A DESIGN OF A REMANUFACTURING NETWORK SYSTEM FOR DIESEL PARTICULATE FILTER CONSIDERING ECONOMICAL AND ENVIRONMENTAL CRITERIA

(DİZEL PARTİKÜL FİLTRESİ ÜRÜNLERİNİN YENİDEN ÜRETİME KAZANDIRILMASI İÇİN EKONOMİK VE ÇEVRESEL ETMENLERİ DİKKATE ALAN BİR AĞ TASARIMI)

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ABSTRACT

In recent years, an increasing number of companies are taking into account reverse logistic to recover their products for a second usage (recycling, remanufacturing, reuse). This is due to changes in legislation for environmental protection and to economic reasons.

This study aims to design and develop a reverse logistic network system that contains remanufacturing processes for a heavy truck manufacturer. We will focus on the design of a reverse logistic system for trucks diesel particulate filter. The company distributes its diesel particulate filter (DPF) both for new trucks and as spare part all over Europe. Nowadays, diesel particulate filter is destroyed at the end of its life. However, the valuable components and material which are parts of DPF are not completely degraded to be destroyed and it will be worthwhile to exploit again.

For creating benefit from these valuable components, the company embraces two strategies: having a remanufacturing system and providing service for customer instead of the product itself. Indeed, in order to improve the performance of its remanufacturing process, the company needs to control the wearing of the used products that are being returned. For this purpose, they have to retain ownership of the DPF and to provide to its client the associated services. With this strategy, the company will be able to decide the time and the service point to return the used product.

To help the design of those strategies, remanufacturing scenario ensuring an optimal compromise between economical and environmental issues has to be defined. The study will begin by creating mathematical models from existing and available models of the Reverse Logistics Network in the literature. These models require the installation cost, the reprocessing cost, the transportation cost and return forecasting in order to determine optimal geographical locations of remanufacturing and collecting centers. Once the required data are obtained, the economical impacts will be compared according to the number and the localization of the collection and remanufacturing centers. Besides, environmental effects of reverse logistic activities will be observed. The decision should be obtained whereby considering the balance between the installation costs and environmental impacts.

RÉSUMÉ

Au cours des dernières années, le nombre d'entreprises qui prennent en compte la logistique inverse pour réutiliser récupérer leurs produits (recyclage, remise à neuf, réutilisation) a augmenté. Cela est dû, d'une part, aux changements dans la législation à propos de la protection de l'environnement et d'autre part, pour à des raisons économiques.

Ce rapport vise à concevoir un système de logistique inverse pour supporter l'activité de remanufacturing de composants pour un fabricant de poids lourds. Nous nous concentrerons sur la conception d'un système de logistique inverse pour les pots catalytiques de ces camions. La société distribue ses pots catalytiques à la fois pour les camions neufs et en tant que pièces de rechange dans toute l'Europe. De nos jours, le pot catalytique est détruit à la fin de sa durée de vie. Cependant, les composants précieux et les matières qui font partie du pot catalytique ne sont pas complètement dégradés et pourraient être réutilisés après avoir été remis en état.

Pour profiter de ces composants, la société voudrait adopter deux stratégies: avoir un système de remanufacturing et mettre le service associé au pot catalytique à ses clients plutôt que le produit lui-même. En effet, pour améliorer la performance de son processus de remanufacturing, l'entreprise a besoin de contrôler l'usure des produits usagés qui lui sont retournés. En restant propriétaire du Pot catalytique et en vendant à ses clients le service associé, la société peut mieux contrôler l'usure, des produits à remettre en état.

Pour aider à la conception de ces stratégies, ce travail propose de trouver la localisation des centres de remanufacturing qui minimise certains coûts économiques et impacts environnementaux. L'étude commence par la création un modèle mathématique à partir de modèles existants et disponibles dans la littérature sur la Logistique Inverse. L’implémentation de ce modèle a nécessité des données sur le coût d'installation, le coût de retraitement, le coût du transport et des informations sur les flux prévisionnels de retours. Ce travail propose l’étude de différents scenarios en fonction de la capacité des centres de remanufacturing.

La solution optimale obtenue se trouve à l’équilibre entre la totalité des couts et impacts environnementaux liés à l’ouverture du centre et ceux liés aux transports.

ÖZET

Son yıllarda şirketler, tersine lojistik (geri dönüşüm, yeniden üretim, yeniden kullanım) uygulamalarını kullanılmış ürünlerini yeniden kullanabilmek için dikkate alıyor. Bu tarz uygulamaların yaygınlaşması, çevre koruma için hazırlanan hukuksal değişiklikler ve ekonomik nedenlerden kaynaklanmaktadır.

Bu çalışma, bir ağır kamyon üreticisi için yeniden üretim süreçleri içeren, tersine lojistik ağ sistemi tasarımı ve geliştirmesini hedeflemektedir. Bu çalışma, kamyon dizel partikül filtresi için, ters lojistik sisteminin tasarımı üzerine odaklanacaktır. Şirket, tüm Avrupa'da hem yedek parça olarak hem de yeni kamyonlar için dizel partikül filtresi üretmektedir. Günümüzde, kullanılmış bir dizel partikül filtresi ömrünün sonunda imha edilir. Ancak, değerli bileşenleri olan bu ürün imha aşamasında tamamen değerini kaybetmiş değildir, yani üründen tekrar yararlanmak faydalı olacaktır.

Çalışmadaki model, literatürde “Tersine Lojistik Ağ Tasarımı“ için mevcut bulunan, uygun matematiksel modellerden yola çıkılarak ürüne özel olarak kurulacaktır. Bu modeller kurulum maliyeti, yeniden işleme maliyeti, taşıma maliyeti ve dönüş tahmin değerleri verilerinin hesaplanmasını gerektirir.

Modelin amacı yeniden üretim merkezleri için toplam maliyetleri en küçükleyecek, en iyi coğrafi konum ve kapasite seçimini gerçekleştirmektir. Ayrıca, tersine lojistik faaliyetlerinin çevresel etkileri karbondioksit salınımı kıstas alınarak da yer seçimi ve kapasite sonuçları olusturulacaktır. Kurulum maliyetleri ve çevresel etkileri dikkate alan optimal bir sonuç elde edilmesi amaçlanmıştır.

1. INTRODUCTION

1.1. Context

Supply chain (SC) can be defined traditionally as logistics systems that start at the supply of raw-materials and end with the sales of goods to final consumers (Barbosa-Povoa et al., 2007). The efficient management of supply chain is a major problem that has attracted attention in recent years. Thereby excessive energy and natural resource consumptions, carbon dioxide emissions cause to global warming, climate change and resource scarcity, the apprehension of environment protection come into prominence. Because of changes in legislation, both for environmental protection and for economic and social reasons, an increasing number of companies have been forced to consider environmental aspect in different levels of their supply chain activities. Then, companies must reorganize the design and operations in order to reduce their ecological footprint (Barbosa-Povoa et al., 2007). The solution is found and introduced into related literature with the name of “Reverse Logistics (RL)”. In the end of the nineties, Rogers & Tibben-Lembke (1998) describe RL as “*The process of planning, implementing, and controlling the efficient, cost-effective flow of row materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for purpose of recapturing value or proper disposal*”. In consideration of this definition, the ecological purpose of RL activities is to reduce the use of scarce resources and to recover the valuable parts of used products in the production. For this purpose, there are four steps for the used products: Firstly, they are collected, then they enter the combined of inspection & selection & sorting process. As the third step, they are re-processed or they are directly recovered and finally they are redistributed. At the end of all RL processes, the valuable parts are re-gained to the production. However, RL processes may not be as beneficial as we think. RL processes also require energy consumption even if they reduce the use of raw materials. On the other hand, the use of various chemicals that is required for reprocessing procedure is harmful to human health or to the environment. Another important invisible element of Reverse Logistics process is the product design stage. Remanufacturing operations need processes and these processes may sometimes require more energy consumption than the production of new product. Otherwise, transportation process has a significant role of carbon dioxide emissions extent because of the air pollution. In fact, all processes in RL involve both economic and environmental costs.

1.2. Objectives

This study aims to design and develop a Reverse Logistics network system that contains remanufacturing and repairing processes for a heavy truck manufacturer. We will focus on the design of a reverse logistic system for diesel particulate filter (DPF).

The objective of this study is to determine geographical locations of remanufacturing centers considering economical and environmental costs. The study will begin by creating mathematical models from existing and available models of the Reverse Logistics Network in the literature. These models require the installation cost, the reprocessing cost, the transportation cost and return forecasting in order to determine optimal geographical locations of remanufacturing and collecting centers. Once the required data are obtained, the economical impacts will be compared according to the number and the localization of the collection and remanufacturing centers. Besides, environmental effects of Reverse Logistic activities will be observed taking into consideration the carbon emission of RL process.

Briefly, this research proposes to:

- Show that Capacitated Facility Location Problem (CFLP) is suitable for choosing optimal location of remanufacturing centers
- Demonstrate that CFPL can be used with a cost function expressed from environmental impacts

- Help the decision making the design of the remanufacturing process

1.3. The Research Topic

This study aims to design and develop a model based on a flow model, for the construction of a Reverse Logistics network system that contains remanufacturing and repairing process for a heavy truck distributing DPF. For the implementation of this logistics model, we will consider two important focuses: economical and environmental impact.

The mathematical model should allow to answer to the following questions:

- How many remanufacturing center are required?
- Where should these be geographically located?
- What are theirs capacity?

The proposed mathematical model will execute with different probable capacities and the results of different scenarios will be examined to compare both economical and environmental impacts. The decision will be obtained by considering the balance between the economical costs and the carbon emissions.

1.4. The Originality of the Research

Unlike other network systems, RL has a number of risks and uncertainties. These are related to quality, quantity, timing and variety of returns. Decisions about product returns and cost of coordination along the reverse supply chain; estimation of operation and cost related parameters for reverse logistic networks are not predefined. Customer behavior and preferences are other important criteria. Obviously, RL supply chain activities are more complex than traditional manufacturing supply chains (Srivastava, 2007).

1.5. The Methodology of the Research

In order to handle with unknown quality of return product, the components' characteristics of used DPF will examine. The conditions of the end of life products' components are defined and fitted into the probability. The available data should be examined attentively. Conveniently inspection solutions, we will make a selection for which part can be repaired or recycled. Possible processes in the reverse distribution channel are collecting, testing, sorting, transportation and processing. One important issue is to determine suitable locations for these processes. Therefore, we will examine which place is more suitable to carry out these operations. In the selection of convenient place, the environmental impact is taken into consideration. If the required remanufacturing process is easy, it can be realized in the service point. In this manner, the transportation cost could be decreased. Otherwise, if the situation needs the usage of detrimental chemicals, the process should be placed far from the city center. After we clarify replacement of required process, we will make a decision for physical design of logistics network for product recovery activities having regard to minimize initialization and transportation cost.

The results obtained through the implementation of a proposed project will be described. For example, through the establishment of probable scenarios, the annual benefit created by the usage of reusable materials will be calculated. This amount could be compared with the annual investment costs and it can be presented to the company as an investment decision. With environmental point of view, if remanufacturing process contains harmful consequences to the environment and human health which are caused by the reprocessing operations, these effects need to be examined. In the event of results exceeding the legal requirements, cancellation of the project is foreseen. Otherwise, the decision should be obtained by considering the balance between the installation costs and environmental impacts. The aim of this study is to define a remanufacturing scenario ensuring an optimal compromise between economical and environmental issues.

The remainder of the paper is organized as follows: Section 2 focuses on related literature survey about RL. In Section 3, RL network design and the main characteristics of Capacitated Facility Location Problem are presented in detail and its general mathematical formulation is given. In the fourth section, we present case study. Case study is explained and proposed model is formulated as a CFLP. In fifth section, experimental results for different capacity scenarios are examined. This thesis ends with conclusions and possible directions for future.

2. LITERATURE SURVEY

2.1. Reverse Logistics

In the past, companies were used to reuse materials and products or partial equipment. The main objective was not the environmental matters or sustainable development. The primary concern was scarcity of resources. After the exploration of cheap materials and technological innovations, companies begun to mass consumption and routine throw away. In 1970s, the study for the Club of Rome stated that there is a limit to the growth. The report claimed that mankind was going to disintegrate around 2050 (Meadow, 1974). During the following decades, academicians, politicians and media addressed the disasters to such issues in general. Especially in Europe, since 1995, regulations forced companies for green products and materials in product. The interest of environmental aspects increased the importance of green line of product, and accordingly, customer perception changed, expecting companies to reduce the environmental burden of their products and activities. For that reason, number of companies started to explore recovery of their products and options for take-back (Brito & Dekker, 2002). Reverse Logistics is the underlying operational function necessary for extending the life of materials and products and product stewardship, two critical aspects of reducing environmental burden from industrial operations. As a principal option of recovery, remanufacturing provides not only means to companies to tackle the disposal of their used products, but can also reduce effectively the costs of production and save raw materials.

2.2. Historical Definitions of RL

RL appeared in the beginning of 1990’s simultaneously in Germany and in the USA. In the USA, it was pushed by environmental consciousness of consumers who wanted the recycling of packaging and product in the end of lives, while in Germany and Europe, RL emerged because of regulatory constraints. (Lamert & Riopel, 2003).

The concept of Reverse Logistics appeared in the earlier 90s with Giuntini and Andel (1995). They define it as "*The management of the organization of material resources obtained from customers*". Fleischmann et al. (1997) indicate that the reverse logistics "*contains the logistics, to the end, used for products that are no longer required by the users to the products that can be reused in the market"*. The definition focuses on distribution planning, inventory management and production planning.

In the end of the 90's, Rogers and Tibben-Lembke (1998) describe Reverse Logistic 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 purpose of recapturing value or proper disposal* "(Rogers & Tibben-Lembke, 1998).

