UNIVERSITÀ DI PISA

DIPARTIMENTO DI INGEGNERIA DELL’ENERGIA DEI SISTEMI,
DEL TERRITORIO E DELLE COSTRUZIONI

RELAZIONE PER IL CONSEGUIMENTO DELLA
LAUREA MAGISTRALE IN INGEGNERIA GESTIONALE

# Development of a Reverse Supply Chain Model for Home Appliances Remanufacturing in China

---

RELATORI

Prof. Ing. Gino Dini

*Dipartimento di Ingegneria Civile e Industriale*

Dott. Yuchun Xu

*School of Applied Sciences, Cranfield University*

CANDIDATO

Matteo Grava

*matteograva@hotmail.it*

Sessione di Laurea del 03/12/2014
Anno Accademico 2013/2014
Consultazione consentita

**Development of a Reverse Supply Chain model for Home Appliances Remanufacturing in China**
**Matteo Grava**

---

## SOMMARIO

Questo lavoro di ricerca deriva dell’Individual Project svolto presso la Nanjing University of Aeronautics and Astronautics (NUAA) nel periodo Maggio/Settembre 2014, nell’ambito del programma di Double Degree tra l’Università di Pisa e Cranfield University per l’anno 2013/2014. Il progetto fa parte di un programma di ricerca chiamato “*7 th Framework Programme for Research and Technological Development (FP7)”, sponsorizzato dalla Comunità europea ed* è stato svolto interamente a Nanjing in Cina. Tradizionalmente le aziende che producono elettrodomestici considerano i prodotti che sono arrivati alla fine del loro ciclo di vita come una perdita automatica piuttosto che una un ulteriore opportunità di aumentare i profitti. Tuttavia, il remanufacturing sembra una strada economicamente vantaggiosa che permette di recuperare il valore dei prodotti alla fine del loro ciclo di vita e dunque incrementare i profitti aziendali riducendo sia sprechi che inquinamento. In questo riguardo, diventa necessario sviluppare un modello di Reverse Supply Chain (RSC) che spinga le aziende a ritirare i prodotti alla fine del loro ciclo di vita con il fine del remanufacturing. Questo progetto di tesi si pone come obbiettivo lo sviluppo di un modello di RSC che renda il remanufacturing di elettrodomestici alla fine del ciclo di vita una strada economicamente percorribile nel mercato cinese.

## ABSTRACT

This research project derives from the Individual Project that was developed at Nanjing University of Aeronautics and Astronautics (NUAA) in the period May/September 2014, because of the Double Degree agreement set between Pisa and Cranfield for the year 2013/2014. The project is a work package of a research program called “*7 th Framework Programme for Research and Technological Development (FP7)”,* sponsored by the European Community and it was wholly carried out in Nanjing, China*.* Traditionally, Chinese home appliances companies consider End-of Life (EOL) products as an automatic financial loss rather than an opportunity to increase the business profitability. Remanufacturing seems an EOL alternative, which could increase profits and at the same time reduce waste and pollution. In this regard, there is a need to develop a profitable Reverse Supply Chain (RSC) model, which motivates Chinese home appliances companies to take back EOL products for remanufacturing. This thesis seeks to develop a RSC model, which makes EOL home appliances remanufacturing an economically viable EOL alternative in the Chinese market.

# ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to all those people, which have helped and supported me during these 3 months of thesis project in China.

Firstly, I would like to thank my supervisors Dr. Yuchun Xu and Prof. Ing. Gino Dini. Their support, encouragements and guidance have been fundamental to reach new goals and accomplish successfully this project. Especially, I am profoundly grateful for the opportunity they offered to me. This period in China has been a beautiful experience, which I will never forget.

Secondly, I would like to thank the PhD students in NUAA University in Nanjing. Their continuous help and support to handle and solve every day problems has been fundamental. Especially, I would like to acknowledge Dr. Kun Zheng for its collaboration in the market research carried out.

Thirdly, I would like to express my gratitude to my family back home in Forte dei Marmi for the continuous support they gave me during my MSc in Cranfield and especially during these three months in China. Their love has been determinant for the success of my studies. In addition, I would like to dedicate this thesis to my grandmother Bruna, which passed away last November.

Lastly, I would like to extend my gratitude to all those people I had the chance to meet in China. Thank you for all moments we spent together. I will never forget you.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF EQUATIONS

# LIST OF ABBREVIATIONS

| | |
|---|---|
| RSC | Reverse Supply Chain |
| EOL | End-of-Life |

# 1 INTRODUCTION

## 1.1 Background

Waste Electrical and Electronic Equipment (WEEE) Management is a well known fast increasing waste stream in China with a growth rate from 13 to 15 % per year and nowadays represents one of the main challenges to sustainability (Wei and Liu, 2012).

Over past decade, the life cycle of the home electrical appliances has been considerably shortened, due to technology advancements, compatibility issues, marketing and attractive customer designs. The result is a larger volume of WEEE, which is seriously affecting the environment and causing high pollution level (Kiddee, et al., 2013). The WEEE often contains a large amount of different hazardous materials such as heavy metals and organic pollutants, which can be harmful for both environment and humans. When EOL home appliances are not remanufactured or recycled, new raw materials have to be extracted to produce a new product, resulting in further environmental burden (Zhou and Zang 2009; Cui and Forssberg, 2003; Bains e al., 2006: Bohr, 2007).

Some countries have already implemented regulations to cope with the WEEE growth’s rate in order to reduce it, while others are still lagging behind. In particular, China is considered the biggest producers, importer and exporter of WEEE (Yang at al., 2008). The country represents a huge market for home electrical appliances, which saw its rapid expansion in 1980s (Li et al., 2006; Yang et al., 2008). Nowadays the yearly amount of e-wastes produced in China is over 2.3 million tonnes including refrigerators, air conditioners, printers, computers, washing machines and mobile phones and it is expected to grow considerably (Wei and Liu, 2012; Qu et al., 2013).

Over past years, Chinese government has published industrially-oriented regulations to reduce environmental damages caused by manufacturers, such as eco-industrial parks (Zhu and Cote, 2004; Zhu et al., 2007), circular economy

(Geng et al., 2009) and energy savings and pollution reduction (ESPR) policies (Zhu et al., 2011). Thus, the Chinese government is putting under pressure home appliances manufacturers to take back- EOL products for remanufacturing and this needs RSCs to support. By remanufacturing EOL products, the yearly amount of WEEE generated by home appliances could be reduced, thus benefitting the environment (Plambeck, 2012; Zhang and Wang 2013).

## 1.2 Problem statement

Although, the Chinese government is encouraging companies to take back and remanufacture EOL products in order to reduce e-wastes and pollution, most organisations are lagging to do it, as it is considered a nuisance rather than a profitable avenue. In this regard, Gome Electrical Appliances Ltd set-up its RSC to take back products, which do not meet customers' expectations due to poor quality and EOL products for recycling or landfilling. However, the current RSC adopted is experiencing significant asset value losses due to long products Lead-Time (LT), resulting in low profits generated. Moreover, it is not designed for products remanufacturing, as it is not considered an economically viable EOL alternative.

## 1.3 Project motivation

At light of this, there is a need to improve the current RSC and redesign it for remanufacturing in order to meet the government encouragements and reduce environmental damages. On one side, remanufacturing leads to economic benefits, but it also incurs in extra cost due to the RSC activities carried out to bring back an EOL product to the remanufacturing facility. Therefore, a cost estimation model is needed to assess whether the redesigned RSC is economically viable or not.

## 1.4 Aim and Objectives

The aim of the project is to improve the current Gome’s RSC, redesign it for remanufacturing and develop a cost estimation model to evaluate the economic viability of home appliances remanufacturing in the redesigned RSC. The objectives of this project are:

- To identify RSC activities, strategies and state of art for returned and EOL home appliances in China
- To model the current RSC adopted by Gome
- To improve and redesign the RSC model for remanufacturing
- To develop a cost model to estimate the RSC cost for EOL home appliances remanufacturing
- To apply the developed cost estimation model on a selected case study of EOL refrigerators remanufacturing in order to assess the economic viability of the redesigned RSC model

## 1.5 Thesis structure

This thesis is composed by eight chapters. Chapter 2 explains the relevant literature review on the research topic. In Chapter 3, the research methodology adopted to carry out this project is presented. In Chapter 4, the current RSC adopted by Gome is modelled, improved and redesigned for remanufacturing. In Chapter 5, the cost estimation model is developed and described. In Chapter 6, a case study is performed to assess the economic viability of the redesigned RSC model. In Chapter 7, the discussion about the results of the project is accomplished, and the future work on the research topic is explained. Finally, conclusions are drawn in Chapter 8.

# 2 LITERATURE REVIEW

## 2.1 Introduction

This chapter describes the previous work carried out in the main areas for this project. Literature review has been performed in RSC, remanufacturing and cost estimation. The goal is to have a wider understanding of the state of art in the areas within this project.

## 2.2 Reverse supply chain

The definition of reverse supply chain (RSC) introduced by Guide & van Wassenhove (2002) has been embraced in several studies, which describes RSC as “the series of activities required to retrieve a used product from a customer and either dispose of or reuse it. From a business point of view, the implementation and monitoring of RSC necessitate many investments, though it also carries economic and strategic advantages to enterprises (Brodin, 2002). Indeed, it leads to significant opportunities of cost reductions due to lower prices of raw materials and spare parts and additional profits by capturing the remaining value of EOL products (Álvarez-Gil et al., 2007).

A clear evidence of what mentioned is for example a company in the phone remanufacturing industry, named Recellular, which has remanufactured over a million phones for 10 years and developed a significant profitable market in this area.

Moreover, reverse supply chain has a strategic importance, by helping the enterprise to develop its ‘green image’ with sustainable acknowledgements. (Álvarez-Gil et al., 2007) It helps the firm to create a positive link with consumers in order to improve its competitive edge. For example, Nike encourages its clients to give back their old shoes to be recycled and converted into the basketballs. By doing so, Nike has slowly developed its green management in environmental sustainability and increased number of costumers. From a customer perspective, the product returned are shipped back to repair points for reparation and maintenances. As a result, consumers are free from the risks of buying broken, non-functioning and unsatisfied products. (Álvarez-Gil et al., 2007)

The “green image” combined with improved customer satisfaction increases the customer loyalty to the brand, generates a more stable long-term demand and finally maximizes its long-term success (Wei, 2011).

### 2.2.1 Reverse supply chain activities

If a company is taking in account to set up a RSC, one of the main challenges is to define the proper structure that is designed to keep the cost low and at least maintain the efficiency and effectiveness of the entire organisation. In order to reach the strategic objectives, Guide & van Wassenhove (2002) specified it is critical for the enterprise to evaluate its processes, to decide whether some processes should be outsourced, and choose how to increase the cost efficiency and value recovery of the system. Aside from having the understanding about product groups and waste management processes in the reverse logistics systems, the enterprise should identify the key activities of the RSC processes so as to improve the control and manage its supply chain among all the channel members. According to Blackburn et al. (2004), the majority of RSCs consist of five major processes as shown in Figure 2-1, namely product acquisition, reverse logistics, inspection and sorting, remanufacturing and distribution and sale. Remanufacturing represents one of the viable EOL alternatives. Indeed used products could also be recycled or landfilled depending on the conditions assessed during inspection.

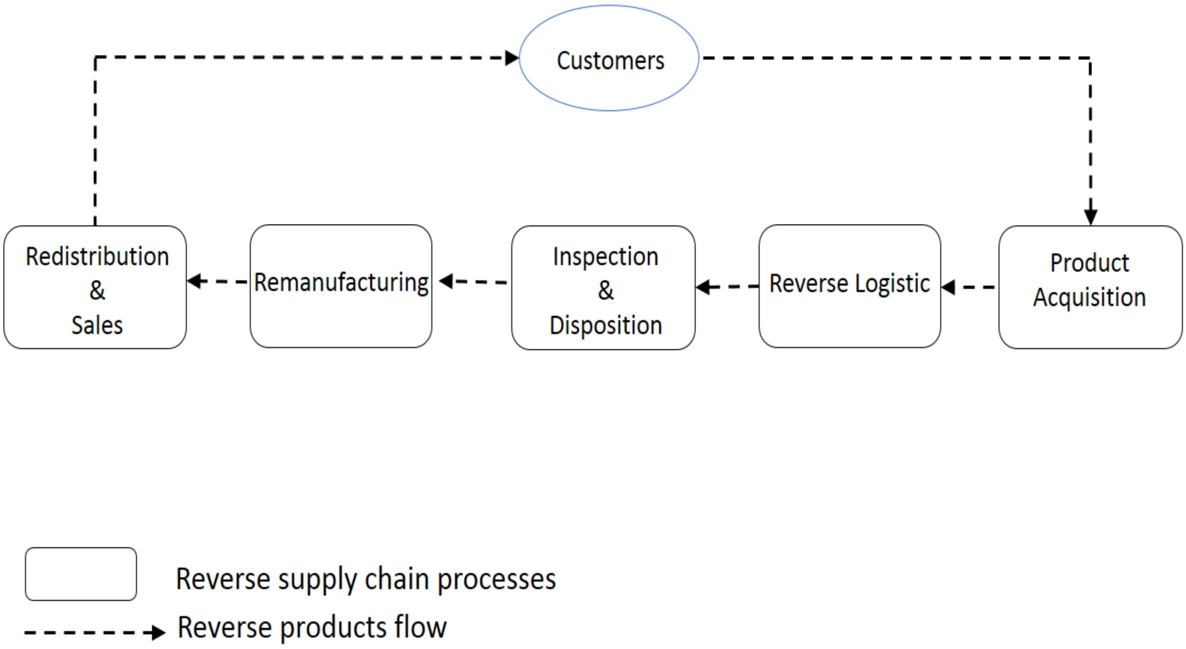


**Figure 2-1 RSC activities (Blackburn et al., 2004)**

- **Product acquisition:** It refers to products collection. Classic examples of product acquisition is the commercial returns or recalls, because defective or damaged products.  Another example are products pulled upstream by several incentive policies, such as deposits or reimbursements for product returns. Lastly, the source of EOL product acquisition is the waste stream, in which products can be recycled, remanufactured and landfilled (Prahinski and Kocabasoglu, 2006). Proper management of all these activities is necessary for the enterprises to guarantee that the cost of restoring an EOL product to its original specifications will not be higher than the cost of manufacturing a new product.

- **Reverse logistics:** It delivers returned and EOL products to the selected facilities for inspection, sorting and disposition (Blackburn et al., 2004). The main activities involved are transportation, warehousing, distribution, and inventory management, with the shared objective of cost reduction and value maximization (Prahinski and Kocabasoglu, 2006).

- **Inspection and disposition**: It aims to determine the quality of returned and EOL products in order to sort them in different groups, according to the recovery strategy selected (Guide and Van Wassenhove, 2002; Prahinski and Kocabasoglu, 2006). Guide and Van Wassenhove (2002) pointed out that to maximise the recovery value of EOL products, the inspection activity should be carried out as early as possible so that the logistics costs related to transportation can be reduced, while restored units can be resold quicker.

- **Remanufacturing**. This process aims to repair or recondition valuable products in order to capture their remaining value (Guide & van Wassenhove, 2002; Blackburn et al., 2003). An important strategic concern regarding the reconditioning process is high degree of uncertainty due to both the timing and quality of returns, leading to low predictability (Guide & van Wassenhove, 2002; Prahinski & Kocabasoglu 2006). Therefore, inspection plays a fundamental role to reduce as much as possible these uncertainties in the earliest stages of the RSC (Guide and Van Wassenhove, 2002).

- **Redistribution & Sales.** It aims to sell the remanufactured products to other market segments composed by those customers that are not interested in new products or that they cannot afford them (Fleischmann et al., 2000; Prahinski and Kocabasoglu 2006).

### 2.2.2 Reverse supply chain strategies

The implementation and management of the RSC involves a huge amount of investments. Every activity implies a considerable volume of costs, from waste acquisition to its final disposition. Most of the companies view the commercial product returns, for either repair or maintenances, not as a need of daily tasks but as a nuisance instead. Therefore, the majority of RSCs have been designed with the main goal to keep the cost associated to product recovery down as much as possible.

The first step of RSC design is to select the best take-back channel, namely the most suitable collection process that send products back to the manufacturers. There are three typical collection methods. Manufacturer collects directly:

- From the users

- Via retailers

- By third-party companies. Outsourcing of the collection process seems increasing in popularity among companies. This alternative enable companies to reduce the investment and cost associated to reverse logistics. Manufacturers such as Compaq, Dell, Cisco and 3M have outsourced the handling of the reverse product flow. The handling of returned products was not a core competency of the companies. Therefore, they estimated high benefit in freeing their distribution centres by the returned flow and moving it into the operations of outsourcers. These outsource suppliers can bring to companies significant cost cutting related to the reverse flow, by achieving economies of scale. In addition, they can provide companies further value-added services such as refurbishment.

### Marginal Time Value

The reverse flow is a considerable asset for several organisations. However, most of that asset value is lost, because it drops with time as it moves through the different steps of the RSC until its final disposition. This loss is mainly due to time delays, which could be minimised, by adopting the proper strategy. Referring to Figure 2-2, the upper line shows the declining value over time for a new product (Blackburn et al., 2004).

