Reverse Logistics and the Creation of Reverse Flows for the Mobile Phone Industry
Abstract
This paper studies the supply chain management field of reverse logistics which can be defined as “the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal” (Hawks, 2006). In today’s world, where the environment has become a primary concern for the population and legislations are put in place by governments in order to obligate companies to reduce their waste and recycle their damaged, returned and aged products, reverse logistics has become more important than ever. The first goal of this thesis is to describe this business discipline and its different challenges. This is done so the reader can gain the necessary background knowledge of the subject, before reverse logistics is investigated in connection with the mobile phone industry.

Among the many industries where reverse logistics has become a necessity, the mobile phone industry faces an important problem as its products’ lifecycle have shortened and millions of cell phones are thrown away each year. Therefore, the second objective of this thesis is to study and analyze the reverse logistics characteristics of the mobile phone industry and to design a recovery network for these devices. Derived from the information gathered throughout the research process and other analyses, it was first concluded that the system’s objective should be to maximize asset recovery. That being said, other conclusions were made and it was discovered that many strategic decisions and challenges have to be overcome in order to generate an efficient reverse logistics network for the mobile phone industry. In addition, supply forecasting is a complex issue and, although one can use different variables to forecast the returns, a high level of uncertainty remains. To prevent intermittent supplies, incentives have to be put in place by the reverse logistics companies and mobile phone manufacturers. Additionally, a reverse flow for the mobile phone industry requires high levels of processes’ automation in order to construct an efficient system and reduce the processes’ lead times. Furthermore, the model analysis also indicates that the testing procedures and methods, required in the recuperation process of mobile phones, are critical activities when one seeks to maximize the recovered assets’ value. In fact, the presented model includes two different testing steps to ensure high control measures and to determine which process sequence the phones and components should be forwarded to, whether it is repairing, remanufacturing, recycling or disposal. Finally, the generated model also explores which type of recycling should be used to maximize asset recovery.
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**Introduction**

Over the past decades, environmental issues have become increasingly important and one of today’s major concerns is how to reduce waste and properly dispose of it. As the population, and living standards increase, the disposal rate of goods has accelerated and many landfills have reached their maximum capacity (Knemeyer et al., 2002). On a regular day, humans will destroy approximately 300 square kilometers of rainforest and add 15 million tons of carbon in the atmosphere (Pourmohammadi et al., 2008). Additionally, today’s electronic products have an extremely short lifecycle and customers dispose of them at a fast rate in order to obtain the newest versions. At the same time, the population’s demand for “green” products and for companies to adopt environmentally friendly behavior is on the rise while new government legislations are put into place in order to oblige businesses to adopt environmentally responsible practices. For these reasons, among many others, “collection and recycling of post-consumer waste in a cost-efficient manner is of increasing interest in business as well as in research” (Jahre, 1995).

In Europe, where electronic waste is estimated to reach 12 million tons by 2010 (Shneiderman, 2004), the European Union has put in place a new directive which imposes the manufacturers of electrical and electronic equipment to fund the collection, treatment and recycling of their products (WEEE Directive\(^1\)). The purpose of such a directive is to avoid sending hazardous materials to landfills, to recuperate precious metals and to recycle possible components. The target of the WEEE Directive is to collect electronic and electrical products at a rate of 4kg per capita, which represents two million tons per year (Dickinson, 2005). By reaching such a target, components would no longer be sent to landfills, but recycled into (Dickinson, 2005):

- Enough steel to build 200 Eiffel towers
- Sufficient aluminum foil to circle the earth 15 times
- Copper that could be extracted into tubes that stretch to the moon and back four times
- Glass that could be blown into 1.5 billion drinks bottles
- Enough mixed plastic for 400 million traffic cones.

