantities of new components from the suppliers, and transportation-distribution amounts to the retailers by considering collection of returnable’s through these retailers. At the end of that study, sensitivity analysis are conducted in order to investigate the influence of changes in demands for recovered products with different quality levels on revenue, total cost and profit/cost ratio [41].

(Datet al., 2012)proposed a deterministic mathematical model that considers three recovery options: disassembly, recycling and repairing is for reverse logistics network design of waste electrical and electronic products so that minimize the total reverse logistics costs composed of collection, fixed investment, disposal, treatment and transportation as well as considering revenue obtained from the sales of returned products and renewable materials. The purpose of their study is deciding the optimal facility locations and material flows in the reverse logistics network. They took into account aforementioned three recovery options: disassembly, recycling, repairing and disposal since each type of waste product tracks different recycling processes based on its characteristic. The proposed model is illustrated by a numerical example which involves computers, televisions and cell phones as returned product types. According to the results, transportation costs constituted the large amounts of the total cost structure and can be reduced by different ways such as consolidation etc [42].

(Almnur et al., 2012) introduced a mixed-integer linear programming (MILP) model for multi-period reverse logistics network design. The proposed model addresses many features of practical relevance namely, a multi-period setting, modular capacities, capacity expansion of the facilities, reverse bill of materials, minimum throughput at the facilities, variable operational costs, finite demands in the secondary market, and a profit-oriented objective function. The proposed model was conducted extensive parametric and scenario analysis to illustrate the potential benefits of using a dynamic model as opposed to its static counterpart, and also to derive a number of managerial insights [43].

(Kannan et al., 2012) Proposed MILP model for handling reverse logistics network design. The model objective is minimizing the total cost including the climate change (CO_2 footprint) in a multistage reverse logistics network. The model was aimed to find the location of collecting the returned products and for implementing recovery options such as recycling and disposal options [44].

3.2.2 Stochastic network models

Stochastic network models address uncertainties in a system which can be solved by using Robust Deviation Decomposition approach Fuzzy Petri Net, Artificial Intelligence (AI)-based simulations, and many others. Stochastic models are able to generate qualitatively different solutions and are flexible in multiple situations. Details of these methods are explained below.

(Realff et al., 2000) identified a reverse production system in process engineering. They recognized five decision problems, namely: number and size of collection and processing sites, geographic location and allocation problems, routes in the network, transportation modes and capacity of the facilities. In order to overcome the uncertainties within in the reverse production system, they applied a robust modeling approach. Unlike stochastic methods, this approach did not solve the uncertainties by using probabilities and expectation of random variables. Instead, they applied a robust deviation, where the performance was measured to evaluate the decision across all scenarios. The performance was measured by subtracting the optimal solutions of each scenario from the robust solution and determining its proximity by maximum deviation. The optimal robust solution was determined as the scenario which had the minimum maximum deviation. However, this method only applied to single scenario decisions. Thus, it was distinctive and not flexible for different types of industries [45].

(Bruzonne and Orsoni, 2003) compared three different methods to measure the performance of a logistics network were, these methods were the mathematical model, stochastic discrete events simulation model, and AI based model by using Artificial Neural Network (ANN). Performance of the logistics network was measured by logistics costs. These costs were associated with transportation costs and costs of expected production losses. Since mathematical models were exceedingly complicated for a complex structure such as reverse logistics network, stochastic discrete events simulation models were preferred. A set of data was generated by the simulation model and were then trained by the ANN [46].

(Listes, 2002) used another approach in modeling the closed-loop supply chain by using a generic stochastic model; he applied a Decomposition approach to the model and considered the presence of uncertainties. In modeling the system, the author decomposed the problem into several sub-problems using a branch-and-cut procedure, called Integer L-shaped method. The author modeled the uncertainties in the network by using a stochastic programming approach. This approach was extended into a large-scale location model for product recovery network design to account for uncertainties. The model was tested on a case study of recycled sieved sand. The author found problems with regards to logistical cost in setting up a network and location of both storage depots and cleaning facilities. The model was set up as a two-level network. The objective function is the net revenue, which is computed as the value of fees charged for sand entering the network, revenue from selling recycled sand to projects minus the various costs involved. The model concentrated on finding the appropriate location for the new facilities. The location dilemma was chosen as it was motivated by the investment, based on uncertain information. Since the network was expensive and difficult to change, a robust location needed to be established. The author applied a stochastic programming approach and in this approach, the probabilities were associated with scenarios and a solution was weighed against the various scenarios. However, usually the solution will only be optimum for at least one set of parameters [47].

(Listes and Dekker, 2005) presented a stochastic mixed integer programming (SMIP) to maximize the total profit in a sand recycling network problem in a large-scale, real-world reverse logistics network considering the uncertainties. In this approach, the uncertainty is related to the demand sources and quality. They used GAMS as the modeling environment and CPLEX as the solver [48].

(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 proposed a capacitated multi-product reverse logistics 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 [49].

(Fonseca et al., 2009) develop bi-objective two stage stochastic MIP model for multi echelons, multiple products, multi used technology reverse logistics network with uncertainty of transportation costs and waste generation. The model aims to minimize the cost for building and operating the networks, in addition to minimize the obnoxious effect caused by the reverse network facilities. A set of different scenarios were applied tithe deterministic equivalent. To get non dominated solutions they combined the two different objectives and by using a general solver [50].

(Pishvaee et al, 2009) developed a two stage stochastic programming MILP model for handling an integrated forward/ reverse logistics network design under uncertainty. First, an efficient deterministic MILP model was developed for integrated logistics network design to avoid the sub-optimality caused by the separate design of the forward and reverse networks. Then different scenarios was applied to deal with uncertainty of demand and returned quantity [51].

(Lee and Dong, 2009) applied two stage stochastic model for handling a dynamic reverse logistics network design under uncertainty of demand and returned products, solution method was integrated with the sample average approximation (SAA) method with a simulated annealing (SA) based heuristic algorithm, to get an efficient framework for identifying and statistically solving the large-scale dynamic product recovery network problems [52].

(El Sayed et al, 2010) developed a stochastic mixed integer linear programming (SMILP) a multi-period multi-echelon forward–reverse logistics network design model under risk (including demand and return uncertainties) to maximize the total expected profit [53].

(Kara and Onut, 2010) proposed a two-stage stochastic programming model for single product, two-echelon capacitated RL network design in waste paper recycling industry in order to maximize revenue. Locating collection centers and recycling centers and allocating flow amounts between the nodes efficiently were the main aims of that study. Demand and amounts of collected products are assumed tube uncertain and fitted to the normal distribution while generating alternative scenarios. For providing the relevant data such as possible location alternatives, comprehensive questionnaire is conducted. Also, face to face interviews are held.Location and allocation decisions are assigned in sequence in the first and second stages of the stochastic programming model. Consequently, it is proved that their stochastic model yields more economical and compromised solutions for the recycling network design [54].

(Lee et al., 2010)proposed a stochastic programming based approach to account for the design of sustainable logistics network under uncertainty. They used a two-stage stochastic programming model to explicitly account for the design of sustainable logistics network under uncertainty. A solution approach integrating the sample average approximation scheme with an importance sampling strategy was developed to solve a case study with a large number of scenarios [55].

(Hasani et al., 2011)tried to avoid some disadvantages of the stochastic programming such asdifficulty related to availability of historical data and complex modeling, uncertain(dynamic) demand and purchasing cost in a strategic agile CLSC network design problem of perishable goods (food and high-tech industries) was handled via interval robust optimization technique. The study considered the common characteristics of these industries or time dependent properties such as perishable lifetime and perishable price; and also the BOM based on reusing the returned products and disassembling the returned products in order to reuse their parts. It provided decisions regarding supplier selection, production, transportation, purchasing and recovery planning in each period. All of the non-linear constraints which involve max and min terms were transformed into the linear form. Solution of the deterministic and robust models was obtained by LINGO8.0 commercial optimization solver. At the end of the study, total cost of the system in the presence of uncertainty is obtained greater than the deterministic condition duet the additional costs imposed on the system (increased cost of unsatisfied demand) [56].

(Wang et al., 2011) provided a multi-objective mixed-integer formulation for the supply chain network design problem it was the first model that considers the environmental investment decision in the supply network design phase. The multi-objective model explicitly considers the environmental issues by introducing a new category of decision variables: the environmental protection level. Objectives of that study are minimization of total costs and minimization of the total CO_2 emissions along the supply chain. A normalized normal constraint method was applied, which is a posteriori articulation of preference method and can find a set of even distributed Pareto optimal solutions so that the result obtained can be easily applied to the decision support systems which the industry needs. Sensitivity analysis have shown that supply chain network with larger capacity provides lower costs and lower CO2 emission and increasing the supply range reduced both the CO2 emission and transportation costs [57].

(Ayvaz and Bolat, 2012)addressed reverse logistics network design (RLND) problem under uncertainty by designing amulet product and multi echelon RL network system under uncertainty in terms of product return quantity. They presented a stochastic counterpart of the developed mixed integer linear programming (MILP) model by using scenario-based stochastic(SBSM) approach that addressed return amount as uncertain parameter. The proposed scenario based stochastic model (SBSM) was applied to real case study on an electrical and electronic equipment recycling facility in Turkey [58].

(Subramanian et al., 2013) Proposed a deterministic demand single-period and single product close loop network and address the uncertainty of returned products in this study. The study considered four variants of the network two distribution planning scenarios and two location selection distribution planning scenarios.

Integer linear programming models were formulated for the four network variants considered . A constructive heuristic based on Vogel"s approximation method–total opportunity cost (VAM–TOC) method and a priority-based simulated annealing search heuristic was developed to find near optimal solution for the problem. Constructive heuristic gave the initial solution helps faster convergence of the search heuristic. A decoding algorithm with recursive cost function is developed to solve this

multi-stages supply chain problem. The study also discussed the implication on sustainability in using a dedicated warehouse supply in this study [59].

As discussed before, a most of available reverse and CLSC and RLND models neglect the nature of parameters uncertainty in a strategic planning horizon and deal with it as deterministic parameters. Even, in a few papers that the uncertainty in parameters is considered, the uncertainty is modeled through stochastic programming. As mentioned in Section 3.2.2, there are several major drawbacks that make the application of stochastic programming approach impossible in real network design cases. The uncertainty in RL literature is still scarce. As a result, there is still scarce when it comes to combining several features relevant in RLND such as multiple objectives, multiple commodities, multiple echelons, real life cases and uncertainties**.** Therefore in this study, we develop for multi- objectives, multi- echelons, and multi commodities scenario base stochastic programming for reverse logistic network model under product return uncertainty.

Table 3.1 summaries the studies in literature about Reverse Logistic Network Design.

Table 3.1: Summary of Reviewed Papers Based on Reverse Logistics Network Design.

NO	**Studies**	**Properties of Network**				**Product Variety**		**Multi Objective**	**Objective**	**Used Technique**	**Solution Method**	**Used Program**	**Uncertain parameters**
		No. of Levels	Open	Close	Capacity Constrained	Single	Multi						
Deterministic models													
1	**Spengler et al.(1997)**	Multi for case 1, Two for case 2	√		√		√		Cost Min	MILP		LINDO	-
2	**Barros et al.(1997)**	Two	√		√	√			Cost Min	MILP	Linear Relaxation		-
3	**Krikke.(1999)**	Two	√			√			Cost Min	MIP		LINGO	-
4	**Louwers et al.(1999)**	Two	√		√		√		Cost Min	MILP			-
5	**Shih.(2001)**	Multi		√	√		√		Profit Max	MIP			-
6	**Jayaraman et al.(2003)**	Two	√		√	√			Cost Min	MIP	Heuristic Concentration	CPLEX	-
7	**Du and Evans.(2008)**	Single		√	√		√	√	Cost and total tardiness Min	MILP	Sccatter Search Algorithm		-
8	**Pati et al.(2008)**	Multi	√		√		√		Cost Min	MIGP		LINDO	-
9	**Rivera and Ertel(2009)**	Two	√			√			Cost Min	MILP		SITATION	-

10	**Pishvaee et al. (2011)**	Multi		√	√	√			Cost Min	MILP		CPLEX	-
11	**Paksoy et al. (2011)**	Multi		√	√		√		Cost Min	LP		LINDO	-
12	**Das and Chowdhury (2012)**	Multi		√	√		√		Profit Max	MILP		LINGO	-
13	**Dat et al. (2012)**	Multi	√		√		√		Cost Min	MILP		CPLEX	-
14	**Kannan et al. (2012)**	Multi	√		√	√			Cost Min	MILP		LINGO	-
15	**Almnur et al. (2012)**	Multi	√		√		√		Profit Max	MILP		CPLEX	
Stochastic models													
1	Realff et al. (2000)	Single	√		√	√			Cost Min	MILP		AIMMS/CPLEX	Returen Quantity
2	Bruzonne and Orsoni (2003)	Single	√		√	√			Cost Min	MILP	Simulation and ANN	ARENA	Demand
3	Listes (2002)	Multi		√		√			Cost Min	MILP		CPLEX	Demand and Return Quantity
4	Listes and Dekker (2005)	Two	√		√	√			Cost Min	MILP		GAMS/ CEPLEX	Demand and Return Quantity
5	Salema et al. (2007)	Multi		√	√		√		Cost Min	MIP		GAMS/ CEPLEX	Demand ,Transportation Costs, Return Quality
6	Pishvaee et al. (2009)	Multi		√	√	√				MILP		LINGO	Return Quantity, Return Quality, Variable Cost
7	Lee and Dong (2009)	Multi		√	√		√		Cost Min	MILP		CPLEX	Demand and Return Quantity
8	Fonseca et al. (2009)	Multi	√		√		√	√	Cost Min, Obnoxious Effect Min	MIP		CPLEX	Demand and Return Quantity
9	El Sayed et al. (2010)	Multi		√	√	√			Profit Max	MILP		Mosel language	Demand and Return Quantity
10	Kara and Onut (2010)	Multi	√		√	√			Profit Max	MILP		GAMS/ CEPLEX	Demand and Return Quantity
11	Lee et al. (2010)	Two		√	√		√		Profit Max	MILP	Sample average approximation	ILOG CPLEX 9.0, Microsoft Visual C++ 6.0.	Demand and Return Quantity

12	Wang et al. (2011)	Multi		√	√		√	√	Cos Min, CO2 Emission Min	MILP	Sensitivity Analysis	CPLEX	Demand and Return Quantity
13	Hasani et al.(2011)	Multi		√	√		√		Cost Min		Robust Optimization	LINDO	Demand and Purchasing Cost
14	Ayvaz and Bolat (212)	Multi	√		√	√			Cost Min	MILP		CPLEX	Demand and Return Quantity
15	Subramanian et al. (2013)	Multi		√	√	√			Cost Min	ILP	Vogel's approximation method	ILOG CPLEX 9.0, Microsoft Visual C++ 6.0.	Return Quantity
16	Our Study	Multi	√		√		√	√	Cos Min, CO2 Emission Min	MIP	Constraint Method	GAMS/ CEPLEX	Return Quantity
LP: Linear Programming									**ILP: Integer Linear Programming**				
MILP: Mixed Integer Linear Programming									**MIGP: Mixed Integer Goal Programming**				

CHAPTER 4

MULTI OBJECTIVE OBITMIZATION AND SOLUTION METHOD

4.1 Multi-objective Optimization and Pareto-optimal Solutions

Reverse logistic optimization frameworks often feature multiple objectives (criteria) for evaluating simultaneously notions of economics, environmental, responsiveness, risk and/or sustainability .A generic mathematical form of a multi-objective optimization problem can be understood easily by be familiar with the basic single-objective optimization problem; which can be formulated as follows:

$$\text{Min } f(x) \tag{4.1}$$

$$X \in S \tag{4.2}$$

Where f is a scalar function and S is the (implicit) set of constraints that can be defined as:

$$S = \{x \in Mr. : h(x) = 0, g(x) \geq 0\} \tag{4.3}$$

Multi-objective optimization can be described in mathematical terms as follows:

$$\text{Min } [\, f1(x), f2(x), \ldots, FN(x)] \tag{4.4}$$

$$X \in S \tag{4.5}$$

Where $n > 1$ and S is the set of constraints defined above. The space in which the objective vector belongs is called the *objective space*, and the image of the feasible set under F is called the *attained set*. Such a set will be denoted in the following with

$$C = \{y \in Run : y = f(x), x \in S\} \tag{4.6}$$

The scalar concept of "optimality" does not apply directly in the multi-objective setting. Here the notion of Pareto optimality has to be introduced. Essentially, a vector $x^* \in S$ is said to be Pareto optimal for a multi-objective problem if all other vectors $x \in S$ have a higher value for at least one of the objective functions f_i, with i = 1, . . . ,n, or have the same value for all the objective functions. Formally speaking, we have the following definitions:

- A point $x*$s said to be a weak Pareto optimum or a weak efficient solution for the multi-objective problem if and only if there is no $x \in S$ such that $f_i(x) < f_i(x^*)$ for all $i \in \{1, . . . ,n\}$.
- A point $x^*$is said to be a strict Pareto optimum or a strict efficient solution for the multi-objective problem if and only if there is no $x \in S$ such that $f_i(x) \leq f_i(x^*)$for all $i \in \{1, . . . ,n\}$, with at least one strict inequality.

We can also speak of locally Pareto-optimal points, for which the definition is the same as above, except that we restrict attention to a feasible neighborhood of x^*. In other words, if $B(x^*,\varepsilon)$ is a ball of radius ε >0 around point x^*, we require that for some ε >0, there is no $x \in S \cap B(x^*,\varepsilon)$ such that $f_i(x) \leq f_i(x^*)$ for all $i \in \{1, . . . ,n\}$, with at least one strict inequality.

The image of the efficient set, i.e., the image of all the efficient solutions, is called Pareto front or Pareto curve or surface. The shape of the Pareto surface indicates the nature of the trade-off between the different objective functions. An example of a Pareto curve is reported in Fig. 4.1, where all the points between $(f_2(\hat{x}), f_1(\hat{x}))$ and $(f_2(\tilde{x}), f_1(\tilde{x}))$ define the Pareto front. These points are called non-inferior or non-dominated points.