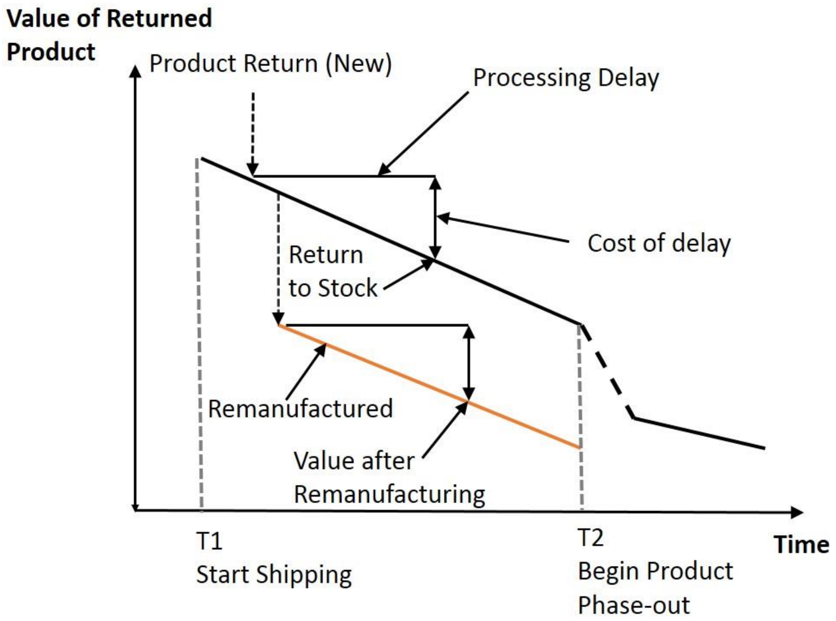


**Figure 2-2 Time Value of Product Returns (Blackburn et al., 2004)**

The lower line represents the decreasing value over time for the remanufactured version of the same product. The time value of returned products differs broadly depending on both the specific industry and product. Indeed, some products are more sensitive to value losses due to time delays in processing. In Figure 2-2, the marginal time value (MTV) is represented by the slope s of the lines. Time-sensitive, consumer electronics goods such as PCs could lose value at rates up to 1% per week, and the rate is even higher as the product is closer to the end of its life cycle (Blackburn et al., 2004). In this regard, depending on the MTV of products, companies have to set-up different RSC strategies in order to reduce as much as possible the value losses and maximise the asset recovery. The three main strategies that can be adopted are the centralised, decentralised and leagile model, which are discussed in further detail below.

**Centralised Model: efficient reverse supply chain**

A scheme of a returns supply chain with centralized testing and evaluation of returns is shown in Figure 2-3. This structure is tailored to achieve economies of scale, both in processing and transport of products. Each returned product is shipped to a central location for testing and evaluation to assess its condition and issue credit.  No effort is made to evaluate the state or quality of the item at the retailer or reseller. The returned products are shipped in bulk in order to minimize shipping costs. When the quality of the product has been defined, it is channelled to the appropriate facility for disposition: restocking, refurbishment or repair, parts salvaging, or scrap recycling. Repair and refurbishment facilities also tend either to be outsourced or centralised, often outsourced.  The structure is tailored to reduce processing costs, but long delays are often experienced and they can be excessive.

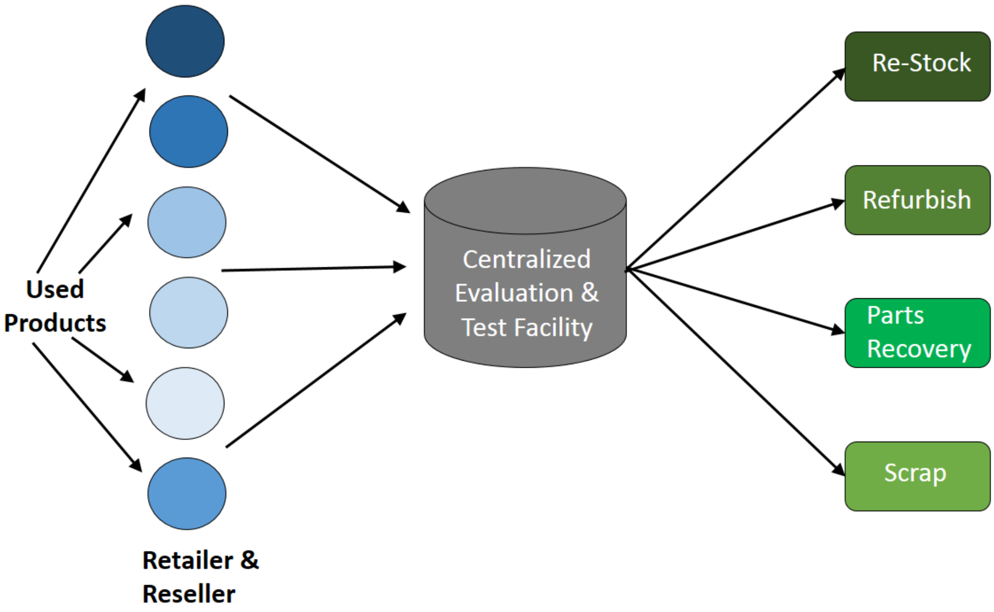


**Figure 2-3 Centralised RSC model (Blackburn et al., 2004)**

The centralized and efficient RSC structure achieves processing economies by delaying credit issuance, testing, sorting and grading until it has been collected at a central location.  Managers of RSCs have broadly implemented this approach, maybe because it embraces postponement, which is typical of the forward supply chain. Postponement (or delayed product differentiation) is an effective strategy, which enables companies to deal with the cost of variety. In forward supply chain, manufacturing and stocking a generic product and delaying the addition of customized modules until the product is closer to the customer, is cheaper. Indeed, it enables companies to avoid the cost associated with separate inventories of all varieties of final product. This structure is also convenient from a third party provider point of view, which offers credit issuances. In addition, the retailer can ship all the items back to a central site, avoiding sorting the returns and shipping to multiple.

High speed and time saving are very expensive and useless when the product has a low MTV, as they add little value to products. In this case, the evaluation and test activities have to be centralised in a single facility to reduce both processing and transportation cost (Blackburn et al., 2004).

### Decentralised Model: responsive reverse supply chain

On the other hand, significant time advantages can be achieved, if the product differentiation is done earlier rather than late. This principle design to achieve early differentiation is called Preponement. Early analysis of product quality can maximizes asset recovery by minimizing the delay cost. When the products are returned by the customer, it can be in four different conditions: new, refurbishable, salvageable for components, or scrap. At arrival, these products can seems identical and they need be tested and assessed to define their real conditions. Using Preponement, a field test is done to divide products into three groups: new, reparable, and scrap. The new, unused products can be replaced in the market immediately, scrap units can be shipped for recycling, and the rest of the units can be sent to a central facility for further assessment and repair. To achieve a responsive RSC through the Preponement techniques, the testing and evaluation of units must be decentralized. The reverse supply chain to achieve responsiveness is shown in Figure 2-4. Rather than having a single point of collection and evaluation, Firstly the unit is assessed at multiple sites, when possible at the point of return from the customer.

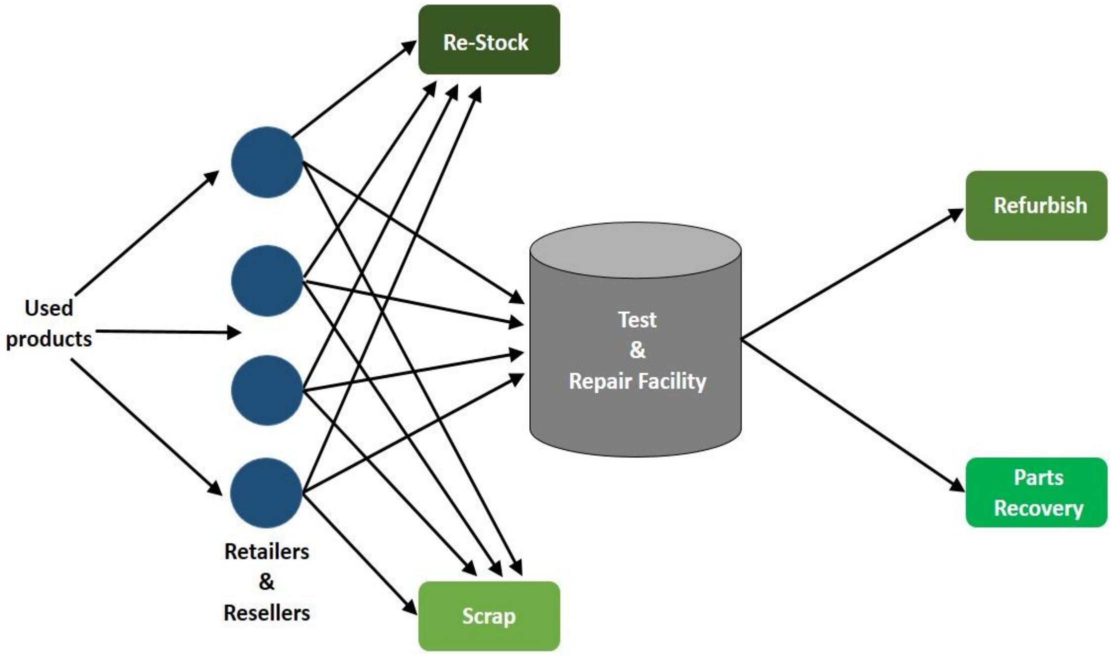


**Figure 2-4 Decentralized RSC model (Blackburn et al., 2004)**

The benefits achievable by using Preponement are:

- Time delays reduction for disposition of new and scrap products; new, unused products have the highest marginal time value and the most to lose from delays in processing.

- The processing of the remaining units is faster, namely the products that necessitate of further testing and repair. By diverting the extremes of product condition (new and scrap) from the main returns flow, the remaining products that need to be shipped to specialist for further analysis of their conditions is reduced. Decreasing the size of recoverable product flow cuts the time delays in queuing and further evaluation, therefore reducing the asset loss for these products as well. For high marginal time value products, Preponement can help companies to increase asset recovery. If a returned product is unused, shipping it to a centralized test and evaluation site could keep the product off the shelves for months. Consequently, the unit could easily lose more than 5 % of its value.

Preponement can reduce part of the loss in that product segment, as well as reduce the return flow to only those products that necessitate of expert technicians to evaluate their conditions.

Two significant issues must be addressed to reach a responsive, decentralized RSCs:

- Technical feasibility: The condition of the product returned must be determined easily and inexpensively in the field

- Induce the reseller to carry on these activities at the point of return. One solution could be the incentive alignment via shared savings contracts, which may help the cooperation between manufacturers and resellers. However, in this case companies needs to understand the precise value of these activities. Vendor-managed inventory (VMI) approach at large retailers represent another option. This would enables the company using their own technicians to carry on the disposition activities at the reseller.

This strategy is suitable for high MVT products as products are processed faster and value losses could be reduced in order to improve the asset recovery (Blackburn et al., 2004).

### Leagile Reverse Supply Chain

It aims to achieve the benefits generated by both the lean and agile approach and the scheme of this strategy is shown in Figure 2-5.

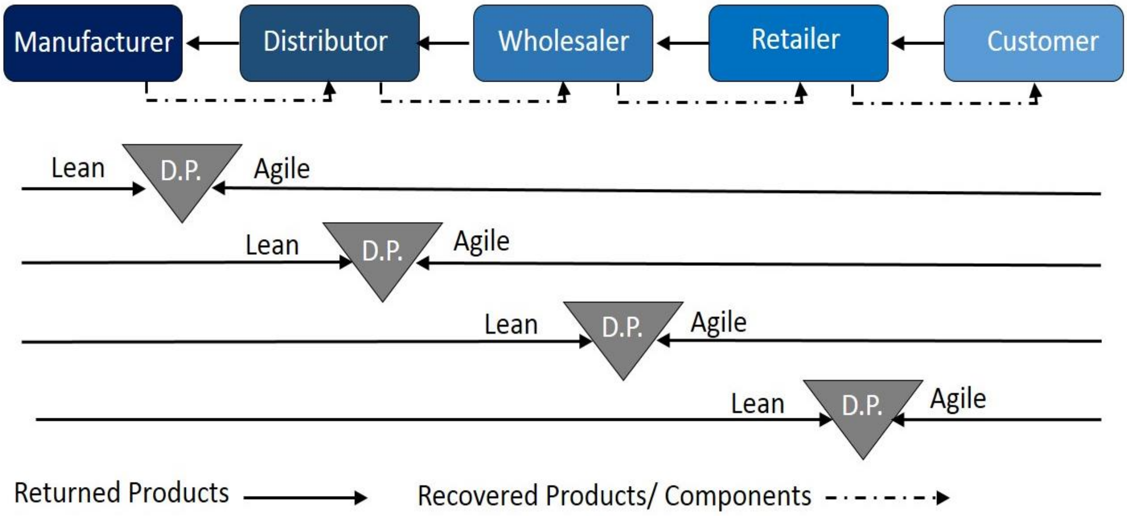


**Figure 2-5 Leagile Supply Chain (Wei, 2011)**

The de-coupling point into the RSC network represents the application of postponement strategy. The aim is to adopt a lean approach for predictable standard products or components and agile strategy for unpredictable, special products or components. Hence, the lean approach is applied from the manufacturer side until the de-coupling point to eliminate the waste and the agile strategy is adopted from the de-coupling point downstream to the customer in order to achieve a quicker response to the volatile market demand and increase the customer satisfaction. By implementing this solution, a company can achieve the benefits coming from both the lean and agile approach such as overall lead-time and cost reductions, and customer service improvements (Christopher et al., 2006).

Several de-coupling point locations in the leagile RSC are shown in Figure 2-5, which act as service spots for products repairs and maintenances, in order to cope with the unpredictable customer demands. Most of the returned products are tested, disassembled, inspected and repaired at the service points, by achieving a reduction in lead-time and waiting time for repairs. Moreover, the closer the position of service point is to the end customers, the higher flexibility and responsiveness the supply chain could reach. Afterwards, from the decoupling point to the manufacturer, a lean strategy is implemented, aiming to cut down the transportation costs using economy of scale, because the demands for spare parts or products are consolidated in the service sites and can be easily measured and precisely predicted. The drawback of this system relies on the creation of inventories at the repair centre sites, leading to extra costs. However this cost can be kept as down as possible, using reliable methods of demand forecasting.

In conclusion a case study conducted by Banomyong et al. (2008), about the comparison between lean or agile reverse system and leagile reverse logistics process, highlight that overall the leagile strategy lead to considerable savings. Indeed the transportation costs and space rental costs for repair spots have been decreased, while more operation costs and inventory holding costs have been caused, which on the total contribute to a large amount of savings from the leagile reverse supply chain structure.

Nevertheless, the application of leagile strategy in a RSC design has some prerequisites:

- generic modular product designs
- productions for various products
- special product designs
- Information technology system to keep track of all the information on sales, demand and inventory level for every type of components or products at each site for repairs and maintenances.

## 2.3 Technologies supporting Reverse Supply Chain management

Several companies have proposed on the market different solutions to cope with the product returned in order to minimize the cost and maximize the customer satisfaction:

- **Online return capabilities and electronic processing of returns:** When customers and retailers want to return a product, they can access to the manufacturer’s website, search by order number of stock keeping units (SKU) to find their product and check the processes and policies for its return. The website and its related software are used to record the reason behind the return, so that the appropriate disposition strategy can be selected in advance. Thereby, the cost of transportation and processing time can be reduced. An example online return capabilities combined with appropriate collection process is represented by Return Valet by catalogue retailer, Spiegel, Inc. In collaboration with Newgistics and local postal offices, Spiegel has implemented a procedure where the mail-ordered products can be returned to local post facilities. The employee authorises and confirms the return procedure online, prints a receipt with the credit amount and ships the item back to Spiegel’s distribution centre, which automatically issues a credit when the product arrives.

- **RFID:** This technology makes it possible to tag almost everything, triggering a revolution in how physical objects are integrated in information services. It is offering important cost reductions in retailers, automotive, pharmaceutical and personal computer both forward and reverse supply chain processes. The RFID technology can also be utilised to avoid fake items return, which are increasing in some industries such as the electronic. One big problem faced by retailers is determining whether a returned products was sold by a store or have been stolen at some point along the supply chain or purchased below the retail value at an outlet store and then returned to a retailer for refund. The serial number on the electronic product code (EPC) of a tag is used to evidently recognise the unique product. Software companies are now proposing RFID-based applications to evaluate the product's validity, so that the proof of purchase is moved from the customer to the item itself. These applications use a reader to 'lock' the tag at the checkout counter for each product when it is sold. If the product then is returned, the tag can proof the product's validity. Networked RFID solutions enable the connection between products tagged with an RFID to an information networks, giving data about the product' s life cycle to all the partners along the supply chain. This technology is helping organisations to improve asset tracking, inventory control and supply-chain operations.

- **Built-in technologies:** Nowadays, the technology built-in in some goods can decrease the cost of field assessment to make Preponement convenient even for items with low marginal costs of time. To achieve this goal, the technology must offer an easy and cheap way to decide:

  - If the product is new and has never been used
  - If the product needs repair
  - If the product has exceeded its useful life

For instance, automobiles have always been equipped with odometers and nowadays automobiles have on-board computers that can make available a time profile of engine usage and warning of potential problems. Designed and built in technology, also is present in simpler goods such as printers and power tools. In Germany, Bosch has built into its power toll, a "data logger; a cheap chip is connected to the electric motor of every tool to record the number of hours of use and the speed at which the tool has been operated. By connecting a returned tool to a test machine, Bosch (or a retailer) can quickly determine if the product is better used for remanufacturing or recycling (operated above a certain number of hours) and if the product has been run at high speed. Tools that have been used under extreme conditions can be recognised and shipped to a recycling centre; the remainder can be sent back directly to dedicated remanufacturing site. Some printers have similar technology to monitor the usage of the product and record the number of pages that have been printed. By equipping the reseller with a handheld device, it is easier and quicker determining the conditions of the product. Using this data, the printer can be more effectively shipped to the selected processing facility, saving time, and improving asset recovery. Hence, companies should focus carefully on the design of the products, developing built-in software able to provide all the necessary information to evaluate properly the condition of the product in the collection point.