2.3. Main Motivation of RL

The main motivations of Reverse Logistics can be examined into three headings economics, ecologic and legislation respectively. The economical drivers of reverse logistics regards profit from recovery actions because of reducing costs, decrement on the use of materials and saving valuable spare parts. The primary ecological driver is the scarcity of resources. Existing legislation that emerges after depletion of landfill and incineration capacities leads the producers to recover their products or to accept them-back. Another important driver for product recovery is the growing environmental concern among customers. Customers increasingly expect companies to reduce the environmental burden of their activities and products. Therefore, a "green" image has become an important marketing element. Variable customers understanding anticipate from producers keep on green line when their process (Fleischmann et al., 2001). Producers keep on green line with their process in order to satisfy expectation of costumers. In this aspect, the reasons of producers are obtaining a customer appreciation (Srivastava, 2008).

2.4. RL Processes

A reverse logistics system comprises a series of activities, which form a continuous process to treat return-products until they are properly recovered or disposed of (Thierry et al., 1993; Banlieu et al., 1999; Dekker& Van Der Laan, 1999). There are four main reverse logistic processes. First there is collection, next there is the combined inspection & selection & sorting process, thirdly there is re-processing or direct recovery and finally there is re-distribution (Brito & Dekker, 2002). Fleischmann et al. (2000) defined reverse logistics process as shown in **Fig.2.1**.

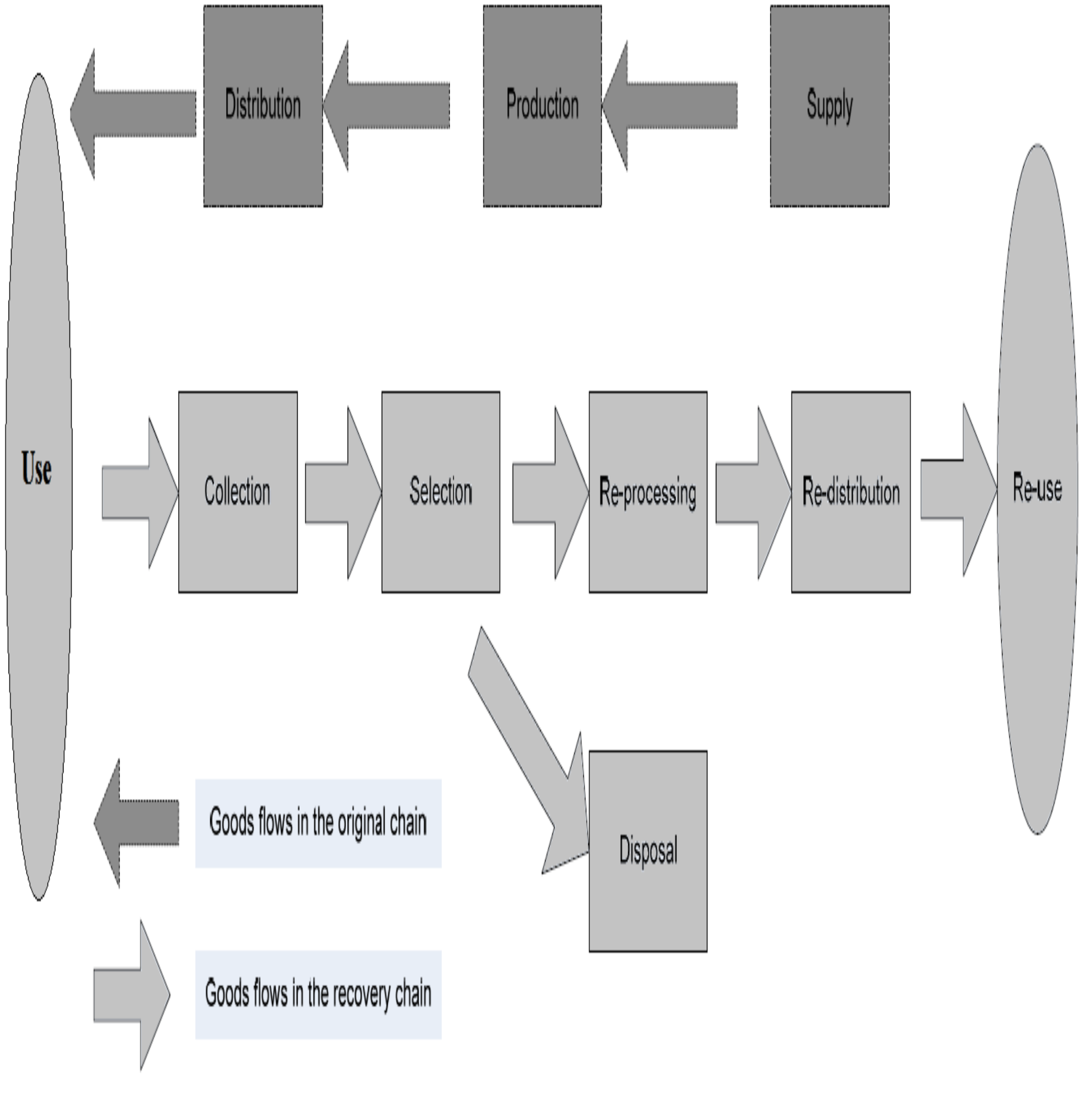

Figure 2.1 : Reverse Logistics Process (Fleischmann et al., 2000)

2.4.1 Collection

It refers to all activities gathering used products from end user. It may include purchasing, transportation and storage activities.

2.4.2 Inspection & Separation & Sorting

This denotes all operations determining whether a used product has really a condition appropriate to reuse or which components of product is valuable.

2.4.3 Re-processing

It means the transformation operations of a used product into a usable product (components) again. This transformation may take different forms according to various recovery operations. Re-processing may include repair, refurbishing, remanufacturing, retrieval, recycling operations.

2.4.4 Disposal

This is an option for rejected products in the inspection stage. It may result in excessive retreatment cost or product conditions. Disposal option may include transportation incineration or land filling steps.

2.4.5 Re-distribution

It means the physical movement of re-usable product to future user or to potential market. It may include transportation, storage and sales activities.

One important issue is to determine suitable locations for these processes. The early testing might save transportation of useless production. On the other hand sophisticated testing might involve expensive equipment which can only be afforded at a few locations. Product composition has most importing aspect for deciding which operation will be realized in future. In the product composition part, we will look at the ease of disassembly, homogeneity or multiple, presence of hazardous materials and ease of transportation. The product usage pattern affects the collection of the items and is related to the amount of deterioration that the product has experienced. Deterioration level changes in each case of product life cycle. This variation strongly effects the recovery operation.

2.5. RL Operations

Operations of reverse logistics can be divided into two main processes: direct recovery and re-processing (Brito & Dekker, 2002). Direct recovery embraces reuse, resale and redistribution. Re-processing includes the following options: repair, refurbishing, remanufacturing, retrieval, recycle and incineration (Brito & Dekker, 2002). Landrieu (2001) shows reverse logistics operations as in **Fig.2.2**.

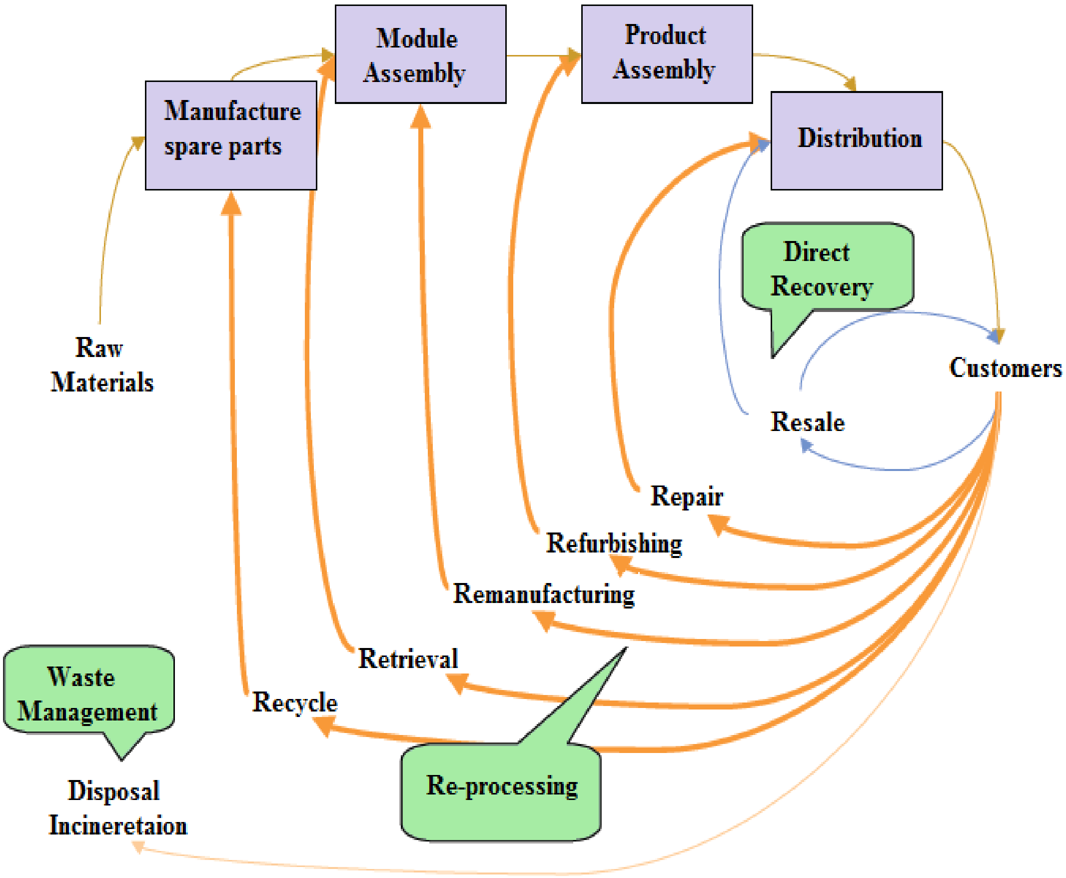

Figure 2.2 : Reverse Logistics Operations (Landrieu, 2001)

2.5.1 Direct Reuse

This implies items are reused without prior repair operations.

2.5.2 Refurbishment

It aims to restore products to working order, though possibly with a loss of functional quality.

2.5.3 Remanufacturing

This 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. There are different definitions for the term remanufacturing. The US Automotive Parts Rebuilders Association defines remanufacturing as the “process of restoring worn and discarded durable products to like-new condition” (APRA, 2007). Sundin and Bras (2005) define remanufacturing in their study as ‘‘the process of rebuilding a product, during which the product is cleaned, inspected and disassembled; defective components are replaced; and the product is reassembled, tested and inspected again to ensure it meets or exceeds newly manufactured product standards’’. Kerr and Ryan (2001) consider remanufacturing the most efficient way to maintain products in a closed loop. Through remanufacturing, products can be restored to a like-new condition, with the same quality and function as new products. Thus, remanufacturing of End of Life (EoL) products and components can reduce environmental and economic costs both in new product manufacturing as well as in the final disposal stage of products. During the remanufacturing process, the product is treated in several steps, which are carried out in order to guarantee the product meets new product standards. Overall, the remanufacturing process is divided into the following steps: disassembly, testing, repair, cleaning, parts inspection, updating, parts replacement and reassembly. Williams & Shu (2001) describe remanufacturing as the recycling of durable products at a component part level. The used product, or core, is disassembled, cleaned, repaired or refurbished, reassembled and tested to produce a like-new product. For obtaining clear understanding, Umeda et al. (2005) divided remanufacturing into three different scenarios:

Product remanufacturing – Used products are remanufactured to “as-new” or upgraded status; an example of this category is the remanufacturing and upgrading of Tetra Pak filling machines.

Component remanufacturing – Used components are remanufactured to “as-new” or upgraded status; an example of this category is the remanufacturing of automotive components (UBD case) and toner cartridges (Ostlin et al., 2009).

Component cannibalization – Used products are cannibalized for components, and the components are then remanufactured to an “as-new” or upgraded status. An example of this category is the cannibalization of components from heavy trucks and forklift trucks. In these cases, the component cannibalization option is mainly a supporting activity for the product and component remanufacturing scenarios (Ostlin et al., 2009).

2.5.4 Recycling

It denotes material recovery without conserving any product structure (Oh & Hwang, 2006). Recycling is a process focused specifically on material recovery. Recycling can be defined as the reprocessing of materials both from residues of manufacturing processes or waste in a new production cycle. Recycling requires disassembly and/or sorting of the products involved into homogeneous material fractions as a preprocessing operation (Duflou et al., 2008).

Fig.2.3 demonstrates the most known example of recycling.