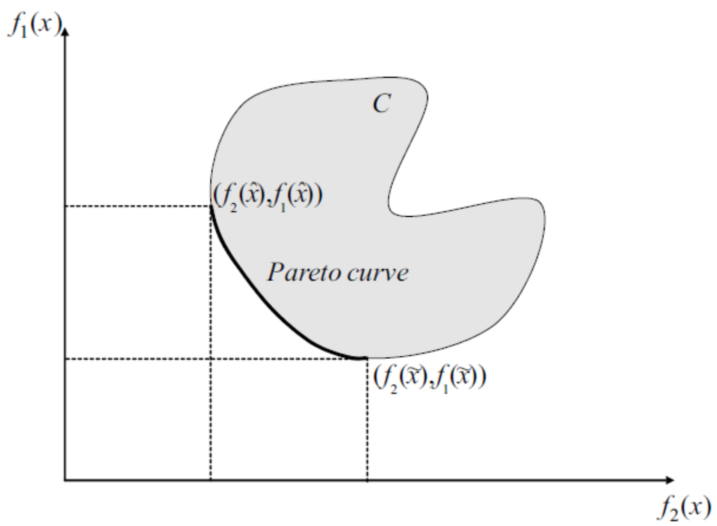

Figure 4.1: Pareto curve of two objective functions F_1, and F_2

An example of weak and strict Pareto optima is shown in Fig. 4.2: points P_1 and P_5 are weak Pareto optima; points P_2, P_3, and P_4 are strict Pareto optima.

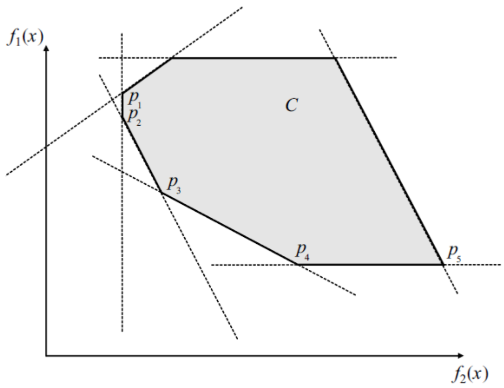

Figure 4.2: Week Pareto optimal solution

The type of model depends on the objective functions and the constraints of the model; if the objective function and the constraints are all linear, it is a linear programming (LP) problem. The problem takes the form of a nonlinear programming (NLP) model if at least one of the functions defining the objective function or the constraints is nonlinear. LP and NLP problems require in general different solution algorithms. If an LP problem contains discrete variables (integer or logical) in addition to continuous ones, then it becomes a mixed-integer linear programming (MILP) problem. Mixed-integer nonlinear programming (MINLP) problems contain at least one nonlinear equation. The model developed in this research is MILPs.

4.1.1 Techniques to Solve Multi-objective Optimization Problems

4.1.1.1Weighted Sum Method

In the weighting method, the weighted sum of the objective functions is optimized. The problem is stated as follows:

$$Max\ (w_1 \times f_1(x) + w_2 \times f_1(x) + \ldots + w_p \times f_p(x)) \quad (4.7)$$

$$\text{S.t } x \in S \quad (4.8)$$

By varying the weights (w_i) we obtain different efficient solutions.

4.1.1.2 ε-Constraint Method

In the ε-constraint method we optimize one of the objective functions using the other objective functions as constraints, incorporating them in the constraint part of the model as shown below:

Max f_1(x) (4.9)

S.t. $f_2(x) \geq e_2$ (4.10)

$f_3(x) \geq e_3$ (2) (4.11)

. . .

$f_p(x) \geq e_p$ (4.12)

$X \in S$ (4.13)

By parametrical variation in the right hand side of the constrained objective functions (e_i) the efficient solutionsof the problem are obtained.The e-constrained method has several advantages over the weighting method which are they:

1. The weighted sum method only finds extreme points for linear models, thus a lot of runs are redundant because they result in the same solution. The ε-constraint method is able to produce non-extreme efficient solutions.

2. The weighted sum method cannot find solutions for non-convex regions, while the ε-constraint method does not suffer from this pitfall.

3. The ε-constraint method can control the number of efficient solutions, while this is not so easy for the Weighted Sum Method.

Research that has been done to improve the "ε-constraint method, e.g. Laumanns et al., and Mavrotas. The former presents an adaptive scheme that finds appropriate constraint values during the run. Mavrotas proposes a novel version of the ε-constraint method: the augmented ε-constraint method (AUGMECON). This is an effective implementation of the ε-constraint method using lexicographic optimization for the payoff table, and can be used in an interactive context and which will be implemented in this research [60];[61].

4.1.1.3 Other Methods

A third secularization method minimizes the distance to an ideal point (i.e., the solution in which all objectives are minimized simultaneously). However, the ideal point is not a feasible solution when there are conflicting objectives. The compromise programming method applies this principle, and one example shown in Ehrgott (2008) is the following minimization problem (with a weighting vector $\lambda.0$> 0, an integer$1 \leq q < \alpha$, and ideal point $y^1$and $x \in S$ representing the constraints):

$$min\{(\sum_{k=1}^{P} \lambda_k (f_k(x) - y_k^I)^q)^{1/q} : x \in S\} \quad (4.14)$$

4.2Optimization under Uncertainty

Uncertainty is a significant issue in RL optimization, and if not addressed can contribute to sub-optimal decision making. Sen and Hingle provide an introductory tutorial on stochastic programming, where modeling future recourse (a response to the realization of uncertain parameters)is discussed as an approach to deal with uncertainty (stochastic parameters) in the model. Stochastic parameters are commonly assumed to follow continuous probability distributions. Multi-stage stochastic programming approaches have been proposed in the literature for the treatment of uncertainty in design, planning, and scheduling problems. In the multi-stage framework, some decisions are made “here-and-now” prior to the uncertain event taking place, and the remaining decisions are postponed in a “wait-and-see” manner after uncertainty has-been resolved and more information is available Birge and Louveaux [62]. Typically, variables determined after the second-stage can be interpreted as corrective (recourse) measures to avoid infeasibility arising due to the realization of uncertainty. In general, as discussed in the recent review paper by Kara and Onut developed a two-stage stochastic model using a MIP approach to identify the facility locations and transportation quantities for reverse SC network under uncertainty [54].In a similar study, Ayvaz develop two stages stochastic model using MILP for multi echelon, multi products reverse logistic network with uncertainty of the quantity and the quality of returned products[58]. However, Lee and Dong [52] addressed a stochastic approach for the dynamic reverse logistics network design under uncertainty of demand and returned products. A two-stage stochastic programming model was developed by formulate a deterministic model for dynamic RLND design was extended to take into account the uncertainties.

For a two-stage stochastic program the objective is to optimize the deterministic first-stage cost and the expectation of the second-stage cost, which is dependent on the probability space of uncertain parameters. Evaluation of the expected second-stage cost is a key challenge in two-stage stochastic programming, where two approaches include a scenario-based approach, where the expectation is approximated via scenario analysis, and a probabilistic approach, where probability distributions are applied directly in the formulation, and the expectation is evaluated through an analytical integration method. The latter approach can lead to a reasonably sized deterministic optimization formulation; however, at the expense of adding nonlinearities into the model. The scenario-based approach has been applied in this thesis for capturing uncertainty in terms of a finite number of discrete realizations of stochastic parameters. The scenario-based approach allows for flexible uncertainty representation since the underlying structure of the model is unchanged and independent of how scenarios are generated. To reduce the model size (number of scenarios) an Arena Input Analyzer is applied for generating scenarios [52]. This method entails generating a discrete set of scenarios by sampling from the continuous probability distributions describing uncertain parameters. The complete realization of all uncertain parameters in the model gives rise to a scenario. Furthermore, each scenario is assigned an equivalent probability of occurrence, where the summation of probabilities for all scenarios is 1.

4.3 Two-Stage Stochastic Program

Two-stage stochastic linear program is defined as follows:

$$\min f = C^T x + E\xi[\min q(\omega)^T y(\omega)] \tag{4.15}$$

$$s.t Ax = b \tag{4.16}$$

$$T(\omega)x + Wy(\omega) = h(\omega) \tag{4.17}$$

$$x \geq 0, y(\omega) \geq 0 \tag{4.18}$$

Where C is a known vector inR^{n_1}, b a known vector inR^{m_1} , A and W are known matrices of size$m_1 * n_1$ and$m_2 * n_2$, respectively, and W is called the recourse matrix, which we assume as fixed. This allows us to characterize the feasibility region in a convenient manner for computation. If W is not fixed, it will be difficult to do so. x is the vector of first-stage decisions and y is the vector of second-stage decisions.

$Ax = b$composes the deterministic set of constraints while $T(\omega)x + Wy(\omega) = h(\omega)$ constructs the stochastic set of constraints.

For eachω ,$T(\omega)$ is$m_2 * n_1$, $q(\omega) \in R^{n_2}$ and $h(\omega) \in R^{m_2}$. Piecing together the stochastic components of the problem, we obtain a vector

$\xi^T(\omega) = \left(q(\omega)^T, h(\omega)^T, T_1.(\omega), \ldots, T_{m_2}.(\omega)\right)$(4.19)

with $N = m_2 + n_2 + (m_2 * n_1)$ components, where $T_i.(\omega)$ is thei^{th} row of the *technology matrix*. $E\xi$ represents the mathematical expectation with respect toξ . Let $E \in R^N$ also be the support ofξ , i.e., the smallest closed subset in R^Nsuch that$P(\xi \in E) = 1$. The constraints are assumed to almost certainly hold.

Problem which was formulated in equation set (4.15 to 4.18) is equivalent to the deterministic equivalent program:

$$\min f = C^T + Q(x) \quad (4.20)$$

$$\text{S.t}, Ax = b \quad (4.21)$$

$$x \geq 0 \quad (4.22)$$

$$Q(x) = E_\xi Q\big(x, \xi(\omega)\big) \quad (4.23)$$

$$Q\big(x, \xi(\omega)\big) = min_y\{q(\omega)^T y(\omega) | Wy(\omega) = h(\omega) - T(\omega)x, y \geq 0\} \quad (4.24)$$

This representation clearly illustrates the sequence of events in the recourse problem. First-stage decisions x are made in the presence of uncertainty about future realizations of . In the second stage, the actual value of ξ becomes known and some corrective actions or recourse decisions y can be made. First-stage decisions are, however, chosen by taking their future effects into account. These future effects are measured by the recourse function, $Q(x)$ which computes the expected value of making decision$x$.

The difficulty inherent in stochastic programming clearly lies in the computational burden of computing$Q(x)$, for all $x$in (4.20 to 4.24).

The previous model concerned stochastic programs with two stages. Many practical decision problems, however, involve a sequence of decisions that react to outcomes that evolve over time. The multistage stochastic linear program with fixed recourse then takes the following form.

$$\min f = c^1 x^1 + E_{\xi^2}\left[\min c^2(\omega)x^2(\omega^2) + \ldots + E_{\xi^H}[\min c^H(\omega)x^H(\omega^H)]\right] \quad (4.25)$$

$$S.t. \qquad W^1x^1 = h^1 \tag{4.26}$$

$$T^1(\omega)x^1 + W^2x^2(\omega^2) = h^2(\omega) \tag{4.27}$$

$$\dots\dots\dots\dots\dots.$$

$$T^{H-1}(\omega)x^{H-1}(\omega^{H-1}) + W^Hx^H(\omega^H) = h^H(\omega)(4.28)x^1 \geq 0, x^t(\omega^t) \geq 0,$$
$$t = 2, \dots\dots, H \tag{4.29}$$

where c^1 is a known vector inR^{n_1}, h^1 is a known vector inR^{m_1}, $R^{m_1}, \xi^t(\omega)^T = \left(c^t(\omega)^T, h^t(\omega)^T, T_1.^{t-1}(\omega), \dots, T_{mt}.^{t-1}.(\omega)\right)$ is a random $N_t$vector in definedon (Ω, Σ^t, P), (where $\Sigma^t \subset \Sigma^{t+1}$) for all *t= 2,……, H*, and each W^t is a known $m_t * n_t$matrix. The decisions reflected by x values depend on the history up to time *t*, which is indicated by ω^t . We also assume that $E^t$is the support of ξ^t.

CHAPTER 5

Reverse Logistics Network Design: Modeling Approach

5.1 Reverse Logistic Optimization

We have discussed that a reverse logistic is a dynamic system whose behavior changes over time and the future state of the system cannot be predicted with certainty. As a result, it is essential to capture and monitor system dynamics and any disturbances affecting the overall performance of the system elements. Model Predictive control will be employed. Most of the reverse logistics problems have been known to have characteristics of being combinatorial, where combinatorial optimization problems can generally be defined as problems that require searching for the best solution among a large number of finite discrete candidate solutions.

More specifically, it aspires to find the best allocation of limited resources that can be used to achieve an underlying objective. Certain constraints are usually imposed on the basic resources, which limit the number of feasible alternatives that can be considered as problem solutions. Yet, there are still a large number of possible alternatives that must be searched to find the best solution.

5.2 Decision Making Layers

Due to the complex nature of the decision making in the reverse logistic network design, RL optimization is typically decomposed into three hierarchical layers like the normal supply chain optimization: strategic, tactical, and operational. The strategic layer aims to identify capital investment opportunities over a long-term horizon (several years) that can include: the selection of used products to be recycled, process technology, and process configuration at recovery facilities, and general configuration of the network structure. The tactical planning level is characterized by an intermediate planning horizon (weeks to a few months) where decisions include collection process, transportation logistics (i.e. contracts with transportation companies), resource procurement (i.e contracts with suppliers), and high-level planning, allocation, and distribution decisions among the echelons in the reverse network. The operational level captures the short-term horizon (days to a few weeks) and typically addresses the week-to-week planning, or day-to-day scheduling and sequencing of collection, inspection, and remanufacturing tasks in the different facilities in the network.

A number of strategic formulations have been proposed for RLND [49];[36]; [54]; however, this research addresses the strategic and tactical/operational decisions layers of decision making explicitly. Some studies concerned with environmental factors when they design the network beside the economical factors [40];[57] in strategic decision layers. Some of studies conceded the obnoxious effect caused by the reverse network facilities [50] in both strategic and tactical /operation decision layers.

5.3 Reverse logistic network design with uncertainty

The reverse logistic network design problem is one of the most comprehensive strategic level decisions, which influence tactical and operational decisions which need to be optimized for long-term efficient operation of whole reverse supply chain. It identifies the optimum number and location of the service providers (e.g. collection\inspection and recovery points) to assist the returned products movement from customer to the recovery facilities or suppliers through the network. It also determines the capacity and type of collection and recovery centers to be used and establishes reverse distribution channels and the amount of materials and items to consume, produce, and ship from suppliers to customers. RLND problems cover wide range of formulations ranged from simple single product type to complex multi-product one, and from linear deterministic models to complex non-linear stochastic ones.

One of the main characteristics of reverse logistics network problem is uncertainty that further amplifies the complexity of the problem. As mentioned earlier uncertainty associated with the recovery process (in time requirements, quality, and quantity of returned products, packaging, and/or containers); and the reverse distribution process itself (collection and transportation of used products, packaging, and/or containers).

The majority of researches in this field did not consider the uncertainty explicitly in the model. Instead, deterministic models were developed and scenario based approaches were used to assess the effect of uncertainty present in the real life problem. Uncertainty degrees and types depend on the case understudy, for example, in some cases; expected return volume variation may be relatively small for the products with relatively long life-cycles. Such uncertainties can be studied through sensitivity analysis which was the classical tool for dealing with uncertainty has also been used in reverse logistics in combination with deterministic models. The main objective was to determine how the output of the model will be changed due to the uncertainties present in the model inputs as it appeared in Sadany and Kharboutl; and Kara et al. in 2007 carried out a sensitivity analysis to study the effect of different parameters, like amount returned, number of disassembly locations, and batch size on relative cost (the total cost of the problem divided by the cost of the forward problem). The approach of parametric sensitivity analysis was extended by generating scenarios for the input parameters and finding individual solution that performs best over a set of scenarios like [54]

Realff et al. (2004) represent uncertainty through scenarios to minimize a measure of the deviation of the solution of the objective function value from the objective function value of the best configuration achieved for each of the scenarios. The authors found the approach suitable for the design of reverse production systems when there is not enough quality information to formulate a stochastic programming-based approach.

Another approach that has been adopted recently to the reverse logistics network design problem is stochastic programming. It is a mathematical programming technique capable of dealing with the stochastic elements present in data. Instead of using deterministic numbers probability distributions are used. The type of stochastic programming applied to the network design problem is the recourse type. In this type of modeling the problem is approached stage wise. In the first stage a decision is made and a set of decision variables are determined. In the second stage a recourse action is allowed after the random event has taken on certain value. The recourse action ensures that the constraints are not violated after the realization of the stochastic element. Generally, the decision variables of the first stage are binary variables representing the opening of different facilities. The recourse decision variables of the recourse problem are the flow allocation.

In order to take into account the effects of the uncertainty in the quantity and quality of returned products scenarios, a two-stage stochastic model is proposed in this research.

Binary decision variables which represent the location of candidate collection and recovery facilities in RL network, normally they are considered in the first stage variables. While the variable related to the amount of returned products move between the facilities of RL network are consider in the second stage variables, corresponding to decisions taken after the uncertain parameters have been revealed.

In traditional stochastic programming approaches, the objective function consists of the sum of the first-stage performance measure and the expected second-stage performance, and most commonly, the dominant uncertain parameters are the quantity of returned products. Approaches differ primarily in the selection of the decision variables and the way in which the expected value term, which in principle involves a multi dimensional integral involving the joint probability distribution of the uncertain parameters, is computed. There are a few researches work addressing comprehensive (strategic and tactical issues simultaneously) design of RL networks using two-stage stochastic models. Kara and Onut [54], Lee and Dong [55] used a two-stage stochastic programming model for reverse logistics network design and considered the demand as the source of uncertainty.

Despite of the importance of stochastic programming to handle the uncertainty parameters in RLND problem, there are severely limited owing to its inability to handle risk aversion or decision-makers' preferences in a direct manner, subsequently excluding many important mains of application.

The main disadvantages of traditional stochastic RL network design approaches are as follows:

Most of proposed models deal with a single objective is often the optimization focus like minimizing cost or maximizing profit as [48]; [49].

1. Most of multi-objective RL models are either deterministic [36];[48]; or only demand is considered as the source of uncertainty [53].
2. Most of model did not discuss minimizing the risk reflected by the variance of the total cost and the financial risk has not been considered in existing comprehensive RL design models.
3. Reliability did not consider during the strategic planning phase.

To avoid these disadvantages, we develop two stages stochastic programming approach for designing reverse logistic network under uncertainty. In our approach, not only the retuned products amount, but also the quality of returned products was considered as the uncertain parameters. The first objective function of our proposed model is the minimization of the sum of first-stage investment costs and the expected second-stage processing.

5.4 Problem Definition

The proposed RL network considers a general framework, where it considers a set of customer zones in each of different used products is generated. In this research aim to design a simple recovery network design at which different type of returned products gathers in customer zone and collected in a collection/inspection center where the returned products are separated and inspected; and from there sent to a recovery center if they can be recovered (recycled) or can be sent directly to disposal center if it does not. Collection/inspection centers responsible on inspect, disassembly and separate the returned products part, after that disassembly parts went to recovery centers and some of them send to disposal centers. Collection/inspection centers are facilities where disposal is compacted and inspected.