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\(^1\) WEEE Directive: The Waste Electrical and Electronic Equipment Directive. The WEEE Directive aims to both reduce the amount of electrical and electronic equipment being produced and to encourage everyone to reuse, recycle and recover it. The WEEE Directive also aims to improve the environmental performance of businesses that manufacture, supply, use, recycle and recover electrical and electronic equipment. (United Kingdom Environment Agency, 2009). This directive is symbolized on all electronic and electrical equipment in the European Union with the following symbol to remind customers not to throw away but to recycle these products.
Such an initiative only targets the European Union at this point but if each individual country implemented such a legislation, it is estimated that raw materials saved by remanufacturing worldwide could be loaded into over 155,000 railroad wagons annually. (Rogers and Tibben-Lembke, 1998)

As products’ life-cycle become shorter and governments obligate companies to recycle and take back their damaged or aged products, many firms look for new possibilities to create and improve their return systems in order to gain a competitive advantage (Harrington, 2006). In other words, many companies are now looking into reverse logistics (RL) in order to optimize their return flows and gain momentum.

Reverse logistics can be defined by “the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal” (Hawks, 2006). Such a concept has existed for almost 20 years and authors have studied its processes, goals and complexity from different angles and within different industries. In today’s world, where the environment has become a major concern for the population and legislations are put in place, the field of reverse logistics has become more important than ever.

Among the many industries in which reverse logistics has become a necessity, the mobile phone industry faces an important challenge as the lifetime of its products have become shorter and millions of cell phones retire each year to be stored in people’s homes or simply thrown in the trash. In fact, Motorola estimates that no less than 55% of aged mobile phones are simply kept in consumers’ homes (Canning, 2006). Due to legislations and environmental concerns, mobile phone manufacturers, carriers and retailers have started to implement recovery networks in order to recycle and remanufacture their “out of date” products. The major mobile phone manufacturers, as well as other businesses, can gain different advantages by doing so as up to 80% of each device is recyclable (Nokia, 2009). One can find in a mobile phone different materials that can be reused such as plastic, iron, aluminum, copper, nickel, silver and gold. "If all of the 3 billion people globally who own mobiles brought back just one unused device, we could save 240,000 tons of raw materials and reduce greenhouse gases to the same effect as taking 4 million cars off the road" (Keong, 2008).
Research Goals and Problem Statement
This thesis will cover two important topics; reverse logistics and the creation of recovery networks for the mobile phone industry. In order to first gain a better and more profound understanding of reverse logistics, the present thesis will strive to answer the following questions regarding the subject:

- What is reverse logistics and what activities do these networks include?
- What are the reverse logistics motivators?
- What are the differences between reverse logistics and forward logistics?
- What research has been carried out on the topic?
- What are the challenges and constraints of the reverse flow in the supply chain?
- How can the reverse logistics process be integrated with the forward process?
- Why would reverse logistics or part of the process be outsourced?

The second part of this thesis will focus on the use of reverse logistics for the mobile phone industry. Unlike other industries such as the personal computer industry or the automobile industry, the reverse logistics process for the mobile phone industry has not been extensively studied and models representing the possible recovery networks, their activities, processes and characteristics have not been analyzed.

In other words, this thesis will first examine the general reverse logistics networks and characteristics in order to gain a deeper understanding of the subject. This will be done so as to acquire the necessary background information required to study, understand and analyze the different reverse logistics characteristics of the mobile phone industry and to create a model for the recovery, repairing, remanufacturing and recycling of mobile phones in today’s environmental context.