- **Web-enabled systems:** They enable all the players belonging to supply chain to collaborate and exchange data. Buyers and seller of components can meet online using Internet trading hubs and warranty aggregators, reducing the need of holding large inventories of components. Vendors of e-service solutions, such as Viryanet and iMedeon, have created systems that integrate wireless communications with Internet applications to build a portal. These portals offer a virtual-service environment to companies in field service such as depot repair and remanufacturing support services. Thus, companies can communicate and interact on an online, real-time basis concerning the status of a single, specific transaction regardless of who made the demand, who is providing the solution, or where in time the transaction is occurring. Web-based collaborative return authorisation (WCRA) seems to be a commercially feasible system that has been introduced to cope with different reverse logistics activities. WCRA improve the visibility of suppliers, manufacturers, third-party logistics providers, repair depots and customers and controls the flow of material from one point to another point along the reverse supply chain. The host ERP has to receive a notification that a third party has received a returned product and a new product has been sent out. The host ERP has also track the disposition of the returned items and coordinate various actions.

Customers can access to the portal, type the information in the system and the ERP enter data manually and the ERP will identifies that inventory, provide the authorisation and product-specific labels. At this point the product will be moved from one point to another in the recovery environment. Being the host ERP installed securely on the web, anyone can access to it and thus reducing the investment related to databases.

## 2.4 Challenges

Increased rules by U.S., European and Chinese governments are obliging manufacturers to invest in reverse logistics processes to enable an appropriate disposition of their goods. Computer manufacturers such as Dell and Hewlett-Packard have been criticised for not properly disposing of the e-waste they have produced. Some organisation are committed to carry on internal research in order to environmentally friendly procedures. Nevertheless, no company will develop processes, which cannot be carried on in the long term because they are not suitable for the company. Therefore, if the regulations will oblige the companies to do so, they simply have to sustain increased manufacturing cost, so the final purchase price for a product will increase for the customer.

In the near future, the returned product flow is predicted to increase drastically, therefore companies need to be aware of the importance of RSC to avoid substantial losses due to inefficiencies in operations. The following challenges have to be addresses by each company in order to set-up an efficient and effective RSC:

- **Meeting consumer needs:** Customers require for the best price and hassle-free returns policies.

- **Volume management:** Particularly in peak seasons, several returned products are time-sensitive to process and restock for resale.

- **Management of costs:** The cost of a returned product can achieve up to 7% to 8% of the cost of goods. If the product has to be remanufactured, this process is labour intensive, because most of the time is not automated.

- **Data management:** Having accurate and reliable information is fundamental to understand why products are returned and develop processes to reduce this flow

- **Disposition of product:** Understanding the optimal location to handle, destroy, salvage and even where to donate goods is fundamental.

- **Regulatory compliance:** Companies necessitate of a global knowledge about waste management laws, regulations, and the company's corporate social responsibility as well.

- **Partnership throughout the product lifecycle:** Creating partnerships along the reverse supply chain is the key to improve the bottom line for each partner. This is the best approach, which leads to well structure and strong supplier agreement, cost and information sharing, therefore to a successful strategy.

Shortened life cycles, increased global competition, new environmental legislation, and ever more lenient commercial take-back policies at resellers for customers will increase product returns. This will lead to a decrease of profit margins in global markets with overcapacity and combined to increased returned product it will make too expensive for organisation the handling of goods. To overcome these problems companies need to design products with an approach that includes the product returns and the operations to carry on with it. This approach has to be a fundamental part of each company/s business model. Companies need to set up the forward supply chain and the reverse supply chain with a design that take benefits of all kinds of product returns and to embrace a final environmentally friendly disposal. Nowadays, the pressure experienced by organisations to find out a convenient process to manage the returned product flow should drive them to develop new strategies to exploit the benefits achievable by the revers supply chain.

## 2.5 Remanufacturing

It is an industrial process to restore products to original conditions or to upgrade products to new specifications. According to Sundin (2005), it allows manufacturers to reuse materials and components and to upgrade the quality and performances of their products, leading to significant economic benefits (Kerr et al., 2001; Smith et al., 2004). A generic remanufacturing process is described by several authors as composed by the steps shown in Figure 2-6 (Sundin, 2004; Van Nunen and Zuidwijk, 2004; Steinhilper, 2001).

**Figure 2-6 Generic remanufacturing process (Steinhilper, 1998)**

- **Disassembly:** This activity aims to separate components and modules from the product in order to remove faulty or damaged parts (Brennan et al., 1997). According to Johansson (1997), in order to set-up an efficient remanufacturing process, companies have to design products, which parts are easy to identify, access, handle and separate, by integrating Design for Disassembly (DFD) techniques in the product development cycle. DFD is an approach to assess the ease of disassembly in the remanufacturing process during new product design (Gupta et al., 2001).

- **Cleaning:** Components and modules have to be cleaned up in the early stages of the remanufacturing process in order to be processed in the next activities. The time required to accomplish this step depends on the quantity of dust, oil and grace that the products accumulates during its life cycle and whether if it has been cleaned by the customer on a regular basis or not. In the home appliances remanufacturing, dust and dirt are removed from products by applying a pressurised cleaning solution composed by water and detergent.

- **Inspection**. Typically, this activity is performed through either visual checks or measurements, employing small hand tools. Recently, built-in technologies such as “data logger” have been embedded in some products to collect and provide comprehensive information about the conditions, under which a product has been run during its life cycle (Errington, 2009). The information given by the data logger can be loaded into a software such as Kirus, used by DecionOne (Schatteman, 2002). This software includes the manufacturer’s own decision rules in order to determine easily whether to repair, remanufacture, recycle or scrap EOL products according to the conditions monitored. Several authors pointed out that these new technologies would significantly decrease the time required to inspect and test products, leading to improvements in the selection of the recovery strategy (Parlikad et al., 2006, Ilign and Gupta, 2012).

- **Reconditioning.** It refers to the activity to bring an EOL product into like new conditions. Depending on the product and industry, this step can be performed using both machining and manual operations to restore surface dimensions or material properties and repair geometrical faults. According to Sundin (2005), in the home appliances industry these activities are accomplished manually by workers, as the only machines used are for testing and cleaning.

- **Reassembly.** Once modules and components are repaired, they have to be reassembled into remanufactured products. This activity is usually performed by workers using the same equipment and power tools utilised in the assembly of a new product.

- **Testing:** The products performances and functionalities are tested in order to guarantee that remanufactured products meet the quality and specifications standards. If the remanufactured product's requirements are satisfied, it can be delivered to the retailing store to be resold.

It has to be highlighted that some steps depicted in Figure 2-6, could be omitted or have a different order, depending on the specific product in order to increase the efficiency and effectiveness of the whole process (Sundin, 2004).

Moreover, when a remanufactured product is placed again into the market, it will compete with new products. Hence, the market gets 'segmented 'into new-product customers and remanufactured product customers. The nature of this segmentation is defined by the amount of products of the two category demanded by the customers and their prices. Thereby, defining the appropriate pricing strategy is a critical decision to avoid the cannibalization of the new product (which generally have a higher profit margin) from the remanufactured one. The possible pricing strategies are as it follows:

- **High pricing:** Setting a high price to give the impression of exclusivity and luxury

- **Low pricing:** Setting a low price to sell high volumes of a product

- **Market segmentation:** Creating differences between products so that they appeal to different segments of the market and pricing them accordingly

- **Price skimming:** Setting a high initial price and dropping it over time as the product becomes outdated

- **Penetration pricing:** Setting a low price initially to gain market share

- **Revenue management:** Changing the price dynamically to adjust for consumer demand.

The choice of the appropriate price discrimination strategy to create a new market segment has to be aligned with the company business goal and therefore with the reverse supply chain design implemented. The common objective is to maximise the revenues stream coming from remanufactured product in order to capture as much value as possible and finally to increase the company's profit. To implement a successful RSC not focuses on the cost minimisation, but on the revenues maximisation, the pricing choice has to be carefully taken. A wrong strategy may lead the cannibalization of new products with higher profit margin and consequently a loss of profit.

Overall, products remanufacturing could lead to significant economic benefits to companies (Kerr et al., 2001; Smith et al., 2004), if the RSC set-up to take back EOL products is properly designed, according to the MVT of the specific products.

## 2.6 Reverse supply chain in the Chinese home appliances industry

Since 1980s, the Chinese economy has been featured by rapid industrial growth, becoming the worlds' top consumer of natural resources and producer of e-wastes generated by household appliances (Abdulrahman, 2014). In 2005, under the pressure of the European Community Directive on WEEE, it has been asked to companies to set-up their RSCs to retrieve faulty products or pay extra money when these products are exported (Zhu and Sarkis, 2006). Thus, Chinese home appliances companies have gradually adopted RSCs in order to have unified environmental standards and avoid inconsistencies in their international operations (Zhu et al., 2011; Zhu and Cote, 2004; Geng and Cote 2003). According to Zhu and Sarkis (2006) , most of the Chinese manufacturers are currently aware of the importance of RSC, but only those companies which export products have initiated their take-back programs (Wu et al., 2001). As reported by Zhu (2004), in the home appliances industry, just 13.4% of the companies have implemented their own RSCs to take-back faulty products, as companies have not realized yet the economic benefits achievable by EOL products remanufacturing (Ying, 2009). Moreover, several barriers are further slowing down the implementation of RSCs between Chinese companies. From a financial perspective, most companies do not have the initial funds to set-up and monitor the returns systems, while from an infrastructure point of view, there is lack of in-house facilities such as storage, vehicles and equipment to handle and transport EOL products (Abdulrahman, 2014). As pointed-out by Zhu and Sarkis (2004), Chinese home appliances companies may lack of experience and of the required management skills to implement their RSCs. One possible option to boost companies to take back and remanufacture EOL products is to make them aware of the economic benefit achievable.

## 2.7 Cost estimation techniques

According to Stewart et al. (1995) and Humphreys et al. (1996), cost engineering has been defined as a scientific and engineering approach, which aims to explore the techniques and principles to predict the cost of activities or outputs. From a broader perspective, it includes aspects of profitability analysis (Curran et al., 2004). Several techniques have been developed to estimate the cost of a product (Lutters et al. 1997). An exhaustive overview of the methodologies and techniques has been provided by Nazi et al. (2006), in which they have been classified into qualitative and quantitative. Moreover, each category has been further divided into more detailed techniques as depicted in Figure 2-7 and explained in the following sections.

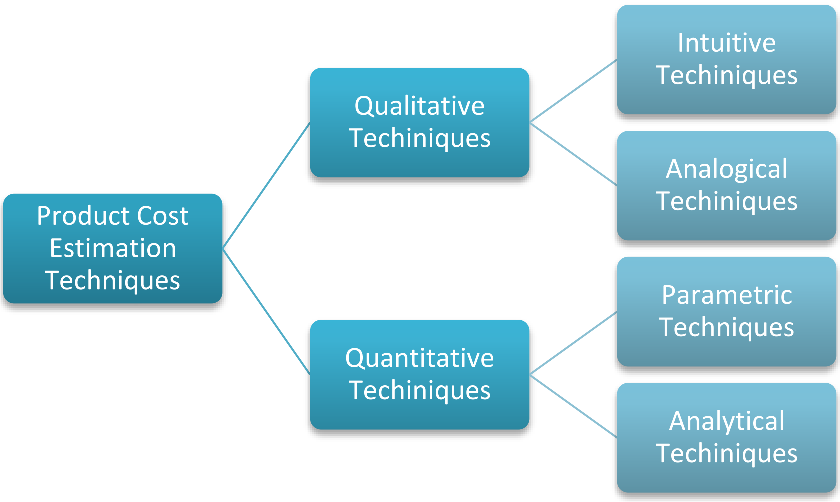


**Figure 2-7 Cost estimation techniques (Niazi et al., 2006)**

### 2.7.1 Qualitative Techniques

They establish the common features between new products and existing products in order to use past data to ease the evaluation of the cost of new products. These techniques can be divided into intuitive and analogical.

a) **Intuitive techniques:** They estimate the cost of a new product, by systematically relying on the stored expertise and knowledge of experts. This knowledge is captured and formalised in a way that can be reused in order to be available when required (Mills et al., 1987, Jackson, 1986). These techniques can be further classified in Case-based methodologies and Decision support systems (DSS).

b) **Analogical techniques:** They estimate the cost of a new product by using historical data technically representatives of the cost of the new product to be calculated. These past data are adjusted upward or downward, according to the complexity of the new product compared to the past one (NASA, 2002; Curran et al., 2004). Therefore, the effectiveness of these techniques rely on the skills of experts to determine accurately the differences between the new and old products (Asiedu, 1998). The cost estimation can be carried out either using regression analysis or back propagation neural-network models.

### 2.7.2 Quantitative Techniques

They evaluate the characteristics, processes and design associated to a specific product in order to estimate its cost. These techniques can be classified into parametric and analytical.

a) **Parametric Techniques:** Statistical techniques based on historical data and mathematical algorithms are employed to express cost as a function of its parameters, also called cost drivers, which change as cost changes. In this regard, a relationship is established between cost as the dependant variable and the cost driving parameters as independent variables (Curran et al., 2004). The implicit assumption besides these techniques is that the same factors, which affected the cost of a product in the past, will affect the cost of the new product in the future (NASA, 2002). According to Curran et al. (2004), these techniques are the easiest to implement and can be applied even by non-technical experts.

b) **Analytical Techniques:** These techniques are used to estimate the cost of activities and components (Curran et al., 2004). Thus, the total cost of a product is calculated by aggregating the cost of all resources consumed. Analytical techniques can be used just if detailed information and data regarding the product design and configuration are available. They can be further divided into different subcategories, namely Operation–based approach, Activity-based approach, Featured-based approach, Breakdown approach and Tolerance-based cost models. In particular, Activity-based approach or Activity-based Costing (ABC) allocates accurately costs among product categories, depending on the amount of resources consumed. The ABC technique aims to identify the relationships among resources, activities and products in order to understand the amount of activities and therefore the resources consumed by a cost object (Jagolinzer, 1999; Needy et al., 2003). As products consume resources at different rates and require different level of support (Cima, 2001, Hughes et al., 2003), this approach enables companies to get reliable information about the true cost of products and therefore their profitability (Cardos et al., 2008; Johnson, 2008).

## 2.8 Research gap analysis

The previous work carried out in this research area shows that some effort have been done to understand why Chinese companies are lagging behind to implement their RSCs. Much attention has been dedicated to which drivers could possibly motivate companies to set-up RSCs in order to remanufacture EOL products. Most of the previous models developed focuses on recycling systems, laws and regulations, as major mean to reduce the amount of WEEE and pollution. In this regard, relevant researches have been carried out regarding the environmental performances of EOL home appliances remanufacturing compared to new products manufacturing. In addition, some earlier studies have been accomplished to investigate the economic benefit of remanufacturing by estimating the cost at component level. However, no RSC and cost estimation models have been developed to evaluate the RSC cost for EOL home appliances remanufacturing from a high-level perspective.

# 3 RESEARCH METHODOLOGY

## 3.1 Introduction

The methodology embraced to accomplish this research is presented in this chapter. The activities carried out to reach the objectives stated in section 1.4 and the respective outputs are exhibited in Table 3-1. Furthermore, an exhaustive explanation of the research methodology adopted is provided.

| OBJECTIVE | ACTIVITY | OUTPUT |
|---|---|---|
| • Identify RSC activities, strategies and state of art for returned and EOL home appliances in China | ○ Carry out literature review | ➢ Understanding of the RSC activities, strategies and state of art for returned and EOL home appliances in China |

| | | |
|---|---|---|
| • Model the current RSC adopted by Gome | ○ Collect data from previous studies, reports and face-to-face interview carried out in Nanjing retailing store<br>○ Understand the policies and services that triggers the current RSC activities through the analysis of the data gathered<br>○ Model the current RSC processes | ➢ Current RSC model in Gome |
| • Improve and redesign RSC model for remanufacturing | ○ Analyse the current RSC processes from a time perspective based on the strategy adopted and information collected<br>○ Define the key performance indicator (KPI) to improve the RSC profit<br>○ Identify the improvements to increase the KPI value | ➢ Redesigned RSC model |

| | | |
|---|---|---|
| | o Redesign RSC processes | |
| • Develop a cost model to estimate the RSC cost for EOL home appliances remanufacturing | o Develop the cost breakdown structure (CBS)<br>o Identify the cost drivers<br>o Establish the cost estimation relationships (CERs)<br>o Develop the cost model framework and architecture<br>o MS Excel programing | ➢ Cost breakdown structure (CBS)<br>➢ Cost drivers<br>➢ Cost estimation relationships (CERs)<br>➢ Conceptual cost estimation model<br>➢ Cost estimation model implemented |
| • Apply the developed cost estimation model on a selected case study of EOL refrigerators remanufacturing in order to assess the economic viability of the redesigned RSC model | o Perform a case study related to EOL refrigerators remanufacturing | ➢ Economic viability assessed |

**Table 3-1 Research methodology adopted**

## 3.2 Research methodology adopted

First of all, the literature review was carried out in order to gather knowledge on the main project areas, namely reverse supply chain, remanufacturing and cost estimation techniques. Moreover, returned and EOL home appliances strategies adopted by Chinese companies were investigated in order to understand the state of art.

The RSC adopted by Gome Electrical Appliances Ltd. was selected as case study to be improved and redesigned for remanufacturing. Data and information about the current reverse processes implemented were collected, by reviewing previous studies, annual and interim reports, press releases and announcements made by the company. An additional information source was used to increase the understanding of Gome reverse processes. A non-structured interview was conducted in the retailing store of Nanjing to Gome's employees. The data collected from these different sources were compared and combined to identify the policies adopted by Gome and the services offered to customers.

The current reverse processes were analysed from a time perspective and the recovery efficiency of the system was selected as KPI to drive the improvements. Afterwards, the remanufacturing process was modelled and integrated together with the improvements identified in the redesigned RSC.