A set of locations for installing a capacitate collection centers were considered this location could be near to recovery and disposal centers. The study assumed there is a set of potential locations for installing a collection/ inspection centers as well as recovery center, and each collection/ inspection center can deal with any disposal center. A fixed set of potential locations for uncapacitated disposal centers is considered in this research to process any product cannot be recovered.

The research assumes the different costs in the proposed RL network including fixed cost for installing a collection/inspection, and recovery centers; and transportation costs between the facilities, can addition to collection cost, inspection and separating cost, processing cost of used product in recovery center and disposal cost.

In addition to the costs associated with the facilities, we consider transportation costs:

– From the customer zones to collection centers,

– From the collection/inspection centers to the recovery centers, and

– From the collection/inspection to the disposal centers.

In this research, transportation costs depend on the types of disposal and transportation modes since different used products have different features such as volume, risk management procedures, weight, etc. Transportation costs are lower if used products are compacted. In the model we are presenting, we assume that the transportation cost between two points in the network depends on the shortest road distance and the corresponding unitary transportation cost. Figure 5.1 depicts structure and the flows involved in a reverse network like the one we are considering. One aspect to point out in this figure is its convergent nature.

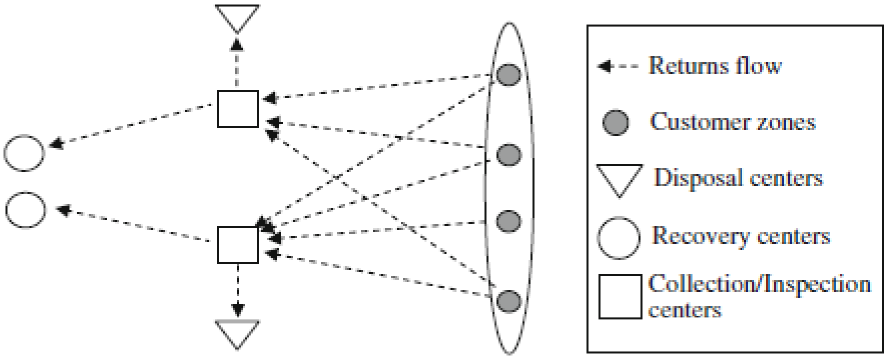

Figure 5.1: The returned flow in the proposed a reverse logistics network

We assume that the shipment of used products from the customer zones to the collection\ inspection centers allows less than truckload (LTL) transportation, while full truck load (FTL) transportation between the collection\ inspection centers, and recovery centers and between the collection\ inspection centers and disposal centers are imposed as a general policy in order to increase efficiency. Multimodal transportation is allowed for the transportation from collection centers to recovery centers, which can be done either by road or by train. Depending on the transportation links, two transportation modes may be considered: road and rail. Road transportation may use LTL(Less than Truck Load) or FTL (Full Truckload) vehicles, while rail transportation is restricted to a minimum load. Transportation costs will distinguish costs applied to full load means of transport and costs applied to quantity shipped by LTL mode.

One objective of the problem is to minimize all the above-mentioned costs. However, there is another objective that cannot be neglected in this type of problems, which is the minimization of the amount of CO_2 emitted for the transportation between customer zones and collection\ inspection centers, and from collection\ inspection centers to recovery centers or disposal centers.

Many studies have been conducted to compute emissions factors for transportation systems according tithe transportation mode used; see for example Artemis(Foulard et al, 2007), or INFRAS-HBEFA (Rexeis etal., 2009) [22]. According to these studies, the total emissions depend on the emission factor and the activity data as follows:

Emissions = “activity data” x “emission factor”

Activity data means the amount of energy burned. The emission factor is the amount of CO_2 generated by eachactivity data, for example, tons of CO_2 per tons of goodtransported.The emissions factor aims to compute the amount of CO_2emitted by any transportation mode. The factor that we used depends on quantity transported, the traveled distance and the truck loading factor. This emissions factor retained is based on the MEET report (Hickman *et al*, 1999) and (Pan *et al*., 2011) with the following assumption: for road transportation, the vehicles are Heavy Duty Vehicles of 38 t, the average speed is 80 km/h, a road gradient of 0% is considered; the capacity of the trucks varies from 20 to 50 tons depending on the product transported. We obtain the following formula:

$$E_{g/km}(\alpha) = 772 + 324\,\alpha \tag{5.1}$$

Where α is the loading factor with $\alpha \in [0,1]$.Depending on the loading factor, we can compute two emission factors: one for the full load trucks E_{full}^{v} ; and one for empty trucksE_{empty}^{v}. So, given these assumptions for road transportation:

$$E_{full}^{v} = 1.096\,\frac{\text{kg}}{\text{km}} \tag{5.2}$$

$$E_{empty}^{v} = 0.772\,\frac{\text{kg}}{\text{km}} \tag{5.3}$$

Considering these emissions factors, the travel distance and the truck load in terms of number of tons, the amount of CO2 emitted is calculated by:

$$\varepsilon(d,c,x) = d.\left(\frac{E_{full} - E_{empty}}{c}\right).x + E_{empty}.\left\lceil\frac{x}{c}\right\rceil \tag{5.4}$$

With d=distance, c=transport capacity in tons, x=number of tons transported.

For rail transportation, the train considered here is an electric “short train”; the gross weight of short train’s has-been estimated to be around 500 - 600t, the average speed considered is 100km/h and the total capacity in ton is 36 in each railcar with 13 railcars per train. Given these assumptions, the emission factor for rail transport is:

$$E_{g/km}(\alpha) = 0.498 + 0.0014\,x \tag{5.5}$$

Where $x$is the number of tons transported. The emissions factors retained are:

$$E^{v}_{empty} = \frac{0.498\text{kg}}{\text{km}} \tag{5.6}$$

$E^{v}_{full} = 1.16$ kg/km. Considering a train with 13 railcars (5.7)

As discussed before, Uncertainty is one of the main challenges face RLND planning. The high degree of uncertainty in terms of time, quantity and quality of returned products, and the capacities of different facilities inside the network increase the complexity of reverse network designing problems.

Summing up, it is needed a comprehensive model for reverse logistics planning which have to consider many real-world features such as the existence of several facility echelons, multiple commodities, and different transportation modes with uncertainty associated with the quantity and the quality of returned products. So this research aims to develop a multi-stage, multi-products, bi-objective stochastic location problem. In the next section a formulation for this problem is proposed.

5.5 Problem formulation

In this section we begin by introducing the notation needed to formulate the problem. Afterwards, we present and discuss a stochastic programming formulation for the problem.

Notation and definition of decision variables:

Index Sets

P	:	Set of products
I	:	Fixed set of points for customer zones.
J	:	Set of the candidate points for collection/inspection centers.
K	:	Fixed set of the candidate points for recovery centers.
L	:	Fixed set of points for disposal center.
V	:	Set of transportation mode (truck/train).
V_1	:	Set of less than truck load (LTL) transportation modes.
V_2	:	Set of full truck load (FTL) transportation modes.
V_3	:	Set of rail transportation mode.
V_{1i}	:	Set of V_1 transportation modes used from any entity i.
V_{2i}	:	Set of V_2 transportation modes used from any entity i.
V_{3i}	:	Set of V_3 transportation modes used from any entity i.

V_i : Type transportation modes used from any entity *i*.

S : Set of Scenarios.

Parameters

r_{ps} : Average fraction of each disposed product (percent) for each scenario *s*.

M_{ps} : Amount of each returned product quantity from customer zones for each scenario *s*.

fj : Fixed cost to set up collection/inspection center*j*.

fk : Fixed cost to set up recovery center*k*.

C_p^v : Transportation cost for a ton of product *p* by the mean of transport *v*.

C_f^v : Transportation cost for a full load means of transport *v*.

CC_{pj} : Collection and Inspection cost for a ton of disposal products *p* at collection/inspection center *j*.

Cp_{pk} : Processing cost per ton for product *p*at recovery center *k*.

Cd_{pl} : Disposal cost per ton for product *p* at disposal center *l* .

D*ij* : Transportation distance from customer zone *i* to collection/inspection center *j*.

D*ike* : Transportation distance from collection/inspection *j* center to recovery center *k.*

D*ill* : Transportation distance from collection/inspection center *j* to disposal center *l.*

SMAXpj : Maximum capacity of the collection/inspection center *j* for each product *p.*

SMAXp*k* : Maximum capacity of the recovery center for product *p*.

Cap_v : Capacity in ton of mean of transport *v*.

Nmin*j* : Minimum number of collection/inspection center *j*.

Nmin*k* : Minimum number of recovery center *k.*

Nmax*j* : Maximum number of collection/inspection center *j*.

Nmax*k* : Maximum number of recovery center *k.*

G : Very huge number

π_s : Probability of scenario *s*.

Variables

X_{pijs}^{v} : Amount of returned products transferred from customer zone *i* to collection/inspection center *j* for each product*p* for each scenario *s.*

X_{pjks}^{v} : Amount of scrapped products transferred from collection/inspection center to disposal center for product *p* for each scenario *s*.

X_{pjls}^{v} : Amount of recoverable products transferred from collection/inspection center to recovery center *l* for product *p* for each scenario *s*.

V_{pijs}^{v} : Integer variable express the number of full load means of transport *v* used between the entities *i* and *j* for product *p* for each scenario *s*.

V_{pjks}^{v} : Integer variable express the number of full load means of transport *v* used between the entities *j* and *k* for product *p* for each scenario *s*.

V_{pjls}^{v} : Integer variable express the number of full load means of transport *v* used between the entities *j* and *l* for product *p* for each scenario *s*.

Y_j : Binary variable equal to 1 if a collection\inspection center is open at location

0 otherwise

Y_k : Binary variable equal to 1 if a recovery center is open at location

0 otherwise

In terms of the above notations, the reverse logistics network design problem can be formulated as follows:

Min

$$F(1) = \sum_{j}^{J} f_j Y_j + \sum_{k}^{K} f_k Y_k$$

$$+ \pi_s \left(\sum_{i}^{I} \sum_{j}^{J} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} D_{ij} C_f^v X_{pijs}^v + \sum_{j}^{J} \sum_{k}^{K} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} D_{jk} C_f^v X_{pjks}^v \right.$$

$$+ \sum_{j}^{J} \sum_{l}^{L} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} D_{jl} C_f^v X_{pjls}^v + \sum_{i}^{I} \sum_{j}^{J} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} X_{pijs}^v CC_{pj}$$

$$+ \sum_{i}^{I} \sum_{j}^{J} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} X_{pijs}^v CC_{pi} + \sum_{j}^{J} \sum_{k}^{K} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} X_{pjks}^v Cp_{pk}$$

$$\left. + \sum_{j}^{J} \sum_{l}^{L} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} X_{pjls}^v Cd_{pl} \right) \qquad (5.8)$$

$$F(2)$$

$$= \pi_s * (\sum_{i}^{I} \sum_{j}^{J} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} D_{ij} \left[X_{pijs}^v \left(\frac{E_{full}^v - E_{empty}^v}{Cap_v} \right) + E_{empty}^v \cdot \frac{X_{pijs}^v}{Cap_v} \right]$$

$$+ \sum_{j}^{J} \sum_{k}^{K} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} D_{jk} \left[X_{pjks}^v \left(\frac{E_{full}^v - E_{empty}^v}{Cap_v} \right) + E_{empty}^v \cdot \frac{X_{pjks}^v}{Cap_v} \right]$$

$$+ \sum_{j}^{J} \sum_{l}^{L} \sum\nolimits_{v}^{Vi} \sum_{p}^{P} D_{jl} \left[X_{pjls}^v \left(\frac{E_{full}^v - E_{empty}^v}{Cap_v} \right) \right.$$

$$\left. + E_{empty}^v \cdot \frac{X_{pjls}^v}{Cap_v} \right]) \qquad (5.9)$$

Subject to:

Flow Constraints

$$\sum_{i}^{I}\sum_{v}^{V_i}\sum_{p}^{P} X_{pijs}^{v} = M_{ps}\,, \qquad \forall\, i \in I \;, s \in S \qquad (5.10)$$

$$\sum_{i}^{I}\sum_{v}^{V_i}\sum_{p}^{P} X_{pijs}^{v} \le \sum_{k}^{K}\sum_{v}^{V_i}\sum_{p}^{P} X_{pjks}^{v} + \sum_{l}^{L}\sum_{v}^{V_i}\sum_{p}^{P} X_{pjls}^{v} \;, \forall\, j \in J\,, s \in S \qquad (5.11)$$

$$\sum_{k}^{K}\sum_{v}^{V_i}\sum_{p}^{P} X_{pjks}^{v} = r_{ps}\sum_{i}^{I}\sum_{v}^{V_i}\sum_{p}^{P} X_{pijs}^{v}\,, \qquad \forall\, j \in J\,, s \in S \qquad (5.12)$$

$$\sum_{l}^{L}\sum_{v}^{V_i}\sum_{p}^{P} X_{pjls}^{v} = \left(1 - r_{ps}\right)\sum_{i}^{I}\sum_{v}^{V_i}\sum_{p}^{P} X_{pijs}^{v}\,, \quad \forall\, j \in J\,, s \in S \qquad (5.13)$$

Capacity Constraints

$$\sum_{i}^{I}\sum_{v}^{V_i}\sum_{p}^{P} X_{pijs}^{v} \le SMAX_{pj}Y_j\,, \qquad \forall\, j \in J\,, s \in S \qquad (5.14)$$

$$\sum_{k}^{K}\sum_{v}^{V_i}\sum_{p}^{P} X_{pjks}^{v} \le SMAX_{pk}Y_k, \qquad \forall\, j \in J\,, s \in S \qquad (5.15)$$

Transportation Mode Constraint

$$\sum_{p}^{P} X_{pijs}^{v} \le Cap_v\, V_{ij}^{v} \;, \quad \forall\, i \in I, j \in J, v \in V1_i \;, s \in S \qquad (5.16)$$

$$\sum_{p}^{P} X_{pjks}^{v} \le Cap_v\, V_{jk}^{v}\,, \qquad \forall j \in J, k \in K, v \in V2_i\,, s \in S \qquad (5.17)$$

$$\sum_{p}^{P} X_{pjks}^{v} \le Cap_v\, V_{jk}^{v}, \qquad \forall j \in J, k \in K, v \in V3_i\,, s \in S \qquad (5.18)$$

$$\sum_{p}^{P} X_{pjls}^{v} \le Cap_v\, V_{jl}^{v}\,, \qquad \forall j \in J, l \in L, v \in V2_i \;\; s \in S \qquad (5.19)$$

$$\sum_{p}^{P} X_{pjls}^{v} \leq Cap_v \, V_{jl}^{v}, \qquad \forall j \in J, l \in L, v \in V3_i \;\; s \in S \qquad (5.20)$$

Logic constraints

$$\sum_{i}^{I} \sum_{v}^{V_i} \sum_{p}^{P} X_{pijs}^{v} \geq GY_j \,, \quad forj = 1, \ldots., J \qquad (5.21)$$

$$\sum_{j}^{J} \sum_{v}^{V_i} \sum_{p}^{P} X_{pjks}^{v} \geq GY_k \,, \quad fork = 1, \ldots., J \qquad (5.22)$$

Facilities Constraint

$$Y_j \geq N_j \qquad for\ j = 1, \ldots., J \qquad (5.23)$$

$$Y_k \geq N_k \qquad for\ k = 1, \ldots., K \qquad (5.24)$$

$$Y_j \in \{0,1\} \,, \qquad for\ j = 1, \ldots., J \qquad (5.25)$$

$$Y_k \in \{0,1\} \,, \qquad for\ k = 1, \ldots., K \qquad (5.26)$$

Non-Negativity Constraints

$$X_{pijs}^{v}, X_{pjks}^{v}, X_{pjls}^{v} \geq 0 \qquad (5.27)$$

In the previous formulation, the model we describe here is a Mixed Integer Linear Programming Problem, It investigates customer zones, locations of the collection/ inspection centers, locations of recovery and disposal centers and the transportation modes between the entry points and collection/ inspection, as well as from the collection/ inspection to the recovery centers, and from the collection/ inspection to the regional disposal centers. In this model there are two kinds of objective functions: one for calculation the logistics costs and one for calculating different types of emissions, both to be minimized. In equation (5.8) computes the first objective, which aims to minimize the total cost for the overall network. This cost function takes into account the overall cost of the network; it involves the fixes cost associate with setting up collection/ inspection and recovery centers, the transportation costs between the different facilities over the network which vary for the different transportation modes, collection and inspection, recovery, and disposal costs. Equation (5.9) Objective function F2 computes the amount of CO_2 emitted for the transportation between customer zones and collection/ inspection centers, and from collection/ inspection to recovery centers, and between collection/ inspection center to disposal centers. Constraint (5.10) ensures that all of the returned products are collected from each customer. Constraints (5.11, 5.12, 5.13) defines that amount of collected product coming collection/inspection center is equal to total of product amount transporting recycling centers and disposal centers. Constraint(5.14) shows maximum capacity limitations for collection/inspection centers, while constraint (5.15) shows maximum capacity limitations for recovery centers. Constraints (5.16 to 5.20) are the transportation mode capacity constraints when moving from the customer zone to the collection/inspection center and respectively when moving from collection/inspection center to recovery center, and to disposal center. Constraint (5.21) ensures that each collection center should be allocated only one collection/inspection center and constraint, and constraint (5.22) shows that each collection inspection center should be allocated only one recovery center. Constraints (5.23, 5.24) show maximum number of collection/inspection centers and recovery respectively,. Constraint (5.25-5.27) shows integer and non negativity variables respectively.

5.6 The solution Method

First of all, it have to be noted when we deal with multi-objective problem, its solution will be a Pareto front possible design alternatives representing the trade-off between both objectives rather than a unique solution. The proposed problem considers determination of facility locations before knowing the quantity of returned products. The uncertainty of returned quantity is considered in this problem. For this , a two-stage stochastic linear model is developed. The general formulation of a two-stage stochastic program with fixed recourse is:

$$\text{Min } z = ct\, x + \text{E } \xi \{\min q(\omega)y | \mathbf{W} = h(\omega) - \mathbf{T}(\omega)x, y \in Y\} \quad (5.28)$$

$$\text{Subject to: } \mathbf{A}x = b \quad (5.29)$$

$$x \in X \quad (5.30)$$

Where the first-stage decisions are represented by the $n_1\times 1$ vector x. Corresponding to x are known data vectors c, b and the matrix A of sizes $n_1\times 1$, $m_1\times 1$ and $n_1\times m_1$, respectively. And the second-stage decisions are represented by the $n_2\times 1$ vector y. In the second stage, a number of random events ω ∈ Ω may realize. For a given realization of ω, the second-stage data q(ω), h(ω) and T(ω) become known, where q(ω) is n2 × 1, h(ω) is $m_2\times 1$ and T(ω) is $n_2\times m_2$. ξ is the vector formed by the components q, h and T, and Eξ is the expected value respect to ξ. W is called the recourse matrix which is fixed (it means, do not depend on the random variable).