Structure
In order study and analyze the mobile phone industry’s different reverse logistics characteristics and bring forward a possible recovery networks, this thesis will be divided into four different parts. Before one can investigate the reverse logistics aspects of the mobile phone industry, one shall first get acquainted with the main concept of reverse logistics. The first part of this paper will therefore focus on the concept of RL, its activities, motivators, drivers and actors. Additionally, the main differences between forward network designs and reverse network designs will also be presented. The first part will be concluded by a brief literature review of reverse logistics in order to give the reader a concise overview of the studies that have been carried out on the topic beforehand.
The second part of this thesis will present the different challenges of reverse logistics. Through theoretical concepts and various examples, the different challenges present in recovery networks such as the collection challenges, inventory management difficulties as well as the disassembling and production planning challenges encountered when creating reverse logistics systems will be presented. This will be done so the reader clearly understands the difficulties and complexities that can be met when implementing a reverse network and this will serve as a fundamental premise for the possible mobile phone recovery network presented in the last part of this paper. Finally, part two will be concluded by presenting the challenges of integrating reverse logistics with the forward supply chain and the different outsourcing possibilities.

Part three will give a brief introduction to the mobile phone and its industry. The different important characteristics and facts regarding this industry, within a recuperation context, as well as the components and materials present in each devices will be introduced. This will be done in order to give a better picture of the product and its industry, from a recoverable perspective, before studying the different reverse logistics characteristics for the mobile phone industry.

The last part of the thesis will depict the reverse flow characteristics of the mobile phone industry, present the different challenges existing within this industry and give examples of some initiatives taken by certain mobile phone companies and third parties to recycle old devices. Finally, based on all the information presented in this section as well as in the previous ones, a suggested reverse logistics model designed for the mobile phone industry will be presented and its operational execution will be explained and analyzed in details.

Methodology
This thesis is based on theoretical literature of the topic studied. In order to create this paper and the model presented in Section 4. Creation and Design of Reverse Flows in the Mobile Phone Industry, different types of data and information were used: visual data (video, figures, models), cases and examples, quantitative models and qualitative studies created by different authors. The construction of the model for the mobile phone industry is based on a reflection process and on interpretations of different theories, models, data and researches scrutinized during this exercise.

The framework used in this paper is based on Taylor’s (1996) suggested framework for the
analysis of logistics and supply chain management cases. As the author explained, there are 5 steps to be considered when building an analysis in a supply chain management context: situation analysis, identification of the main issues and problems, generation and evaluation of alternative solutions, recommended solutions and implementation. In the case of this thesis, these five steps correspond to:

- **Step 1: Situation analysis:**
  - Part 1 – Reverse Logistics:
    - Presentation of reverse logistics and its context.
  - Part 3 – The Mobile Phone Industry:
    - Brief presentation of the mobile phone industry, the mobile phones and their recyclable components (in a recovery context).

- **Step 2 and 3: Identification of the main issues and generation of alternative solutions**
  - Part 2 – Reverse Logistics Challenges:
    - Presentation of the main issues present in the field of reverse logistics and some solutions brought forward by authors and companies.
  - Part 4: Creation and Design of a Reverse Flow for the Mobile Phone Industry:
    - Presentation of the different initiatives taken by some of the mobile phone manufacturers and third parties.

- **Step 4 and 5: Recommended solution and Implementation:**
  - Part 4: Creation and Design of a Reverse Flow for the Mobile Phone Industry:
    - Presentation of the model for the recovery of the mobile phones, its characteristics, processes and complexities.

**Assumptions and Limitations**

In order to design the present thesis, many assumptions and limitations had to be set in order to create the appropriate boundaries around the subject studied to remain focus. It is assume, from the start, that the readers of this thesis have a certain knowledge of supply chain management which explains why none of the basic supply chain management concepts are explained. It is also assumed that the readers know about forward flows as well as the different activities involved in a regular forward logistics process. On the other hand, it is assumed that the readers do not have an extensive knowledge of the researched field, reverse logistics, which explains the in-depth depiction of the subject studied in Section 1. In other words, the paper limits itself to the field of reverse logistics and does not include other supply chain management concepts and activities nor their description and roles.