The development of the cost estimation model was conducted by adopting the procedure described in the "NASA Cost Estimating Handbook" (NASA, 2002). Thus, the cost breakdown structure was built, the cost drivers identified and the cost estimation relationships established. In this way, it was possible developing the framework and architecture of the cost model. Moreover, the cost model developed was implemented in MS Excel in order to provide a tool, which enables the user to estimate the total RSC cost for home appliance remanufacturing. The key elements which drove the selection of this software platform were the user friendliness, compatibility with other software applications, popularity, flexibility and software availability.

The economic viability of the redesigned RSC model was assessed by carrying out a case study. In this regard, the cost estimation model was applied to assess the RSC cost for refrigerators remanufacturing. In addition, a market research was carried out to estimate the potential market and retailing price for a remanufactured refrigerator in China in order to understand the profit margin achievable.

# 4 DEVELOPMENT OF THE REDESIGNED REVERSE SUPPLY CHAIN WITHIN GOME

The methodology shown in Figure 4-8 has been adopted to improve and redesign Gome's RSC for remanufacturing.

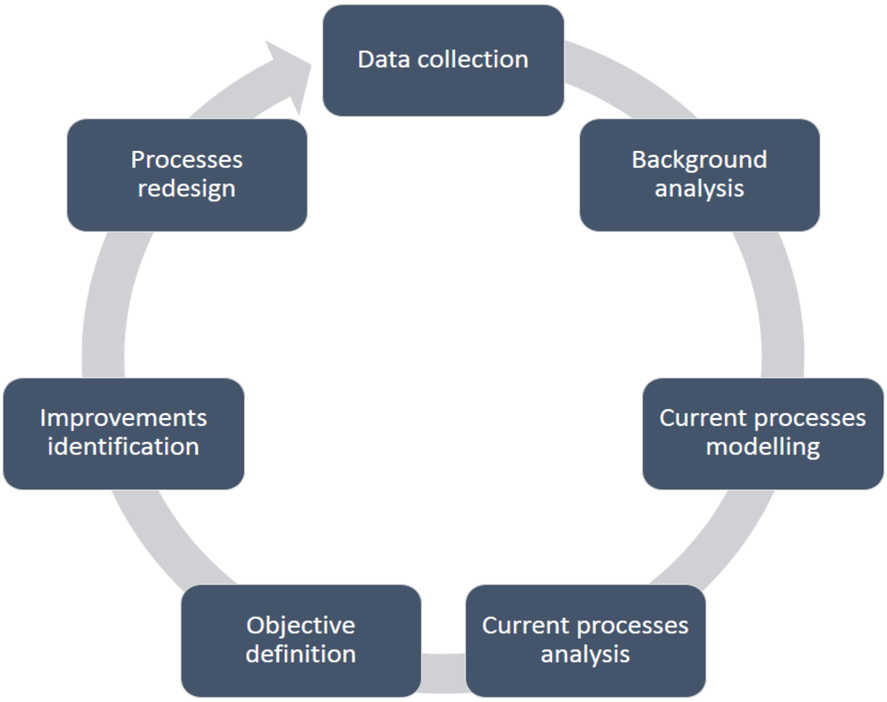


**Figure 4-8 Methodology adopted for RSC redesign**

## 4.1 Data collection

This step has been carried out in order to understand which products trigger the reverse activities and which policies Gome put in place. The information gathered relies on the following different sources:

- Gome's annual and interim reports
- Gome's press releases
- Gome's announcements

- Previous studies and interviews conducted in Gome
- Face-to-face interview to Gome's employees in Nanjing's retailing store

Due to confidentiality issues, the data acquired about the reverse processes set-up by Gome are mainly qualitative.

## 4.2 Background analysis

The current RSC takes back products covered by the Safeguard and Recycling policy in order to offer customers value-added services and increase the completive edge.

The Safeguard policy allows customers to return products in retailing stores within an allotted time for both refunding and exchanging, if products are defective or fail to fulfil the customer's expectation (Gome Electrical Appliances Ltd., 2009).

The Recycling policy offers customers the collection of EOL home appliances. Customers can log-into Gome's website and take an appointment for the collection of used products in order to receive a payment according to the quality of the product returned (Gome Electrical Appliances Ltd., 2014).

## 4.3 Current processes modelling

The current RSC adopted by Gome has been modelled based on the analysis of data and information collected and it is shown in Figure 4-9.

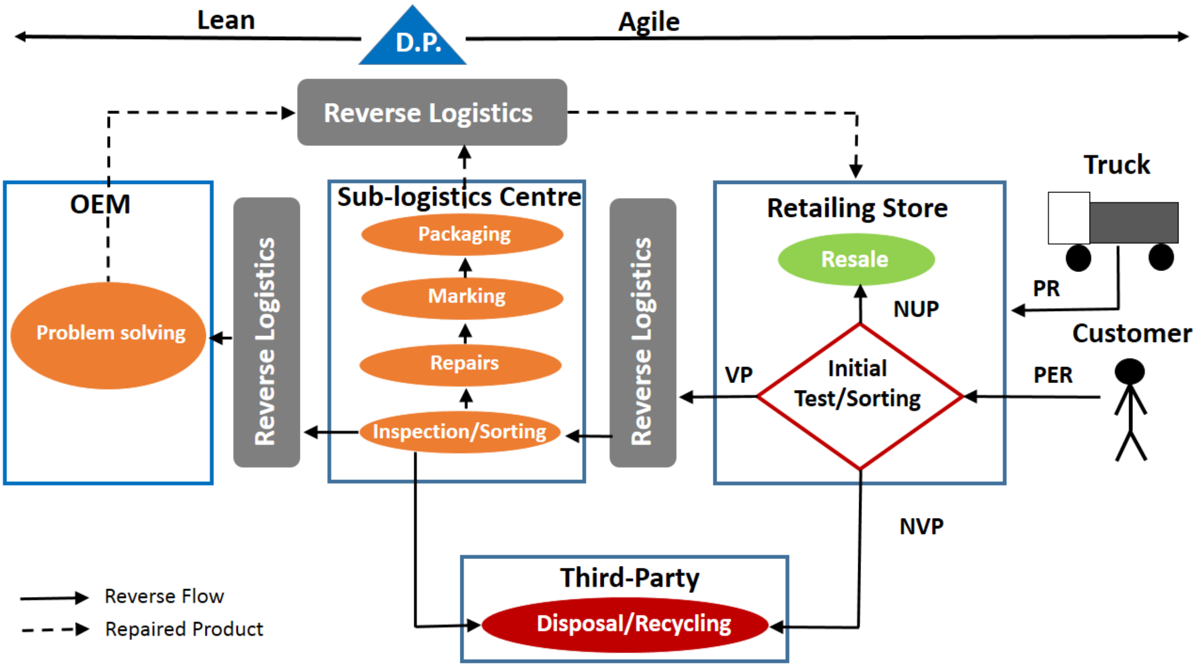


**Figure 4-9 Current RSC model (adapted from: Wei, 2011)**

Referring to Figure 4-9, products for exchange and refunding are returned from customers directly to the retailing store (PER). Products for recycling are collected by Gome in the customer's house and then delivered by truck in the retailing store (PR). Afterwards, PER are tested to evaluate their quality and sorted in three sub-categories, namely New or Unused Products (NUP), Non-Valuable Products (NVP) and Valuable Products (VP).

### New or Unused Products (NUP)

These products after simple renewing tasks carried out by specialists are immediately sent to counters and resold.

**Non-Valuable Products (NVP)**

These products are shipped together with PR to the Third Party for recycling or scraps, as their remaining value is not sufficient to generate a profit margin.

**Valuable Products (VP)**

The remaining value of these products is enough to achieve a profit margin, so they are shipped in bulk by truck to the associated sub-logistics centre through the reverse logistic. In this centre, skilled engineers are employed to perform a further evaluation of the product quality and determine its remaining value. According to the extent of damages, products can be either delivered to the Third Party for scrap or recycling or can be repaired, marked and wrapped in plastic to be resold in the retailing store.

However, some of these products could have complex internal problems that cannot be solved by specialists. In this case, they are delivered to the Original Equipment Manufacturer (OEM). In the OEM facility, products are inspected again to identify the root causes of low quality and performances, problems are solved and products are delivered to the sub-logistics centre and eventually resold in the retailing store.

## 4.4 Current processes analysis

In this section, the current reverse processes are analysed from a time perspective according to the benefits and drawbacks associated to the different RSC strategies and design discussed in section 2.2.2. The current problems experienced have been identified based on the data gathered and confirmed during the interview conducted in Nanjing retailing store.

### Leagile strategy

The current RSC model has been designed in order to achieve the benefits of the leagile strategy, as it follows:

- From customers to sub-logistics centre, the system aims to speed up the collection and sorting to ensure responsiveness and high customer satisfaction, by adopting the decentralized model.

- From sub-logistics centre to the OEM, the system aims to reduce wastes. In this case, the centralised model is adopted. Indeed once the product has been collected, refunded or exchanged, the customer is already satisfied, so next activities focus on cost reduction. The enabler of this strategy is the decoupling point in the sub-logistics centre, which acts as a repair spot to cope with the unpredictable customer demand and hold the spare parts inventory. By centralising the repair activities, products are consolidated to achieve operations efficiency. In addition, the valuable products (VP) are shipped in bulk among facilities to achieve full-load trucks in order to reduce transportation cost.

### Problems experienced

The main problem experienced is long products Lead-Time (LT), defined as the time that elapses from the moment a product is collected in the retailing store to the moment a product is repaired and ready to be resold. The long products LT, which is approximately 15 days, is caused by:

- The size of the reverse flow from the retailing store to the sub-logistics centre, due to the large amount of returned product for exchange or refunding

- The full-load trucks policy adopted by both retailer and manufacturer. Indeed, products are held in storage areas for several days before being delivered to the selected facility in order to achieve cost reductions in transportation.

The slow products processing causes significant asset value losses, especially for high MVT products, resulting in reduced profitability of the whole system.

## 4.5 Objective definition

The goal is to reduce the asset values losses caused by the current RSC design and integrate the remanufacturing process to capture the remaining value of EOL products.

The current system performances are evaluated based on the recovery efficiency (RE), which is estimated as it follows:

$$\boldsymbol{RE = Value\ Recovered \div Resources\ used} \tag{4-1}$$

According to Geethan et al. (2011), the recovery efficiency is one of the major key performance indicators (KPIs) to evaluate the profitability of the whole RSC. Indeed, if the value recovered increases and the resources consumed decrease, the profit generated by reselling a recovered product will be higher.

## 4.6 Improvements identification

Relevant opportunities to reduce asset value losses and the amount of resources used to perform the reverse activities have been identified, by benchmarking the RSC strategies and design solutions adopted by Gome’s competitors both in China such as Suning Appliance (Wei, 2011) and worldwide. The improvements proposed with the respective benefits and impact on the RE of the current RSC are shown in Table 4-2.

| IMPROVEMENT | BENEFITS | IMPACT ON RE |
|---|---|---|
| **Early and complete products categorisation** | • Shortened LT for valuable products<br>• Waste reduction | ➢ Increased value recovered<br>➢ Decreased resources used |
| **Delocalisation of repair activities in the retailing store** | • Shortened LT for repairable products<br>• Reduced operations cost for repairable products | ➢ Increased value recovered<br>➢ Decreased resources used |
| **Implementation of EOL products remanufacturing** | • Capture the remaining value of EOL products | ➢ Increased value recovered |

**Table 4-2 Improvements identified to increase the RE**

- **Early and complete products categorisation:** The quality of both returned products and EOL products is completely assessed in the retailing store through an accurate field test. This test aims to select early the best recovery strategy for each product according to the remaining value. In this way, the size of the returned flow is decreased, as just valuable products are delivered to the sub-logistics centre, so they can be processed faster. Furthermore, the resources consumed to handle, inspect and transport non-valuable products are a waste, as these products do not contribute to generate profits. By identifying these products during the initial test, they are handled and inspected just in the retailing store and directly transported to the Third Party, leading to increased operations efficiency. Overall, the products value losses due to time delays could decrease and the value recovered increase. Moreover, operations could be carried out saving a significant amount of resources, resulting in higher RE.

- **Delocalisation of repair activities:** The repair activities are moved from the sub-logistics centre to the after-sale service centre set up in the retailing store. In this way, the LT of repairable products is shortened and operations efficiency increased, as transportation between the retailing store and the sub-logistics centre and inspection/sorting in the sub-logistics centre are not necessary anymore. Indeed, the best repair strategy is selected in the after-sale centre, where products are handled and repaired. Overall, the value recovered for repairable products could increase and the resources consumed to accomplish repair activities decrease, leading to higher RE.

- **Implementation of EOL products remanufacturing:** In the current RSC, EOL products are collected just for recycling or disposal. This leads to decreased RE, as no value is recovered from those products, while resources are consumed for their collection, handling and transportation. Therefore, in the redesigned RSC model, the remanufacturing process is integrated as a viable EOL option in order to increase the amount of value recovered and achieve higher RE.

## 4.7 Processes redesign

The current RSC model has been redesigned in order to increase the RE of the system and consequently the profit, by implementing the improvements previously identified. The redesigned RSC model is shown in Figure 4-10.

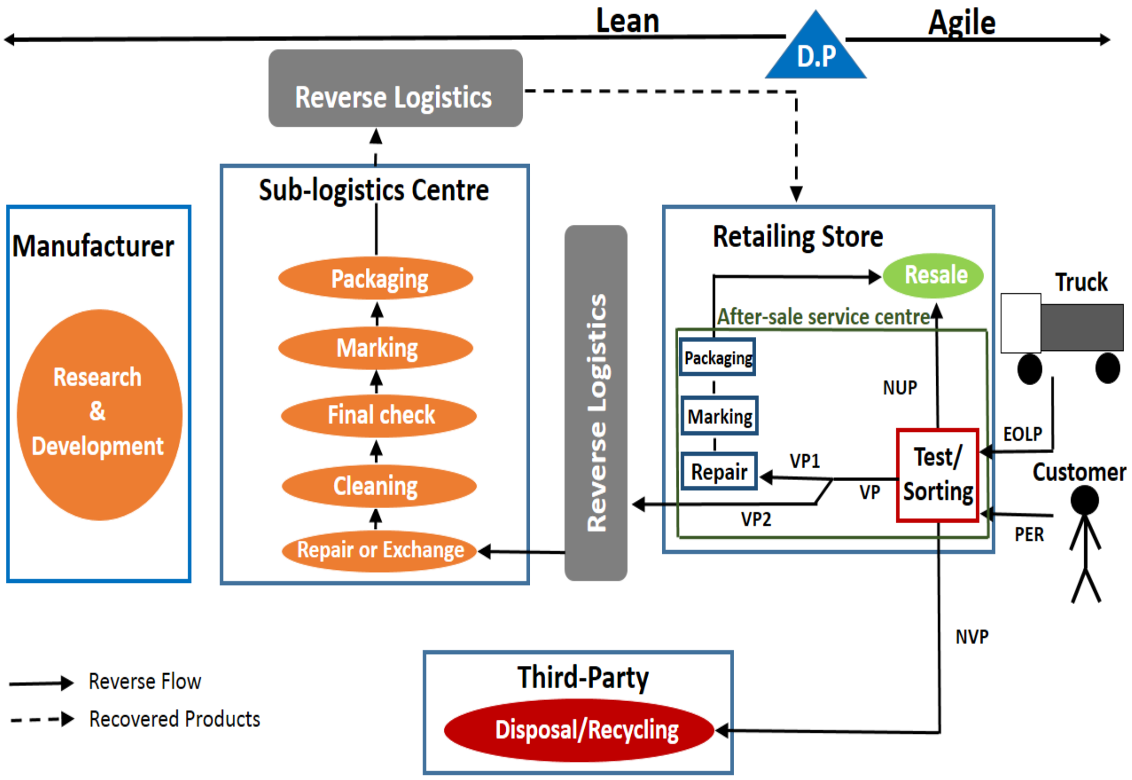


Figure 4-10 Redesigned RSC model

The reverse flow is triggered by both End-Of-Life products (EOLP) collected by truck in the customers' houses and Products for Exchange and Refunding (PER), returned directly from customers to the retailing store. Instead of delivering EOLP directly to the Third Party for recycling or disposal, EOLP are collected into the retailing store, disassembled and tested together with PER. The test performed by specialists aims to determine the remaining value of both EOLP and PER in order to select the best recovery strategy. Hence, valuable products (VP) are sorted further in two sub-categories, namely VP1 for quick repair and VP2 for remanufacturing.

### VP1 for quick repair

This sub-category is composed by those products, which have simple problems that can be easily solved, by adjusting mechanical parts. These goods are immediately repaired in the after-sale service centre, where worktables adjustable in height are installed to ease the accomplishment of the task, then marked, packed and eventually resold.

### VP2 for remanufacturing

This sub-category is composed by those valuable products, which cannot be repaired in the retailing store and have to be remanufactured in the sub-logistics centre to be restored to their original specifications. In the sub-logistics centre, the home appliances remanufacturing line operates to bring EOL products into like new conditions. The line is labour intensive as activities are carried out manually and the only machines used are for testing and cleaning. According to Sundin (2005), the steps, which compose a generic home appliances remanufacturing line are shown in Figure 4-11.

**Figure 4-11 Remanufacturing steps (Sundin, 2005)**

- **Repair or Exchange:** Once the VP2 has reached the sub-logistics centre, according to the recovery strategy selected, faulty and damaged parts are either repaired or replaced with new and recovered spare parts.

- **Cleaning:** According to Sundin (2005), this activity could be time-consuming depending on the structure of the specific product. Therefore, it should be carried out by using a steam pressure-cleaning machine in order to remove dust, oil and grace efficiently.

- **Final check**: According to Adler (2006), each home appliances has to pass electrical safety tests in order to guarantee that the product respect the international safety standards. Each test is executed automatically by an inspector machine, which investigate the electrical behaviour of the product’s components according to the requirements previously defined. In this activity, workers are employed just for plugging and unplugging the product in the machine.