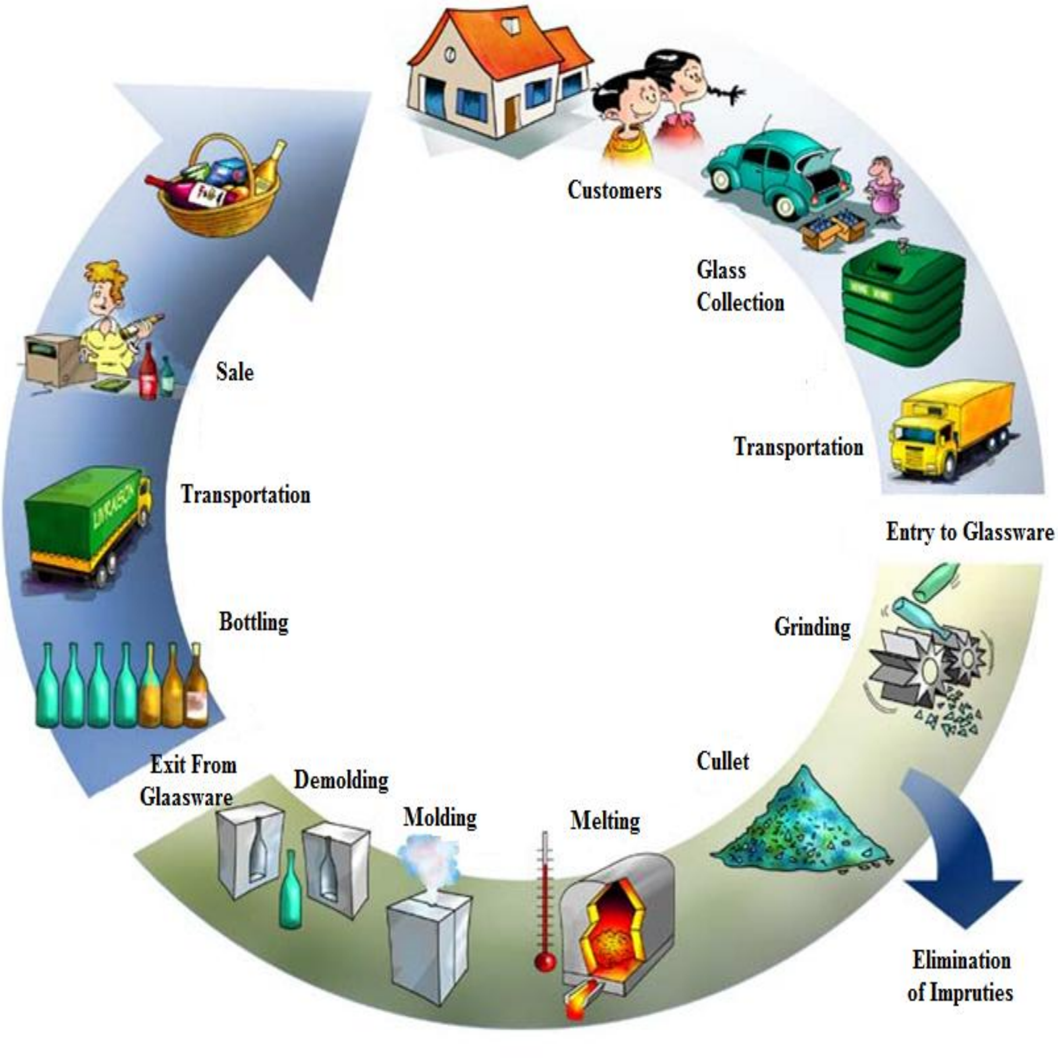

Figure 2.3 : Recycling and Life Cycle of Bottle

2.6. Main Differences with Other Logistics

We provided misunderstanding confusion meanings, and created clear understanding frameworks of reverse logistics. Now we will look at the differences from the other logistics system.

First of all, reverse logistics differ from traditional distribution networks. Primarily, the direction of the physical material and information flow is not necessarily a symmetric picture of traditional. It is not only the opposite of traditional logistics but it is part of a larger process that begins with product design and ends when it is fully upgraded or destroyed. Also the other specific characteristic of reverse distribution network is to contain high degree of uncertainty in timing, quality and quantity of used products returned by the consumers. In the network design part of reverse logistics, an additional cost component representing collection and return handling is added to transportation cost (Wu et al., 2006). Min et al. (2006) summarized difference between reverse and forward logistics as in **Table 2.1**.

Table 2.1 : Comparison between RL and Forward Logistics (Min et al., 2006)

	Reverse Logistics	**Forward Logistics**
Quantity	Small quantities	Large quantities of standardized items
Information Tracking	Combination of automated and manual information system used to track items	Automated information system 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	Push and pull	Pull
Channel	More complex	Less complex

Reverse Logistics differs from reverse distribution. The reverse distribution corresponds to the first terminology of Reverse Logistics. It is built by Lambert and Stock (1981) as "going in the wrong direction on a one-way street because the vast majority of the flow of shipments in one direction". Carter and Ellarm (1998) described reverse distribution as "the return movement against the current of a product or material arising from the reuse, recycling or disposal. This movement against the current may be associated with environmental problems, as the quality and wear (damage over time) and are often made by new auxiliary members in the system."

Reverse Logistics is different from Waste Management. The difference arises from the definition of waste. Waste Management is not that critically dependent on the quality of the collected goods. Waste network is interested collecting and processing products for which there is no new usage. Reverse Logistics collects the products that contain some valuable parts and the outcomes enter a new supply chain. Similar to other processes like testing and re-processing, the transportation is a major cost component. This is a reason for a decentralized network including depots close to customer locations (Brito & Dekker, 2002).

Finally, Reverse Logistics differs from Green Logistics. Regarding the term green logistics, Wu and Dunn (1995) mention that it is wider than the reverse logistics because green logistics seeks to conserve resources, eliminate waste and improve productivity. Hart (1997) adds that Green Logistics must have the smallest footprint on the environment. In 2001, Rodrigue et al. described green logistics as a distribution system and efficient transport and friend of the environment. Green logistics also considers environmental aspects, but it concentrates specifically on forward logistics. Reverse logistics can be seen as a part of sustainable development. The latter has been defined by Brundland as "to meet the needs of the present without compromising the ability of future generations to meet their own needs" (Brito & Dekker, 2002). In fact one could regard reverse logistics as the implementation at the company level by making sure that society uses and re-uses both efficiently and effectively all the value which has been put in products (Brito & Dekker, 2002).

Fig.2.4 summarizes the different definitions in literature. Note that the reverse logistics includes reverse distribution and the majority of green logistics. Portion of the green logistics is not included in the reverse logistics processes of product design.

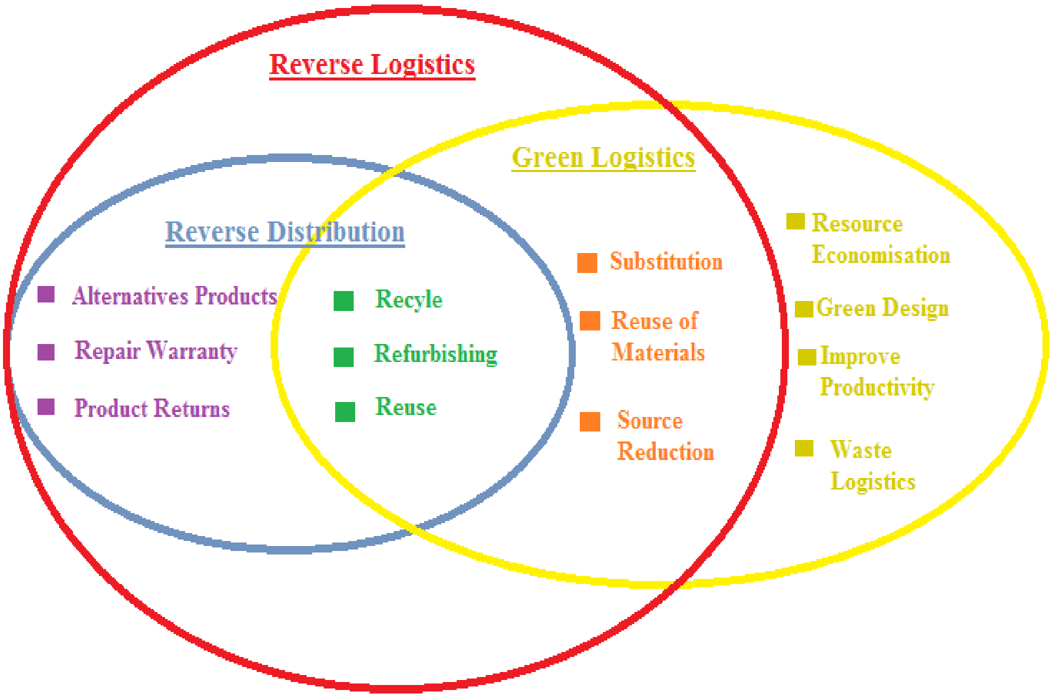

Figure 2.4 : Definition of Reverse Logistics (Lambert and Stock, 1981)

The decisions regarding reverse logistics are divided into three phases: strategic, tactic and operational. At the strategic level, befall decisions that are long-lasting also because they are hard to change. It encompasses recovery option strategy, product design, network design and strategic tools. Determining the number and location of recovery facilities is a central task in the network design problems described above. In almost all cases geo-graphical distribution and volume of both supply and demand are considered as exogenous variables. Sources and sinks are fixed while intermediary nodes are to be specified. Demand for recovered products and materials appear to be difficult to forecast (Brito & Dekker, 2002).

At the tactical level and internally one has to integrate product returns with the overall organization. It includes procurement& integrated management, reverse distribution, co-ordination, product planning, inventory management, marketing, information & technology. At the operational level, production scheduling & control related decisions as the disassembly and reassembly operations can be found. It contains production scheduling & control and information management (Brito & Dekker, 2002).

Over the past twenty years, considerable numbers of case studies were published related to the design of reverse logistics networks. In this study, especially quantitative model for network design will be on focused. Three aspects can be mentioned to justify reverse activities: economic aspects (Fargher, 1996), government legislative directives (Cairncross, 1992) and consumer expectation (European Union WEEE Directive, 2007) . Goal of those studies is to determine appropriate locations and capacities for required new centers taking into account investment, processing and transportation costs. Generally, in the literature on Reverse Logistics Network Design, case studies are product-oriented (Kuehn & Hamburger, 1963; Wu et al., 2006; Srivastava, 2008) or process oriented (Van Roy, 1986; Fleishmann et al. 2001; Min et al., 2006). This means each study is formed depend on the product or process specialties. The most frequent mathematical solution, that is admitted by scientists, is the Mixed Integer Linear Programming (MILP). Constructed mathematical model changes depending on the problem characteristics (one product or multi product, one period or multi-time, the problem size and considering stock level) If the problem size is big, it means that optimal solution finding takes a long time, the authors prefer to use heuristics methods, LP-relaxations (Lu & Bostel, 2007) or Lagrangian relaxation (Vandermerwe & Oliff , 1990) applications.

Facility Location Problem (FLP) is a specific area in MILP for determination of geographical location of new centers. FLP has been used in reverse logistic network design area since 1997. In this recent field much of the subsequent research is encouraged by the early articles by Barros et al. (1998), Fleischmann et al. (1997) and Jayaraman (2003). In Appendix C, articles about reverse logistics network design are participated in groups.

3. MATHEMATICAL MODEL

3.1. RL Network Design

Facility location problem has been used for tracking a wide range of problems and it is a well-known research area within NP-hard (non-polynomial) Operations Research (OR). Specific facilities often support the reverse logistic activities. Collection centers (i.e., service points where used products are collected from customers) and remanufacturing facilities (i.e., remanufacturing centers where returned products are remanufactured) are two different actors of reverse logistics systems. In this manner, extending the network structure with transportation links is needed for return flows from customer locations to sites where remanufacturing activities take place (Melo et al., 2009). **Fig.3.1** shows a generic supply chain network that includes both forward and reverse activities.

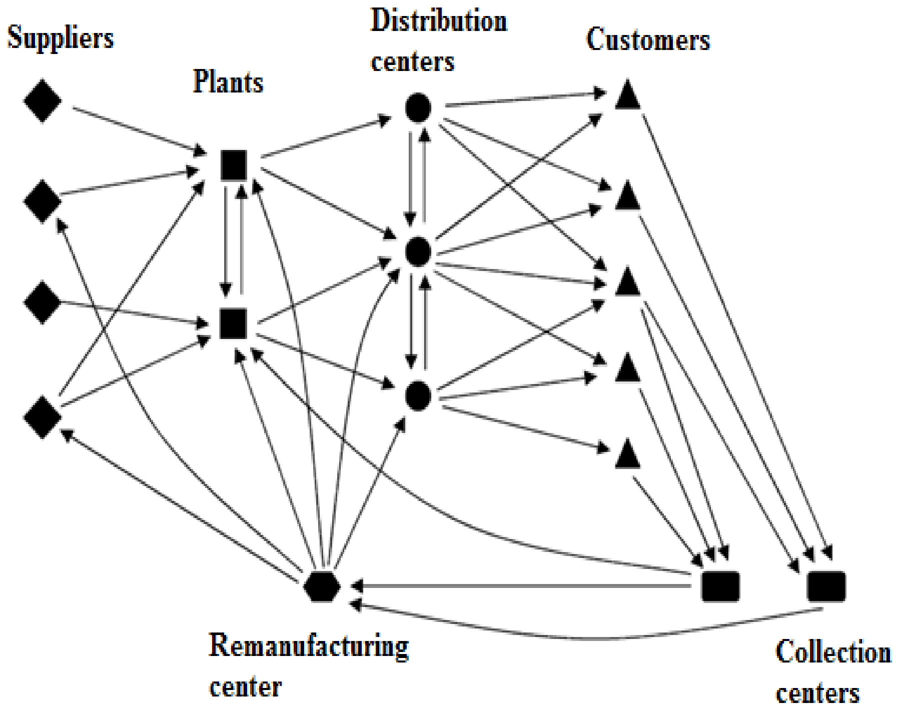

Figure 3.1 : Actors of General Supply Chain Network

3.2. Facility Location Problem (FLP)

The most frequent usage of facility location problem is in the supply chain network design. Lots of exact and heuristic algorithms have been developed in the past decades (Avella et al., 2009). A general facility location problem involves a set of customers and a set of facilities to serve customer demands. The objective of general facility location problems is to satisfy the demand of a set of clients while minimizing the sum of the (annualized) fixed setup costs and the variable transportation cost between facilities and clients. Possible questions to be answered are:

i Which facilities should be used (opened)?
ii Which customers should be serviced from which facility (or facilities) so as to minimize the total costs?

In order to setup the simplest version of the location problem, it must be selected *p* facilities to minimize costs or the total (weighted) distances for supplying customer demands. This is called that *P*-Median Problem (Melo et al., 2009). Arbitrary number of customers can be connected to a facility; in this case the problem is called Uncapacitated Facility Location Problem (UFLP). If there is a limit for each facility on the number of customers it can serve, name of the problem becomes a capacitated facility location problem (Wu et al., 2006). The Capacitated Facility Location Problem (CFLP) focuses on the distribution and production of a single commodity over a single time period, during which the demand is assumed to be known with certainty. The customer zones and facility location are considered as discrete points on a plane (Eiselts & Marianov, 2011). However, the multi-commodity, multi-echelon and dynamic versions also exist in the literature.