In addition, the concepts of reverse logistics and recovery networks in the present thesis are mainly written focusing on the after life possibilities for aged products with a high focus on
electronic goods. Although briefly touched, reverse logistics for product under warranty and after sales services are not the main focus of the thesis at hand as the objective is to create a recovery network for aged mobile phones. Therefore, the focus of reverse logistics tends to revolve around aged and outdated electronic products and their possible recovery options. That being said, it is important to know that reverse logistics and recovery networks can also be created to provide after sales services and to manage efficiently products under warranty requiring repairs.

The actors present in the reverse flow often have an opposite role to the one they have in the forward flow. That being said, the terminology used to name these actors, in the RL context, remains the same as in the forward logistics context. In other words, the term “supplier”, in reverse logistics, is used to identify the entities that are the suppliers in the forward flow. Although these suppliers are, in fact, the buyers/customers of the reverse flow as they buy the recovered goods and materials, they are still labeled “suppliers” in RL literature and in this thesis. These suppliers will use the goods bought from the reverse logistics networks to supply the forward flows. The same goes for the term “customer”, which identifies the customers of the forward flow. In the reverse logistics context, although the customers supply the returned goods to the RL networks, they are still named “customers”. For these reasons, one should be aware that in the reverse logistics context, the terminology used to identify the different actors is not representative of their roles but is simply the names (and roles) these actors have in the forward logistics context.

Finally, many other assumptions and limitations were used specifically for the creation of the recovery model for the mobile phone industry, which will presented and explained in Section 4. Creation and Design of Reverse Flows in the Mobile Phone Industry. These limitations and assumptions, which were required to put in place in order to construct the model, will be brought forward in Section 4 as the model’s creation process and objective are explained.

1. Reverse Logistics
Supply chain management and logistics are two key business processes in today’s world and companies spend millions every year trying to better their logistics network, reduce their costs and improve their efficiency. Already in 1998, logistics costs were estimated to account for 10.7% of the US economy (Moore, 2005). Supply chain management is a wide field and it includes many different activities such as customer relationship management, customer service, demand management, order fulfillment, inventory management, supplier relationship
management, return management etc (Croxton et al., 2001) Among the many processes included in supply chain management is reverse logistics. Such a concept was already briefly defined in the introduction of this thesis, but many aspects of it remain to be explained, which will be the purpose of this section. As stated before, reverse logistics concerns all operations associated to the reuse of products and materials, damaged merchandise, recalls, asset recovery, products having reached the end of their life-cycle and hazardous material disposal (Harrington, 2006). Many of today’s major firms have changed their view on the subject and now consider RL to be a managerial priority due to possible assets recovery as well as the reverse logistics’ prospective influence and consequences on customer relations (Skinner et al., 2008). For these reasons, reverse logistics has become an organizational activity which can lead to potential competitive advantages and companies have started to include it in their strategic decision making processes (Meade and Sarkis, 2002).

1.1 The Size of Reverse Logistics
In the United States, it is estimated the reverse logistics costs account for almost 1% of the total national GDP (Moore, 2005). In addition, RL costs in the USA are estimated to be above 35$ billion per year and the product returns average to be around 6% of the total sales done within the country (Daugherty et al., 2003). That being said, it remains quite hard to track the exact costs of RL as most firms do not track their reverse logistics costs with great details (Smith, 2005). In addition, to these returns, all western countries of the world have seen massive increases of their recycling rates over the past 30 years. For example, the recycling rate of glass went from 20% to 52% in France between 1980 and 1997. For the same years, the paper recycling rate jumped from 34% to 70% in Germany and in the Netherlands, close to 70% of all industrial waste was retrieved by 1996 (Fleischmann, 2004). This shows that RL is an important element of today’s business world.

1.2 The Reverse Logistics Activities
Many companies create reverse logistics networks in order to achieve asset recovery. Asset recovery is

The classification and disposition of returned goods, surplus, obsolete, scrap, waste and excess material products, and other assets, in a way that maximizes returns to the owner, while minimizing costs and liabilities associated with the dispositions. […] The objective of asset recovery is to recover as much of the economic (and ecological) value as reasonably possible, thereby reducing the ultimate quantities of waste. (Rogers and Tibben-Lemke, 1998).