Under this structure, we will consider as a priori decisions the collection/inspection and recovery centers locations choice on the three levels of the reverse network (variables Y_j, Y_k), while the a posteriori decisions will be the flows between facilities (variables $X_{pijs}^{v}, X_{pjks}^{v}, X_{pjls}^{v}$). We are considering uncertainty only at the returend quantity of reused products, that means that our unique random parameter is the right hand side h(ω); the matrices T and W are fixed.

As we deal with multi objective ε-constraint is applied to get non dominant Pareto solution. Despite its advantages over the weighting method the ε-constraint method has two points that need attention: the range of the objective functions over the efficient set and the guarantee of efficiency of the obtained solution. So the Augmented ε-constraint method was used in order to overcome these obstacles.

To accelerate solution time, this issue is solved by constructing a payoff table. This table contains the (best) and the nadir (worst) values of every objective function. Lexicographic optimization of the objective functions is recommended in order to avoid producing weakly efficient solutions in presence of alternative optima. Based on the above points, to solve the multi-objective problem with k objectives using the augmented ε-constraint, the mentioned model can

$$\text{Max} f_i(p) + eps \times \sum j \neq i (s_j / r_j)$$

$$s.t.\ p \in F$$

$$f_j(p) - s_j = \varepsilon_j; \forall j \neq I, s_j \in R+$$

Where F is the feasible space of the original problem; $f(p)$ is the vector of objective functions; s_j is slack variables of j-th constrained objective function; r_j is range of j-th constrained objective function obtained from the payoff table, and *eps* is a small number usually between 10^{-6} and 10^{-3}.

The augmented ε-constraint method is applied in the following steps, based on aforementioned considerations:

Step 1: select one of the two objectives as objective function whiles the other one as constraint and evaluates the payoff table.

Step 2: Divide the range of j-th objective function into m_j equal intervals; hence, (m_j+1) represent grid points are emerged. These points used to vary parametrically the right hand side of the j-th objective function. The values of ε_j are obtained by employing this method.

Step 3: The augmented ε-constraint model is solved for each vector of ε which is obtained from step 2.

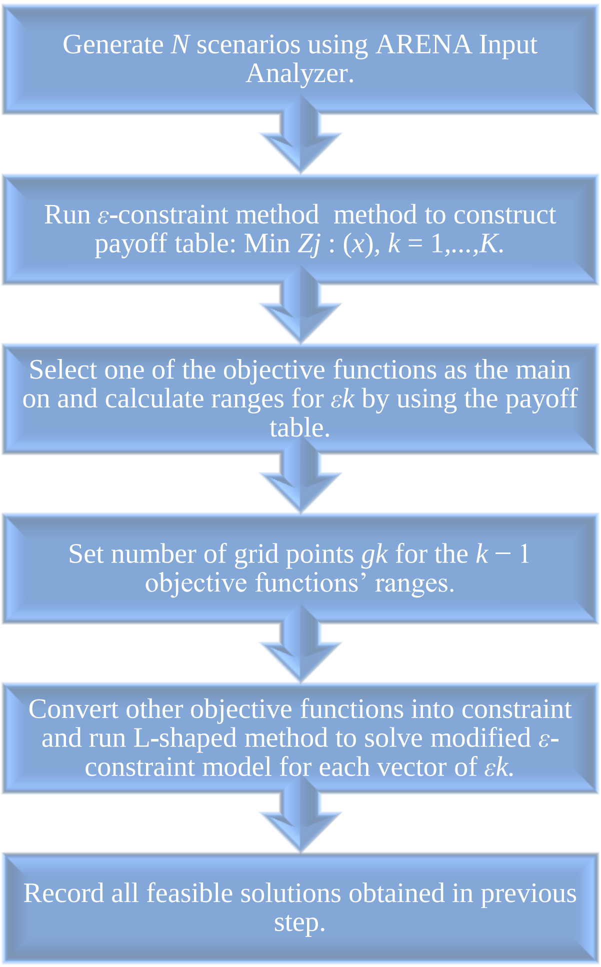

Figure 5.2: Flowchart of the proposed method.

CHAPTER 6

CASE STUDY

6.1 WEEE Sector in Turkey

The sustainable management of waste electrical and electronic equipment (WEEE) has increasingly become a global environmental issue. WEEE is the fastest-growing waste stream worldwide as a sequence of being the electrical and electronics equipment (EEE) industry is one of the fastest growing in the industrialized world. As we live in the age of telecommunications, this peaked in the early wake of the 1990s. The emergence of new electrical and electronic equipment (EEE) that have been incorporated into routines and increasingly frequent customs have generated a dependency on this type of technology, manufacturing a need not only to possess but also of renewal to be to last and not be technically and socially obsolete. Their products include mobile phones, music players, televisions, refrigerators, computers, printers, and even medical equipment.

Waste electrical and electronic equipment means all devices and components, subassemblies and consumables which are part of the product, which no longer work, they have no further use for their owners or have become obsolete. The UNEP (United Nations Environment Program) estimates that the world produces up to 50 million tons of Waste Electrical and Electronic Equipment-WEEE (or e-waste for short) per year; Majority of the e-waste comes from items that fall under both large and small domestic products. The current annual production of e-waste is 1.8 million tons in Germany, 1.5 million tons in France, and roughly 6 million tons in Europe.

Unfortunately, quantity of e-waste in Turkey cannot be stated clearly because of the lack of statistical data. However, Turkey's annual e-waste production is assumed to be around 1 million tons, with reference to Germany's e-waste quantity. This assumption is made on the similarity between Turkey's and Germany's population and consumption habits. The European Commission identified the need for legislation to address the escalating problem of wastes, especially WEEE at the Community level, and this has taken the form of the WEEE Directive .

The EU's WEEE Directive (waste of electronic and electrical equipment) obligates manufacturers of electronic and electrical equipment to take back old equipment from customers free of charge and to dispose of these wastes in an environmentally sound manner. Turkey, as one of the candidates for EU membership, is also on the way to prepare a new regulation about WEEE for the purpose of adaptation to EU's legislation. In the near future, this new regulation will be promulgated by Ministry of Environment and every EEE producer in Turkey should reform its organization and take the responsibility of its wastes.

In this research, we will accept the definition of EU's Directive 2002/96/EC. Waste generated from electrical and electronic equipments is potentially hazardous due to heavy metal (zinc, cadmium, mercury, chromium and copper) effluent content. As such, they require special treatment and disposal techniques. At present, most waste arising from the industrial sector is released into the surrounding atmosphere, discharged into adjacent water bodies (rivers, streams, sea), stored on site, disposed of in privately owned disposal centers, incinerated in the open, or dumped haphazardly[12].

There are generally three different ways of treating of WEEE: reuse, recycling and disposal (such as incineration, disposal center). The disposal in disposal center is the least desirable option. However, in Turkey's conditions, the reuse and recycling methods are much expensive and underdeveloped because the lack of technologies and know-how. So unfortunately, disposal in disposal center is, for now, preferable to the other ways of treating e-wastes. In this search, the focus will be on recycling and disposal – disposal center in order to reduce the disposed waste quantity and to dispose the rest in an environmentally friendly manner.

6.2Computational Case Study

6.2.1 Data description

In order to see the usefulness, validity and practicality of the proposed model, a case study is derived which depends on inspiration from WEEE industry case in Turkey. The proposed model is including twenty two customer zones where is located some city in Turkey. Regarding the potential locations for installing reverse facilities (either collection centers, recovery centers); eleven collection\ inspection centers (j_1:Istanbul,j_2:Ankara, j_3:Bursa, j_4:Manisa, j_5: Isparta, j_6:Aksaray, j_7: Samsun, j_8:Erzerum, j_9:Diyarbakır,j_{10}:Adana, and j_{11}:Sivas), five recovery centers (k_1:Istanbul, k_2:Ankara,k_3:Kocaeli, k_4:Kahramanmaraş, and k_5:Izmir), and Four disposal centers (l_1:Ankara, l_2:Kocaeli,l_3: Denizli, and l_4:Gaziantep) which can received hazardous materials as shown in Figure 6.1 .

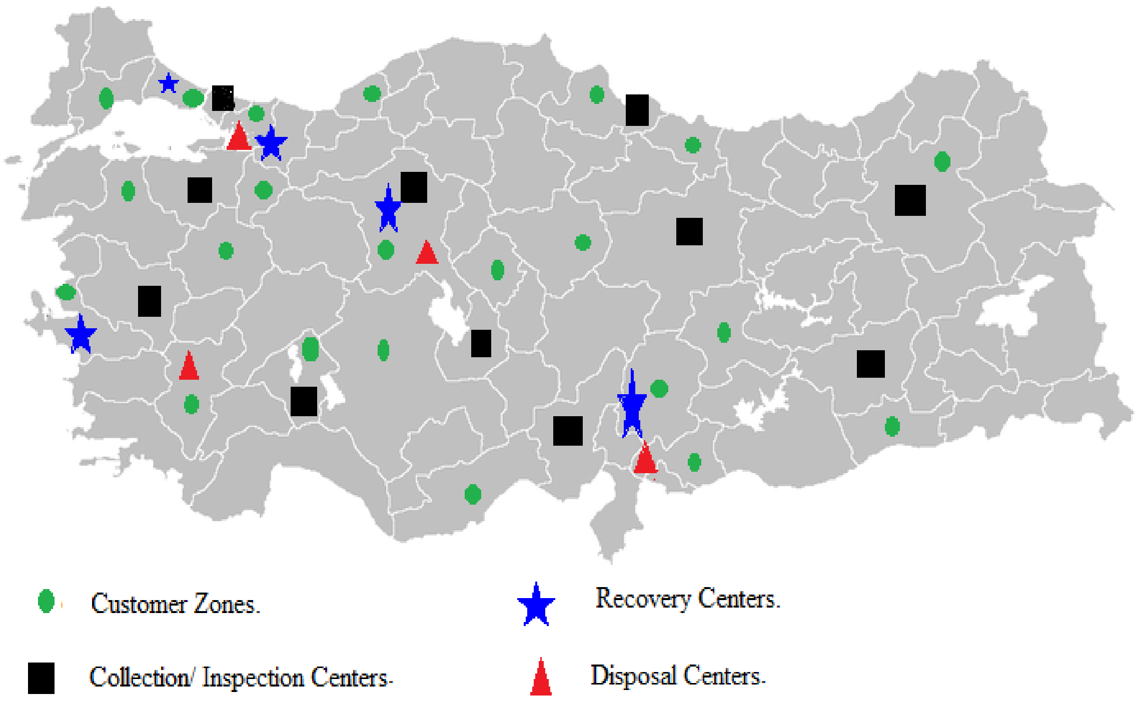

Figure 6.1: The graph of proposed WEEE reverse logistic network in Turkey.

When a facility located in a region this does not mean locating it in the center of the town or close by but somewhere in the municipal area. This is typically the case with collection/inspection centers, recovery centers, and disposal centers. As shown in Figure 5.1, returned products are collected from customer zones in collection/inspection centers where it is divided into recoverable products and scrapped products. The recoverable products are transported to the recycling centers and scrapped products are sent to the disposal centers.

When many reverse facilities are to be located in the same region, it is assumed the same potential location for all of them. This is the case in many real life situations in which a location can have a collection/inspection center, a recovery center, and a disposal center or any combination of these facilities. Based upon the coordinates of all regions and on the coordinates of the potential locations for the reverse facilities, the distance between every two points has been calculated. Note that the CO_2 emission depends on these distances. Besides, the road distances between every two locations were also obtained, which is of major importance for evaluating the transportation costs.

In each customer zone tree types of WEEE disposal have to be collected namely Cooling & Freezing, Large Household Appliances, and Monitors & LCD. After being recovered, these products can be converted into different valuable commodities.

6.2.2Forecasting of Product Return Quantity

Demand uncertainty and also uncertainty in the quantity and quality of returned products is an important factor in designing reverse logistic networks problem. It is possible to handle uncertainty by using scenarios. In this study, it is generated ten scenarios for the amount of returned products collected from customers. By using historical data, Uniform distributions are generated for each customer zone *(i)* by ARENA Input Analyzer 10.0. Table 6.1 shows the uniform distribution for each customer zone.

Table 6.1: Uniform distribution of returned products amounts.

Amounts of Returned Product Scenarios			
Customer zones\ Products	Cooling & Freezing	Large Household Appliances	Monitors & LCD
Customer Zone 1	UNIF(743, 1.47e+004)	UNIF(1.23e+003, 2.44e+004)	UNIF(697, 1.38e+004)
Customer Zone 2	UNIF(85, 1.69e+003)	UNIF(141, 2.80e+003)	UNIF(80, 1.59e+003)
Customer Zone3	UNIF(211, 4.18e+003)	UNIF(349, 6.93e+003)	UNIF(198, 3.93e+003)
Customer Zone 4	UNIF(199, 3.94e+003)	UNIF(329, 6.53e+003)	UNIF(186, 3.70e+003)
Customer Zone 5	UNIF(268, 5.31e+003)	UNIF(443, 8.80e+003)	UNIF(251, 4.99e+003)
Customer Zone6	UNIF(89, 1.77e+003)	UNIF(147, 2.93e+003)	UNIF(83, 1.66e+003)
Customer Zone 7	UNIF(215, 4.27e+003)	UNIF(356,7.06e+003)	UNIF(202,4.0 e+003)
Customer Zone 8	UNIF(162, 3.22e+003)	UNIF(268, 5.33e+003)	UNIF(152, 3.02e+003)
Customer Zone 9	UNIF(150, 2.98e+003)	UNIF(248, 4.93e+003)	UNIF(141, 2.8e+003)
Customer Zone 10	UNIF(150, 2.98e+003)	UNIF(248, 4.93e+003)	UNIF(141, 2.8e+003)
Customer Zone11	UNIF(121, 2.4e+003)	UNIF(201, 4.0e+003)	UNIF(114, 2.27e+003)
Customer Zone12	UNIF(203, 4.03e+003)	UNIF(336, 6.66e+003)	UNIF(190, 3.78e+003)
Customer Zone13	UNIF(166, 3.30e+003)	UNIF(275, 5.46e+003)	UNIF(156, 3.1e+003)
Customer Zone14	UNIF(81, 1.61e+003)	UNIF(134, 2.66e+003)	UNIF(76, 1.51e+003)
Customer Zone15	UNIF(52, 1.61e+003)	UNIF(87, 1.73e+003)	UNIF(49, 982)
Customer Zone16	UNIF(162, 2.96e+003)	UNIF(268, 5.33e+003)	UNIF(152, 3.02e+003)
Customer Zone17	UNIF(162, 2.96e+003)	UNIF(268, 5.33e+003)	UNIF(152, 3.02e+003)
Customer Zone18	UNIF(284, 5.64e+003)	UNIF(470, 9.33e+003)	UNIF(266, 5.29e+003)
Customer Zone 19	UNIF(81, 1.61e+003)	UNIF(134, 2.66e+003)	UNIF(76, 1.51e+003)
Customer Zone 20	UNIF(203, 4.03e+003)	UNIF(336, 6.66e+003)	UNIF(190, 3.78e+003)
Customer Zone 21	UNIF(121, 2.4e+003)	UNIF(201, 4.0e+003)	UNIF(114, 2.27e+003)
Customer Zone 22	UNIF(121, 2.4e+003)	UNIF(201, 4.0e+003)	UNIF(114, 2.27e+003)

Table 6.2 summarizes returned product scenarios' for customer zone 1as an example.

Forty random numbers are generated and ten scenario values are calculated by taking into consideration uniform distributions related to each collection points. The probabilities assigned to scenarios represent the importance of each scenario in an uncertain environment (Pishvaee et al 2009) [64] . Probabilities of all scenarios are assumed as same in order not to emphasize any of the scenarios, so each scenario in our case has the same probability which equal 0.025.

Table 6.2: Amount of Returned Product Scenarios for Custoe Zone 1.

Amounts of Returned Product Scenarios for Customer Zone 1			
Scenario numbers	Cooling & Freezing	Large Household Appliances	Monitors & LCD
Scenario1	2334	13220	9290
Scenario2	5233	9245	7955
Scenario3	5894	5036	5210
Scenario4	6390	17647	2489
Scenario5	9449	13913	10872
Scenario6	4438	17619	12074
Scenario7	975	20429	7390
Scenario8	13990	14882	12665
Scenario9	4022	3630	12829
Scenario10	1626	15974	12503
Scenario11	3168	21230	3465
Scenario12	3839	18918	13347
Scenario13	10323	15217	7227
Scenario14	6389	13269	12970
Scenario15	7092	13955	7889
Scenario16	14205	3117	7194
Scenario17	9203	3916	13393
Scenario18	2045	15138	4726

Scenario19	13518	18010	8615
Scenario20	4788	20171	9957
Scenario21	928	17085	3868
Scenario22	2103	23612	5889
Scenario23	1984	6992	2247
Scenario24	1941	13972	7021
Scenario25	1247	15434	8725
Scenario26	9256	1872	13229
Scenario27	2150	14561	1443
Scenario28	10708	22998	5939
Scenario29	5860	4004	7123
Scenario30	1249	12272	979
Scenario31	3278	16623	8667
Scenario32	5846	10422	12031
Scenario33	8811	22478	5480
Scenario34	2568	2943	9111
Scenario35	1976	10583	12916
Scenario36	6585	13094	6724
Scenario37	12609	4909	7826
Scenario38	2042	21606	5007
Scenario39	7657	3228	874
Scenario40	10462	1805	7716

To deal with quality uncertainty a predefined percentage of returned amounts of each customer zone is assumed to result in return products and a predefined value is determined as an average disposal rate. The average disposal rate is associated with the quality of returned products; because high quality returns have a capability for recovery process (remanufacturing and de-manufacturing) and low quality returns should be entered to a safe disposal process. In our case we deal with the quality of return product by using predefined percentage of retuned WEEE quantity that can be recoverable (remanufacturing), and the disposal amount that will send to disposal center, this percent could be uncertain percent according to Listes and Dekker [48]; or a fixed percentage according to Ko and Evans[36]. If we use it as stochastic percentage we have to use three stage stochastic model and lake of information in this study push us to use a predefined percentage for the returned product that can be recovered, and use it as indication of the quality of return products.

Finally, three types of transportation modes with can be used for the transportation processes which have different capacities, costs and environmental impact. These modes were less than track load (LTL) 16 tons to transport returned products from customer zones to collection inspection centers, full load truck (FTL) with different capacities 28tons to transport returned products from collection inspection centers to disposal centers as the quantities are a little small; and 40 tons capacity full load trucks to transport returned products from collection inspection centers to recovery centers as the quantities are big. We avoid to use rail trains in our case study as we mention in chapter five because of lack of information about rail freight in Turkey and the smallest amount of returned products, while rail train transportation mode knead a capacity of 540tone for each train which cannot meet the available quantities of returned quantity [65].