In order to approach situations in which parameters change over time in a predictable way, multi-period location problems have been proposed. The aim is to adapt the configuration of the facilities to these parameters. Thus, a planning horizon divided into time periods is considered (Nauss, 1978). The inclusion of stochastic components in facility location models (Synder, 2006) is regarded in another important extension. Uncertainty can often be associated with some of the parameters such as future costs and customer demands. This extension is motivated by uncertainty. An overview of research on facility location which through the consideration of uncertainty and time is provided by Owen and Daskin (1998). **Table 3.1** shows 24 articles in last 16 years that were published in reverse logistics area.

Table 3.1 : Assignement Numbers to References

Article No	**Authors**	**Year**
1	Srivastava S.K.	2008
2	Fleischmann M., Beullens P., Bloemhof-Ruwaard J.M., Van Wassenhove L.N.	2001
3	Wu L., Zhang X., Zhang J.	2006
4	Min H., Ko C.S., Ko H.J.	2006
5	Kuehn A.A., Hamburger M.J.	1963
6	Van Roy T.J.	1986
7	Beasley J.E.	1988
8	Amini M.M., Donna Retzlaff-Roberts D.,Bienstock C.C.	2005
9	Ramezani M., Bashiri M., Tavakkoli-Moghaddam R.	2013
10	Pishvaee M.S.	2009
11	Shih L.H.	2001
12	Govindan K., Kannan D., Diabat A., Mahmoud K., Yong G.	2012
13	Ko H.J., Evans G.W.	2007
14	El-Sayed M., Afia N., El-Kharbotly A.	2010
15	Dat L.Q., Linh D.T.T., Chou S.Y., Yu V.F.	2012
16	Kannan G., Sasikumar P., Devika K.	2010
17	Louwers D., Kip B.J., Peters E., Souren F., Flapper S.D.P.	1999
18	Spengler T., Piichert H., Penkuhn T., Rentz O.	1997
19	Vahdani B., Tavakkoli-Moghaddam R., Modarres M., Baboli A.	2012
20	Schweiger K., Sahamie R.	2013
21	Cardoso S.R., Barbosa-Póvoa A.P.F.D., Relvas S.	2013
22	Pishvaee M.S., Torabi S.A.	2010
23	Mutha A., Pokharel S.	2009
24	Lee D.H., Dong M.	2009

Table 3.2 shows an examination of references. Most detailed version of **Table 3.2** is in Appendix C.

Table 3.2 : Literature Survey about Reverse Logistic Facility Location Problems

Article No	Deterministic	Fuzzy	Stochastic	One echelon	Two echelon	Three echelon	Four or plus	Capacity Constraint
1	*					*		*
2	*					*		
3	*					*		
4	*			*				
5	*				*			*
6			*		*			*
7	*					*		
8	*							
9			*			*		*
10	*		*			*		*
11	*					*		*
12	*			*				*
13	*				*			*
14			*				*	*
15	*					*		*
16	*						*	*
17	*			*				*
18	*				*			*
19		*			*			
20	*					*		*
21	*				*			*
22		*					*	*
23	*						*	*
24			*			*		*

Because of capacitated model frequency in the literature and convenience to real life situation we choose to use the CFLP model.

3.3. Capacitated Facility Location Problem (CFLP)

In 1963, Kuehn and Hamburger (1963) published one of the earliest models for the CFLP which propose a heuristic procedure to solve the CFLP. Akinc and Khumawala

(1977) developed branch and bound procedures for this problem. In the procedures, Akinc and Khumawala (1977) used linear programming relaxation and through Lagrangean Relaxation by Nauss (1978). The cross-decomposition algorithm of Van Roy (1986) and the Lagrangean-based approach of Beasley (1988) are among the most effective ones.

Specific facilities often support the reverse logistic activities. That is why facility location problems are used in reverse logistic area from 1997 on. In this recent field much of the subsequent research is encouraged by the early articles by Fleischmann et al. (1997), Barros et al. (1998) and Jayaraman et al. (1999).On the other hand there also exist in the literature multi-product and multi-echelons version of Mixed Integer Linear Programming (MILP) that considers also inventory amounts.

3.4. RL Problem Modeling

Because of capacitated model in the literature and convenience to real life situation, we choose the CFLP model between facility location models to determine the number and the location of remanufacturing centers (one-echelon) and optimal transported quantity of used product.

3.4.1 Identification of the Processes

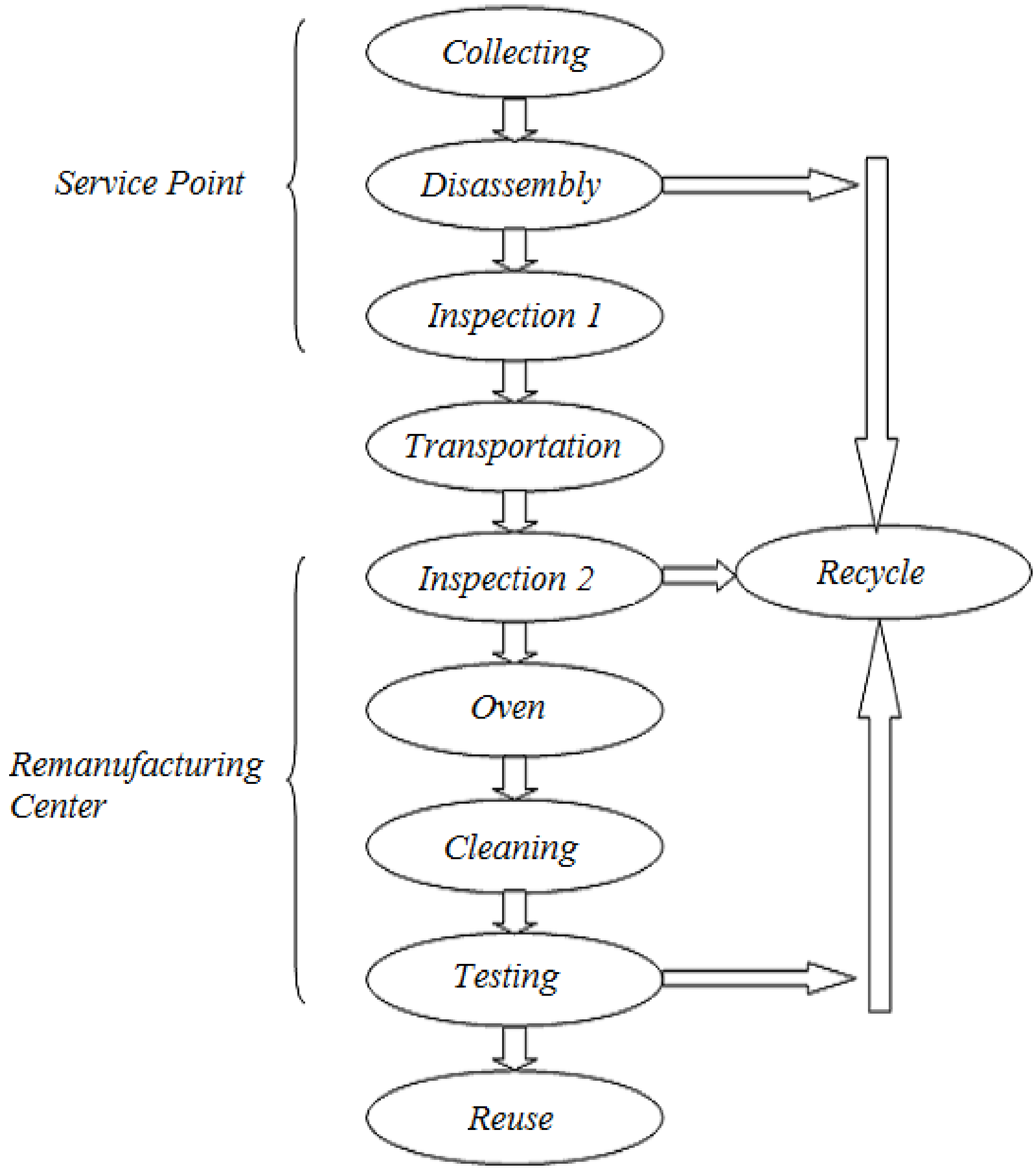

Figure 3.2 : Remanufacturing System Process

Fig.3.2 gives a graphical representation of the returned product operations. The used product should be gathered in the service point. It can be assumed that all users will come to the service point after a certain years if the system is stable. Considering the easiness of disassembling and first testing, the service point will carry out collecting, disassembling and testing operations. The first inspection stage is an easy stage because it could be made without usage of machine. If the product passes the first inspection, it means that the product is ready for transportation. After the transportation stage, the used products arrive to remanufacturing center. Before the operation, the second inspection is conducted to determine the damage caused by transportation. If the product is not able to pass inspection stage, the next stage will be recycling stage. If the product passes the inspection, it proceeds to repairing process. The first operation starts with oven. Up to a certain degree, the product is heated and the physical particles are burned. After the oven stage, the product waits for cool down and for the preparation cleaning stage. In the cleaning stage, the burned particles are ejected. Then, the last testing is realized by machine and if the repaired product passes inspection, it is ready to be reused but it waits the transportation. If the last testing stage cannot be passed, it will be send to recycling.

3.4.2 Assumptions

1. The customers bring their products to the service point. Transportation cost between customer and service point is not included in the model.
2. After the result of the inspection, if the product is failed, its transportation until recycle center is not considered.
3. The set of service points will be thought as a set of proposed remanufacturing center.
4. The transportation vehicles are identical type and they have the same capacity (30 products per each vehicle). Their fuel consumption is also known.
5. The demand of each service point is deducted from the annual demand and its turnover rate.
6. Total demand will be considered as constant after the balance of remanufacturing system.
7. The return rate information after the inspection process is considered convenient as being known.

3.5. Data Construction

The model depends on the location and the capacity level of the new remanufacturing centers. The aim of the study is to determine capacities and the locations of the new remanufacturing centers that minimize the total cost the remanufacturing of the DPF. The costs are represented by two indicators: financial amount and carbon dioxide emissions.

The required data for the model are; demand of each service point, opening cost of new remanufacturing center for each capacity, unit transportation cost and unit reprocessing cost.

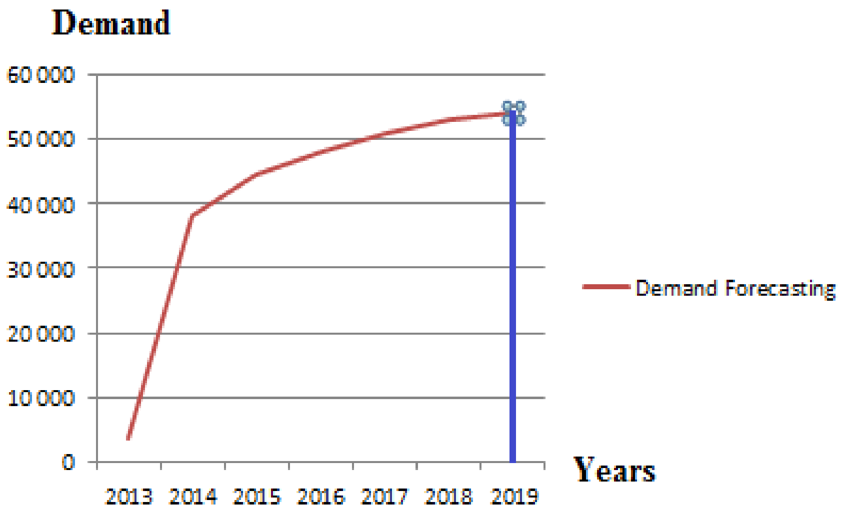

Figure 3.3 : Annual Demand Forecasting

Previous turnover data is considered to determine the demand estimation of each service points. The demand forecasting is given by the manufacturer and constant annual demand is handled as data of year 2019. This means it is chosen after the balance of remanufacturing system. **Fig.3.3** illustrates variations of expected demand amounts in coming years. The division of each service point demand is calculated by their turnover percentages.

Three cost components are identified to establish a mathematical model for the remanufacturing of a DPF.

3.5.1 Opening Cost

This is the first cost which is the cost of opening a new remanufacturing center. In calculation stage of opening cost, relevant factor is to consider capacities of machines. Opening cost of a new remanufacturing facility can be divided into two parts.

First part contains the purchasing cost of the required new machines. For opening a new remanufacturing center, the required machines are oven, cleaning machine and testing machine. Capacity of the remanufacturing centers drives the calculation of the required machines in it. For considering capacity factor, we need the machine characteristics as their processing time and energy consumptions. For processing one product, working time of each machine is calculated and the machine capacities are examined. For example, among these machines, oven has the longest process time and it has also two programs. While first program takes 4 hours per product, the second one takes 10 hours per product. We should gather how many product is processed by program 1 and program 2. We assume that 80% of products are passed into first program. Thus, we obtain the required process time for oven as approximately 5.2 hours per product. As an ordinary facility, machines could work maximum of 16 hours. This means that the oven processes only 3 products per day. Besides, we assume that remanufacturing center can work 300 days in a year. The minimum remanufacturing center capacity is calculated by usage of one oven with annual capacity of 900 products. While cleaning machine takes 20 minutes per product, testing machine takes 5 minutes per product. The number of required machines is calculated based on machine capacity. For each case, the required machine numbers are illustrated in **Table 3.3**.

Cost of each machine is a given data. Price of the oven is 7000 euro, price of the cleaning machine is 25000 euro and price of testing machine is 4000 euro. After obtaining total machine purchasing cost, to find annual machine purchasing cost, it is used constant depreciation method by assuming that the machine could be used 5 years.