In order to achieve such recovery, reverse logistics networks are put in place and these systems include many different activities. After comparing many major reverse logistics
authors\textsuperscript{2} and studies, one can conclude that most, if not all authors seem to agree on the same basic reverse logistics activities. These are:

- Collection and transportation
- Sorting, testing, inspecting
- Disassembly (if required)
- Disposition options:
  - Reuse
  - Repair
  - Remanufacture
  - Recycle
  - Dispose

In order for one to better conceptualize the different activities present in a basic general reverse logistics network, the main general models of reverse logistics created by different authors\textsuperscript{3} of reverse logistics theories were compiled and adapted into this reviewed version:

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure_1.1_The.Reverse.Logistics.Network.png}
\caption{The Reverse Logistics Network}
\end{figure}


\textsuperscript{2} The main reverse logistics authors will be introduced and discussed in the Section 1.8, the literature review section of this chapter.

\textsuperscript{3} The different models on which this model was based on can be found in Appendix I- The Main Reverse Logistics Models.
The figure shown above depicts a basic reverse logistics network and its possible activities\(^4\). To start with, the goods, which were in possession of the customers (business or private), shall be collected. Collection can be done through different mediums such as, for example, central warehousing or at local stores. This step includes all actions required to recover the goods. After the goods are collected, they are transported to converging facilities in order for the products to be sorted and tested (Srivastava and Srivastava, 2006). That being said, it is important to mention that the collection site will usually carry out a pre-processing process and act as a gatekeeper so unwanted products will not be collected and will not enter the reverse logistics system (Mollenkopf et al., 2007).

Once goods have reached the converging facilities, each product will be sorted out depending on its condition, model, brand, its components and its components’ conditions. At this step, each product has to be looked at, either manually or with the use of an automated/semi-automated system, in order to assess the products’ respective states and determine which parts can be reused, repaired, remanufactured or recycled. If the product cannot be disassembled for further use, nor can any of its components, the good will be sent on to be recycled or properly disposed. When it comes to disposing of a product or one of its components, certain steps are necessary to be done as it may contain hazardous material and therefore special treatment shall be performed before disposal to assure safe and environmentally friendly dumping (Lee and Chan, 2009). Parts that can be recycled will be and the recycled materials will be sent on to suppliers that want to buy these different materials.

Products and goods that can be fully or partially reused, repaired or remanufactured will be sent to the disassembly line in order for the products to be dismantled and for the different components to be sent to the right succeeding process. The reuse of a product or its components designates that it will be traded as is, without being modified. The product or its components will usually be used in their original functionality. For example, a computer could be dismantled and the motherboard could be reused, as is, for another computer (Lee and Chan, 2009). The same motherboard could also be remanufactured to be installed an electronic toy. Remanufacturing includes the different steps required to transform a product or its components so it can be usable again, either by bringing back the component to its original state or by altering it so it can serve a new purpose like in the example presented here. In

\(^4\) All the processes presented in the general reverse logistics model contain different complexities and challenges, which will be discussed in greater details in section 2. Reverse Logistics Challenges.
addition, the broken computer’s screen could be *repaired*, while the hard drive casing could be *recycled*. These examples show that by dismantling the computer, many of its parts will re-enter the market for another trading cycle while other parts will enter new markets (Kokkinaki *et al.*, 2002). It is important to remember that remanufacturing and repairing are two different activities. Repairing only occurs when a product or one of its constituents is defective whereas remanufacturing occurs for any part that can be renewed or restored to their original state without having to be broken or damaged. Products and components that are reusable or have been repaired or remanufactured will be sent for redistribution to different markets, either secondary ones or original markets depending on the demands as well as the components/products possible remarketing possibilities.