The following data are used for testing the proposed model:

- Potential collection/ inspection centers are assumed to be equally capacitated, being able to process 12,000 tons of Cooling & Freezing, 20,000 tons of Large Household Appliances, and 11,000 tons of Monitors& LCD every year; and required number of potential collection/ inspection centers is seven.
- Potential recovery centers are assumed to be equally capacitated, being able to process 20,000 tons of Cooling & Freezing, 36,000 tons of Large Household

Appliances, and 18,000 tons of Monitors& LCD every year; and the required number of potential recovery centers is three.

- Unit transportation costs of the three products using less than track load (LTL) with 16 tons capacity from customer zones to collection\inspection centers, full load truck (FTL) with28 tons capacity from collection\inspection centers to recovery centers ,full load truck (FTL) with40 tons capacity from collection\inspection centers to disposal centers are $12, $17, $22 per ton for the three types of product respectively.(NOTE: we avoid to use rail trains because lake of data, and the quantity of returned product is small with comparison with the capacity of train)
- Quality specification rates for the product can be recovered or recycle are %70, %80 and %70for respectively cooling& freezing, large household appliances, and monitors & LCD.
- Some of the other monetary data which is used in the case study are given in Tables 6.3, and 6.4.
- The fixed and installation investment cost of collection/ inspection centers alternatives and recovery centers alternatives are given in table 6.3.

Table 6.3: Fixed cost of Collection\Inspection and Recovery Facilities of the Reverse Logistic Network.

Collection and Inspection Center	Fixed Cost	Recovery Center	Fixed Cost
Collection/Inspection Center1	$ 1,200,000	Recovery Center1	$ 3,200,000
Collection/Inspection Center2	$ 1,200,000	Recovery Center2	$ 3,000,000
Collection/Inspection Center3	$ 1,000,000	Recovery Center3	$ 3,000,000
Collection/Inspection Center4	$ 1,000,000	Recovery Center4	$ 2,800,000
Collection/Inspection Center5	$ 800,000	Recovery Center5	$ 2,800,000
Collection/Inspection Center6	$ 800,000		
Collection/Inspection Center7	$ 1,000,000		

Collection/Inspection Center8	$ 800,000		
Collection/Inspection Center9	$ 800,000		
Collection/Inspection Center10	$ 1,000,000		
Collection/Inspection Center11	$ 800,000		

- The operation costs of returned products in each facility of the reverse logistic network are given in table 6.4

Table 6.4: Operation Cost of Returned Products in each Facility of the Reverse Logistic Network.

	Cooling & Freezing	Large Household Appliances	Monitors & LCD
Collection process (in Customer zones)	$130.00	$200.00	$100.00
Collection and Inspection cost per ton	$100.00	$120.00	$110.00
Recovery cost per ton	$150.00	$200.00	$120.00
Disposal cost per ton	$100.00	$287.00	$130.00

- Due to the lack of additional information, we assume two set of scenarios the first one consists of 40 scenarios that all the fourth scenarios have the same probability, which is ρs = 0.025, $s \in S$.

6.2.3Model Results

In this section, both deterministic and scenario base stochastic model are solved in Windows 7 Pentium 2.2 GHz computer with 1 GB RAM. The Proposed scenario base stochastic model is solved by commercial software GAMS 23.6/CPLEX 12.2. Here to assess the performance of the proposed scenario base stochastic model, a deterministic model is developed. The results are presented in Table 6.5[66].

Table 6.5: The Results of Deterministic and Stochastic Models

Model Type	Deterministic Model		Stochastic Model	
Objective Function	Cost ($)	CO2 Emissions (Kg)	Cost ($)	CO2 Emissions (Kg)
	$922,803,500	55277240 Kg	$ 853,376,400	50698340 Kg
Solution Time	9.97 Seconds		1435.09 Seconds	
Number of Iterations	909		38065	
Blocks Of Equations	19		19	
Blocks Of Variables	11		11	
Non Zero Elements	8,503		337,975	
Single Equations	272		10,568	
Single Variables	1,046		41,060	
Discrete Variables	16		16	

According to solutions, runs of deterministic model were done within 9.97seconds. Compared to deterministic model, runs of stochastic model were done within 1435.09seconds respectively. Deterministic model running time is lower than scenario base stochastic model because of the complexity of stochastic model. The deterministic model is developed by using the mean value of ten scenarios. As it can be seen at Table 6.5, total cost and CO_2emissions of deterministic model ($922,803,500 and 55277240kg of CO_2emissions) are higher than total cost and CO_2emissions of the stochastic model when the number of scenarios are ten the total cost and CO_2emissions are($ 853,376,400, and 50698340 kg of CO_2emissions).

Table 6.6 showes the selected locations of each model for locating collection \inspection centers.

Table 6.6: Locations of Collection\ Inspection Centers.

	j_1	j_2	j_3	j_4	j_5	j_6	j_7	j_8	j_9	j_{10}	j_{11}
Deterministic	●	●	●	●	●				●	●	
Stochastic	●	●	●	●	●				●	●	

According to the results of deterministic model and stochastic model in Table 6.7, the seven locations of collection\ inspection centers of both models (Deterministic and Stochastic) are located in the following cities: Istanbul, Ankara, Bursa, Manisa, Isparta, Diyarbakır, and Adana as they are shown in Figure 6.2.

While the recovery centers according to the results of deterministic model and stochastic model in Table 6.7are located in the following cities for both models (Deterministic and Stochastic): Kocaeli, Ankara, and Kahramanmaras as they are shown in Figure 6.2.

Table 6.7: Locations of Recovery Centers.

	k_1	k_2	k_3	k_4	k_5
Deterministic		●	●	●	
Stochastic		●	●	●	

As results of having in this case the selected collection\ Inspection centers and recovery centers are the same in both models (Deterministic and Stochastic); the following Figure 6.2 shows the selected locations of collection\ Inspection centers and recovery centers in Turkey for both models (Deterministic and Stochastic).

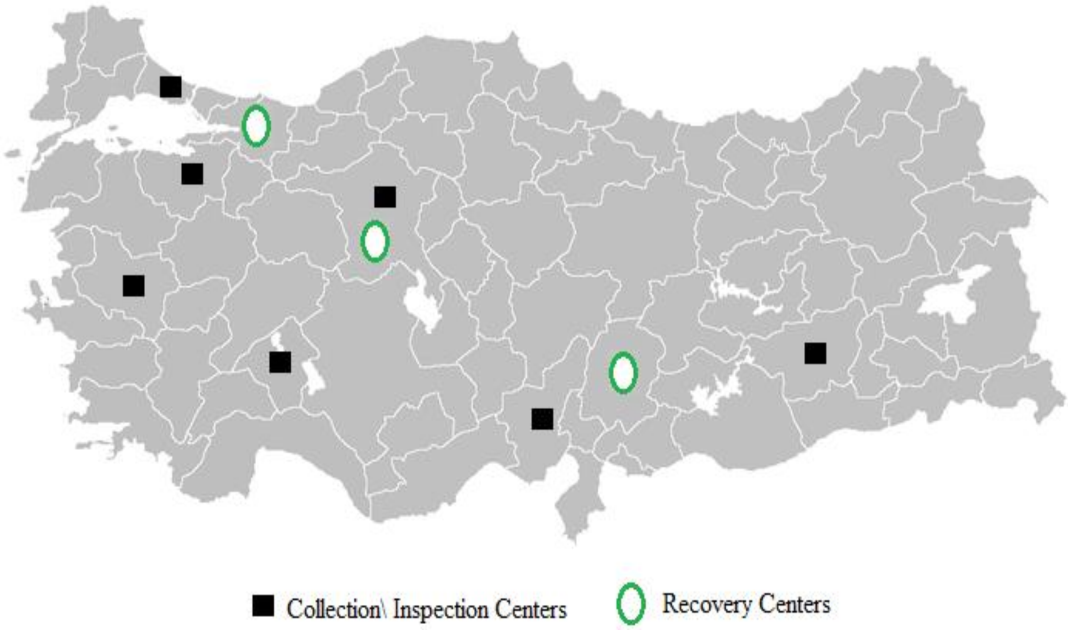

Figure 6.2: Facility Locations for Deterministic and Stochastic Models.

The results of deterministic model shows the needed 9629 LTL trucks with capacity of 16 tons to transport the quantity of returned products from the customer zones to collections centers, and the quantity transported from collections centers to recovery centers require 4105FTL trucks with capacity of 40 tons. While the quantity transported from collections centers to disposal centers require 979FTL trucks with capacity of 28 tons. In Appendix A contains the quantities of distributed in each stage of proposed reverse logistic network. While Appendix B contains the quantities of each stage in reverse logistic network for stochastic model with 40 scenarios.

According to the applied augment constraint method the Payoff table of deterministic model is shown in Table 6.8 which contains the maximum and minimum value of each objective function.

Table 6.8: Payoff Table of Deterministic Model

Total Cost ($)	CO_2 Emission (Kg)
$ 891,073,319.40	56644532.93
$ 922,803,452.30	55277243.56

The first objective function, in order to reduce the total costs, tends to the whole network as much as possible whereas the second objective function has a propensity for creating a more decentralized network to minimize the CO_2emission . In Figure 6.3, the result confirm that two objective function (i.e., minimization of cost and minimizing of CO_2emission) are in conflict with each other since an increase of total network costs leads to decrease in CO_2emissions.

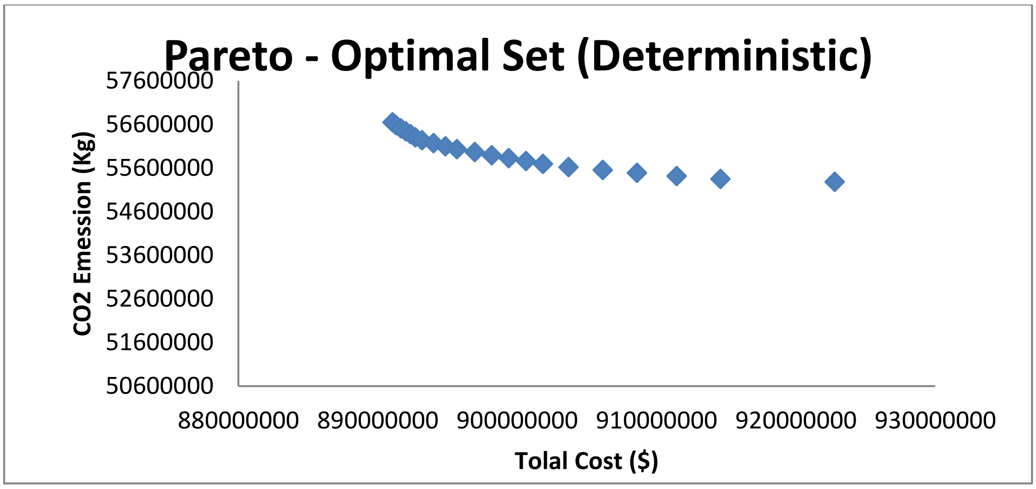

Figure6.3: The Pareto-Optimal Set for Deterministic Model

For Stochastic Model the payoff table is shown in Table 6.10, it is noted the total cost value is more economical when it compared with the deterministic model the same for CO_2emission.

Table 6.9: Payoff Table of Stochastic Model

Total Cost ($)	CO_2 Emission (Kg)
$ 821,221,675.78	51895698.69
$ 853,376,402.95	50698339.44

Figure 6.4 shows there is no change on the confliction between the toll cost and CO_2emission objective function of the stochastic model, the result confirm that two

objective function (i.e., minimization of cost and minimizing of CO_2emission) are in conflict with each other since an increase of total network costs leads to decrease in CO_2emissions.

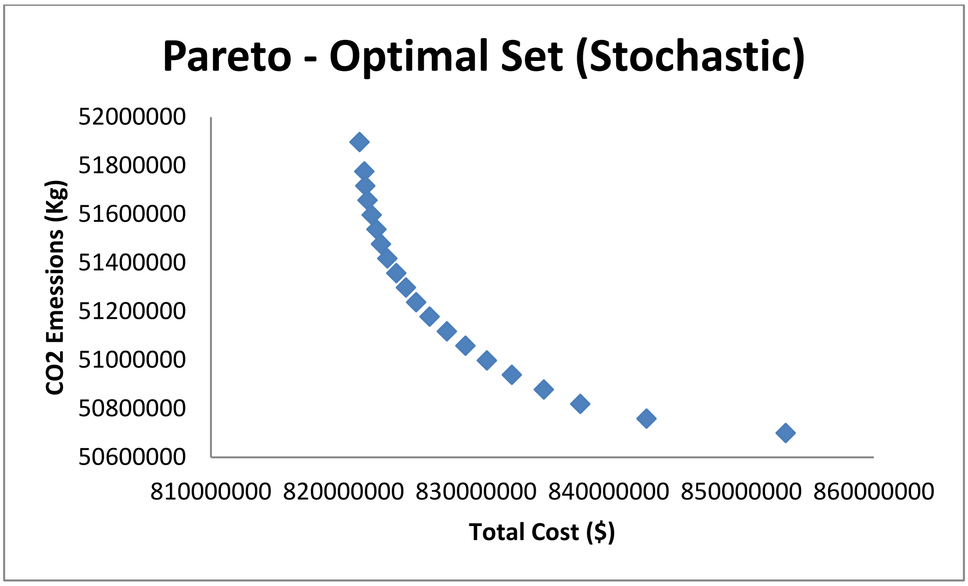

Figure 6.4: The Pareto-Optimal Set for Stochastic Model

Generally the choices are meaningful because of chosen location for inspection and recovery centers are nearer to the industrial zones this will cause a decrease in transportation cost and response time. In order to find the parameter effects on the results, a sensitivity analysis is required.

6.2.4 Sensitivity Analysis

In order to discuss the effect of different parameters on the results of scenario base models, we have to remind the random variable of proposed model which affect on the results of proposed model. The main random variable is the quantities of returned products for the two objective functions; for the first objective function any change in transportation cost of products in each stage of reverse network design will lead to change in the value of it . In addition to different types of cost like collection , inspection, recovery and disposal costs. While the change in the second objective function will be limited because the quantities of returned products is multiplied with two constant the emission value which is constant; and the distance between facilities which is constant too. In this section we assumed the collection, inspection ,recovery and disposal cost is constant because of lack of data, and we will examine the effect of number of scenarios on the value of the global solution, and the effect of change in transpiration cost in the objective functions.

6.2.4.1 The Effect of Scenarios Numbers

We test the deterministic model with different set of scenarios, where the number of scenarios of each set was as following: N=10, N=20, N=40, N=50, N=60. We noted the change in the value of both objective functions, as the number of scenarios increase in each set we get more economical cost, and increasing in the value of CO_2 emissions, and this emphasis on the conflicting between the two objectives that is concluded from the deterministic pare to optimal solution. The payoff table of each set of each scenario is showmen in Table 6.11.

Table 6.10:Payoff Table of Different Set of Scenarios of Stochastic Model

	Total Cost ($)	CO2 Emissions (Kg)
N=10	$ 837,279,775.96	53,519,488.47
	$ 880,130,996.65	52,285,817.80
N=20	$ 853,119,695.99	54,711,527.23
	$ 896,038,958.04	53,301,154.08
N=40	$ 821,221,675.78	51,895,698.69
	$ 853,376,402.95	50,698,339.44
N=50	$ 847,883,631.96	54,377,322.05
	$ 890,632,216.43	52,906,710.04
N=60	$ 845,945,274.64	54,259,978.25
	$ 888,323,471.96	52,787,346.54

According to results of payoff table it is noted when the number of scenarios increase the value of total cost is decreasing but it is not as a condition for CO_2emission objective functions. It is known in multi objective function their is no optimal solution but their is a soultion satisfy both objective, in our case the prefered solution will be the model with forty scenarios which h satisfy both objective($ 853,376,400, and 50698340 kg of CO_2 emissions) and it is showmen in Figure 6.5.

From the test results there is no change on the selected location for collection\ inspection centers and the locations of recovery centers with the change of the number of scenarios in each set.

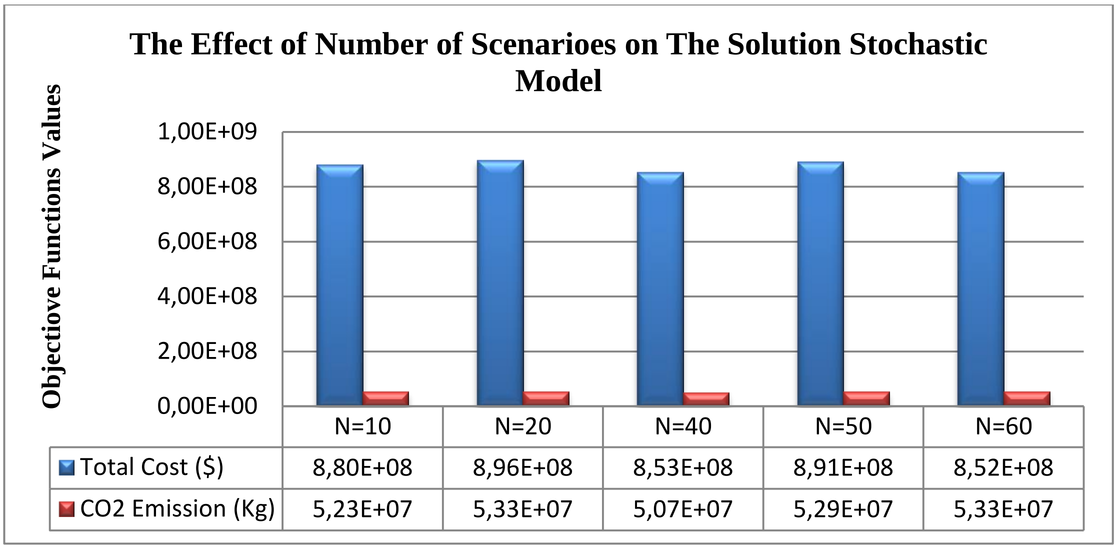

Figure 6.5: The Effect of Number of Scenarios on the Solution Stochastic Model

As the number of scenarios increase the CPU time will increase as results of complexity of stochastic model. Figure 6.5 shows the needed time for each set of scenarios; and it is clearly form the results increasing of solution time with the increasing of number of scenarios of each set is tested as it shown in Figure 6.6.