Table 3.3 : Number of Required Machines for Each Capacities

Case Number	Capacity (thousand)	Number of oven	Number of cleaning machine	Number of testing machine
1	0,9	1	1	1
2	1,8	2	1	1
3	2,7	3	1	1
4	3,6	4	1	1
5	4,5	5	1	1
6	9,0	10	1	1
7	13,5	15	1	1
8	18,0	20	2	1
9	22,5	25	2	1
10	27,0	30	2	1
11	31,5	35	3	2
12	36,0	40	3	2
13	40,5	45	3	2
14	45,0	50	4	2
15	49,5	55	4	2
16	54,0	60	4	2

Second part assumes that it contains the purchasing cost of the required space for each capacity. The purchasing cost per m^2 is a given data and the total amount for each capacity level is calculated by taking into account the necessary machine areas. We assumed that each machine requires 12, 5 m^2 of space. After obtaining total purchasing cost of required space, to find annual value of this cost, constant depreciation method is used by assuming that the building could be used 10 years.

3.5.2 Unit Reprocessing Cost

The next cost is the unit reprocessing cost that is generated for the remanufacturing itself. Hourly energy consumption of each machine is a given data. For calculation of this cost, the processing time of each machine per product is taken into consideration. It is assumed that there are no economies of scale in the energy consumption for reprocessing. Then, the total reprocessing cost only depends on the annual demand. Thus, for all scenarios its amount takes the same value.

3.5.3 Unit Transportation Cost

Final cost is the unit transportation cost which is needed to carry the DPF from service points to the remanufacturing center and vice versa. For calculating this cost, we assume that a transportation vehicle can take 30 products and their fuel consumption per km is a given data. The distance between service points is found by usage of Google Map®.

However, in real life, the remanufacturing price often depends on the reprocessed product size. Each possible size yields a certain price and the price function is often a step function associated with economies of scale. But in this case, the total reprocessing cost is constant for each capacity level because the annual demand is assumed constant and reprocessing cost depends on the amount of products.

Opening cost depends on the opening probability which includes the purchasing cost of the required new machines and the purchasing cost of the required space to receive these machines. In our case, as reprocessing cost depends on the number of product treated in each remanufacturing center, it could be integrated into the cost called “transportation cost” in CFLP literature. Finally, it will be called generalized transportation cost. It includes:

- The transportation cost of a product is calculated with parameters like the capacity of trucks and fuel consumption of trucks.
- The reprocessing cost. This amount consists of energy consumption of each reprocessing element. The energy consumption of each machine is given. It is assumed that there are no economies of scale in the energy consumption for reprocessing. Under this assumption the reprocessing cost only depends on the annual demand.

3.6. Capacitated Facility Location Problem

Let $I = \{ 1, . . . , n \}$ be a set of facilities and $J = \{ 1, . . . , m \}$ be a set of clients. Let $G(I \cup J, A)$ be a complete bipartite graph where A is a set of arcs (i , j) with $i \subset I$ and $j \subset J$. Let D_j be the j-th client demand, let c_{ij} be the cost of sending one unit of flow from facility i to client j and let f_i be the fixed cost of opening facility i. Every facility i has a capacitys_i. Let y_i be the binary variable associated with each facility condition of each facility i. If it is equal to 1, facility i is open ($i \subset S$), otherwise facility i is close. S is a feasible subset $S \subset I$ of open facilities. Let x_{ij} be a continuous variable expressing the fraction of client j 's demand satisfied by facility i. CFLP choose a feasible subset S minimizing the sum of opening and transportation cost. The formulation of CFPL is:

$$\min \sum_{i \in I} f_i y_i + \sum_{i \in I} \sum_{j \in J} c_{ij} D_j x_{ij}$$

s.t.

$$\sum_{i \in I} x_{ij} \geq 1 \qquad j \in J \tag{1}$$

$$\sum_{j \in J} d_j x_{ij} \leq s_i y_i \qquad i \in I \tag{2}$$

$$x_{ij} \leq y_i \qquad i \in I, j \in J \tag{3}$$

$$x_{ij} \geq 0 \qquad i \in I, j \in J \tag{4}$$

$$y_i \in \{0,1\} \qquad i \in I \tag{5}$$

Constraints (1) ensure that the whole demand of each client must be satisfied. Capacity constraints (2) ensure that the total demand supplied from a facility does not exceed its capacity. Variable upper bounds (3) ensure that no client can be supplied from a closed facility. Constraints (4) are responsible of the non-negativity and constraints (5) give binary values to y_i variables.

Specifically, in our case, the repairing system design process includes analysis of the following questions:

1. How many part of inventory to carry from service point to the remanufacturing center (RC)?
2. Where to locate envisaged remanufacturing centers?

In order to determine the number and the location of remanufacturing centers and optimal transported quantity of used product, we choose to use the CFLP modeling.

3.7. Problem Statement and Model Reformulation

Our model is an extension of single-product problem model that is defined by Feldman et al. (1966). To formulate the problem we define the following notation:

3.7.1 Index

I : set of remanufacturing centers, indexed by $i = \{1, . . ., m\}$
J: set of service points, indexed by $j = \{1, . . ., m\}$
K: set of remanufacturing centers' capacity, indexed by $k = \{1, . . ., n\}$

3.7.2 Decision Variables and Parameters

x_{ij} : the fraction of service point j 's demand satisfied by the facility at i ,
y^k_i : binary variable that assume a value of 1, if a facility is to be established at location i, and 0 otherwise.
f_i^k : installation cost of a new remanufacturing center i depending to change correspondent the capacity k
D_j : demand at service point j
$RR1$: return rate after first inspection (0,19)
$RR2$: return rate after second inspection (0,05)
$RR3$: return rate after third inspection (0,06)
URC : unit remanufacturing cost (486)
UTC : unit transportation cost of used product per kilometer (0,02)
d_{ij} : distance between remanufacturing center i and service point j

UTC_{ij} : unit transportation cost between remanufacturing center i and service point j
UIC : unit testing and inspection cost (3,75)
$c_{ij}\ (D_j)$: generalized transportation cost

Calculation of unit transportation cost between i and j UTC_{ij} is made with the distance between i and j d_{ij} and unit transportation cost. That is illustrated in Formule (6).

$$UTC_{ij} = (UTC)d_{ij} \tag{6}$$

Generalized transportation cost that consists of transportation and reprocessing cost that is illustrated in Formule (7).

$$c_{ij}(\,D_j) = (UTC_{ij})\left[D_j\left[\frac{1}{(1-RR2)} + (1-RR3)\right]\right] + (URC + UIC)[D_j] + UIC\,D_j\left[\frac{1}{(1-RR2)}\right] \tag{7}$$

3.7.3 Objective Function

$$\text{Min} \sum_{ij} c_{ij}(D_j)x_{ij} + \sum_{ik} f_i^k\, y_i^k$$

s.t.

$$\sum_i x_{ij} \geq (1-RR1)(1-RR2) \qquad j \in J \tag{8}$$

$$\sum_j x_{ij}D_j \leq \sum_k S_i^k y_i^k \qquad i \in I \tag{9}$$

$$x_{ij} \leq \sum_k y_i^k \qquad i \in I, \quad j \in J \tag{10}$$

$$\sum_k y_i^k \leq 1 \qquad i \in I \tag{11}$$

$$x_{ij} \geq 0 \qquad i \in I, \quad j \in J \tag{12}$$

$$y_i^k \in \{0{,}1\} \qquad i \in I, \quad k \in K \tag{13}$$

Constraints (8) ensure that the demand of each customer is satisfied. Constraints (9) ensure that all demand is met, while constraints (10) force a remanufacturing center to be open if any demand is supplied by reproduction at that remanufacturing center. Between the different capacities, only one capacity will be chosen, is guaranteed by constraints (11). Constraints (12) means that demand fractions will be positive. Finally, constraints (13) impose the requirement that a remanufacturing center either be opened or not.

Calculation of the transportation cost we need to clarify the quantity on flow chart. **Fig.3.4** shows us amount of material flow.

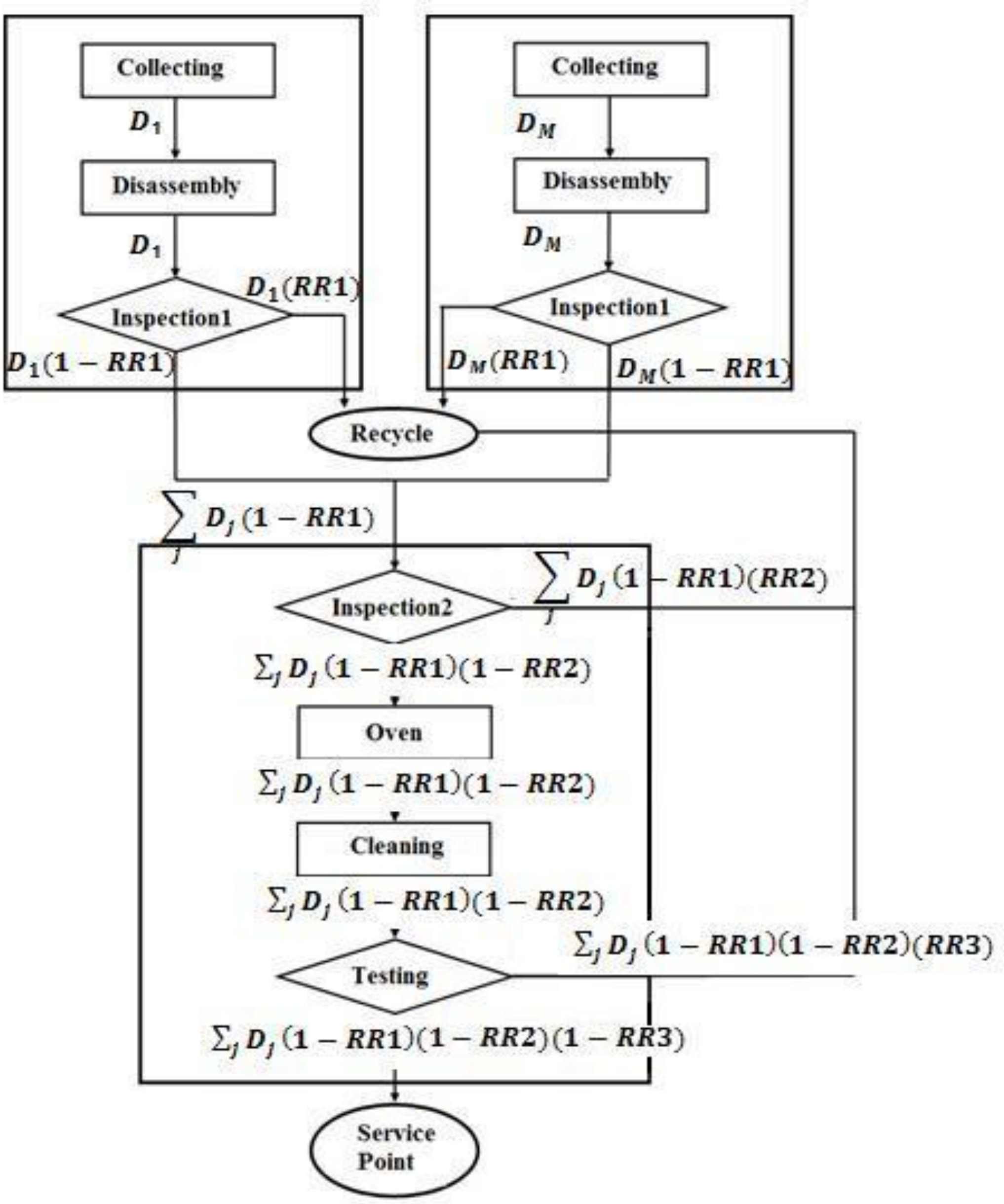

Figure 3.4 : Demand of Each Remanufacturing System Process

The objective function minimizes the total costs: the setup costs of opened remanufacturing sites, transportation cost between service points and the opened remanufacturing center, and the reprocessing costs at the opened remanufacturing center.

4. CASE STUDY

4.1. Current Situation

The case study involves a major international manufacturer of truck industry. The manufacturer’s customers are the users of highway, distribution and construction trucks. Thousands of transportation firms around the world utilize these trucks. The manufacturer is preparing to enter the European market with a recently developed innovative Diesel Particulate Filter (DPF) which prevents from releasing nocive small particules into the air. The price of a new diesel particulate filter is high because it is composed of expensive materials such as platinum, palladium and rhodium. Nowadays, the DPF is destroyed at the end of its life. However, the valuable components and materials which are part of DPF are not completely degraded to be destroyed and it will be worthwhile to exploit again. In order to save these valuable components, the manufacturer has envisioned the remanufacturing of DPF. Herein, though remanufacturing, three object of this study arise:

- Customer spends less money
- Manufacturer obtain profit
- Less environmental impacts

Customer will obtain a service while he also spends less money. With a reduction of raw material consumption, the manufacturer will obtain profit. Further, we expect to generate less environmental impact.

The manufacturer has 6 manufacturing centers all over the world: 2 in the USA, 1 in Switzerland, 1 in France, 1 in China and 1 in Japan. However, production and remanufacturing of DPF is only available in the USA. The manufacturer has 307 service points in France and is thinking about developing a remanufacturing system and a service system for its diesel particulate filter. **Fig.4.1** describes the main actors within the reverse supply chain of DPF.