Finally, the home appliances are marked as remanufactured products and eventually wrapped in plastic. If a product has low MVT, it is shipped in bulk to the retailing store to achieve full-load truck and cut down transportation cost. If a product has high MVT, a trade-off between transportation cost and product value losses due to time delays is taken into account to maximise the profit reachable.

# 5 COST ESTIMATION MODEL DEVELOPMENT

## 5.1 Cost estimation process adopted

The aim of the cost estimation model is to assess the high-level RSC cost for EOL home appliances remanufacturing. The model has been developed by following the methodology adopted by NASA (2002) show in Figure 5-12, which is described in further detail in the next sections.

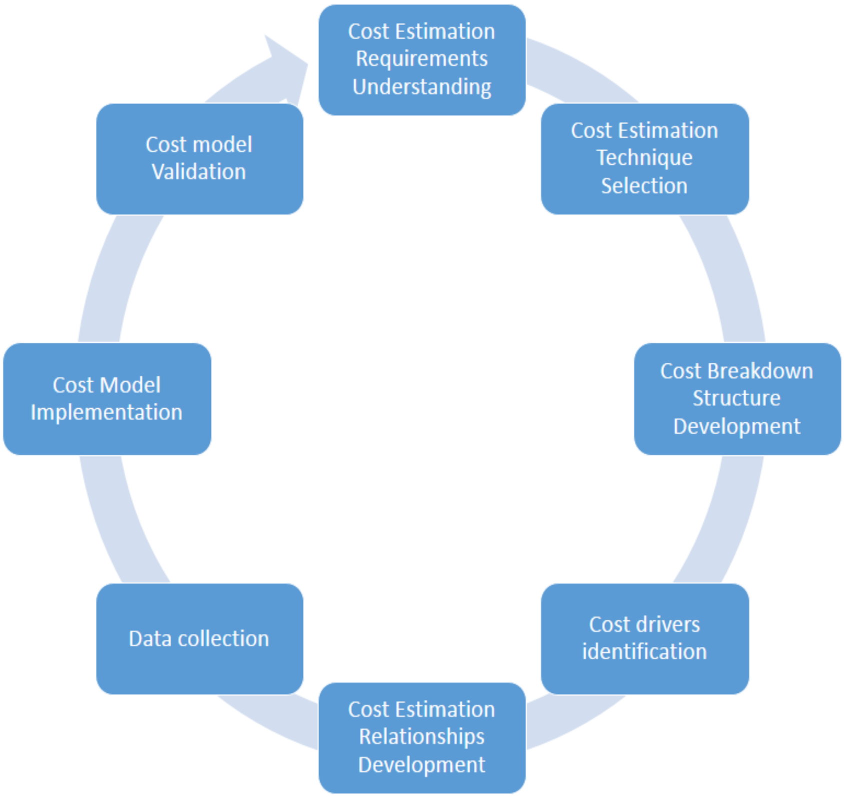


**Figure 5 12 Cost estimation process (adapted from: NASA, 2002)**

The aim of the cost estimation model is to assess the high-level RSC cost for EOL home appliances remanufacturing. The model has been developed by following the methodology adopted by NASA (2002), which is described in further detail in the next sections.

## 5.2 Cost estimation technique selection

In order to select the most suitable cost estimation technique to evaluate the total RSC cost for home appliances remanufacturing, the four elements shown in Figure 5-13 have to be understood.

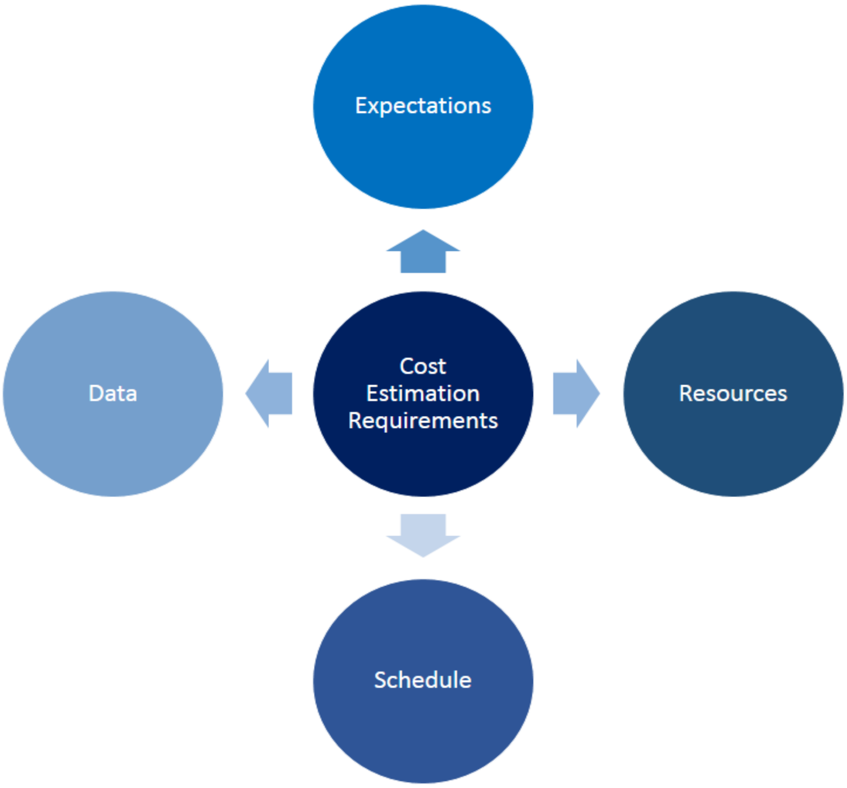


**Figure 5-13 Cost estimation requirements (NASA, 2002)**

**Expectations:** The cost model developed is expected to provide the total RSC cost for remanufacturing a home appliance in the redesigned RSC model. The outcome of the model could be used to assess the economic viability of the redesigned RSC.

**Data:** The data gathered to develop the cost model consists of:

1. Remanufacturing process data. They include the Operation Time (OT) needed to carry out each activity, labour cost, machine cost, electricity cost

and new spare parts cost. This data have been gathered from a previous work carried out by Sundin (2004) in the Electrolux remanufacturing facility in Sweden, a non-structured interview conducted to the Shop Floor Manager in Siemens factory in Nanjing and from Internet websites.

2. Transportation cost data. They include the distance between facilities, the labour cost and the fuel cost. This data have been gathered both from literature review and internet websites.

3. Storage cost data. Due to lack of significant information, the estimation of this cost element rely on the total cost breakdown for home appliances remanufacturing developed by Sundin (2004).

4. Retailing price. It has been estimated through surveys (see Appendix B) to potential Chinese customers in Nanjing.

**Resources.** One cost estimator (MSc student) has been in charge of developing the cost model. Two PhD. Students of Nanjing University of Aeronautics and Astronautics (NUAA) have been employed as translators for the surveys.

**Schedule.** The development of the cost estimation model has to be accomplished in approximately four weeks.

By taking in consideration the cost estimation requirements previously defined, the qualitative and parametric techniques have been discarded to develop the cost model, due to lack of significant past data regarding home appliances remanufacturing. Consequently, analytical techniques are the most suitable to be adopted in order to estimate the total RSC cost for home appliances remanufacturing. In particular, the Activity-Based Costing (ABC) technique has been selected to carry on the cost estimation. ABC technique estimates the total cost, by identifying the activities needed to collect, handle and remanufacture the product along the RSC and the respective resources consumed. Afterwards, the amount of different resources consumed by the reverse activities is estimated based on the time required to accomplish each of the activities. Finally, the unit cost of each resource consumed is calculated in order to estimate the total cost for each activity.

## 5.3 Cost breakdown structure (CBS) development

The redesigned RSC model described in chapter 4 has been used to identify the activities performed from the collection of an EOL product to the sale of the same remanufactured product in the retailing store. Afterwards, the main cost elements of these activities have been defined. The information needed to identify the cost elements associated to each activity previously identified has been gathered from the literature review. In this way, it has been possible developing the CBS shown in Figure 5-14.

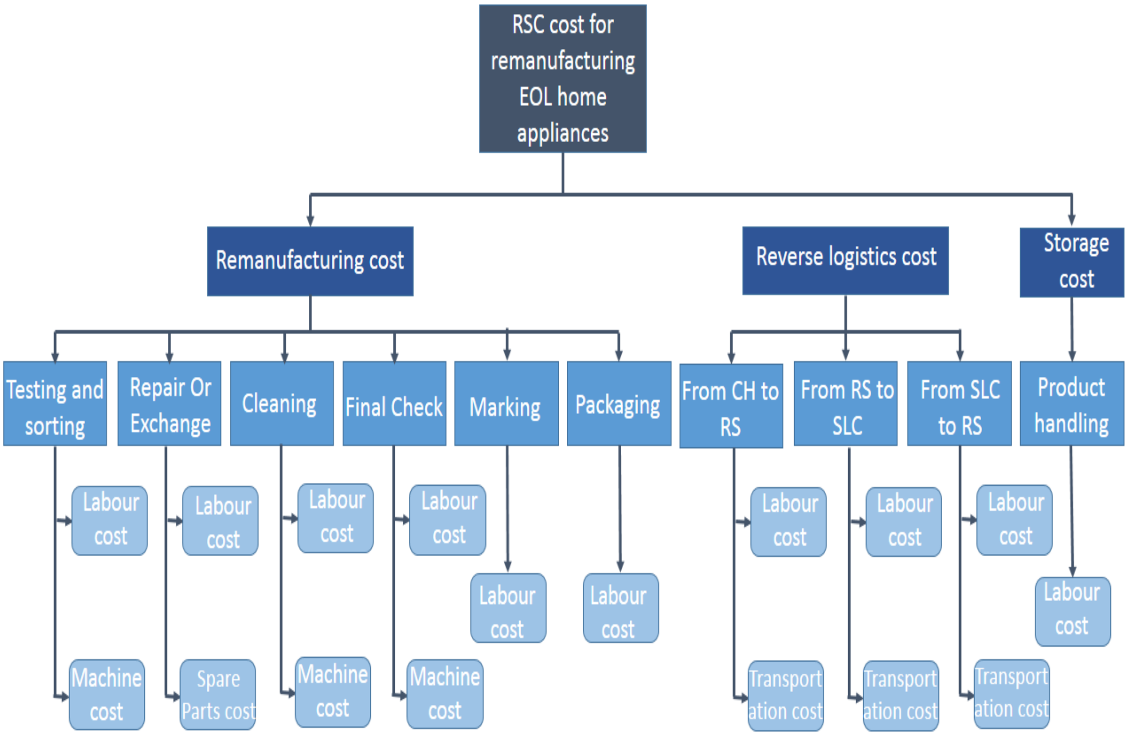


Figure 5-14 CBS for EOL home appliances remanufacturing

### 5.3.1 Activity cost elements identification

The activity cost elements have been identified based on the literature review and are considered as follow:

- Labour cost: It represents the direct cost of workers employed to accomplish the activity taken into consideration.

- Machine cost: It represents the cost of equipment used to accomplish the activity taken into consideration. This category cost includes electricity, depreciation and tools.

- Spare Parts cost: It represents the cost of new or restored components and modules used to replace faulty parts that cannot be repaired due to poor quality.

- Transportation cost: It contains the cost of the fuel needed to transport a product from a facility to another

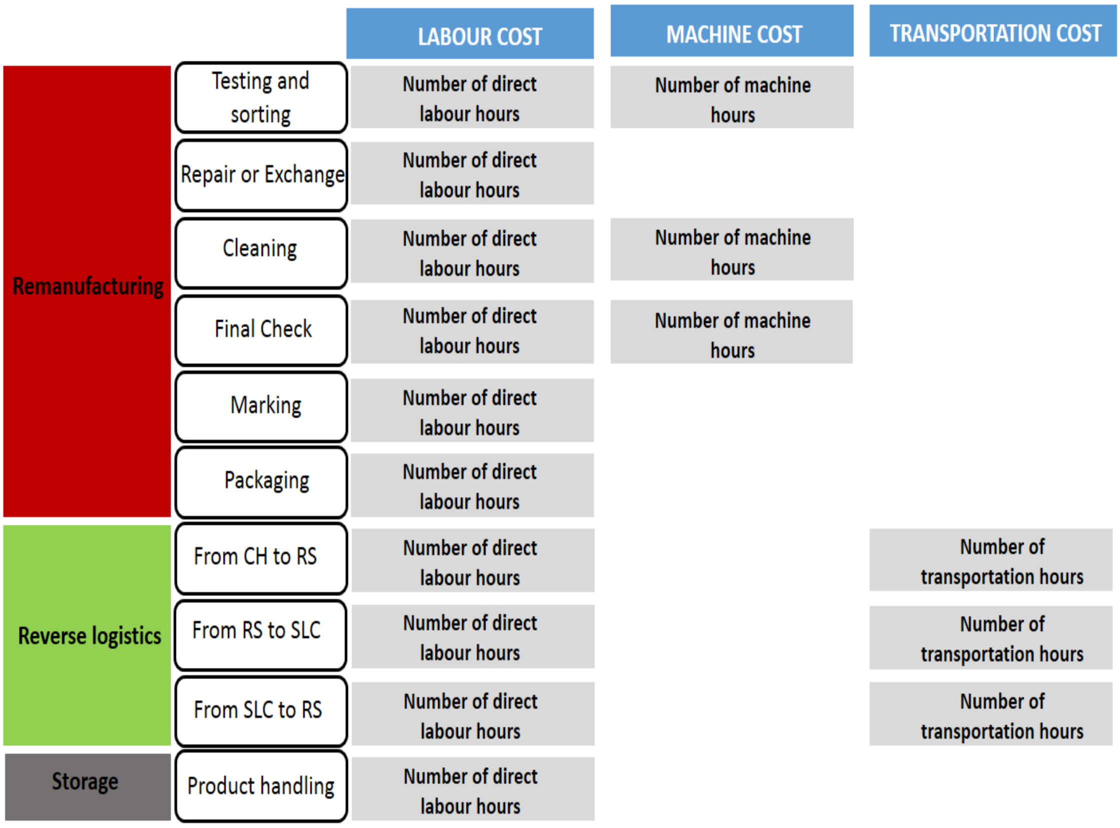
## 5.4 Cost drivers identification

The cost drivers are parameters or variables, which directly affect the cost of an activity. As it can be found in literature, the cost estimation process can be carried out by using the “time-driver ABC technique”. This approach allows cost drivers to be estimated on the base of the practical capacity of resources supplied. Two different types of cost drivers, namely transactional drivers and duration drivers can be used to estimate cost:

- Transactional drivers: They count the number of times an activity is performed and typical examples are number of setups, number of production runs, number of shipments etc.

- Duration drivers: They calculate the time required to carry out an activity and typical examples are number of direct labour hours, number of machine hours, number of material handling hours etc.

Because of the availability of information regarding operation times needed to perform home appliances reverse activities, the cost estimation has been carried out by selecting duration drivers as parameters and variables, which affect the cost. The cost drivers identified for each activity involved in the redesigned RSC model are shown in Table 5-3.



| | | LABOUR COST | MACHINE COST | TRANSPORTATION COST |
|---|---|---|---|---|
| **Remanufacturing** | Testing and sorting | Number of direct labour hours | Number of machine hours | |
| | Repair or Exchange | Number of direct labour hours | | |
| | Cleaning | Number of direct labour hours | Number of machine hours | |
| | Final Check | Number of direct labour hours | Number of machine hours | |
| | Marking | Number of direct labour hours | | |
| | Packaging | Number of direct labour hours | | |
| **Reverse logistics** | From CH to RS | Number of direct labour hours | | Number of transportation hours |
| | From RS to SLC | Number of direct labour hours | | Number of transportation hours |
| | From SLC to RS | Number of direct labour hours | | Number of transportation hours |
| **Storage** | Product handling | Number of direct labour hours | | |

**Table 5-3 Cost drivers for the redesigned RSC model**

The number of spare parts used to replace faulty components and modules varies depending on the quality of each part within an EOL product. Determining the type and quantity of components in advance is complex (Thierry et al., 1995; Seitz and Peattie, 2004). For the purpose of the cost estimation, this cost element is considered as fixed, namely it does not vary according to a cost driver.

## 5.5 Cost estimation relationships (CERs) development

The CERs express the relationships between the cost elements of each activity within the redesigned RSC model and the cost drivers identified. Based on the cost drivers shown in Table 5-3, each cost element is defined as a function of the time consumption. In this way, the cost estimation is performed for the three cost elements within the CBS and it is described in detail below.

**Labour cost:** This cost element affects the cost of remanufacturing, transportation and storage. The relationship between this cost element and the activities involved in these processes is described as it follows:

For the remanufacturing processes, the labour cost is estimated multiplying the labour rate by the total remanufacturing time and it is estimated as it follows:

$$\boldsymbol{C_{labour,r}} = \boldsymbol{R_{labour}} \times (\boldsymbol{t_{remanufacturing}}) \tag{5-2}$$

Where,

$C_{labour,r}$: Remanufacturing labour cost (£)

$R_{labour}$: Labour rate (£/hour)

$t_{remanufacturing}$: Total remanufacturing time, which includes operations time, loading time and operator allowance time.