Finally, in order to gain a pragmatic overview of the RL’s activities, one can look at the computer industry and see which processes are present in a reverse logistics system of this industry. According to Marcotte *et al.* (2008) whom studied the reverse logistics of the computer industry in Canada, although facilities differ greatly in sizes, capabilities and technologies, “*they all focus on activities such as receiving products, testing and sorting products, parts and materials, disassembling products and parts, cleaning and repairing products and parts, storing and shipping items, matching offer and demand, managing flow and operations*” (Marcotte *et al.*, 2008).

### 1.2.1 The Strategic Management Decisions of Reverse Logistics

In addition to the different activities of the reverse logistics process presented in the model, many key management elements are also present through out the reverse logistics system. Such elements are essential for the good functioning of the reverse flow. These are (Rogers and Tibben-Lembke, 1998):

- Forecasting supplies
- Location allocation
- Gatekeeping in order to control the returned goods
- Control and improve disposition time to increase efficiency
- Reverse logistics information systems to control the system and keep information flowing
- Inventory management
- Choice of strategic collection locations to ease the return process
- Financial management
- Outsourcing decisions as outsourcing some parts of the process might be necessary or less costly
- Forecasting demands
- Negotiation with third parties either as they are operating parts of the process or as they are suppliers/buyers

Finally, the reverse logistics activities and the different key management elements are the core
foundations of the reverse logistics flow. The planning of such a system can be highly complicated due to transportation, financial or disposition issues (Meyer, 1999). All these difficulties will be discussed in greater details in Section 2 of this paper.

1.3 The Reverse Logistics Motivators

Any company which decides to implement reverse logistics does so for one or many reasons. The reasons that push a corporation to implement a reverse flow also influences the way this reverse flow will be designed. Therefore, it is important to understand what can be the different motivations behind the creation of a reverse logistics system. Over the recent years, reverse logistics has gain in popularity for two main reasons: environmental concerns as well as new government legislations (Kokkinaki et al., 2002). As an example of such a legislation, the WEEE Directive was presented in the introduction. Besides legislations and environmental concerns, other incentives drive companies to create reverse flows.

According to Rogers and Tibben-Lembke (1998), there are 5 major strategic motivators influencing firms to create reverse flows.

### Table 1.1 – Motives for Creating a Reverse Logistics Network

<table>
<thead>
<tr>
<th>Role</th>
<th>Percentage of the respondents that answered that RL what motivated by this particular reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitive reasons</td>
<td>65.5%</td>
</tr>
<tr>
<td>Clean Channel and protect margin</td>
<td>33.4%</td>
</tr>
<tr>
<td>Legal disposal issues</td>
<td>28.9%</td>
</tr>
<tr>
<td>Recapture value</td>
<td>27.5%</td>
</tr>
<tr>
<td>Recover assets</td>
<td>26.5%</td>
</tr>
</tbody>
</table>

Source: Roger and Tibben-Lembke, 1998

- Competitive reasons: many companies are required to create reverse networks due to internal policies such as return policies for damaged or broken products. Many companies will also create reverse channels in order to embellish their good corporate citizenship image and increase their customer retention and satisfaction (Moore, 2005). For example, Nike prompts customers to bring back their used sneakers as the company donates the shoes’ materials to make basketball courts and well as running tracks (Rogers and Tibben-Lembke, 1998). Firms that do not recognize the potential importance of creating effective reverse flows risk to damage their customer relations and this could harm the firm’s image and reputation (Smith, 2005). In fact, many customers expect the vendors or manufacturers to be able to take returns and many of today’s customer will choose a certain retailer or manufacturer based on their return policies and capabilities (Skinner et al., 2008).
• Clean channel: firms might decide to create reverse logistics networks in order to clean out their business customers’ inventories so that those customers can buy more new products. This is the case for seasonal products as well as when a newer version or newer technology appear.