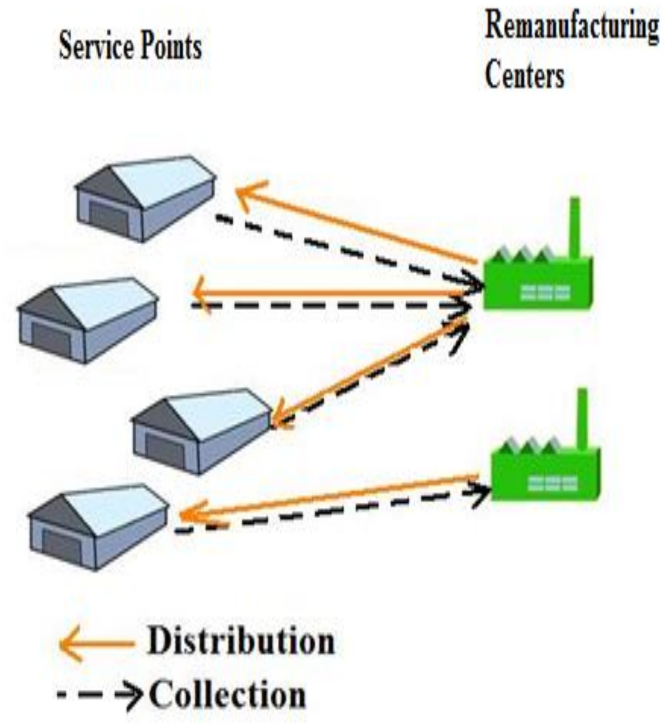

Figure 4.1 : Reverse Logistic Actors of Case Study

For creating benefit from these valuable components, the company embraces two strategies: having a remanufacturing system and providing service for customer instead of the product itself. Indeed, in order to improve the performance of its remanufacturing process, the company needs to control the wearing of the used products that are being returned. For this purpose, they have to retain ownership of DPF and to provide to its client the associated services. With this strategy, the company will be able to decide the time and the service point to return the used product. To help the design of those strategies, remanufacturing scenario ensuring an optimal compromise between economical and environmental issues have to be defined.

4.2. Proposition

The manufacturer embraces two opinions, having a remanufacturing system and providing service for customer instead of the product itself. Firstly, the manufacturer wants to have a remanufacturing system for its PDF after *x* years customers' utilization duration. Because its product still has some valuable components. Some valuable components could be repaired and after they could be used as spare parts in the new product. Furthermore some of them could be processed with direct recovery depending on the quality of used materials. This will reduce the necessity of buying new raw materials. The advantage of using a less quantity of these materials is to decrease the impact on the corresponding environment. Thus also prolonging the life of product, quality of product usage will increase.

Secondly, in order to have a good performance for the remanufacturing process the manufacturer needs to control the wearing of the used product that is being returned. For this purpose, the manufacturer wishes to retain ownership of the DPF and to provide to its client the associated services. With this strategy, the manufacturer will be able to decide the time and the service point to return the used product. The maintenance services also include servicing of products with the goal of prolonging product life cycle comprising maintenance and upgrading.

The first objective is to provide benefit for the customer while using a service system; we also want to create profit from the recovery actions. This cost reduction could be also important for the company to achieve a competitive advantage. The remanufacturing allows us to handle it because the use of materials will dwindle and valuable spare parts will be obtained. Therefore, the intensity of use reduced. With establishing remanufacturing system, customers will take a part in the decrease of environmental impacts.

In order to extend the duration of the life of DPF the manufacturer has chosen to apply remanufacturing option among recovery options. In the remanufacturing system, our primary aim is to get back these products from customers before the end of their lives, thus we will obtain an opportunity to easily repair and they will give as a new one. Thanks to this process, product life can be extended. Customers also make a profit: instead of taking a new product; they can pay fewer and they can profit from service system.

As it is emphasized, before the benefits of established remanufacturing system, the environmental and economic impacts caused by the system have to be determined and examined.

5. MODEL RESULTS

The mathematical model is written by using Java-Cplex® and the results are obtained by Eclipse®. The code is in Appendix A.

5.1. Location Analysis

The optimal location of remanufacturing centers for different allocation scenarios are illustrated in **Fig.5.1** to **Fig.5.3**. The round symbols show the available service points in France and the square symbol(s) represent the possible position(s) of remanufacturing center(s).

The different allocation scenarios show that if there exist a large number of remanufacturing center, they take place where has higher amounts of service points. This means remanufacturing centers locate all corner of France. While the amount of remanufacturing center decreasing, remanufacturing center locations get closer to the west-middle of France. It could be caused of theirs higher demand factor.

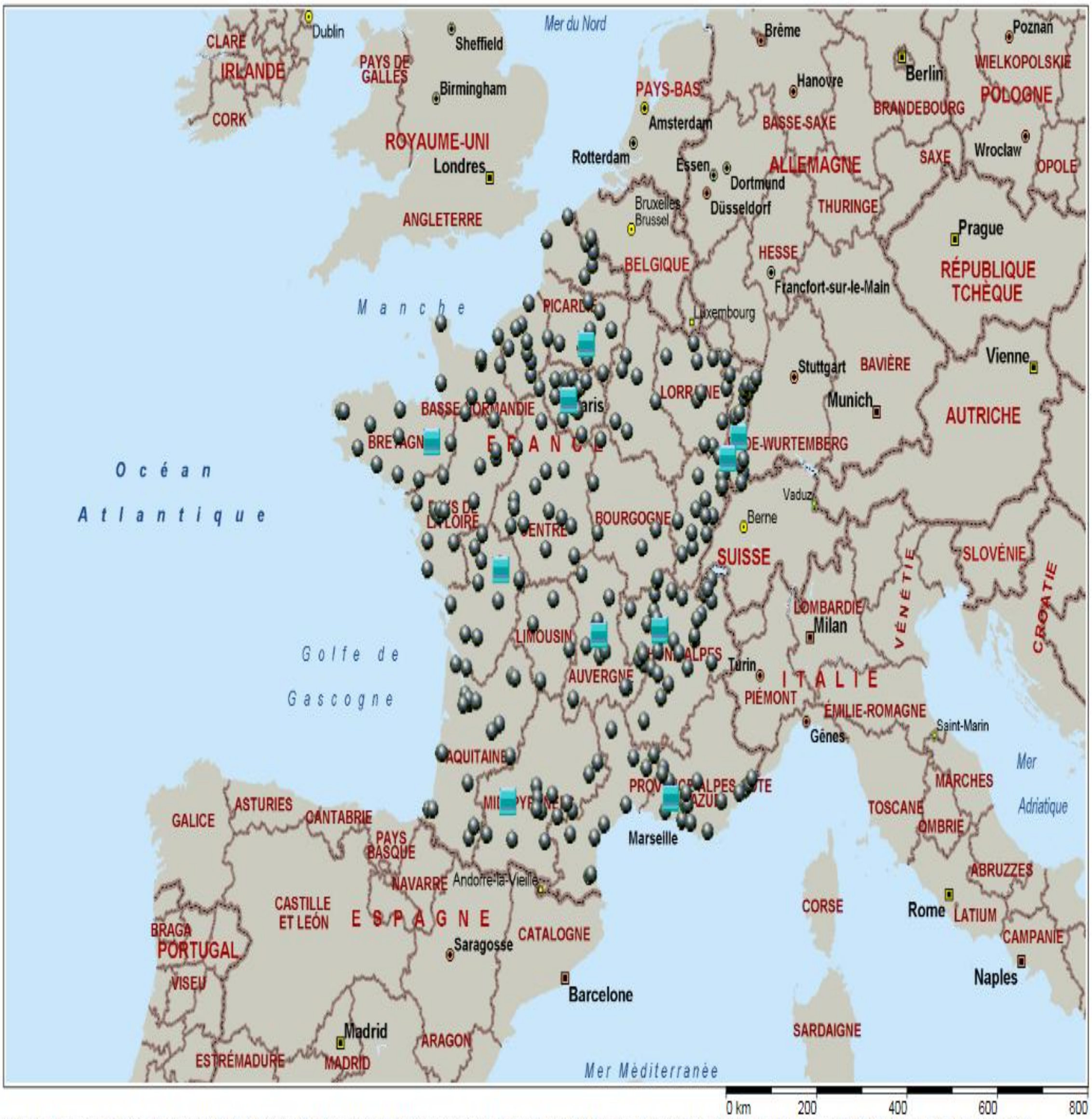

Figure 5.1 : Optimal Solution

Fig.5.1 shows the optimal solution for the localization of 10 remanufacturing centers from existing service point localizations (307 possibilities). These locations are the same for euro and carbon results. The capacity of remanufacturing center is 4500 products/ year. Each remanufacturing center requires 5 ovens, one cleaning machine and one cleaning machine for satisfying annual product demand.

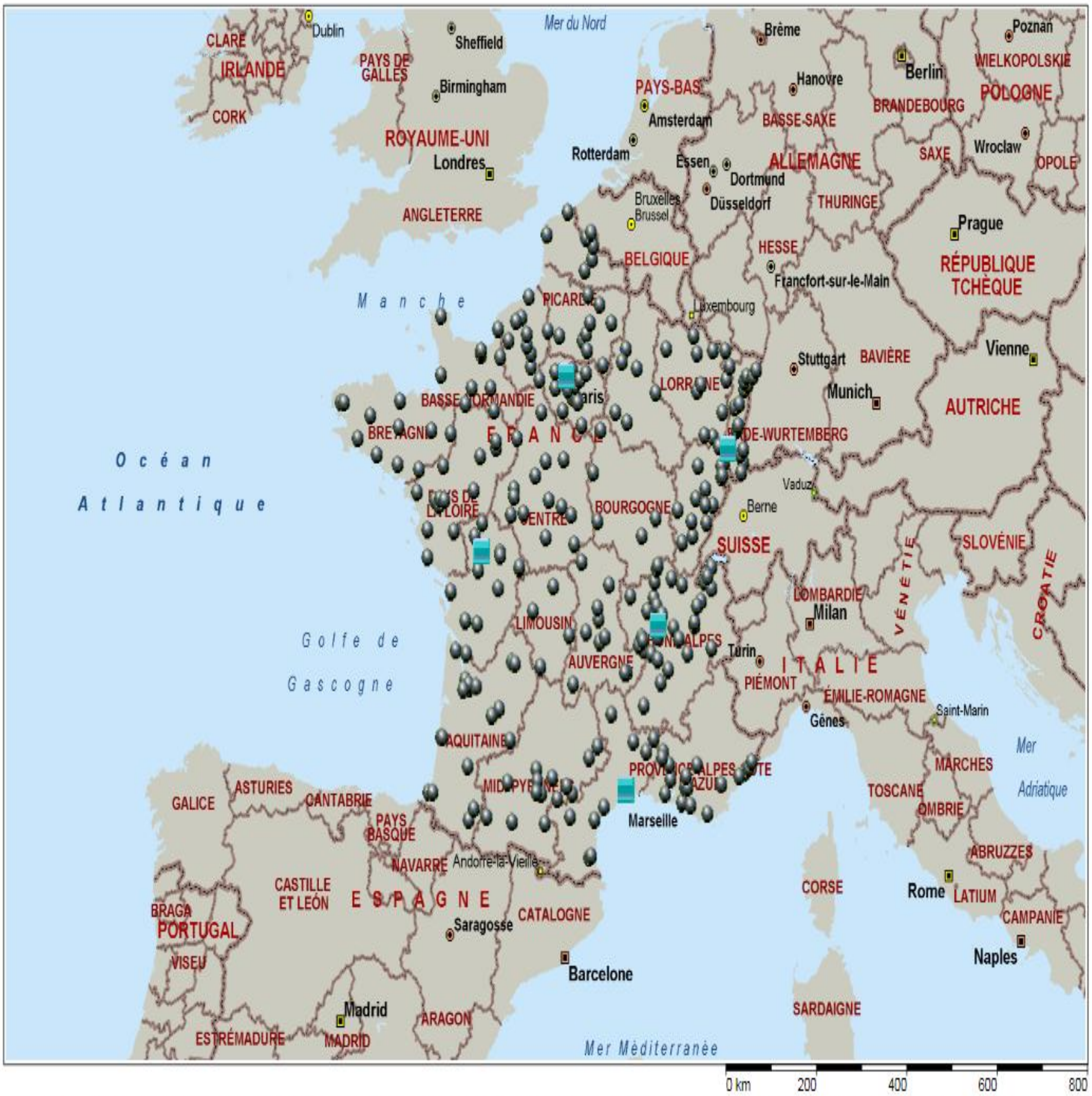

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Figure 5.2 : Best Allocations for 5 RC

Fig.5.2 shows the optimal solution for the localization of 5 remanufacturing centers from existing service point localizations (307 possibilities). These locations are the same for euro and carbon results. The capacity of remanufacturing center is 9000 products/ year. Each remanufacturing center requires 10 ovens, one cleaning machine and one cleaning machine for satisfying annual product demand.