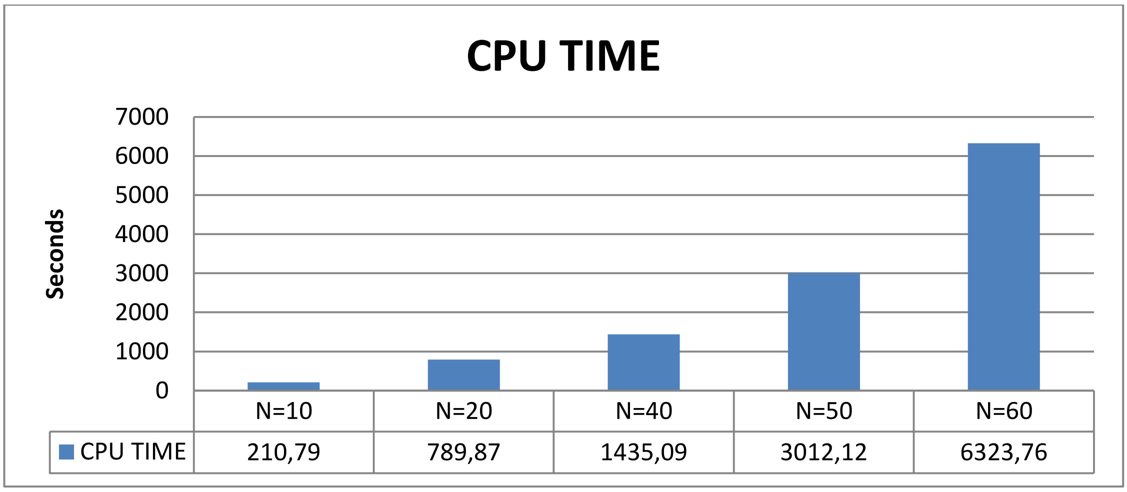

Figure 6.6: Time needed to solve Stochastic Model According to number of Scenarios

Figure 6.7 shows there is no change on the confliction between the toll cost and CO_2emission objective function of the stochastic model in the five sets, the results confirm that two objective function (i.e., minimization of cost and minimizing of CO_2emission) are in conflict with each other since an increase of total network costs leads to decrease in CO_2emissions.

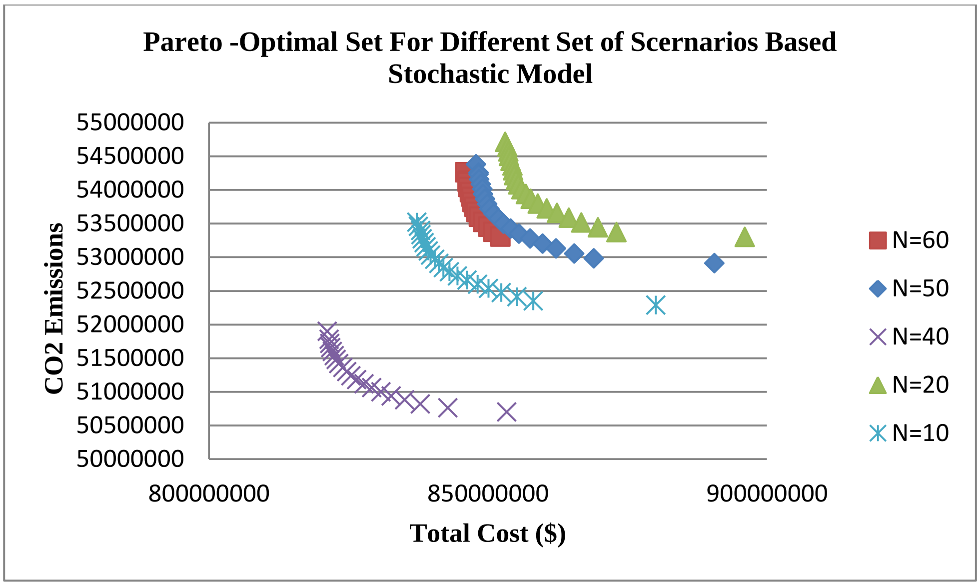

Figure 6.7: Pareto -Optimal Set for Different Set of Scenarios Based Stochastic Model

6.2.4.2 The Effect of Transportation Mode and Tansportation Cost

In section the effect of change the transportation mode in the second and the third stage is tested by using four diffierent cases in the scenario base stochastic model with 40 scenarioes:

Case 1: use two type of FTL - Full Load Truck- with capacities 40, and 28 tons in second and third stages respectivly, from collection\ inspection centers to recovery centers, and from collection\ inspection centers to disposal centers.

Case 2: use one type of FTL - Full Load Truck- with capacity 40 tons in second and third stages from collection\ inspection centers to recovery centers, and from collection\ inspection centers to disposal centers.

Case 3: use one type of FTL - Full Load Truck- with capacity 28 tons in second and third stages from collection\ inspection centers to recovery centers, and from collection\ inspection centers to disposal centers.

Case 4: use two type of FTL - Full Load Truck- with capacities 28, and 40 tons in second and third stages respectively, from collection\ inspection centers to recovery centers, and from collection\ inspection centers to disposal centers.

It is noted their is no change in the amount of CO_2emissions because in the second objective function the quantities of returned products is multiplied with two constant the emission value which is constant; and the distance between facilites which is constant too. But their a notable chang on the value of total cost function. The value of payoff table of each case is showen in Table 6.11.

According to the results in Table 6.11 it more economy to use case three which contains one type of FTL - Full Load Truck- with capacity 28 tons in second and third stages from collection\ inspection centers to recovery centers, and from collection\ inspection centers to disposal centers because it give the lowest total cost with comparison with the other cases, and itis shown clearly in Figure 6.8.

Table 6.11: Payoff Table of Stochastic Model with Diffirent Transportation Modes

	Total Cost ($)	CO2 Emissions (Kg)
Case 1	$ 821,221,675.78	51,895,698.69
	$ 853,376,402.95	50,698,339.44
Case 2	$ 840,935,999.70	51,895,698.88
	$ 874,339,812.74	50,698,339.44
Case 3	$ 742,208,200.73	51,442,062.62
	$ 753,794,659.84	50,698,339.44
Case 4	$ 761,995,867.55	51,553,430.50
	$ 774,758,069.62	50,698,339.44

Figure 6.8 clearly show the effect of selection of transportation Mode on the solution of stochastic model.

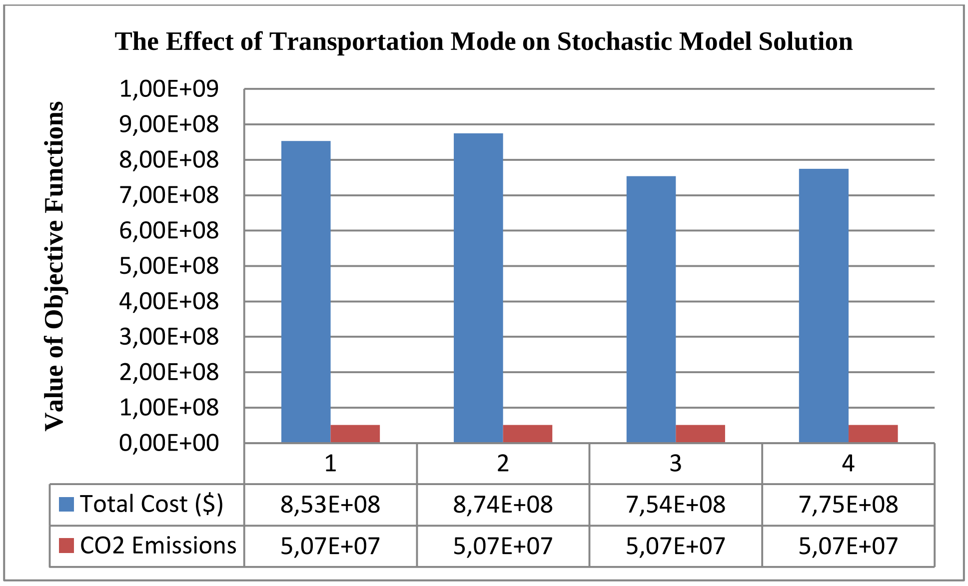

Figure 6.8:The Effect of Transportation Mode on Stochastic Model Solution

CHAPTER 7

CONCLUSION AND FUTURE STUDY

One of the important planning activities in reverse logistic management of reused products is to design the configuration of the returned network having a long-lasting impact on the whole network. Besides, the environmental and economic issueshave significant impacts onreverse logistic management, in particular, growing attention has been recently given to reverse logistic from the governments and Manufacturers. On the other hand, modeling of a reverse logistic network design (RLND) problem can be a challenging process because of uncertainty on parameters, multi-objective are ways to create more flexibility and real-world condition, and the large sacle of bussines problems.

This research proposed a comprehensive model for reverse logistics planning. A single model with several aspects of great practical relevance. The problem was initially formulated as a bi-objective two-stage stochastic MILP problem. By assuming set of different scenarios for the future, we detailed the deterministic equivalent problem.

This research addresses a two-stage bi-objective scenario-based mathematical stochastic mixed-integer linear programming model for designing a reverse logistic network with regard to its uncertainty of product return quantity. Moreover, the model takes into account the maximum capacity in every single area. The quality of the returned products is considered as a fixed value in this research. The proposed mathematical model of the two conflicting objective functions simultaneously optimizes the average sum of costs as well as the CO_2emissions from transportation modes inside the network. The proposed network is considered as an open-loop reverse logistics network including collection and inspection centers, recovery centers, and disposal centers. Moreover, quantity of returned products is assumed to be uncertain. To cope with product return uncertainty, forty scenarios generated from uniform distribution, which is obtained by historical product return data for all customer zones. Probabilities of all scenarios are assumed as same in order not to emphasize any of the scenarios. Computational results show that the scenario base stochastic model gives more economical and efficient solutions compared to deterministic model. Minimization of effect of uncertainty can figure out more cost savings and save the environment from CO_2emissions. The developed model can help managers to handle uncertainty of return amount, in the process of making strategic decision on facility location selection. Although this is a large-scale MIP problem, an augmented ε-constraint method which is revised version of traditional ε-constraint method is applied to provide optimized Pareto solutions of the proposed. To validate the proposed model, a case study of a WEEE reverse logistic network design in Turkey was employed and Pareto solutions based on the two objective functions (total cost and CO_2 emissions).

Regarding to the study there is no effect due to the variability of the returned quantity on the influence of some parameters on the computational. But it is noted the capacity of the collection\ inspection and recovery centers has a high influence on the number of points in the Pareto front as well as the computational time spent to obtain them.

The rustles of the considered case study demonstrate the success of augmented ε-constraint method in providing a list of Pareto-optimal solution as well as the treed of relation between the conflicting objective functions. The environmental and economical risk relevant to solutions has been calculated in order to assist the decision making process. With this approach, the resulted information provides a useful tool for the DMs because the decision making process rarely is performed based on one objective or without considering the financial risk related to randomness of returned quantity of products.

Many possible future research directions can be defined in the area of logistics network design under uncertainty. In this research, the focus was mainly on the impacts of uncertainty on the reverse logistic network designing (RLND) problems; the well-known scenario-based approach is utilized. Thus, employing different uncertainty approaches and comparing the obtained results can be investigated in future researches. Moreover, the model developed here was a single-period one; considering multiple periods can contribute to a more real formulation. Since the complexity of such models by a raise in the number of periods and/or scenarios increases remarkably, developing fast and effective algorithms for solving such models is a necessity. There are other ideas that came to the author's attention as future research that can further improve this proposed reverse logistics design model:

- To reformulate the problem as a stochastic program or a robust optimization model while considering the uncertain quality of returns.
- To consider the uncertainty in the quality of returns. More precisely, considering the proportions of reusable modules, parts and materials in a returned item of given quality level as a random variable instead of a deterministic one, as we did in the current study.
- To integrate the return acquisition pricing problem into the current RL tactical planning model. The latter will lead to a non-linear optimization problem.
- To integrate the proposed RL tactical planning model with the forward supply chain planning model in the context of a closed-loop supply chain. The idea is to line up the forward and backward flow decisions in such a network.

- Extending the proposed model for incorporating risk and uncertainty via stochastic programming and robust optimization models, and application of met heuristics, specifically evolutionary algorithm with variations of the NSGA algorithm; which can be of interest due to their effectiveness in creating a Pareto list.
- Include transshipment in reverse logistic network design model to improve efficiency of merchandise return with high marginal value of time such as laptop, computers, etc.

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APPENDIX-A

THE RESULTS OF DETERMINISTIC MODEL

The quantity of product p transport from cuztomer zone I to collection \inspection center j by using LTL transportation mode.							
p\i	j1	j2	j3	j4	j5	j9	j10
p1.i1	7894						
p1.i2	906						
p1.i3	2243						
p1.i4			2114				
p1.i5		2847					
p1.i6			949				
p1.i7				2286			
p1.i8			1726				
p1.i9					1596		
p1.i10					1596		
p1.i11		1294					
p1.i12							2157
p1.i13							1769
p1.i14		863					
p1.i15		561					
p1.i16		1726					
p1.i17		1726					
p1.i18							
p1.i19							3020
p1.i20						2157	863
p1.i21		1294					
p1.i22						1294	
p2.i1	13061						
p2.i2	1499						
p2.i3	3711						
p2.i4			3497				
p2.i5		4710					
p2.i6			1570				
p2.i7				3783			

p2.i8			2855				
p2.i9					2641		
p2.i10					2641		
p2.i11		2141					
p2.i12							3568
p2.i13							2926
p2.i14		1427					
p2.i15		928					
p2.i16		2855					
p2.i17		2855					
p2.i18							4996
p2.i19							1427
p2.i20						3568	
p2.i21		2141					
p2.i22						2141	
p3.i1	7408						
p3.i2	850						
p3.i3	2105						
p3.i4			1984				
p3.i5		2672					
p3.i6			891				
p3.i7				2145			
p3.i8			1619				
p3.i9					1498		
p3.i10					1498		
p3.i11		1214					
p3.i12							2024
p3.i13							1660
p3.i14		810					
p3.i15		526					
p3.i16		1619					
p3.i17		1619					
p3.i18							2834
p3.i19							810
p3.i20						2024	
p3.i21		1214					
p3.i22						1214	
p3.i20						2024	
p3.i21						1214	
p3.i22						1214	
Transportation Mode		LTL	Truck Capactiy	16 ton	Total Number of care used in this stage		9629.000

The quantity of product p transport from collection \inspection zone (j) to recovery center (k) by using (FTL) transportation mode.			
p\j	k2	k3	k4
p1.j1		7730.1	
p1.j2	7217.7		
p1.j3		3352.3	
p1.j4		1600.2	
p1.j5	2234.4		
p1.j9			2415.7
p1.j10			5466.3
p2.j1		14616.8	
p2.j2	13645.6		
p2.j3		6337.6	
p2.j4		3026.4	
p2.j5	4225.6		
p2.j9			4567.2
p2.j10			10333.6
p3.j1		7254.1	
p3.j2	6771.8		
p3.j3		3145.8	
p3.j4		1501.5	
p3.j5	2097.2		
p3.j9			2266.6
p3.j10			5129.6
Transportation Mode		Total Number of care used in this stage	4105.000
FTL	Capactiy : 40 Ton		

The quantity of product p transport from collection \inspection zone (j) to dispsal center (l) by using (FTL) transportation mode.				
p\j	l1	l2	l3	l4
p1.j1		3312.9		
p1.j2	3093.3			
p1.j3		1436.7		
p1.j4			685.8	
p1.j5			957.6	
p1.j9				1035.3
p1.j10				2342.7
p2.j1		3654.2		
p2.j2	3411.4			
p2.j3		1584.4		
p2.j4			756.6	
p2.j5			1056.4	
p2.j9				1141.8
p2.j10				2583.4
p3.j1		3108.9		
p3.j2	2902.2			
p3.j3		1348.2		
p3.j4			643.5	
p3.j5			898.8	
p3.j9				971.4
p3.j10				2198.4
Transportation Mode		Total Number of care used in this stage		979.000
FTL	Capactiy :28 Ton			

The quantity of product p transport from cuztomer zone I to collection \inspection center j by using LTL transportation mode in Scenario S						
Product (P1)						
P1(i,j)	s1	s2	s3	s4	s5	s6
i1 .j1	9290	7955	5210	2489	10872	11000
i1 .j3						1074
i2 .j1	909	1254	449	1540	128	
i2 .j2					550	1180
i3 .j1	801	987	3884	1933		
i3 .j3	2927				2987	2866
i4 .j3	3652	1669	2117	3378	2506	3273
i5 .j2	2807	4898	4213	4964	3822	1856
i6 .j3	1452	952	1523	1104	121	257
i7 .j4	3007	1023	1304	1059	2891	990
i8 .j3	2873	948	2692	2179	845	338
i9 .j2			1646			1559
i9 .j5	918	1496	940	1800	1568	
i10.j5	1993	2798	290	1909	2653	1859

i11.j2	1094	2202	1623	2067	1460	1532
i12.j10	3028	438	1470	1615	1506	608
i13.j10	1996	503	911	2329	2906	1316
i14.j2	207	1060	1180	929	1141	1440
i15.j1		741				
i15.j2	222	119	464	960	729	324
i16.j2	2337	2721	1874	856	2887	356
i22.j9	1199	1481	154	1234	2014	1375
	s7	s8	s9	s10	s11	s12
i1 .j1	7390	11000	11000	11000	3465	11000
i1 .j3		1665	1829	1503		2347
i2 .j1	655				1303	
i2 .j2		1120	544	839		116
i3 .j1	1802				2051	
i3 .j3		1160	1621	255		455
i4 .j3	2621	929	191	298	2365	1887
i5 .j2	3609	722	676	3631	629	4557
i6 .j3	1522	958	776	499	1443	136
i7 .j4	1974	1549	2968	1033	3573	3551
i8 .j2			214			1807
i8 .j3	1393	2430	1615	1030	601	624
i9 .j2			455			1156
i9 .j5	942	2350		1824	1701	

i10.j5	1049	368	1936	1835	509	1265
i11.j2	2112	745	1701	811	568	193
i12.j10	1329	870	2009	2843	3740	3439
i13.j10	1930	2694	3080	1346	2421	2883
i14.j2	517	1142	1433	378	1265	184
i15.j2	563	563	393	974	208	629
i16.j2	1512	227	2027	944	1294	1715
i22.j9	1113	721	1305	1221	1986	1026
	s13	s14	s15	s16	s17	s18
i1 .j1	7227	11000	7889	7194	11000	4726
i1 .j3		1970			2393	
i2 .j1	1351		1342	1139		1376
i2 .j2		804			616	
i3 .j1	762		1645	2667		1810
i3 .j3		1750		385	569	
i4 .j3	751	1147	3686	3144	1614	588
i5 .j2	3832	4460	2670	3282	4488	3757
i6 .j3	1340	825	1430	366	998	221
i7 .j4	3139	3059	386	2450	1566	3781
i8 .j3	651	630	2646	2785	2689	808
i9 .j2			842			2032
i9 .j5	423	804		1625	435	
i10.j5	2434	2243	1212	384	907	914
i11.j2	301	1370	1648	1972	1204	694