*Labour rate* ($R_{labour}$)

It is estimated by dividing the monthly salary by the number of working days per month and the number of working hours per day. It is estimated as follows:

$$\boldsymbol{R_{labour}} = \boldsymbol{W_m} \div \boldsymbol{D_m} \div \boldsymbol{H_d} \tag{5-3}$$

Where,

$R_{labour}$ : Labour rate (£/hour)

$W_m$ : Monthly wage (£)

$D_m$ : Number of working days per month

$H_d$ : Number of working hours per day

*Loading time* ($t_l$)

The loading time is the time needed to load, unload and transport a component from a workstation to another. It is calculated as a percentage of the operation time as it follows:

$$\boldsymbol{t_l = 0.1 \times t_{op}} \tag{5-4}$$

Where,

$t_l$ : Loading time (hour)

$t_{op}$ : Operation time (hour)

*Operator allowance time* ($t_{oa}$)

It includes the allowance for both personal needs such as water, restroom, phone call etc. and fatigue due to work related stress and conditions. It can be calculates as a percentage of the operation time as it follows:

$$\boldsymbol{t_{oa} = 0.05 \times t_{op}} \tag{5-5}$$

Where,

$t_{oa}$ : Operator allowances time

$t_{op}$ : Operation time (hour)

For the transportation, the labour cost is calculated by multiplying the labour rate by the summation of the transportation time from the customer's house to the retailing store, from the retailing store to the sub-logistics centre and from the sub-logistics centre to the retailing store. It is estimated as it follows:

$$\boldsymbol{C_{labour,t}} = \boldsymbol{R_{labour}} \times (\boldsymbol{t_{transportation,c-r}} + \boldsymbol{t_{transportation,r-s}} + \boldsymbol{t_{transportation,s-r}}) \tag{5-6}$$

Where,

$C_{labour,t}$: Transportation labour cost (£)

$t_{transportation,c-r}$: Transportation time from customer's house to retailing store (hour)

$t_{transportation,r-s}$: Transportation time from retailing store to sub-logistics centre (hour)

$t_{transportation,s-r}$: Transportation time from sub-logistics centre to retailing store (hour)

The transportation time includes both the operation time and loading time. The loading time is the time needed to load a product into a truck and to unload it from the truck. The loading time for the transportation process is estimated as shown in equation 5-4 for the remanufacturing process.

For the storage process, the labour cost is calculated by multiplying the labour rate by the product handling time and it is estimated as it follows:

$$\boldsymbol{C_{labour,s}} = \boldsymbol{R_{labour}} \times \boldsymbol{t_{handling}} \tag{5-7}$$

Where,

$C_{labour,s}$: Storage labour cost (£)

$R_{labour}$: Labour rate (£/hour)

$t_{handling}$: Product handling time (hour)

*Product handling time (* $t_{handling}$)

The product handling time, which includes the time required to move, store, protect and control a product in the RSC cannot be precisely estimated due to unavailability of significant information. As described in literature, product handling can be carried out manually or automatically depending on the system adopted. For the cost estimation, it is assumed as accomplished manually and it is estimated as a percentage of the transportation time as it follows:

$$\boldsymbol{t_{handling} = 0.3 \times t_t} \quad (5\text{-}8)$$

Where,

$t_{handling}$ : Product handling time (hour)

$t_t$ : Total time to transport a product along the reverse supply chain

**Machine cost:** It is calculated by summing up the machine cost related to testing/sorting, cleaning and final check. The estimation is as it follows:

$$\boldsymbol{C_{machine} = C_{machine,t} + C_{machine,c} + C_{machine,fc}} \quad (5\text{-}9)$$

Where,

$C_{machine}$: Total machine cost (£)

$C_{machine,c}$: Machine cost for cleaning

$C_{machine,i}$: Machine cost for testing/sorting

$C_{machine,h}$: Machine cost for final check

The machine cost related to each activity is calculated as a summation between the depreciation rate of the machine used multiplied by the activity time and both the electricity and tools rates multiplied by the operation time. The estimation is as it follows:

$$\boldsymbol{C_{machine,activity} = R_{dep} \times t_{activity} + (R_{electricity} + R_{tools}) \times t_{op}} \quad (5\text{-}10)$$

Where,

$C_{machine,activity}$: Machine cost to accomplish the activity (£)

$R_{dep}$: Depreciation rate of the machine used (£/hour)

$t_{activity}$: Activity time (hour)

$R_{electricity}$: Electricity rate (£/hour)

$R_{tools}$: Tools rate (£/hour)

$t_{op}$: Operation time (hour)

*Depreciation rate ( $R_{dep}$)*

It represents the loss of value of an asset over time and it is estimated by dividing the initial value of the asset by its life cycle time as it follows:

$$\boldsymbol{R_{dep} = v \div t_{lc}} \tag{5-11}$$

Where,

$R_{dep}$: Depreciation rate of the asset used (£/hour)

$v$ : Initial value of the machine (£)

$t_{lc}$ : Life cycle time (hour)

*Electricity rate ($R_{electricity}$)*

The electricity rate is calculated as it follows:

$$\boldsymbol{R_{electricity} = W \times E_p} \tag{5-12}$$

Where,

$R_{electricity}$ : Electricity rate (£/hour)

$W$ : Wattage (W)

$E_p$ : Electricity price (£/Kwh)

The wattage it is calculated as it follows:

$$\boldsymbol{W = I \times V} \tag{5-13}$$

Where,

$W$ : Wattage (W)

$I$ : Current (A)

$V$ : Voltage (V)

**Transportation Cost:** it is calculated by summing up the cost of transporting an end-life home appliance from a location to another along the RSC and it is estimated as it follows.

$$\boldsymbol{C_{transportation} = C_{c-r} + C_{r-s} + C_{s-r}} \tag{5-14}$$

Where,

$C_{transportation}$: Total transportation cost (£)

$C_{c-r}$: Transportation cost from customer's house to retailing store

$C_{r-s}$: Transportation cost from retailing store to sub-logistics centre

$C_{s-r}$: Transportation cost from sub-logistics centre to retailing store

The cost of transporting an EOL home appliance from a location to another is given by the sum of depreciation of the transportation mean used and fuel rate multiplied by the operation time. It is estimated as it follows:

$$\boldsymbol{C_{from-to} = (R_{depreciation} + R_{fuel}) \times t_{op}} \tag{5-15}$$

Where,

$C_{from-to}$: Transportation cost from a location to another within the RSC (£)

$R_{depreciation}$: Depreciation rate (£/hour)

$R_{fuel}$: Fuel rate (£/hour)

$t_{op}$: Operation time (hour)

*Fuel rate ($R_{fuel}$)*

It varies significantly according to the transportation mean selected and it is calculated by multiplying the cost of fuel per km by the distance driven per hour. It is estimated as it follows.

$$\boldsymbol{R_{fuel}} = ( \boldsymbol{C_f} \div \boldsymbol{F}) \times \boldsymbol{S} \qquad (5\text{-}16)$$

Where,

$R_{fuel}$: Fuel rate (£/hour)

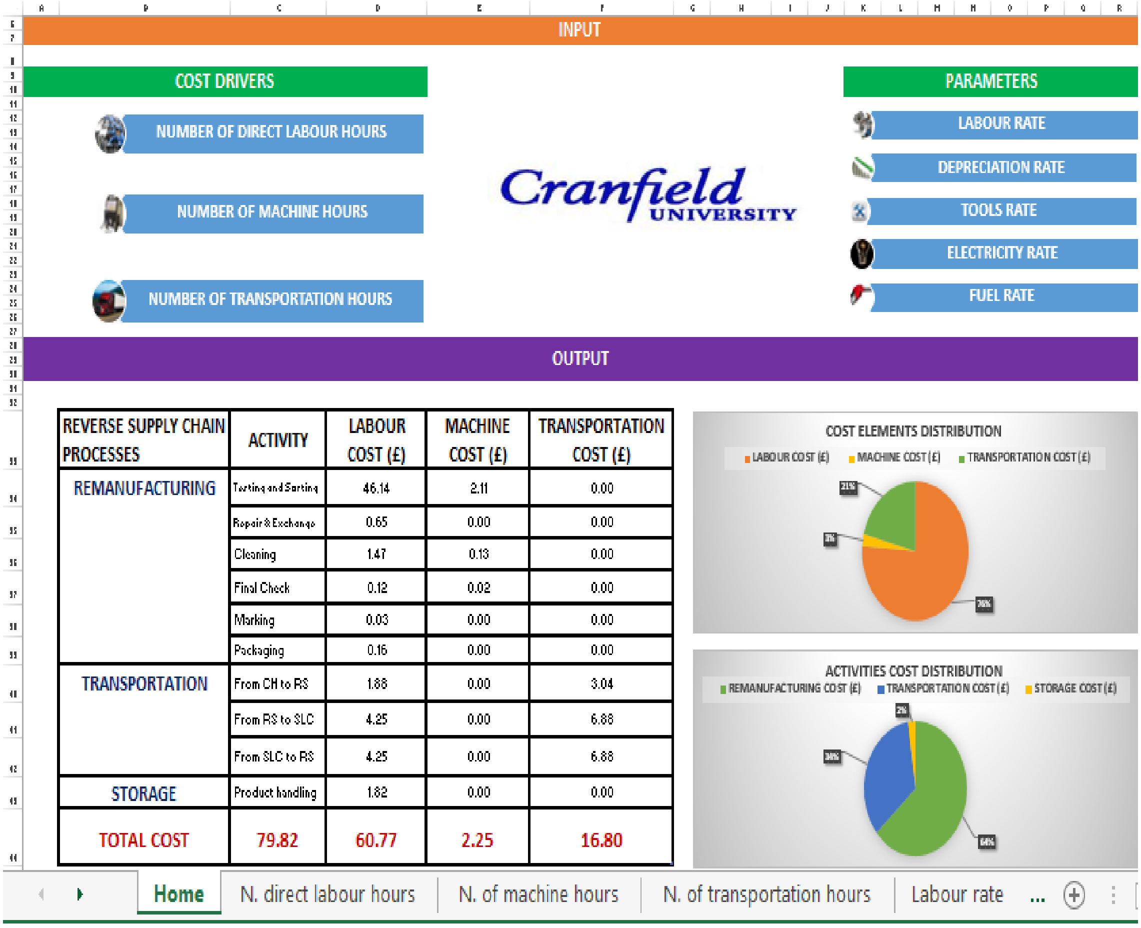
$C_f$ : Cost of fuel (£/l)

$F$ : Fuel consumption rate (l/km)

$S$ : Speed (km/hour)

## 5.6 Cost model implementation

The conceptual cost estimation model developed has been integrated in MS Excel in order to provide a tool, which enables the user to estimate the high-level cost of the redesigned RSC for EOL product remanufacturing. Figure 5-14 shows the menu spreadsheet of the tool, in which the user has to type the value of cost drivers and parameters related to the specific home appliance taken into account in order to get the total cost as output, which is automatically estimated.



| REVERSE SUPPLY CHAIN PROCESSES | ACTIVITY | LABOUR COST (£) | MACHINE COST (£) | TRANSPORTATION COST (£) |
|---|---|---|---|---|
| REMANUFACTURING | Testing and Sorting | 46.14 | 2.11 | 0.00 |
| | Repair & Exchange | 0.65 | 0.00 | 0.00 |
| | Cleaning | 1.47 | 0.13 | 0.00 |
| | Final Check | 0.12 | 0.02 | 0.00 |
| | Marking | 0.03 | 0.00 | 0.00 |
| | Packaging | 0.16 | 0.00 | 0.00 |
| TRANSPORTATION | From CH to RS | 1.88 | 0.00 | 3.04 |
| | From RS to SLC | 4.25 | 0.00 | 6.88 |
| | From SLC to RS | 4.25 | 0.00 | 6.88 |
| STORAGE | Product handling | 1.82 | 0.00 | 0.00 |
| TOTAL COST | 79.82 | 60.77 | 2.25 | 16.80 |

Figure 5-15 MS Excel based cost model

# 6 CASE STUDY

The cost estimation model developed in chapter 5 has been applied in order to assess whether the redesigned RSC model for remanufacturing is economically viable or not. In this way, it is also demonstrated that the cost estimation model can be used to calculate the high-level RSC cost for EOL products remanufacturing.

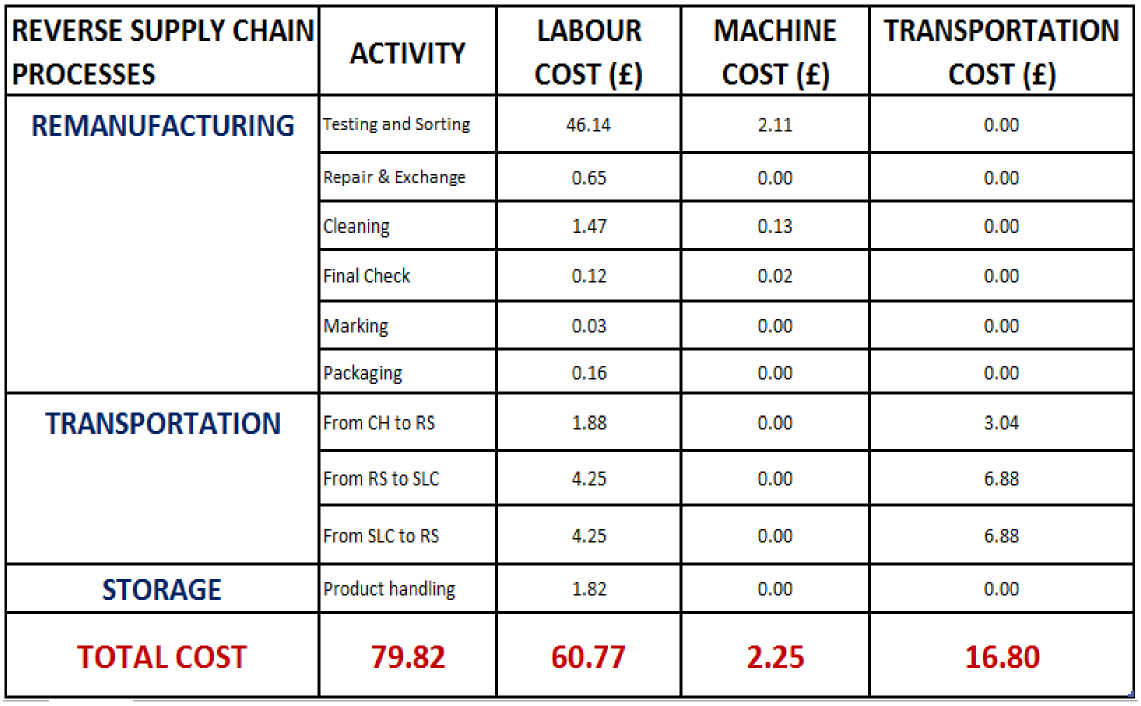
The Haier HT21TS45SW Top Mount Refrigerator (Haier, 2014) shown in Figure 6-15 has been selected to carry on the case study. Details on how the cost estimation is carried out can be found in Appendix A.

**Figure 6-16 Top Mount Refrigerator (Haier, 2014)**

Moreover, a market research (see Appendix B) has been conducted among potential customers in Nanjing in order to understand both the potential market for remanufactured refrigerators and the attractive retailing price. In this way, it has been predicted the profit margin reachable by remanufacturing an EOL refrigerator in the redesigned RSC model in order to assess the economic viability.

**High-level Reverse supply chain cost results**

The output of the cost estimation tool indicates that the total cost to transport, store and remanufacture an EOL refrigerator is approximately £79.82 (see Appendix A), as shown in the breakdown of the RSC cost in Table 6-4.



| REVERSE SUPPLY CHAIN PROCESSES | ACTIVITY | LABOUR COST (£) | MACHINE COST (£) | TRANSPORTATION COST (£) |
|---|---|---|---|---|
| **REMANUFACTURING** | Testing and Sorting | 46.14 | 2.11 | 0.00 |
| | Repair & Exchange | 0.65 | 0.00 | 0.00 |
| | Cleaning | 1.47 | 0.13 | 0.00 |
| | Final Check | 0.12 | 0.02 | 0.00 |
| | Marking | 0.03 | 0.00 | 0.00 |
| | Packaging | 0.16 | 0.00 | 0.00 |
| **TRANSPORTATION** | From CH to RS | 1.88 | 0.00 | 3.04 |
| | From RS to SLC | 4.25 | 0.00 | 6.88 |
| | From SLC to RS | 4.25 | 0.00 | 6.88 |
| **STORAGE** | Product handling | 1.82 | 0.00 | 0.00 |
| **TOTAL COST** | **79.82** | **60.77** | **2.25** | **16.80** |

**Table 6-4 RSC cost breakdown**

As shown in Figure 6-17, the remanufacturing process contributes for the largest share of the RSC cost. In particular, testing and sorting represent the activities that consume most resources in terms of labour and machine hours, accounting for the 95% of the total remanufacturing cost.