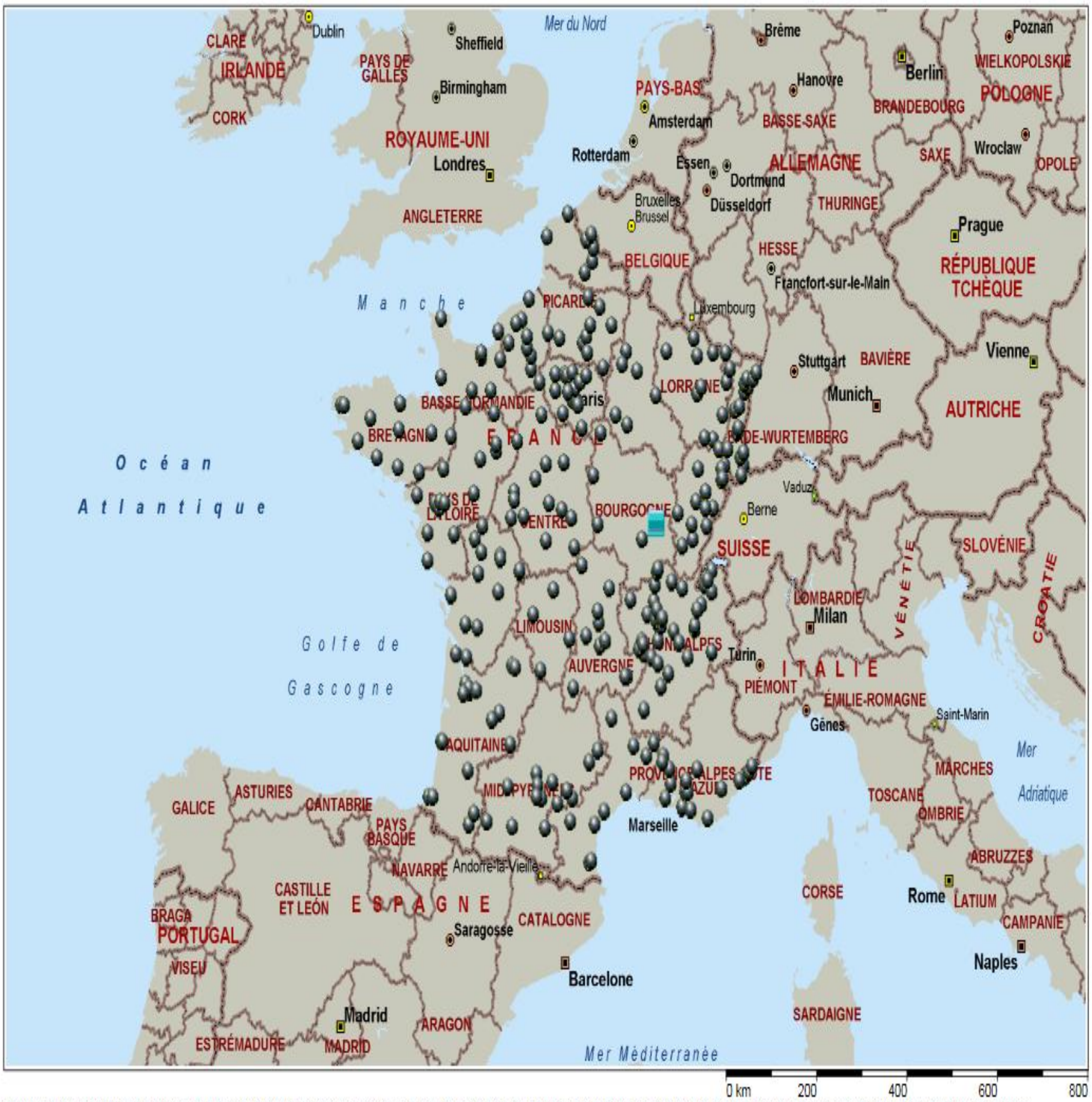

Figure 5.3 : Best Allocation of 1 RC

Fig.5.3 shows the optimal solution for the localization of one remanufacturing center from existing service point localizations (307 possibilities). These locations are the same for euro and carbon results. The capacity of remanufacturing center is 45000 products/ year. The remanufacturing center requires 50 ovens, 4 cleaning machine and 2 cleaning machine for satisfying annual product demand.

5.2. Cost Analysis

Fig.5.4 illustrates that the minimum total value for both euro and carbon emission data analysis takes a place in fourth scenario (each remanufacturing center capacity is 3600.product/year and the required total remanufacturing center amount is 12. Each remanufacturing center has 4 ovens, one cleaning machine and one testing machine pour satisfy the annual total demand.) Case 1 has an oven to create 900 products per year. In other cases, the capacity of each remanufacturing center is augmented as be appropriated to multiple of 900 products until case 5. After case 5, annual production amounts' augmentation is 4500 products between each case.

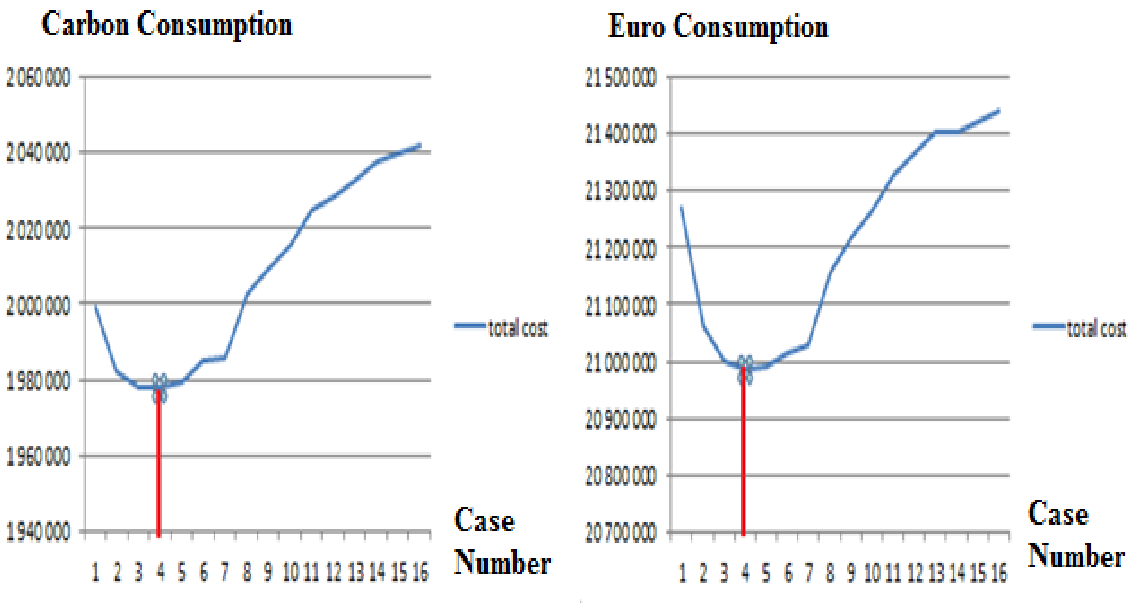

Figure 5.4 : Change of Carbon and Euro Consumption

After obtaining the results, total cost will be examined in three components. First of all, the amount of reprocessing cost has the biggest volume among the three component costs.

Table 5.1 shows that its minimum percentage value is %94. **Table 5.1** also shows the augmentation in the total cost wherefore the capacity augments. One can remark that the reprocessing cost is a constant value as stated in Section 4.5.2. Therefore, it could be said that the optimal solution try to provide a balance between total opening cost and transportation cost.

.

Table 5.1 : Constant Reprocessing Percentage in Total Cost

		Annual Carbon Emission Results		Annual Euro Consumption Results	
Case No	Capacity	Total Cost (z)	Percentage of Reprocessing cost	Total Cost (z)	Percentage of Reprocessing cost
1	0,9	1 999 199	0,96	21 272 137	0,96
2	1,8	1 981 985	0,97	21 061 418	0,97
3	2,7	1 977 947	0,97	21 002 077	0,98
4	3,6	1 977 818	0,97	20 985 792	0,98
5	4,5	1 979 661	0,97	20 992 001	0,98
6	9	1 984 778	0,97	21 013 903	0,98
7	13,5	1 986 005	0,97	21 028 495	0,98
8	18	2 002 846	0,96	21 158 167	0,97
9	22,5	2 009 101	0,96	21 216 667	0,97
10	27	2 015 359	0,96	21 266 628	0,96
11	31,5	2 024 549	0,95	21 327 228	0,96
12	36	2 028 698	0,95	21 366 228	0,96
13	40.5	2 032 870	0,95	21 405 228	0,96
14	45	2 037 826	0,94	21 402 182	0,96
15	49,5	2 039 911	0,94	21 421 682	0,96
16	54	2 041 997	0,94	21 441 182	0,96

In order to understand that phenomenon, the evolution of transportation cost and opening cost are examined while the capacity augments. These results are presented in **Table 5.2**.

Table 5.2 : Data Results

		Annual Carbon Emission Results				Annual Euro Consumption Results			
Case No	Capasity	Total cost (z)	Total opening cost	Transportation cost	Amount of new facility	Total cost (z)	Total opening cost	Transportation cost	Amount of new facility
1	0,9	1 999 199	64 860	8 976	47	21 272 137	690 900	66 630	47
2	1,8	1 981 985	43 128	13 495	24	21 061 418	446 400	100 411	24
3	2,7	1 977 947	35 424	17 160	16	21 002 077	360 000	127 470	16
4	3,6	1 977 818	31 572	20 884	12	20 985 792	316 800	154 385	12
5	4,5	1 979 661	30 479	23 820	10	20 992 001	303 000	174 394	10
6	9	1 984 778	25 667	33 748	5	21 013 903	249 000	250 296	5
7	13,5	1 986 005	27 500	33 143	5	21 028 495	227 200	286 688	4
8	18	2 002 846	29 604	47 879	3	21 158 167	288 900	354 660	3
9	22,5	2 009 101	35 860	47 878	3	21 216 667	347 400	354 660	3
10	27	2 015 359	42 116	47 880	3	21 266 628	270 600	481 422	2
11	32	2 024 549	34 173	65 013	2	21 327 228	331 200	481 422	2
12	36	2 028 698	38 344	64 992	2	21 366 228	370 200	481 422	2
13	41	2 032 870	42 515	64 993	2	21 405 228	409 200	481 422	2
14	45	2 037 826	23 907	88 557	1	21 402 182	231 600	655 976	1
15	49,5	2 039 911	25 992	88 557	1	21 421 682	251 100	655 976	1
16	54	2 041 997	28 078	88 557	1	21 441 182	270 600	655 976	1

Table 5.2 shows that transportation cost increase with capacity augmentation. Indeed, when the individual capacity of each remanufacturing becomes higher, the required number of remanufacturing becomes smaller. On the other hand, transportation cost increase when the number of remanufacturing center decreases.

In order to understand the evolution of the total cost, **Fig.5.5** shows the evolution of opening cost and transportation cost with the capacity augmentation.

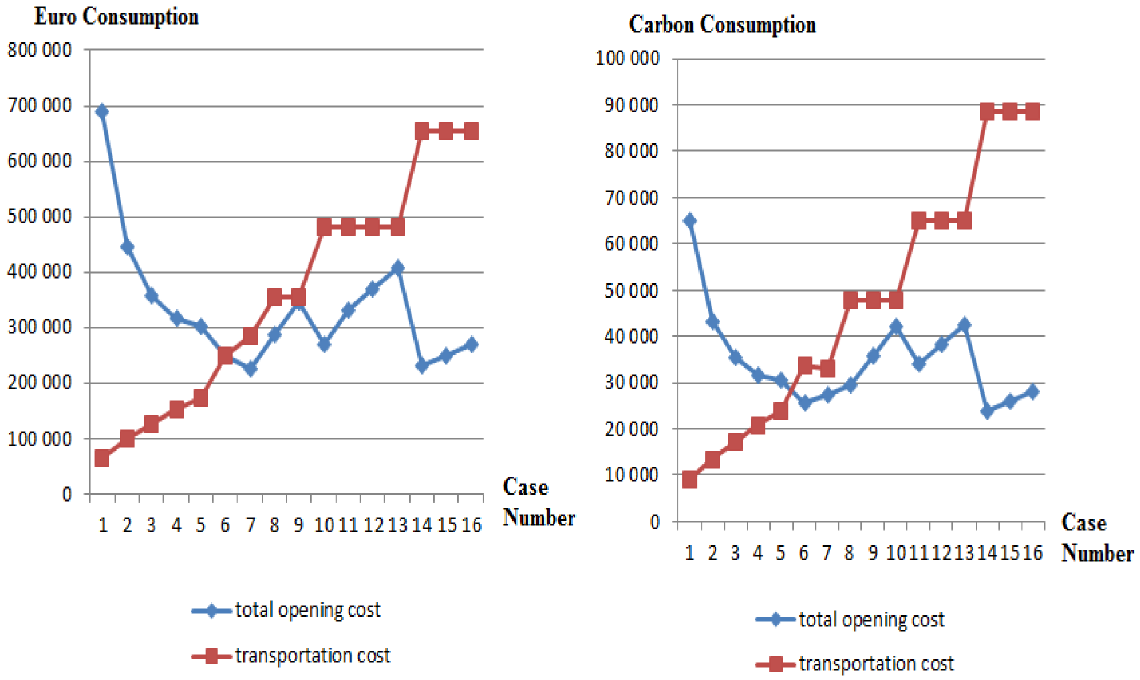

Figure 5.5 : Experimental Results

The most distinctive change is the progressive augmentation in the transportation cost. If the solution has an identical numbers of new facilities, the transportation cost also remains stable. Otherwise the change in the first case and the last case, transportation cost has a bigger difference than total opening cost. Change in the total opening cost depends on the number of facilities and their capacity. If the change of total opening cost is examined attentively, for the same amount of facility there exist an increment in total opening cost just because of the capacity augmentation. Otherwise, in the case of an increase in facility amount there doesn’t exist a regular decrease. For the results of carbon emission, when the transition from case 5 to case 6 there is a decrease, the transition from case 2 to case 3 there is an augmentation. Comparably in the euro results, the augmentation occurs in the transition from case 7 to case 8.

Slight difference can be noted between carbon and euro solutions at the number of new facility column for cases 7 and 10. In this case, the optimal solution for euro results opens the minimum number of required remanufacturing centers whereas the optimal solutions for carbon results recommend opening one more center. This could be explained by the fact that carbon cost, the augmentation of opening costs is smaller than changes on transportation cost. Consequently, it is costless to open one more remanufacturing center in this case.

6. CONCLUSION

Generally, this research has proposed a tool that implements CFPL in order to determine an optimal location of remanufacturing centers using both economical and environmental criteria. Moreover, the proposed tool could be useful for decision making for the design of a reverse logistic network on two points. First of all, it is able to determine the optimal location of the remanufacturing centers. Secondly, it can also indicate which operation (transportation, reprocessing, or opening) generates the most important percentage of costs.

We have proposed a model that is able to choose an optimal location of remanufacturing centers. CFLP is convenient to solve one-echelon localization. The mathematical model aims to minimize all expenses during the reverse logistics network construction. The proposed model can also be used for different capacity possibilities.

Our model works with both economical and environmental cost functions. With this thesis, we also show that available mathematical models in literature can be used for calculation of environmental impacts.

This thesis helps the decision making for the design of the remanufacturing process. We choose more suitable location for reverse logistics process in consideration of machine request, environmental impacts and easiness.