i12.j10	3540	2890	2552	2587	1010	3598
i13.j10	1441	2087	457	1898	2124	2415
i14.j2	518	160	187	1047	746	1280
i15.j2	932	192	244	879	783	291
i16.j2	1673	1050	1149	1915	423	938
i22.j9	1318	956	1323	1592	984	1303
	s19	s20	s21	s22	s23	s24
i1 .j1	8615	9957	3868	5889	2247	7021
i2 .j1	666	710	1143	341	120	698
i3 .j1	873	333	2023	1211	3746	2318
i3 .j3		3154				
i4 .j3	2550	2560	371	3452	3539	3507
i5 .j2	867	1041	3042	2241	1148	631
i6 .j3	1547	453	802	485	751	724
i7 .j4	233	2162	1616	2290	928	1520
i8 .j3	1504	2603	2453	395	709	1847
i9 .j2			1716			1752
i9 .j5	2064	1341		1984	1153	
i10.j5	1860	2207	1936	288	1020	2356
i11.j2	279	1591	357	1229	1995	855
i12.j10	3246	2682	537	2675	2476	1139
i13.j10	1530	2034	1542	195	857	2943
i14.j2	135	558	1113	1100	193	90
i15.j2	66	152	719	924	962	628

i16.j2	2013	1687	479	158	1285	1908
i22.j9	2212	1731	115	895	814	2187
	s25	s26	s27	s28	s29	s30
i1 .j1	8725	11000	1443	5939	7123	979
i1 .j3		2229				
i2 .j1	1166		239	104	1363	917
i2 .j2		140				
i3 .j1	1109		2818	3816	331	2004
i3 .j3	1256	3442				
i4 .j3	2585	2976	2895	1063	1158	1226
i5 .j2	1667	2083	1671	2447	712	3973
i6 .j3	995	662	1420	1018	592	892
i7 .j4	1304	2944	2072	2006	1536	646
i8 .j2		1718				
i8 .j3	523		2358	2141	2044	405
i9 .j2			2056			885
i9 .j5	825	1986		673	1443	
i10.j5	1059	1617	1478	1785	1506	1241
i11.j2	2016	192	1133	2142	2235	1715
i12.j10	2439	2248	1526	735	3718	3322
i13.j10	470	1810	660	510	2255	2071
i14.j2	635	654	568	1430	793	815
i15.j2	446	211	610	590	972	981
i16.j2	1200	470	442	1627	1652	333

i22.j9	1115	1016	598	1352	664	2214
	s31	s32	s33	s34	s35	s36
i1 .j1	8667	11000	5480	9111	11000	6724
i1 .j3		1031			1916	
i2 .j1	328		1191	725		560
i2 .j2		607			1224	
i3 .j1	1943		2452	481		1381
i3 .j3		3008			2475	
i4 .j3	989	822	254	458	379	1438
i5 .j2	4816	4935	2585	1758	789	4354
i6 .j3	652	127	1395	1380	1256	467
i7 .j4	1018	292	3553	1175	2747	1613
i8 .j3	2604	2678	374	2416	1078	2062
i9 .j2			408			1147
i9 .j5	804	431		2470	2777	
i10.j5	697	1856	877	984	1140	562
i11.j2	921	806	2203	725	1700	1361
i12.j10	611	1303	2250	2331	870	2071
i13.j10	2388	272	2486	386	2779	1165
i14.j2	382	471	619	144	1180	1366
i15.j2	164	851	377	623	714	963
i16.j2	1980	356	668	1813	1589	1765
i22.j9	667	1831	1966	897	550	1608
	s37	s38	s39	s40		

i1 .j1	7826	5007	874	7716		
i2 .j1	673	876	804	479		
i3 .j1	2501	597	3676	1241		
i3 .j3	583					
i4 .j3	2497	3400	1467	782		
i5 .j2	4140	4556	297	2915		
i6 .j3	1132	1486	1398	839		
i7 .j4	323	2363	564	3037		
i8 .j3	544	2634	901	2964		
i9 .j2			1138			
i9 .j5	1428	1356		703		
i10.j5	647	1553	214	2570		
i11.j2	1710	1872	2161	1028		
i12.j10	1334	2732	773	3390		
i13.j10	2638	418	1360	1738		
i14.j2	356	307	150	1239		
i15.j2	423	507	618	310		
i16.j2	1676	380	1218	201		
i22.j9	1700	688	321	812		
Product (P2)						
	s1	s2	s3	s4	s5	s6
i1 .j1	13220	9245	5036	17647	13913	17619
i2 .j1	1837	877	1396	2028	1737	1011

i3 .j1	2559	3960	6157	325	3826	1370
i3 .j3				4482		2778
i4 .j3	3165	5291	5784	385	2287	3838
i5 .j2	5805	1853	8769	1326	2906	5839
i6 .j3	304	978	266	2361	187	1761
i7 .j4	5852	1351	4072	4043	3366	1942
i8 .j3	584	416	570	1463	2611	365
i9 .j2			4110			2845
i9 .j5	2549	1600		970	2716	195
i10.j5	3395	1183	4049	1025	4880	4096
i11.j2	3153	1074	443	3977	3247	2349
i12.j10	5022	4545	3930	2141	972	454
i13.j10	4736	3409	2331	1960	3756	1559
i14.j2	2043	1620	1475	2425	519	2564
i15.j2	1657	941	412	1381	1485	159
i16.j2	584	416	570	1463	2611	365
i17.j2	1636	2316	1475	983	2833	3530
i18.j10	4824	1874	5423	5487	7303	8964
i19.j10	790	627	1492	2400	451	1842
i20.j9	5022	4545	3930	2141	972	454
i21.j2	3153	1074	443	3977	3247	2349
i22.j9	3153	1074	443	3977	3247	2349
	s7	s8	s9	s10	s11	s12
i1 .j1	19482	14882	3630	15974	20000	18918

i1 .j3	947				1230	
i2 .j1	518	1927	1316	204		1082
i2 .j2					1398	1291
i3 .j1		3191	1550	3822		
i3 .j3	5103	2715		1168	4381	4025
i4 .j3	697	2734	1879	5499	5854	1647
i5 .j2	8388	2691	3890	4415	1434	1548
i6 .j3	1762	1379	302	2179	2251	1790
i7 .j4	4096	4736	4728	4392	5284	2578
i8 .j3	3318	3587	1958	923	1733	549
i9 .j2			2358			1745
i9 .j5	1382	893	1661	374	3778	
i10.j5	4248	4452	2085	1913	1571	4918
i11.j2	782	1000	3663	2309	721	749
i11.j10	1368					
i12.j10	3711	1186	6358	4934	3195	5442
i13.j10	5061	3285	1487	4417	1254	3639
i14.j2	1189	1582	1718	2051	2612	1659
i15.j2		1572	361	1352	594	1707
i15.j3	98					
i16.j2	3318	3587	1958	923	1733	549
i17.j2	4173	3926	2389	3255	880	1497
i18.j10	5157	3924	618	8342	2149	3550
i19.j10	933	635	1320	710	2251	412

i20.j9	3711	1186	6358	4934	3195	5442
i21.j2	2150	1000	3663	2309	721	749
i22.j9	2150	1000	3663	2309	721	749
	s13	s14	s15	s16	s17	s18
i1 .j1	15217	13269	13955	3117	3916	15138
i2 .j1	2165	1249	2424	1680	976	2584
i3 .j1	2618	4782	557	1223	2508	2278
i3 .j3	1511					1215
i4 .j3	3593	3474	731	2837	4171	2382
i5 .j2	3067	7382	7016	3938	4941	7688
i6 .j3	1770	255	148	586	2228	1447
i7 .j4	6810	2338	1550	6871	5198	5045
i8 .j3	3239	3556	4550	3467	1830	1926
i9 .j2						19
i9 .j5	2401	852	3997	2835	2728	3238
i10.j5	4800	3327	3872	4306	637	2479
i11.j2	3681	498	2284	2965	795	3804
i12.j10	3872	6018	4868	5324	4648	4756
i13.j10	5341	2195	5438	2235	2781	581
i14.j2	2541	597	772	321	1958	779
i15.j1			161			
i15.j2	468	180	921	1179	506	1541
i15.j3	576					
i16.j2	3239	3556	4550	3467	1830	1926

i17.j2	3323	5079	2173	324	875	439
i18.j10	1484	1730	4738	9167	8190	2197
i19.j10	1092	2651	1294	801	620	1782
i20.j9	3872	6018	4868	5324	4648	4756
i21.j2	3681	498	2284	2965	795	3804
i22.j9	3681	498	2284	2965	795	3804
	s19	s20	s21	s22	s23	s24
i1 .j1	18010	19702	17085	20000	6992	13972
i1 .j3		469		3612		
i2 .j1	517	298	1173		444	143
i2 .j2		1750		1218		
i3 .j1	1473		1691		3243	5631
i3 .j3	300	5006		1072		
i4 .j3	1054	4922	1981	3012	841	5927
i5 .j2	7154	3493	3420	3209	1906	2283
i6 .j3	2362	1448	473	928	1954	978
i7 .j4	4316	6731	4369	3785	4421	5367
i8 .j3	2929	3121	983	2833	3530	4173
i9 .j2			2789			3059
i9 .j5	4556	4007		579	2691	1675
i10.j5	1127	4087	3240	4213	4335	2950
i11.j2	2710	3222	662	645	835	2981
i12.j10	4539	4849	883	5924	1920	6194
i13.j10	1369	398	3735	1074	3707	1690

i14.j2	1092	2323	1983	1372	1954	953
i15.j2	332	641	1063	623	1516	204
i15.j3	632					
i16.j2	2929	3121	4131	4799	474	4457
i17.j2	3073	2228	2323	5210	4026	3082
i18.j10	964	3249	3879	6995	5480	8299
i19.j10	232	486	1113	1313	1277	638
i20.j9	4539	4849	883	5924	1920	6194
i21.j2	2710	3222	662	645	835	2981
i22.j9	2710	3222	662	645	835	2981
	s25	s26	s27	s28	s29	s30
i1 .j1	15434	1872	14561	19847	4004	12272
i1 .j3				3151		
i2 .j1	431	460	2056	153	151	1210
i3 .j1	4135	6100	3383		3956	6518
i3 .j3	2740		1526	525		326
i4 .j3	5422	1055	390	5654	4436	6135
i5 .j2	2203	5111	7192	8102	3604	1942
i6 .j3	2814	2883	500	302	218	518
i7 .j4	4152	1648	712	5615	1883	3388
i8 .j3	3926	2389	3255	880	1497	3323
i9 .j2						1170
i9 .j3						#######
i9 .j5	3470	426	2101	856	3669	1441

i10.j5	2525	4310	3197	1136	1922	2776
i11.j2	2671	2963	862		1654	2249
i11.j10			1672	3100		
i12.j10	2653	2518	428	1775	2969	1086
i13.j10	1569	1675	4970	1685	632	3057
i14.j2	1533	2397	2498	653	441	1735
i15.j2	1079	1657			680	372
i15.j3			362	715		
i16.j2	4333	2738	4016	4341	282	5328
i17.j2	4124	2149	2898	5237	2181	4955
i18.j10	8305	4561	635	4518	8508	8316
i19.j10	1948	2434	1661	561	1083	1120
i20.j9	2653	2518	428	1775	2969	1086
i21.j2	2671	2963	2534	1667	1654	2249
i21.j10				1433		
i22.j9	2671	2963	2534	3100	1654	2249
	s31	s32	s33	s34	s35	s36
i1 .j1	16623	10422	20000	2943	10583	13094
i1 .j3			2478			
i2 .j1	2414	2764		2634	2086	2298
i2 .j2			1133			
i3 .j1	963	1100		4069	991	4254
i3 .j3	1004		4833			
i4 .j3	3843	4817	2941	5050	5140	1937

i5 .j2	1461	830	2576	3212	4914	2505
i6 .j3	1107	968	2550	2883	2571	724
i7 .j4	2815	3697	6305	5394	3492	6465
i8 .j3	5079	2173	324	875	439	3073
i9 .j2			2774			658
i9 .j5	1691	271		265	839	
i10.j5	4867	2339	2414	3425	784	4143
i11.j2	2984	2355	629	1278	3490	1276
i12.j10	2659	5182	5925	3683	2137	4204
i13.j10	4453	4147	3589	1055	1927	1019
i14.j2	2327	1071	927	1537	1596	1273
i15.j2	842	508	1459	1508	1193	829
i16.j2	2191	1710	4940	5169	2503	976
i17.j2	3130	4187	2708	866	1037	5186
i18.j10	8871	5314	7136	3951	6951	3206
i19.j10	2177	2442	604	314	1897	175
i20.j9	2659	5182	5925	3683	2137	4204
i21.j2	2984	2355	629	1278	3490	1276
i22.j9	2984	2355	629	1278	3490	1276
	s37	s38	s39	s40		
i1 .j1	4909	18906	3228	1805		
i1 .j3		2700				
i2 .j1	688	1094	344	2788		
i3 .j1	5129		2872	3505		

i3 .j3		5632				
i4 .j3	718	1738	1197	2793		
i5 .j2	6637	5296	3090	7498		
i6 .j3	1787	1599	314	1522		
i7 .j4	845	6191	2011	1254		
i8 .j3	2228	2323	5210	4026		
i9 .j2			4142			
i9 .j5	4422	2172		3866		
i10.j5	3983	3826	929	1047		
i11.j2	1998	918	2276	1508		
i11.j10		766		830		
i12.j10	5330	4943	2952	3519		
i13.j10	617	4301	1912	3389		
i14.j2	1006	2550	1147	1713		
i15.j1				500		
i15.j2	1241		141			
i15.j3		614				
i16.j2	2221	4314	2742	4011		
i17.j2	4873	5238	888	2932		
i18.j10	3710	1864	8909	2783		
i19.j10	678	2380	1994	1284		
i20.j9	5330	4943	2952	3519		
i21.j2	1998	1684	2276	2338		
i22.j9	1998	1684	2276	2338		

Product (P3)						
	s1	s2	s3	s4	s5	s6
i1 .j1	9290	7955	5210	2489	10872	11000
i1 .j3						1074
i2 .j1	909	1254	449	1540	128	
i2 .j2					550	1180
i3 .j1	801	987	3884	1933		
i3 .j3	2927				2987	2866
i4 .j3	3652	1669	2117	3378	2506	3273
i5 .j2	2807	4898	4213	4964	3822	1856
i6 .j3	1452	952	1523	1104	121	257
i7 .j4	3007	1023	1304	1059	2891	990
i8 .j3	2873	948	2692	2179	845	338
i9 .j2			1646			1559
i9 .j5	918	1496	940	1800	1568	
i10.j5	1993	2798	290	1909	2653	1859
i11.j2	1094	2202	1623	2067	1460	1532
i12.j10	3028	438	1470	1615	1506	608
i13.j10	1996	503	911	2329	2906	1316
i14.j2	207	1060	1180	929	1141	1440
i15.j1		741				
i15.j2	222	119	464	960	729	324
i16.j2	2337	2721	1874	856	2887	356

i22.j9	1199	1481	154	1234	2014	1375
	s7	s8	s9	s10	s11	s12
i1 .j1	7390	11000	11000	11000	3465	11000
i1 .j3		1665	1829	1503		2347
i2 .j1	655				1303	
i2 .j2		1120	544	839		116
i3 .j1	1802				2051	
i3 .j3		1160	1621	255		455
i4 .j3	2621	929	191	298	2365	1887
i5 .j2	3609	722	676	3631	629	4557
i6 .j3	1522	958	776	499	1443	136
i7 .j4	1974	1549	2968	1033	3573	3551
i8 .j2			214			1807
i8 .j3	1393	2430	1615	1030	601	624
i9 .j2			455			1156
i9 .j5	942	2350		1824	1701	
i10.j5	1049	368	1936	1835	509	1265
i11.j2	2112	745	1701	811	568	193
i12.j10	1329	870	2009	2843	3740	3439
i13.j10	1930	2694	3080	1346	2421	2883
i14.j2	517	1142	1433	378	1265	184
i15.j2	563	563	393	974	208	629
i16.j2	1512	227	2027	944	1294	1715
i22.j9	1113	721	1305	1221	1986	1026

	s13	s14	s15	s16	s17	s18
i1 .j1	7227	11000	7889	7194	11000	4726
i1 .j3		1970			2393	
i2 .j1	1351		1342	1139		1376
i2 .j2		804			616	
i3 .j1	762		1645	2667		1810
i3 .j3		1750		385	569	
i4 .j3	751	1147	3686	3144	1614	588
i5 .j2	3832	4460	2670	3282	4488	3757
i6 .j3	1340	825	1430	366	998	221
i7 .j4	3139	3059	386	2450	1566	3781
i8 .j3	651	630	2646	2785	2689	808
i9 .j2			842			2032
i9 .j5	423	804		1625	435	
i10.j5	2434	2243	1212	384	907	914
i11.j2	301	1370	1648	1972	1204	694
i12.j10	3540	2890	2552	2587	1010	3598
i13.j10	1441	2087	457	1898	2124	2415
i14.j2	518	160	187	1047	746	1280
i15.j2	932	192	244	879	783	291
i16.j2	1673	1050	1149	1915	423	938
i22.j9	1318	956	1323	1592	984	1303
	s19	s20	s21	s22	s23	s24
i1 .j1	8615	9957	3868	5889	2247	7021

i2 .j1	666	710	1143	341	120	698
i3 .j1	873	333	2023	1211	3746	2318
i3 .j3		3154				
i4 .j3	2550	2560	371	3452	3539	3507
i5 .j2	867	1041	3042	2241	1148	631
i6 .j3	1547	453	802	485	751	724
i7 .j4	233	2162	1616	2290	928	1520
i8 .j3	1504	2603	2453	395	709	1847
i9 .j2			1716			1752
i9 .j5	2064	1341		1984	1153	
i10.j5	1860	2207	1936	288	1020	2356
i11.j2	279	1591	357	1229	1995	855
i12.j10	3246	2682	537	2675	2476	1139
i13.j10	1530	2034	1542	195	857	2943
i14.j2	135	558	1113	1100	193	90
i15.j2	66	152	719	924	962	628
i16.j2	2013	1687	479	158	1285	1908
i22.j9	2212	1731	115	895	814	2187
	s25	s26	s27	s28	s29	s30
i1 .j1	8725	11000	1443	5939	7123	979
i1 .j3		2229				
i2 .j1	1166		239	104	1363	917
i2 .j2		140				
i3 .j1	1109		2818	3816	331	2004

i3 .j3	1256	3442				
i4 .j3	2585	2976	2895	1063	1158	1226
i5 .j2	1667	2083	1671	2447	712	3973
i6 .j3	995	662	1420	1018	592	892
i7 .j4	1304	2944	2072	2006	1536	646
i8 .j2		1718				
i8 .j3	523		2358	2141	2044	405
i9 .j2			2056			885
i9 .j5	825	1986		673	1443	
i10.j5	1059	1617	1478	1785	1506	1241
i11.j2	2016	192	1133	2142	2235	1715
i12.j10	2439	2248	1526	735	3718	3322
i13.j10	470	1810	660	510	2255	2071
i14.j2	635	654	568	1430	793	815
i15.j2	446	211	610	590	972	981
i16.j2	1200	470	442	1627	1652	333
i22.j9	1115	1016	598	1352	664	2214
	s31	s32	s33	s34	s35	s36
i1 .j1	8667	11000	5480	9111	11000	6724
i1 .j3		1031			1916	
i2 .j1	328		1191	725		560
i2 .j2		607			1224	
i3 .j1	1943		2452	481		1381
i3 .j3		3008			2475	