• Legal disposal issues: while some firms focus on gaining a competitive advantage from reverse logistics, others focus their energy on network creation due to mandatory retrieval (Skinner et al., 2008). This is the case for electrical and electronic manufacturers in Europe, but also in other industries. For example, in Germany, consumers are allowed to leave packaging materials at retailer stores. This means that one could leave his/her toothpaste tubes and the store is responsible for disposing of them properly or sending them on the appropriate facility (Wu and Dunn, 1995).

• Recapture value and asset recovery: companies such as Compaq or Xerox will use reverse logistics networks to recapture value and recover assets. For example, Compaq reuses computer parts to create remanufactured computers (Meade and Sarkis, 2002). Xerox collects old photocopiers directly from customers when installing new machines and saves between 40 and 65% in manufacturing costs as it reuses parts and components (Qinglong et al., 2008). Another example is HP, which has been remanufacturing and reselling 2.5 million hardware products per year since 1987. In order to sustain such a program, HP has implemented asset recovery services and created partnership with third parties in order to gather to components and remarket them efficiently (Breen, 2006).

In addition to the different motivators presented by Rogers and Tibben-Lembke (1998), reverse logistics systems can supply organizations with crucial information on their products, problems and potential defects. This is a great competitive advantage as firms operating RL networks get an exclusive insight on their used products (Smith, 2005). This can help firms and manufacturers create better products, avoid problems as well as learn how to design products that are easier to recycle or remanufacture.

1.4 The Reverse Logistics Drivers
Motivators are the different incentives leading to the creation of reverse logistics networks. In addition to those incentives, many drivers play an important role in the creation of such networks. One of the most important drivers of reverse logistics is the product lifecycle (Smith, 2005). Many products are returned or thrown away as they have reached the end of their life. This is especially the case for electronic equipment as products’ lifecycle have shortened over the years and as new improved technologies appear. This can be exemplified
by the mobile phone industry as well as with the personal computer industry where new and better models are constantly put on the market. The product lifecycle stage in which the product is when returned will also influence and/or determine what steps need to be carried out when the product is recovered - younger products might be reused differently than older products. Therefore, creators of reverse logistics systems have to take into consideration the different cycles of the products’ life and how each cycle can demand different processing sequences. In addition, by identifying in advance when products become out of date, companies can better manage their recovery networks.

Another key driver of reverse logistics is the customer-supplier trust relationship, as one cannot create a recovery network without the participation of the business and private consumers. Companies have to promote their reverse flows, be visible and promote communication (Breen, 2006). In other words, reverse logistics systems have to maintain a great relationship with the consumers returning the products and the possible components’ buyers.

1.5 The Reverse Logistics Actors
Many players are involved in reverse logistics networks. First of all, consumers play a key role as the incoming supply depends on them. That being said, other actors play key roles in the creation of reverse logistics networks such as the forward supply chain actors – suppliers, manufacturers, distributors, retailers ect (De Brito et al., 2003). In addition to these actors, one company can do the reverse logistics process “in-house” or part(s) can be outsourced. The activities that are outsourced will be given to specialized reverse logistics players (De Brito et al., 2003). More and more companies specializing in RL (collectors, redistributors, remanufacturers, repair services, recyclers ect.) appear as reverse logistics is implemented into different industries (Fleischmann et al., 1997). This leads to the expansion of the panoply of possible actors present in a reverse logistics network. Finally, no matter the amount of actors present in a specific RL system, tight relations between each player are crucial for the well being on the reverse flow.

1.6 Types of Reverse Logistics Network:
Many activities can co-exist in a reverse logistics network, as shown in Figure 1.1. That being said, a reverse flow can also be created solely for one particular process. Whereas, in some cases, networks will be created in order to repair parts, remanufacture products and recycle materials, other networks, for example, will be constructed for the sole purpose of
recycling. Therefore, the aim of the network will define its type and the activities it will include.