The last goal of this study was to find out a balance between environmental aspect and the financial aspect. Unfortunately, the solutions show that economic cost and environmental cost seems correlated. This is illustrated by the fact that for both cost indictors, the returned optimal solution remains the same. The correlation is explained by the ratio between unit transportation cost per km and the opening cost per m^2 which has a same value for both cases.

Reprocessing cost of a product is 537 euros. This amount is cheaper than creating a new product. So installation of a reverse logistics network is advantageous compared with the current situation. This also reduces the raw materials consumption. The advantage of using a less quantity of raw materials is to decrease the corresponding impact on the environment. Thus company takes place in green line. Costumers also obtain profit through the reverse logistics system.

Finally, as the costs result show that more than 94% of the total cost is due to the reprocessing cost, it could be better to work on the amelioration of the remanufacturing process itself before optimizing the logistics.

The disassembly and testing process at the service point are not considered by CFLP model because these operations do not occurs in the remanufacturing center. In order to overcome this limitation, the idea could be setting up a 2 echelons CFLP model which enables site selection for service points for disassembly and testing operation.

Total demand was considered as constant value. In fact it is known that this demand is going to have an evolution year by year. For solving this handicap, the demand structure should be examined well. Future studies, increasing factor in estimates of future demand should also be considered and the model can be handled as a multi-period problem. The uncertain demand can also be examined using the statistical models or stochastic methods.

In this study, the optimal solution of facility location is handled as a strategic decision. However, optimality can only be guaranteed with full integration of tactical and operational decisions. Facility location problem can also be combined with inventory and production decisions.

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APPENDIX. A

Cplex-Java Code for CFLP

```
import ilog.concert.*;
import ilog.cplex.*;
import java.io.*;
import java.util.Scanner;
public class ModelOptG {
        static class Dimension{
            int     n,m,p;
        }

        static class Data{

                double RR1, RR2, RR3;
    double URC, UTC, UIC;
                double[][] fi;
                int[][] Si;
```

```
int[] Dj;
double[][] dij;

//Read - fi,Si,Dj,cij
Data(Scanner in, Dimension dim, Scanner indij) throws IOException{
        int ni, mi, pi, k, count = 0;

        ni = dim.n;
        mi = dim.m;
        pi = dim.p;

        fi = new double[ni][pi];
        Si = new int[ni][pi];
        Dj = new int[mi];
        dij = new double[ni][mi];

        //Read - RR1, RR2, RR3, URC, UTC, UIC;
        UTC = Double.parseDouble(in.next());
        URC = Double.parseDouble(in.next());
        UIC = Double.parseDouble(in.next());
```

```
                    RR1 = Double.parseDouble(in.next());
                    RR2 = Double.parseDouble(in.next());
                    RR3 = Double.parseDouble(in.next());

                    System.out.println("    UTC="+UTC+"    URC="+URC+"    UIC="+UIC+"            RR1="+RR1+"    RR2="+RR2+"
RR3="+RR3);

                    //Read - Si and fi
                    for(count=0;count<ni;count++)
                    {
                              for(k=0;k<pi;k++){
                                   Si[count][k] = in.nextInt();
                              }
                              for(k=0;k<pi;k++){
                                   fi[count][k] = in.nextDouble();
                              }

                              System.out.print("\n");
                              for(k=0;k<pi;k++){
```

```
                    System.out.print(" Si["+count+"]["+k+"]:" + Si[count][k]);
            }

            for(k=0;k<pi;k++){
                    System.out.print(" fi["+count+"]["+k+"]:" + fi[count][k]);
            }
            System.out.print("\n");
}

//Read Dj and cij
int cc; count = 0;
while(indij.hasNext())
{
        Dj[count] = indij.nextInt();
        System.out.print(" Dj["+count+"]:" + Dj[count]);
        for(cc=0;cc<mi;cc++)
        {
                dij[count][cc] = Double.parseDouble(indij.next());
        }
        count++;
```

```
               }

               System.out.print("\n");
               for(int ii=0;ii<ni;ii++){
                     for(int jj=0;jj<count;jj++){
                           System.out.print(" cij["+ii+"]["+jj+"]:" + dij[ii][jj]);
                     }
                     System.out.print("\n");
               }
     }
   }

   public void buildModel(Dimension dim, IloNumVar[][] x, IloNumVar[][] y, Data data, IloMPModeler  cplex) {
try {
  //Declaration of the constants
   int i,j,k, n, m, p;

 double cija, cijb, cijc;
 double RR1, RR2, RR3;
 double URC, UTC, UIC;
```

```
n = dim.n;
            m = dim.m;
            p = dim.p;

            double[][] fi = new double[n][p];
            int[][] Si = new int[n][p];
            int[] Dj = new int[m];
            double[][] UTCij = new double[n][m];
            fi = data.fi;
            Si = data.Si;
            Dj = data.Dj;
            UTCij = data.dij;//UTC*dij

 //Setting values
 RR1 = data.RR1;       RR2 = data.RR2;     RR3 = data.RR3;

 UTC = data.UTC; UIC = data.UIC; URC = data.URC;

 //Declaration of the system variables
```

```
 // x e [0,1]
 for(i=0; i<n; i++){
             x[i]= cplex.numVarArray(m,0.0,1.0);
 }

 // y e {0,1}
 for(i=0; i<n; i++){
             y[i] = cplex.intVarArray(p,0,1);
 }

 //Creation of the equation
 IloLinearNumExpr expr = cplex.linearNumExpr();

 System.out.print("\n");
 double[][] cij = new double[n][m];
for (i = 0; i<n; i++){
 for(j = 0; j<m; j++){
  cija = UTC*UTCij[i][j]*Dj[j]*( 1/(1-RR2) + (1-RR3) );
  cijb = (URC + UIC)*Dj[j];
  cijc = UIC*Dj[j]/(1-RR2);
```

```
    cij[i][j] = cija + cijb + cijc;
    System.out.print(" c["+i+"]["+j+"]:"+ cij[i][j]);

    expr.addTerm(cij[i][j],x[i][j]);
   }
   System.out.print("\n");

   for(k = 0; k<p; k++){
    expr.addTerm(fi[i][k], y[i][k]);
   }
  }

//Constraints
//sum(xij)=(1-RR1)*(1-RR2)
  for (j = 0; j<m; j++){
   IloLinearNumExpr eqConst1 = cplex.linearNumExpr();
     for(i = 0; i<n; i++){
            eqConst1.addTerm(1.0,x[i][j]);//sum(xij)
     }
     cplex.addEq(eqConst1, (1-RR1)*(1-RR2));
```

```
  }

//sum(Dij*xij)<=sum(sik*yik)
for(i = 0; i<n; i++){
 IloLinearNumExpr eqConst2 = cplex.linearNumExpr();
 IloLinearNumExpr eqConst2a = cplex.linearNumExpr();
 for (j = 0; j<m; j++){
        eqConst2.addTerm(Dj[j],x[i][j]);//sum(Dij*xij)
 }
 for (k = 0; k<p; k++){
        eqConst2a.addTerm(Si[i][k],y[i][k]);//sum(sik*yik)
 }
 cplex.addLe(eqConst2, eqConst2a);
}

//xij<=sum(yik)
for(i = 0; i<n; i++){
 for (j = 0; j<m; j++){
        IloLinearNumExpr eqConst3 = cplex.linearNumExpr();
        for (k = 0; k<p; k++){
```

```
               eqConst3.addTerm(1,y[i][k]);//sum(yik)
         }
         cplex.addLe(x[i][j], eqConst3);
   }
  }

 //sum(yik)<=1
  for(i = 0; i<n; i++){
   IloLinearNumExpr eqConst4 = cplex.linearNumExpr();
   for (k = 0; k<p; k++){
         eqConst4.addTerm(1,y[i][k]);//sum(yik)
    }
   cplex.addLe(eqConst4,1);
  }

  //Adding the expression to minimize
  cplex.addMinimize(expr);
} catch (IloException e) {
  e.printStackTrace();  //To change body of catch statement use File | Settings | File Templates.
}
```

```
}
    public static void main(String[] args) throws IOException, IloException {
        String path = "./src/Data/Data1/";
        String pathR = "./src/Results/Res1/";
        FileReader text = new FileReader(path+"model.txt");
        Scanner in = new Scanner(text).useDelimiter("\\s+");

        //Read - n,m, p
        Dimension dim = new Dimension();
        dim.n = in.nextInt();
        dim.m = in.nextInt();
        dim.p = in.nextInt();

        System.out.println("n=" + dim.n + " m= " + dim.m + " p= " + dim.p);

        //Read - fi,Si,Dj,cij//
        String filedij = path+"dij.txt";
        FileReader textdij = new FileReader(filedij);
        Scanner indij = new Scanner(textdij).useDelimiter("\\s+");
        Data data = new Data(in,dim,indij);
```

```
            textdij.close();
            text.close();

            //Setting the model variables
            IloNumVar[][] x = new IloNumVar[dim.n][dim.m];
            IloNumVar[][] y = new IloNumVar[dim.n][dim.p];

            //Declaration of the system variables
   IloCplex cplex = new IloCplex();

            ModelOptG prob = new ModelOptG();
prob.buildModel(dim, x, y, data, cplex);

//Solving the expression
cplex.setParam(IloCplex.DoubleParam.TiLim, 2000);
cplex.solve();
cplex.getObjValue();
cplex.getBestObjValue();
System.out.println(" Solution status"+ cplex.getStatus());
```

```
//Print x, y and z
FileWriter fileX = new FileWriter(pathR+"FileX.txt");
BufferedWriter buf = new BufferedWriter(fileX);
double auxij;
for (int i = 0; i<dim.n; i++){
   for(int j = 0; j<dim.m; j++){
            auxij = cplex.getValue(x[i][j]);
            System.out.print(" x["+i+"]["+j+"]:"+ auxij);
            buf.write(Double.toString(auxij) + " ");
   }
   buf.newLine();
   System.out.print("\n");
}
buf.close();
fileX.close();
FileWriter fileY = new FileWriter(pathR+"FileY.txt");
buf = new BufferedWriter(fileY);
for (int i = 0; i<dim.n; i++){
   for (int k = 0; k<dim.p; k++){
```

```
            auxij = cplex.getValue(y[i][k]);
            System.out.print(" y["+i+"]["+k+"]:"+ auxij);
            buf.write(Double.toString(auxij) + " ");
  }
  System.out.print("\n");
  buf.newLine();
}
buf.close();
fileY.close();
      FileWriter fileZ = new FileWriter(pathR+"FileZ.txt");
buf = new BufferedWriter(fileZ);
double z = cplex.getObjValue();
System.out.println("\n z: " + z);
double z1 = cplex.getBestObjValue();
System.out.println("\n z1: " + z1);
buf.write(Double.toString(z));
buf.newLine();
buf.write(Double.toString(z1));
buf.close();
fileZ.close();
```

```
        cplex.end();
    }

}
```

APPENDIX. B

Euro data for capacity 900

307	307	1
0.02	486.0	3.75
0.19	0.05	0.06
900	14700	
900	14700	
900	14700	
900	14700	
900	14700	
900	14700	
900	14700	
900	14700	
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900	14700
900	14700…

APPENDIX. C

Article no	deterministic	fuzzy	stochastic	one echelon	two echelon	three echelon	four or plus	recovery	closeloop	recovery options	process uncertainties	demand uncertainty	max	min	secteur	single product	multi product	single period	multi period	multi obj	delivery tardiness	capacity constrainte
1	*					*		*		remanu + refurbis			*		electronic		*		*			*
2	*					*		*	*	recycle+remanufac				*	unknown	*		*				
3	*					*		*		repairing+remanu				*	copymach	*		*				
4	*			*					*	remanufac				*	unknown	*			*			
5	*				*			*		repairing				*	sand	*		*				*
6			*		*			*		refurbishing				*	unknown	*		*				*
7	*					*			*	remanufacturing				*	unknown	*		*				
8	*							*		repairing+remanu				*	medical diognas	*			*	*	*	
9			*			*			*	remanu	*	*	*		unknown		*	*		*	*	*
10	*		*			*			*	remanu	*	*			unknown	*		*				*
11	*					*		*		remanu			*		electroni		*	*				*
12	*			*				*		remanu				*	unknown	*		*				*
13	*				*				*	repairing				*	unknown		*		*			*

Article no	**deterministic**	**Fuzzy**	**stochastic**	**one echelon**	**Two echelon**	**three echelon**	**four or plus**	**recovery**	**closeloop**	**recovery options**	**process uncertainties**	**demand uncertainty**	**max**	**min**	**secteur**	**single product**	**multi product**	**single period**	**multi period**	**multi obj**	**delivery tardiness**	**capacity constrainte**
14	*					*		*		recycle+repair				*	electronic		*	*				*
15	*						*		*	recycle				*	battery		*		*			*
16	*			*				*		reuse				*	carpet		*	*				*
17	*				*			*		recycling				*	building materials		*	*				*
18		*			*				*	recycling	*			*	metal industry		*	*		*		
19	*					*		*		recycling				*	paper		*		*			*
20	*				*			*		recycle+remanufac		*	*		unknown		*		*			*
21		*					*		*	recovery+recycling		*		*	unknown	*			*	*	*	*
22	*						*		*	recycle+remanufac				*	unknown	*		*				*
23			*			*			*	remanufacturing		*		*	unknown		*		*			*

BIOGRAPHICAL SKETCH

Gözde Kızılboğa was born in Manisa on January 01, 1988. She was graduated from Turgutlu Halil Kale Fen Lisesi in 2005 and received her B.Sc. degree in Industrial Engineering from Galatasaray University in 2011. Since 2011 she is working through the completion of M.Sc. program in Industrial Engineering at Galatasaray University. With a programme double degree of M.Sc., she also graduated from Institut Polytechnique de Grenoble. This thesis was written in order to fulfill the requirements for her graduation under the supervision of Müjde EROL GENEVOİS. The article of this thesis was accepted by TESConf2013. Her research interests include Capacitated Facility Location Problem and their applications on remanufacturing network systems.