i4 .j3	989	822	254	458	379	1438
i5 .j2	4816	4935	2585	1758	789	4354
i6 .j3	652	127	1395	1380	1256	467
i7 .j4	1018	292	3553	1175	2747	1613
i8 .j3	2604	2678	374	2416	1078	2062
i9 .j2			408			1147
i9 .j5	804	431		2470	2777	
i10.j5	697	1856	877	984	1140	562
i11.j2	921	806	2203	725	1700	1361
i12.j10	611	1303	2250	2331	870	2071
i13.j10	2388	272	2486	386	2779	1165
i14.j2	382	471	619	144	1180	1366
i15.j2	164	851	377	623	714	963
i16.j2	1980	356	668	1813	1589	1765
i22.j9	667	1831	1966	897	550	1608
	s37	s38	s39	s40		
i1 .j1	7826	5007	874	7716		
i2 .j1	673	876	804	479		
i3 .j1	2501	597	3676	1241		
i3 .j3	583					
i4 .j3	2497	3400	1467	782		
i5 .j2	4140	4556	297	2915		
i6 .j3	1132	1486	1398	839		
i7 .j4	323	2363	564	3037		

i8 .j3	544	2634	901	2964		
i9 .j2			1138			
i9 .j5	1428	1356		703		
i10.j5	647	1553	214	2570		
i11.j2	1710	1872	2161	1028		
i12.j10	1334	2732	773	3390		
i13.j10	2638	418	1360	1738		
i14.j2	356	307	150	1239		
i15.j2	423	507	618	310		
i16.j2	1676	380	1218	201		
i22.j9	1700	688	321	812		
The quantity of product p transport from collection \inspection zone (j) to recovery center (k) by using (FTL) transportation mode in scenario (S).						
Product P(1)						
	s1	s2	s3	s4	s5	s6
j1 .k3	4029.2	5272	7962.3	8267	9600	5222.7
j2 .k2	8400	8894.4	10800	7592.2	6210.4	5662.8
j3 .k3	2469.6	5191.2	5075.1	3331.3	3357.6	2804.4
j4 .k3	1066.8	2171.2	858.6	2145.5	807.2	3694.5
j5 .k2	859.6	4275.2	3632.4	3103.8	4264	1266.3
j9 .k4	4144.7	1866.4	4138.2	1320.9	2855.2	3564.9
j10.k4	7322	5152	10800	5750.5	3294.4	8307
	s7	s8	s9	s10	s11	s12
j1 .k3	2814	9600	7389.9	3663.1	3880.8	5130
j2 .k2	4874.8	9600	9921.6	8400	8777.6	10800
j3 .k3	4685.1	4589.6	4310.1	1725.5	4219.2	5220.9
j4 .k3	2343.6	1168	921.6	2863.7	1812.8	958.5
j5 .k2	3297	1483.2	1717.2	1482.6	3772.8	3155.4
j9 .k4	1194.9	3699.2	3446.1	2482.2	1863.2	5718.6
j10.k4	5889.1	5746.4	9810	4290.3	5236	8391.6
	s13	s14	s15	s16	s17	s18
j1 .k3	8400	8693.6	10800	8400	9600	5148
j2 .k2	4395.3	5072.8	10800	7593.6	9600	9999

j3 .k3	3160.5	2788.8	3789.9	6944	4775.2	2779.2
j4 .k3	2357.6	934.4	2393.1	2846.9	1156.8	3321.9
j5 .k2	830.2	1996.8	675.9	2126.6	926.4	579.6
j9 .k4	2864.4	3812.8	1358.1	1962.8	4297.6	2040.3
j10.k4	5707.8	7384.8	6776.1	3753.4	8307.2	9707.4

APPENDIX-B

THE RESULTS OF STOCHASTIC MODEL

The quantity of product p transport from collection \inspection zone (j) to disposalcenter (l) by using (FTL) transportation mode in scenario (S).						
Product P(1)						
	s1	*s2*	*s3*	*s4*	*s5*	*s6*
j1 .l2	1726.8	1318	884.7	3543	2400	580.3
j2 .l1	3600	2223.6	1200	3253.8	1552.6	629.2
j3 .l2	1058.4	1297.8	563.9	1427.7	839.4	311.6
j4 .l3	457.2	542.8	95.4	919.5	201.8	410.5
j5 .l3	368.4	1068.8	403.6	1330.2	1066	140.7
j9 .l4	1776.3	466.6	459.8	566.1	713.8	396.1
j10.l4	3138	1288	1200	2464.5	823.6	923
	s7	s8	s9	s10	s11	s12
j1 .l2	1206	2400	821.1	1569.9	970.2	570
j2 .l1	2089.2	2400	1102.4	3600	2194.4	1200
j3 .l2	2007.9	1147.4	478.9	739.5	1054.8	580.1
j4 .l3	1004.4	292	102.4	1227.3	453.2	106.5
j5 .l3	1413	370.8	190.8	635.4	943.2	350.6
j9 .l4	512.1	924.8	382.9	1063.8	465.8	635.4
j10.l4	2523.9	1436.6	1090	1838.7	1309	932.4
	s13	s14	s15	s16	s17	s18
j1 .l2	3600	2173.4	1200	3600	2400	572
j2 .l1	1883.7	1268.2	1200	3254.4	2400	1111
j3 .l2	1354.5	697.2	421.1	2976	1193.8	308.8
j4 .l3	1010.4	233.6	265.9	1220.1	289.2	369.1
j5 .l3	355.8	499.2	75.1	911.4	231.6	64.4
j9 .l4	1227.6	953.2	150.9	841.2	1074.4	226.7
j10.l4	2446.2	1846.2	752.9	1608.6	2076.8	1078.6
	s19	s20	s21	s22	s23	s24
j1 .l2	3600	1537.2	404.6	1336.5	1139.6	484.9
j2 .l1	3600	2254	1018	3021.3	2400	729.1
j3 .l2	3352.8	739.4	268.2	1893.3	533.8	138.3
j4 .l3	448.8	844.6	79.4	874.8	228.6	374.4
j5 .l3	450.6	446.8	206.5	378	430.4	45.1

j9 .l4	810.9	539.8	452.9	785.7	984.6	116.8
j10.l4	1018.8	1977.6	1084.2	2704.2	1638.6	253.1
	s25	s26	s27	s28	s29	s30
j1 .l2	1744.8	2380.2	424.3	3600	1726.2	537.3
j2 .l1	3600	2399	1200	2270.7	2319.2	1200
j3 .l2	738.3	611	271.4	1545.3	1419.2	290.3
j4 .l3	300.9	688.6	113.1	248.1	430.2	323.2
j5 .l3	658.2	1090	448.5	1261.8	1122	343.5
j9 .l4	860.7	506.6	507.8	1128.3	337.2	427.8
j10.l4	1871.7	1320.2	726.7	2723.7	1509.6	1194.4
	s31	s32	s33	s34	s35	s36
j1 .l2	1858.2	1691.6	1200	2032.5	1032.4	857.7
j2 .l1	2186.1	2134.4	1138	2073.3	1564	1200
j3 .l2	1525.8	780.2	625.8	1091.1	668.2	702.9
j4 .l3	278.1	68.4	254.5	717	154.6	123.5
j5 .l3	209.4	882.4	63.7	1134.6	484.4	161.8
j9 .l4	504.3	697.4	430	826.5	757.2	478.7
j10.l4	2740.8	1626	741.9	2379.3	1632	529.5
	s37	s38	s39	s40		
j1 .l2	3600	1104.6	1200	3600		
j2 .l1	2688	1645.4	1200	3216.9		
j3 .l2	1783.5	778.4	862.5	2160.6		
j4 .l3	397.5	370	387.2	695.7		
j5 .l3	805.2	743.6	340	1276.2		
j9 .l4	1721.1	1069.6	357.3	716.7		
j10.l4	3600	1607.8	897	1082.7		
Product (P2)						
	s1	s2	s3	s4	s5	s6
j1 .l2	3523.2	2816.4	1258.9	6000	3895.2	2000
j2 .l1	3606.2	1858.8	1769.7	4659.6	3369.6	2000
j3 .l2	810.6	1337	662	2607.3	1017	874.2
j4 .l3	1170.4	270.2	407.2	1212.9	673.2	194.2
j5 .l3	1188.8	556.6	404.9	598.5	1519.2	429.1
j9 .l4	1635	1123.8	437.3	1835.4	843.8	280.3
j10.l4	3074.4	2091	1317.6	3596.4	2496.4	1281.9
	s7	s8	s9	s10	s11	s12
j1 .l2	6000	4000	649.6	6000	4000	2000

j2 .l1	6000	3071.6	2000	4984.2	2018.6	1149.4
j3 .l2	3577.5	2083	413.9	2930.7	3089.8	801.1
j4 .l3	1228.8	947.2	472.8	1317.6	1056.8	257.8
j5 .l3	1689	1069	374.6	686.1	1069.8	491.8
j9 .l4	1758.3	437.2	1002.1	2172.9	783.2	619.1
j10.l4	4869	1806	978.3	5520.9	1769.8	1304.3
	s13	s14	s15	s16	s17	s18
j1 .l2	6000	3860	1709.7	1806	1480	2000
j2 .l1	6000	3558	2000	4547.7	2340	2000
j3 .l2	3206.7	1457	542.9	2067	1645.8	697
j4 .l3	2043	467.6	155	2061.3	1039.6	504.5
j5 .l3	2160.3	835.8	786.9	2142.3	673	571.7
j9 .l4	2265.9	1303.2	715.2	2486.7	1088.6	856
j10.l4	3536.7	2518.8	1633.8	5258.1	3247.8	931.6
	s19	s20	s21	s22	s23	s24
j1 .l2	6000	4000	1994.9	6000	2135.8	1974.6
j2 .l1	6000	4000	1703.3	5316.3	2309.2	2000
j3 .l2	2183.1	2993.2	343.7	3437.1	1265	1107.8
j4 .l3	1294.8	1346.2	436.9	1135.5	884.2	536.7
j5 .l3	1704.9	1618.8	324	1437.6	1405.2	462.5
j9 .l4	2174.7	1614.2	154.5	1970.7	551	917.5
j10.l4	2131.2	1796.4	961	4591.8	2476.8	1682.1
	s25	s26	s27	s28	s29	s30
j1 .l2	6000	1686.4	2000	6000	1622.2	2000
j2 .l1	5584.2	3995.6	2000	6000	2099.2	2000
j3 .l2	4470.6	1265.4	603.3	3368.1	1230.2	1030.2
j4 .l3	1245.6	329.6	71.2	1684.5	376.6	338.8
j5 .l3	1798.5	947.2	529.8	597.6	1118.2	421.7
j9 .l4	1597.2	1096.2	296.2	1462.5	924.6	333.5
j10.l4	4342.5	2237.6	936.6	3921.6	2638.4	1357.9
	s31	s32	s33	s34	s35	s36
j1 .l2	6000	2857.2	2000	2893.8	2732	1964.6
j2 .l1	4775.7	2603.2	1777.5	4454.4	3644.6	1397.9
j3 .l2	3309.9	1591.6	1312.6	2642.4	1630	573.4
j4 .l3	844.5	739.4	630.5	1618.2	698.4	646.5
j5 .l3	1967.4	522	241.4	1107	324.6	414.3
j9 .l4	1692.9	1507.4	655.4	1488.3	1125.4	548
j10.l4	5448	3417	1725.4	2700.9	2582.4	860.4

	s37	s38	s39	s40		
j1 .l2	3217.8	4000	644.4	2579.4		
j2 .l1	5992.2	4000	1670.2	6000		
j3 .l2	1419.9	2921.2	672.1	2502.3		
j4 .l3	253.5	1238.2	201.1	376.2		
j5 .l3	2521.5	1199.6	92.9	1473.9		
j9 .l4	2198.4	1325.4	522.8	1757.1		
j10.l4	3100.5	2850.8	1576.7	3541.5		
Product P(3)						
	s1	s2	s3	s4	s5	s6
j1 .l2	3300	2187.4	954.3	1788.6	2200	1100
j2 .l1	2000.1	2200	1100	2932.8	2117.8	824.7
j3 .l2	3271.2	713.8	633.2	1998.3	1291.8	780.8
j4 .l3	902.1	204.6	130.4	317.7	578.2	99
j5 .l3	873.3	858.8	123	1112.7	844.2	185.9
j9 .l4	359.7	296.2	15.4	370.2	402.8	137.5
j10.l4	1507.2	188.2	238.1	1183.2	882.4	192.4
	s7	s8	s9	s10	s11	s12
j1 .l2	2954.1	2200	1100	3300	1363.8	1100
j2 .l1	2493.9	903.8	744.3	2273.1	792.8	1035.7
j3 .l2	1660.8	1428.4	603.2	1075.5	881.8	544.9
j4 .l3	592.2	309.8	296.8	309.9	714.6	355.1
j5 .l3	597.3	543.6	193.6	1097.7	442	126.5
j9 .l4	333.9	144.2	130.5	366.3	397.2	102.6
j10.l4	977.7	712.8	508.9	1256.7	1232.2	632.2
	s13	s14	s15	s16	s17	s18
j1 .l2	2802	2200	1087.6	3300	2200	791.2
j2 .l1	2176.8	1607.2	674	2728.5	1652	899.2
j3 .l2	822.6	1264.4	776.2	2004	1652.6	161.7
j4 .l3	941.7	611.8	38.6	735	313.2	378.1
j5 .l3	857.1	609.4	121.2	602.7	268.4	91.4
j9 .l4	395.4	191.2	132.3	477.6	196.8	130.3
j10.l4	1494.3	995.4	300.9	1345.5	626.8	601.3
	s19	s20	s21	s22	s23	s24
j1 .l2	3046.2	2200	703.4	2232.3	1222.6	1003.7
j2 .l1	1008	1005.8	742.6	1695.6	1116.6	586.4
j3 .l2	1680.3	1754	362.6	1299.6	999.8	607.8

j4 .l3	69.9	432.4	161.6	687	185.6	152
j5 .l3	1177.2	709.6	193.6	681.6	434.6	235.6
j9 .l4	663.6	346.2	11.5	268.5	162.8	218.7
j10.l4	1432.8	943.2	207.9	861	666.6	408.2
	s25	s26	s27	s28	s29	s30
j1 .l2	3300	2200	450	2957.7	1763.4	390
j2 .l1	1789.2	1093.6	648	2470.8	1272.8	870.2
j3 .l2	1607.7	1861.8	667.3	1266.6	758.8	252.3
j4 .l3	391.2	588.8	207.2	601.8	307.2	64.6
j5 .l3	565.2	720.6	147.8	737.4	589.8	124.1
j9 .l4	334.5	203.2	59.8	405.6	132.8	221.4
j10.l4	872.7	811.6	218.6	373.5	1194.6	539.3
	s31	s32	s33	s34	s35	s36
j1 .l2	3281.4	2200	912.3	3095.1	2200	866.5
j2 .l1	2478.9	1605.2	686	1518.9	1439.2	1095.6
j3 .l2	1273.5	1533.2	202.3	1276.2	1420.8	396.7
j4 .l3	305.4	58.4	355.3	352.5	549.4	161.3
j5 .l3	450.3	457.4	87.7	1036.2	783.4	56.2
j9 .l4	200.1	366.2	196.6	269.1	110	160.8
j10.l4	899.7	315	473.6	815.1	729.8	323.6
	s37	s38	s39	s40		
j1 .l2	3300	1296	535.4	2830.8		
j2 .l1	2491.5	1524.4	558.2	1707.9		
j3 .l2	1426.8	1504	376.6	1375.5		
j4 .l3	96.9	472.6	56.4	911.1		
j5 .l3	622.5	581.8	21.4	981.9		
j9 .l4	510	137.6	32.1	243.6		
j10.l4	1191.6	630	213.3	1538.4		

Number of LTL with capacity of 16 to transport product p from customer zone I to collection\inspection center j in scernario s							
s1	9761	s2	7784	s3	8912	s4	9108
s5	9290	s6	8607	s7	9477	s8	8946
s9	8523	s10	9160	s11	8438	s12	9310
s13	9704	s14	9110	s15	9213	s16	9578
s17	8778	s18	8965	s19	9135	s20	10344
s21	7385	s22	8877	s23	7241	s24	8772
s25	9099	s26	8760	s27	7830	s28	9297
s29	7779	s30	8913	s31	8798	s32	8642
s33	9819	s34	7401	s35	8207	s36	8450
s37	8946	s38	9688	s39	7761	s40	8452

Number ofFTL with capacity of 40 to transport product p from collection\inspection center j to recovery center k in scernario s									
s1	1405	s2	890	s3	509	s4	1562	s5	1062
s6	492	s7	1625	s8	1022	s9	488	s10	1570
s11	964	s12	532	s13	1664	s14	1042	s15	526
s16	1642	s17	1003	s18	512	s19	1567	s20	1182
s21	422	s22	1522	s23	828	s24	502	s25	1560
s26	1001	s27	447	s28	1594	s29	890	s30	509
s31	1508	s32	988	s33	561	s34	1269	s35	938
s36	483	s37	1534	s38	1107	s39	444	s40	1449

Number of FTL with capacity of 28 to transport product p from collection\inspection center j to disposal center l in scernario s									
s1	2921	s2	2491	s3	3208	s4	2550	s5	2973
s6	3099	s7	2654	s8	2863	s9	3068	s10	2565
s11	2700	s12	3351	s13	2717	s14	2915	s15	3317
s16	2682	s17	2809	s18	3228	s19	2558	s20	3310
s21	2658	s22	2485	s23	2317	s24	3158	s25	2548
s26	2803	s27	2819	s28	2603	s29	2489	s30	3209
s31	2463	s32	2765	s33	3535	s34	2072	s35	2626
s36	3042	s37	2505	s38	3100	s39	2794	s40	2366

CURRICULUM VITAE

PERSONAL INFORMATION

Name Surname	: Mohammed F. N. Alamassi
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Foreign Languages	: Arabic, English, Turkish.
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EDUCATION

Degree	**Department**	**University**	**Date of Graduation**
Undergraduate	Industrial Engineer	Islamic University of Gaza	March, 2009
High School	Scientific Stream	Gifted Secondary School	July, 2004

WORK EXPERIENCE

Year	**Corporation/Institute**	**Enrollment**
2012-2013	effective world GmbH, Istanbul office	Business Development Director- Middle East
2009-2010	Palestinian Federation of Industries, Gaza office	Project Engineer