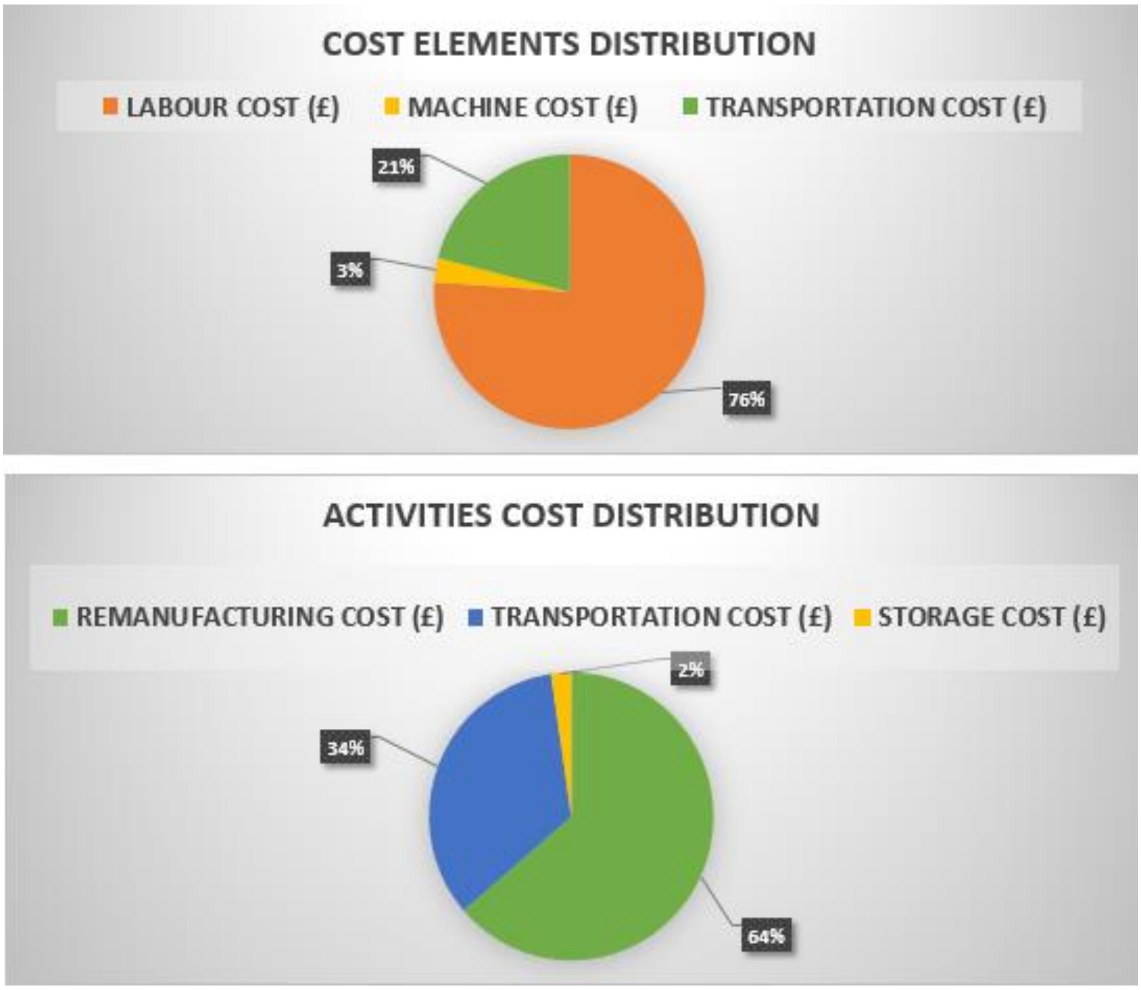


**Figure 6-17 RSC cost distribution**

As no activities are completely automated, the labour cost constitutes the major cost element, accounting for the 76% of the total RSC cost.

### Profit margin

This is the output of the cost estimation and aims to determine whether the remaining value of a remanufactured refrigerator is enough to cover the whole RSC cost and generate a profit margin or not.

The retailing price for a new unit of the refrigerator model taken in consideration has been estimated as £370, which is the average of the retailing prices collected in Walmart, Gome and Suning’s retailing store in Nanjing.

The results given by the market research carried out are shown in Figure  and indicate that a customer would buy the remanufactured product if it can save 60% of the money, the attractive retailing price for the remanufactured refrigerator is £148.

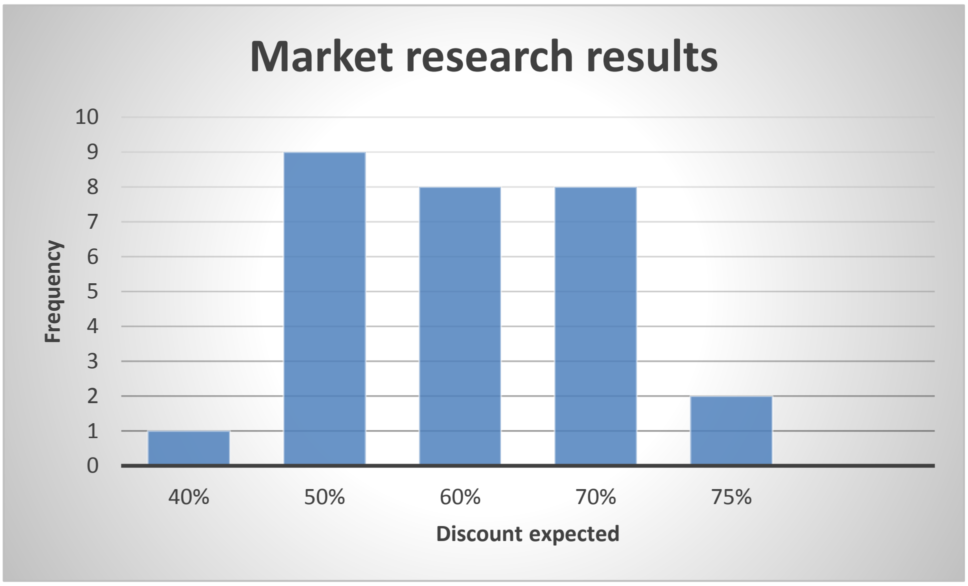


Figure 6-18 Market research results

Therefore, the potential profit margin reachable per unit is calculated as shown in Table B-2.

| | |
|---|---|
| Unit selling price (£) | 148 |
| Cost per unit (£) | 79.82 |
| **Profit margin per unit (£)** | **68.18** |
| **Profit margin ratio (%)** | **46%** |

Table 6-5 Profit margin reachable in the Chinese market

# 7 DISCUSSION

The results of the cost estimation model applied to the refrigerator case study indicate that the RSC model redesigned for remanufacturing is economically viable. In particular, remanufacturing EOL home appliances could generate significant economic benefits in the Chinese industry. If EOL products are remanufactured rather than recycled or landfilled, their remaining value is enough to cover the whole RSC cost and generate further profits.

On the other side, as the cost of labour represents the major cost element, the economic performances of the redesigned RSC could vary considerably according to the labour laws and working conditions related to each specific country. Indeed, if the remanufacturing process is carried out in different countries, where the cost of labour is more expensive than in China, the profit generated by selling remanufactured home appliances will be deeply affected.

Moreover, testing and inspection represent the bottleneck of the redesigned RSC model and are the most expensive activities. On one side, the early and complete categorisation of returned and EOL products speeded-up the processing of valuable products and reduced the waste related to products for recycling and disposal. On the other side, the cost of these activities is increased, as more resources have been allocated to test accurately the quality of each component in order to select the best cost-effective recovery strategy in the retailing store. In this regard, it is necessary evaluating the benefits achievable by integrating built-in technologies and software, which support the strategy selection process in order to reduce the operations time, eliminate the bottleneck and eventually increase further the whole RSC recovery efficiency.

Moreover, some limitations associated with this project can be identified:

- There were no possibilities to directly interact with home appliances companies, apart from an interview carried out in Gome’s retailing store in Nanjing. Consequently, there have been difficulties to collect quantitative data to improve the RSC model and to feed the cost model. In this regard, the data and knowledge used are largely from literature.

- The RSC and in particular the remanufacturing process has been studied and modelled at high-level, considering the whole system. Moreover, the accurate cost of spare parts used to replace faulty or damaged components has not been calculated due to unavailability of reliable data.

In order to overcome the mentioned limitations, the future work is suggested to focus on the following activities:

- Collect quantitative data in order to feed the model with a set of more realistic information.

- Develop further the cost estimation model to integrate the cost estimation at component level. In this way, a more accurate and realistic evaluation of the economic benefit generated by EOL home appliances remanufacturing could be achieved.

# 8 CONCLUSIONS

This research has been motivated by the need to develop an economically viable RSC model in the Chinese home appliances industry to motivate companies to take back EOL products for remanufacturing in order to reduce the amount of WEEE yearly generated. In this regard, the current RSC adopted by Gome has been improved and redesigned for remanufacturing. Furthermore, the economic viability of the redesigned RSC model has been assessed through a cost estimation tool implemented in MS Excel.

The long products LT experienced in the current RSC has been shortened and consequently the asset value losses have been reduced. Moreover, the remanufacturing process has been integrated in the redesigned RSC to provide an EOL alternative, which enables the company to recover the remaining value of used products.

The cost estimation model based on the ABC technique has been developed, which can calculate the cost of the each activity involved in the redesigned RSC model including labour, machine and transportation cost.

The MS Excel based costing tool has been developed based on the cost estimation model framework and architecture, which can estimate the high-level RSC cost for home appliances remanufacturing.

The costing tool has been applied to a selected case study related to refrigerators remanufacturing in order to assess whether the redesigned RSC model leads to economic benefits or not.

The results have confirmed that the retail price estimated through a market research among potential Chinese customers is enough to cover the total RSC cost and generate further profits.

Therefore, the redesigned RSC model is economically viable and it allows the company to capture the profit-making opportunities generated by EOL home appliances remanufacturing.

# REFERENCES

Abdulrahman, M.D., Gunasekaran, A., Subramanian, N. (2014), Critical barriers in implementing reverse logistics in the Chinese manufacturing sectors, *Int. J. Production Economics*, Vol. 147, p. 460-471.

Adler, W D. (2006), *Refrigerator Performance Testing in the Household Refrigerator Industries Today.* Available: http://www.transfairgmbh.homepage.t-online.de/Transfair%20Survey%20Refrigerator%20Performance%20Testing.pdf ,Last accessed 7th Aug.

Álvarez-Gil, M. J., Berrone, P., Husillos, J., & Lado, N. (2007), Reverse logistics, stakeholders' influence, organizational slack, and manager's posture, *Journal of Business Research*, Vol. 60, p. 463-473.

Asiedu, Y., Gu, P. (1998), Product life cycle cost analysis: state of the art review, *International Journal of Production Research*, Vol. 36, No. 4, p. 883-908.

Bains, N., Goosey, M., Holloway, L., Shayler, M. (2006), *An Integrated Approach to Electronic Waste (WEEE) Recycling: Socio-economic Analysis Report*. Rohm and Haas Electronic Materials Ltd., UK.

Banomyong, R., Veerakachen, V., & Supatn, N. (2008), Implementing leagility in reverse logistics channels. *International Journal of Logistics: Research and Applications*, Vol. 11, No. 1, p. 31-47.

Blackburn, J., Guide, V., Souza, G. and Van Wassenhove, L. (2004), Reverse supply chains for commercial returns, *California management review*, Vol. 46, No. 2, p.6--22.

Bohr, P. (2007), *The Economics of Electronics Recycling New Approaches to Extended Producer Responsibility*. PhD thesis, Technischen Universitat, Berlin, Germany.

Brennan L., Gupta, S., Taleb, K. (1994), Operations planning issues in an assembly/disassembly environment, *International Journal of Operations & Production Management*, Vol. 14, No. 9, p. 67-57.

Briney, A. (2014), *A List of China's 23 Provincial Divisions,* available: http://geography.about.com/od/chinamaps/a/chinaprovinces.htm. Last accessed 13th Jul 2014.

Brodin, M. H. (2002), *Logistics Systems for Recycling,* Linköping: Linköping Universitet.

Cardos, I.R., Pete, S. (2008), *"Activity-Based Costing (ABC) and Activity-Based Management (ABM) Implementation – Is this the solution for organizations to gain profitability?*, available at SSRN: http://www.revecon.ro/articles/2011-1/2011-1-9.pdf tp://ssrn.com/abstract=962461.

Christopher, M., Peck, H., & Towill, D. (2006), A Taxonomy for Selecting Global Supply Chain Strategies, *International Journal of Logistics Management*, Vol. 17, No. 2, p. 277-287.

Cima (2001), *Activity-Based Management-An Overview*, available at SSRN: http://www.cimaglobal.com/Documents/ImportedDocuments/ABM_techrpt_0401.pdf.

CleanTechnica (2013), *What's the average price of electricity in....*, available: http://cleantechnica.com/2013/09/30/average-electricity-prices-around-world/. Last accessed 11th Jul 2014.

Cui, J., Forssberg, E. (2003), Mechanical recycling of waste electric and electronic equipment: a review, *Journal of Hazardous Materials*, Vol. 99, No. 3, p. 243-263.

Curran, R., Raghunathan, S., Price M. (2004), Review of aerospace engineering cost modelling: The genetic casual approach, *Progress in Aerospace Sciences,* Vol. 40, p. 487-453.

Daimer Industries. (2014), *Steam Cleaners,* available: http://www.daimer.com/steam-cleaners/. Last accessed 7th Aug.

Errington, M. (2009), Business processes and strategic framework for inspection in remanufacturing, PhD Thesis, University of Exeter, UK.

Fleischmann, M., Krikkle, H.R., Dekker, R., Flapper, S.D.P. (2006). A characterization of logistics networks for product recovery. Omega- International Journal of Management Science 28, 653-666.

Galileo TP. (2014). *PQ ELECTRIC,* Available: http://www.galileotp.com/products/pq-electric-P35.htm, Last accessed 7th August.

Geethan, K. A. V., Jose, S., Chandar, C. S. (2011), Methodology for Performances Evaluation of Reverse Supply Chain, *International Journal of Engineering and Technology*, Vol.3, No.3, p. 213-224.

Geng, Y., Cote, R. (2003), Environmental management systems at the industrial park level in China, *Environmental Management,* Vol. 31, No. 6, p. 784–794.

Geng, Y., Zhu, Q., Doberstein, B., Fujita, T. (2009), Implementing China's circular economy concept at the regional level: a review of progress in Dalian, China, *Waste Management*, Vol. 29, p. 996-1002.

Gimein, M. (2013), *If U.S. Wages Rose as Fast as China's, Factories Would Now Pay $50 an Hour,* available: http://go.bloomberg.com/market-now/2013/03/27/if-u-s-wages-rose-as-fast-as-chinas-factories-would-pay-50-an-hour/. Last accessed 14th Jul 2014.

Gome Electrical Appliances Ltd. (2014), *GOME Announces 201 4 Q1 Results, a*vailable: http://www.gome.com.hk/attachment/2014051912153017_en.pdf, Last accessed 28th June 2014.

Gome Electrical Appliances Ltd. (2014), *Recycling policies, a*vailable: http://huishou.gome.com.cn/?intcmp=sy-D-1-1-0. Last accessed 27th June 2014.

Gome Electrical Appliances Ltd. (2014). *Annual Report 2013,* available: http://www.gome.com.hk/attachment/2014042306300817_en.pdf, Last accessed 2nd July 2014.

Guide, V., Van Wassenhove L. (2009), The Evolution of Closed-Loop Supply Chain Research, *Operations Research*, Vol. 57, No 1, p. 11-13.

Guide, V., Van Wassenhove, L. (2002), The Reverse Supply Chain, *Harvard Business Review*, Vol. 80, No. 2, p. 25-26.

Gupta, S.M., Veerakamolmal, P. (2001), Aggregate planning for end-of-life products. *In: Sarkis, J. (Ed.). Greener Manufacturing and Operations: From Design to Delivery and Back.* Greenleaf Publishing Ltd., Sheffiled, U.K. pp. 205-222.

Haier. (2014), *HT21TS45SW Top Mount Refrigerators,* available: http://www.haier.com/us/products/kitchen/refrigerators/top-mount-refrigerators/ht21ts45sw.shtml, Last accessed 14th Jul 2014.

Hughes, S.B.; Gjerde, K.P. (2003), “Do Different Cost Systems Make a Difference?”, *Management Accounting Quarterly*, Vol. 5, No. 1, p. 22-30.

Humphreys, K., Wellman, P. (1996), *Basic cost engineering*, 3rd edition (Revised and expanded).

Ilgin, M. A. and Gupta, S. M. (2012), *Remanufacturing Modelling and Analysis*, CRC Press / Taylor & Francis Group.

Jackson, P. (1986), *Introduction to experts systems*, Reading, MA: Addison-Wesley Publishing Company, ISBN: 0-201-14223-6.

Jagolinzer, P. (1999), Activity-Based Costing and Management. In: Jagolinzer, P. *Cost Accounting: An introduction to cost management*. South-Western Educational Publishing, p. 120-130.

Johansson, G. (1997), *Design for disassembly-a framework*, Licentiate thesis at the Division of Production System, Department of Mechanical Engineering at Linkoping University, AFR-report 174.

Johnson, R. (2008), *Traditional Costing Vs. Activity-Based Costing,* available: http://smallbusiness.chron.com/traditional-costing-vs-activitybased-costing-33724.html. Last accessed 10th Jul 2014.

Kerr W., Ryan C. (2001), Eco-efficiency gains from remanufacturing – a case study of photocopier remanufacturing at Fuji Xerox Australia, *Journal of Cleaner Production*, Vol. 9, p. 75-81.

Kiddee, P., Naidu, R., Wong, M.H. (2013), Electronic waste management approaches: An overview, *Waste Management*, Vol. 33. No. 4, p. 1237-1240.

Li, J. (2011), *Reverse supply chain in Gome*, (W. Yin, Interviewer).

Li, J., Tian, B., Liu, T., Liu, H., Wen, X., Honda, S. (2006), Status quo of e-waste management in China, *Journal of Material Cycles and Waste Management,* Vol. 8, No. 1, p. 13-20.

Lutters, D.,Streppel, A.H., Kroeze, B., Kals, H.J.J. (1997), *Adaptive press-brake control in air bending*, In: Belfast Proceedings of the fifth international conference on sheet metal.

Mills, P., Jones, R., Sumiga J. (1987), The integration of cost knowledge and uncertainty into expert systems for engineering design, In: Fourth EU conference on automated design. UK: Kempston Publications.

MyTravelCost.com. (2014), *Petrol prices in China, 04-Aug-2014, a*vailable: http://www.mytravelcost.com/China/gas-prices/. Last accessed 8th Aug 2014.

Nasr, N., Hughson, C., Varel, E., Bauer, R. (1998), *"State of the Art Assessment of Remanufacturing Technology”*, Draft Document, Rochester NY: Rochester Institute of Technology.

National Aeronautics and Space Administration (NASA) (2002), "*NASA Cost Estimating Handbook"*, Cost Analysis Division, NASA Headquarters, Washington DC.

Needy, K.L.; Nachtmann, H.; Roztocki, N.; Warner, R.C.; Bidanda, B. (2003), “Implementing activity-based costing systems in small manufacturing firms: A field study”, *Engineering Management Journal*, Vol. 15. No. 1, p. 3-10.

Niazi, A., Dai, J., Seneviratne, L., Balabani, S. (2006), "Product Cost Estimation: Technique Classification and Methodology Review", *Journal of Manufacturing Science and Engineering*, Vol. 128, No. 2, p. 563-575.

Parlikad, A.K., McFarlane, D.C., Kulkarni, A.G. (2006), *"Improving product recovery decisions through product information"*, Innovation in Life Cycle Engineering and Sustainable Development, p. 153–172.

Plambeck, E.L. (2012), Reducing greenhouse gas emissions through operations and supply chain management, *Energy Economics*, Vol. 34, No. 1, p. 64-S74.

Prahinski, C., Kocabasoglu, C. (2006), Empirical Research Opportunities in Reverse Supply Chain, *The International Journal of Management Science*, Vol. 34, p. 519-532.

Qu, Y., Zhu, Q.H., Sarkis, J., Geng, Y., Zhong, Y.G. (2013), A review of developing an e-wastes collection system in Dalian, China, *Journal of Cleaner Production*, Vol. 52, p. 176-184.

Schatteman, O. (2002), *Reverse logistics 2.12*, available at: http://www.ashgate.com/pdf/SamplePages/ghsupplych2.pdf. Last accessed 26th June 2014.

Seitz, M. A. and Peattie, K. (2004), "Meeting the Closed-Loop Challenge: The case of remanufacturing", *California Management Review*, Vol. 46, No. 2, p. 74-89.

Shanghai Highlights. (2013). *Shanghai area, a*vailable: http://www.shanghaihighlights.com/essential/#Features. Last accessed 25th Jul 2014.

Smith, V.M., Keoleian, G.A. (2004), The value of remanufactured Engines: Life-Cycle Environmental and Economic Perspectives, *Journal of Industrial Ecology*, Vol. 8, p. 193-221.

Steinhilper, R. (2001), *"Recent trends and benefits of remanufacturing: from closed loop businesses to synergetic networks"*, in: Ecodesign 2001 Proceedings of the Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing, p. 481- 488.

Stewart, R., Wyskidsa, R. and Johannes, J. (1995), *Cost Estimator's Reference Manual* (2nd ed.), Johan Wiley & sons Inc., New York.

Sundin E. (2004), *Product and Process Design for Successful Remanufacturing. Linkoping studies in science and technology*, Licentiate thesis

No. 906, Department of Mechanical Engineering, Linkopings Universitet, 581 83 Linkoping, Sweden. ISBN 91-85295-73-6.

Sundin, E., Bras, B. (2005), Making functional sales environmentally and economically beneficial through product remanufacturing, *Journal of Cleaner Production*, Vol. 13, p. 913-925.

Thierry, M., Salomon, M., Van Nunen, J. and Van Wassenhove, L. (1995), "Strategic Issues in Product Recovery Management", *California Management Review*, Vol. 37, No. 2, p. 114- 135.

Van Nunen, J. and Zuidwijk, R. A. (2004), "E-Enabled Closed-Loop Supply Chains", *California Management Review*, Vol. 46, No. 2, p. 40- 54.

Wei, L. and Liu, Y. (2012), Present status of e-waste disposal and recycling in China, *Procedia Environmental Sciences*, Vol. 16, p. 506--514.

Wei, Y. (2011), Reverse Supply Chain Management- explore the feasibility to incorporate forward supply chain strategy into the reverse supply chain in the electronic industry (unpublished Master Thesis), University of Gothenburg, Gothenburg.

Wu, C.Y., Zhu, Q.H., Geng, Y. (2001), Green supply chain management and enterprises’ sustainable development, *China Soft Science*, Vol. 16, No. 3, p. 67–70 (in Chinese).

Xiang, Z. (2010), *China electricity consumption to almost double by 2020: China Electricity Council,* available: http://news.xinhuanet.com/english2010/china/2010-12/21/c_13658772.htm, Last accessed 11th Jul 2014.

Yang, J., Lu, B., Xu, C. (2008), WEEE flow and mitigating measures in China, *Waste Management*, Vol. 28, No. 9, p. 1589-1597.

Ying, Q. (2009), *Research on the implementation of household appliances reverse logistics*, In: Proceedings of the international Conference on Information and engineering and Computer Science.

Zhang, B., Wang, Z. (2013), Inter-firm collaborations on carbon emission reduction within industrial chains in China: Practices, drivers and effects on firms' performances, *Energy Economics*, Vol. 42, p. 115-131.

Zhou, X., Zhang, M. (2009), Research on Reverse Logistics Network Design of Household Appliances Based on Green Logistics, *International Journal of Business and Management*, Vol. 4, No. 9, p. 251-255.

Zhu, Q., Geng, Y., Sarkis, J., Lai, K. (2011), Evaluating green supply chain management among Chinese manufacturers from the ecological modernization perspective, *Transportation Research*, Vol. 47, No. E, p. 809-812.

Zhu, Q., Lowe, E., Wei, T., Barnes, D. (2007), Industrial symbiosis in China: a case study of the Guitang Group, *Journal of Industrial Ecology*, Vol. 11, No. 1, p. 31-42.

Zhu, Q., Sarkis, J. (2004), Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises, *Journal of Operations Management*, Vol. 22, p. 265-289.

Zhu, Q., Sarkis, J. (2006), An inter-sectorial comparison of green supply chain management in China: Drivers and practices, *Journal of Cleaner Production*, Vol. 14, p. 472-486.

Zhu, Q.H., Cote, R. (2004), Integrating green supply chain management into an embryonic eco-industrial development: a case study of the Guitang Group, *Journal of Cleaner Production,* Vol. 12, No. 8–10, p. 1025–1035.

# APPENDICES

# Appendix A Further time and cost calculation

## A.1 Activity time calculation

### Total remanufacturing time $(t_{remanufacturing})$

It has been calculated by summing up the activity time required to accomplish each of the remanufacturing activities, which comprises of the operation time, loading time operator allowance time. The result is shown in Table A-1.

| **Remanufacturing Activities** | **Activity time per unit (hours)** | **Activity time in %** |
|---|---|---|
| Initial testing/sorting | 27.6 | 95% |
| Repair or Exchange | 0.38 | 1.4% |
| Cleaning | 0.86 | 3% |
| Final Check | 0.07 | 0.2% |
| Marking | 0.17 | 0.07% |
| Packaging | 0.093 | 0.33% |
| **Total remanufacturing process time** | 29.1 | 100% |

**Table A-1 Activity time for activities within the remanufacturing process**

### Operation time ($t_{op}$)

The operation time required to accomplish each activity of the remanufacturing process have been collected from the study conducted by Sundin (2004) in the Electrolux remanufacturing facility and from information provided by Adler 2006 on Household performance testing. The operation time for each activity within the remanufacturing process is shown in Table A-2.

| **Remanufacturing Activities** | **Operation time (OT) per unit (hours)** | **Operation time (OT) in %** |
|---|---|---|
| Initial testing/sorting | 24 | 95% |
| Repair or Exchange | 0.33 | 1.4% |
| Cleaning | 0.75 | 3% |
| Final Check | 0.06 | 0.2% |
| Marking | 0.017 | 0.07% |
| Packaging | 0.083 | 0.33% |
| **Total remanufacturing time** | 25.24 | 100% |

**Table A-2 Operation time for activities within the remanufacturing process**

## Transportation time ($t_{transportation}$)

It has been calculated by summing up the transportation time required to transport a product from the customers' house to the retailing store, from the retailing store to the sub-logistics centre and from the sub-logistics centre to the retailing store. The results of calculations are shown in Table A-3.

| **Transportation from-to** | **Transportation time (hours)** |
|---|---|
| Transportation from c-r | 1.1 |
| Transportation from r-s | 2.5 |
| Transportation from s-r | 2.5 |

**Table A-3 Transportation time along the RSC**

Further details on the calculations carried out for operation time and loading time can be found below.

### Operation time ($t_{op}$)

The time needed to transport a product between different locations has been determined, by analysing Gome's network, which includes 125 sub-logistics centres and 1585 retailing stores spanned in 14 Chinese provinces as shown in Figure A-1 (Gome, 2014).

**Figure A-1 Gome's network in China**

In this regard, it is assumed that the sub-logistics centre is in Jiangsu province and the retailing store in Shanghai. The sub-logistics centre remanufactures EOL refrigerators collected by retailing stores in the whole Jiangsu area and more specifically, to determine the transportation time required, the case of a retailing store in Shanghai is taken into account. Shanghai is the largest urban area in China and it extends for a maximum of 120 km from North to South (Shanghai Highlights, 2013). Assuming that the retailing store is placed in the middle of the city, in the worst case, a refrigerator have to be transported for 60 km from the customer house to the retailing store. On the other side, Jiangsu province has an area of 102,600 sq. km (Briney, 2014). Assuming, that the sub-logistics centre is in the middle of the province, it can be estimated that in the worst case products for remanufacturing have to be transported by truck from the retailing store to the sub-logistics centre for a maximum of 226 km. Therefore, the operation time required to transport the refrigerator along the different facilities in the redesigned RSC model is shown in Table A-4.

| Transportation from-to | Operation time (hours) |
|---|---|
| Transportation from c-r | 1 |
| Transportation from r-s | 2.26 |
| Transportation from s-r | 2.26 |

Table A- 4 Operation time to transport a product along the RSC

### Loading time ($t_l$) for transportation

Table A-5 shows the loading time for each transportation along the RSC.

| Transportation from-to | Loading time (hours) |
|---|---|
| Transportation from c-r | 0.1 |
| Transportation from r-s | 0.33 |
| Transportation from s-r | 0.33 |

Table A- 5 Loading time to transport a product along the RSC

## Product handling time ( $t_{handling}$)

Table A-6 shows the total handling time required as summation between the handling time from retailing store to sub-logistics centre and the handling time from sub-logistics centre to retailing store.

| Handling from-to | Handling time (hours) |
|---|---|
| $t_{r-s}$ | 0.915 |
| $t_{s-r}$ | 0.915 |
| $\boldsymbol{t_{handling}}$ | **1.82** |

**Table A- 6 Handling time to transport a product along the RSC**

## A.2 Cost parameters calculation

### Labour rate ($\boldsymbol{R_{labour}}$)

In China, the average monthly salary for factory workers varies significantly depending on the province and the number of working hours per month (Gimein, 2013). The monthly salary value has been collected from an interview conducted to a shop floor worker in Siemens factory in Nanjing and the labour rate estimated is shown in Table A-7.

| | |
|---|---|
| Monthly salary (£) | 300.6 |
| Number of working days per month | 22 |
| Number of working hours per day | 8 |
| **Labour rate (£/hour)** | **1.71** |

**Table A-7 Labour rate for a factory worker**

### Depreciation rate ( $R_{dep}$)

The information about the value of the machines used to carry on the remanufacturing activities have been collected by benchmarking the different solutions proposed by vendors. The machine selected to perform the initial test and final check is an electrical safety test machine (Galileo TP, 2014), while the machine selected for cleaning is a steam pressure washer (Daimer Industries, 2014). The depreciation rate for each of the machines selected is shown in Table A-8.

| | **Electrical safety test machine for initial test and final check** | **Steam pressure washer for cleaning** | **Tractor trailer-truck<br>for transportation** |
|---|---|---|---|
| $v$ (£) | 4,750 | 3,350 | 80,000 |
| $t_{lc}$ (hours) | 70,080 | 70,080 | 87,600 |
| **$R_{dep}$ (£/hour)** | **0.067** | **0.048** | **0.91** |

**Table A-8 Depreciation rate for the machines selected**

### Electricity rate ($R_{electricity}$)

In China, the electricity price varies according to the province in which the remanufacturing facility operates. Data regarding the electricity prices in different provinces have been collected and the average has been estimated approximately as £ 0.047 per Kwh (CleanTechnica, 2013; Xiang 2010).

Table A-9 shows the results of calculations performed in order to estimate the electricity rate.

| | **Electrical safety test machine** | **Steam pressure washer** |
|---|---|---|
| $W\ (Kw)$ | 5 | 2.4 |
| $E_p$ (£/Kwh) | 0.047 | 0.047 |
| $\boldsymbol{R_{electricity}}$ **(£/hour)** | **0.23** | **0.11** |

**Table A-9 Average electricity rate per in China**

### Tools rate ($\boldsymbol{R_{tools}}$)

Both the electrical safety test machine and the steam pressure washer do not utilise consumable tools such as cutting tools to accomplish the related activities, therefore this parameter is not taken into account for the cost estimation.

### Fuel rate ($\boldsymbol{R_{fuel}}$)

The mean used to transport a product along the RSC is a diesel tractor trailer-truck. Typically, these trucks consumes approximately 1 litre of diesel each 20 km. In China, the price of diesel has been estimated as 0.71 £/l (MyTravelCost.com, 2014). Table A-10 shows the fuel rate estimated for a diesel tractor trailer-truck.

| | |
|---|---|
| $C_f$ (£/l) | 0.71 |
| $F$ (km/l) | 20 |
| $S$ (km/hour) | 60 |
| $\boldsymbol{R_{fuel}}$: **Fuel rate (£/hour)** | **2.13** |

**Table A-10 Fuel rate for a diesel tractor trailer-truck**

## A.3 Cost elements estimation

### Labour cost$(C_{labour})$

Table A-11 shows the labour cost estimated respectively for remanufacturing, transportation and storage.

| | |
|---|---|
| $C_{labour,r}$ **(£)** | 48.58 |
| $C_{labour,t}$ **(£)** | 10.37 |
| $C_{labour,s}$ **(£)** | 3.11 |

**Table A-11 Labour cost estimation**

### Machine cost $(C_{machine})$

Table A-12 shows the machine cost estimated respectively for initial test, cleaning and final check.

| | |
|---|---|
| $C_{machine,i}$**(£)** | 2.11 |
| $C_{machine,c}$ **(£)** | 0.13 |
| $C_{machine,fc}$ **(£)** | 0.02 |

**Table A-12 Machine cost estimation**

### Transportation cost $(C_{transportation})$

Table A-13 shows the transportation cost estimated respectively from the customer's house to retailing store, from retailing store to sub-logistics centre and from sub-logistics centre to retailing store.

| | |
|---|---|
| **$C_{c-r}$ (£)** | 3.04 |
| **$C_{r-s}$ (£)** | 6.88 |
| **$C_{s-r}$ (£)** | 6.88 |

**Table A-13 Transportation cost estimation**

### Spare parts cost ($C_{spare\ parts}$)

According to Sundin (2005), it accounts for the 5% of the total remanufacturing cost for a home appliance. Due to lack of significant data and information, this cost element has not been included in the cost estimation.

## A.4 Activities cost estimation

The costs estimated to carry out the activities involved in remanufacturing, transportation and storage of an EOL refrigerator and identified in the CBS are respectively shown in Table A-14.

| | |
|---|---|
| **Remanufacturing activities cost (£)** | **50.83** |
| **Transportation activities cost (£)** | **27.17** |
| **Storage activities cost (£)** | **1.82** |

**Table A-14 Cost of activities involved in the RSC**

# Appendix B Surveys and profit margin

## B.1 Market research

In order to understand the Chinese customer's attitude toward remanufactured refrigerators, a market research has been performed in collaboration with PhD students of Nanjing University of Aeronautics and Astronautics (NUAA). The market research consists of the survey shown below, which has been translated in Chinese and sent to potential customers in Nanjing.

**Remanufactured Refrigerator Survey**

To answer the following questions, please tick the box.

**Question 1**

Would you be willing to buy a remanufactured refrigerator, which has the same performances and quality of a new one?

Yes ☐

No ☐

If you answered yes to Question 1, please answer to Question 2.

**Question 2**

How much discount would you expect to achieve for a remanufactured refrigerator compared to the same new model?

10% ☐ 15% ☐ 20%

25% ☐ 30% ☐ 40%

45% ☐ 50% ☐ 55%

60% ☐ 65% ☐ 70%

75% ☐ 80% ☐ 85%

### Survey Results

The results of the survey are shown in Table B-1.

| Name | Gender | Q1 | Q2 |
|---|---|---|---|
| BoSong | male | No | |
| ChunchunChen | female | No | |
| HaihuaZhu | male | Yes | 70% |
| HuixingLi | female | Yes | 70% |
| JianGuo | male | No | |
| JuanTang | female | Yes | 70% |
| JunChen | male | Yes | 60% |
| JunLin | male | Yes | 70% |
| KunZheng | male | Yes | 75% |
| LicaiYe | male | Yes | 50% |
| LichengZhang | male | Yes | 60% |
| LingYang | female | Yes | 50% |
| MinWang | female | No | |
| PeiZhu | male | Yes | 50% |
| PengfeiGuo | male | No | |
| PengYang | male | Yes | 60% |
| PingYang | female | No | |
| QingyaXia | female | Yes | 50% |

| | | | |
|---|---|---|---|
| RuiZhao | male | Yes | 50% |
| ShengZhou | male | Yes | 40% |
| ShouzhengYe | male | Yes | 70% |
| WenbinGu | male | Yes | 60% |
| WengangLing | male | Yes | 60% |
| XianzhenMeng | female | No | |
| XiaofeiXue | male | Yes | 70% |
| XiaoleiHuang | male | No | |
| Xiaoliang Jin | male | Yes | 50% |
| XuemeiZhao | female | Yes | 60% |
| YangLiu | male | No | |
| YangYu | male | Yes | 60% |
| YubinZheng | male | Yes | 60% |
| YupingZheng | female | Yes | 50% |
| YuxiaZheng | female | Yes | 70% |
| YuyunKang | male | No | |
| YuZheng | female | Yes | 65% |
| ZeleiSangmale | male | No | |
| ZequnZhang | male | No | |
| ZhiguiLiu | male | Yes | 50% |
| ZiyuWang | male | Yes | 50% |
| ZongwenAn | male | Yes | 70% |

**Table B-1 Survey results**