In addition, in these different contexts, the created networks can either be public or private (De Brito et al., 2003). Private networks will be operated by companies who desire to acquire a particular type of product in order to recycle it and/or repair it and/or remanufacture it and sell the materials and/or components to manufacturers and/or suppliers. Public networks are quite common nowadays. Many countries operate public recycling networks for paper, glass, and plastic recycling. For example, the Netherlands created the Glass Recycling Foundation in order to handle and manage the glass recycling process that became obligatory due to Dutch legislation. Such a foundation is responsible for the collection and recycling of the glass from the Dutch households (De Brito et al., 2003).

1.7 The Differences between Forward Network Designs and Reverse Network Designs

When discussing reverse logistics, one is discussing a constituent of the overall supply chain. Most people think of the supply chain as a forward network in which raw materials are brought in, transformed into products which are then are distributed to consumers. Reverse logistics operates in an inverse way, but there are many other differences between the two processes. Among the many differences existing between forward and reverse logistics, the first and most prominent difference is that reverse logistics is product (supply) dependent (Kokkinaki et al., 2002). In other words, where forward logistics is mainly dependent on customers’ demand or forecasted customers’ demand, which pulls product through the supply chain, reverse logistics depends on final products being pushed back into the supply chain. This makes the RL process fully driven by supplies (Lourenço and Soto, 2002).

There are many other differences present when comparing forward and reverse networks such as routes, destinations, costs, quality, disposal options, inventory management, visibility, cycle time, etc (Marcotte et al., 2008). For example, in reverse logistics, the cycle time required to collect the product is uncertain, which is not usually the case when it comes to the collection of raw materials in the forward supply chain (Lee and Chan, 2009). Due to this major uncertainty, reverse channels tend to be harder to manage. Returned products can vary in size, quality, types etc.

In a forward channel, quality and delivered inputs can be controlled according to the system’s
needs whereas, in a reverse logistics networks, the inputs’ quality cannot be controlled in the same way (Fleischmann, 2004). Moreover, where forward logistics can account for its product in units or boxes, reverse logistics might use weight as the measuring unit. For example a drink producer will account for the number of drinks’ unit produced where as in the reverse process, the products returned will be accounted in number of kilograms of aluminum from the drinking cans (Lee and Chan, 2009).

As forward and reverse logistics have many differences Tibben-Lembke and Rogers (2002) listed them and here are, according to the two authors, some of the most important differences between the two logistics networks:

<table>
<thead>
<tr>
<th>Table 1.3 – Differences between Forward and Reverse Logistics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forward Logistics</strong></td>
</tr>
<tr>
<td>Forecasting based on demand</td>
</tr>
<tr>
<td>Uniform product quality</td>
</tr>
<tr>
<td>Uniform product packaging</td>
</tr>
<tr>
<td>Clear processing sequence</td>
</tr>
<tr>
<td>Pricing relatively uniform</td>
</tr>
<tr>
<td>Forward distribution costs are closely monitored by accounting systems</td>
</tr>
<tr>
<td>Inventory management consistent</td>
</tr>
<tr>
<td>Real-time information readily available to track products</td>
</tr>
</tbody>
</table>

Adapted from Tibben-Lembke, 2002.

As one can see, many differences exist between the two types of logistics. In addition, reverse logistics networks will vary according to the products that are recovered and the type of network that is put in place.

### 1.8 Literature Review

Over the past 20 years, many research papers and studies have focused on reverse logistics. Before moving on to Section 2, which will discuss the main challenges encountered when creating reverse logistics networks, the global overview of RL should be concluded by a literature review. This is done in order to give the reader an insight on what studies have been done on the issue, which elements of reverse logistics have been analyzed, and within which industries, so that one obtains a good overview of the background this thesis is based on.

Reverse logistics was first brought forward by Stock in 1992 where the author presented the application of such a process, its potential and current use in business and society.
The two authors who have contributed the most over the past 20 years are Tibben-Lembke and Rogers as they published many studies including “Going Backwards: Reverse Logistics Trends and Practices” in 1998. This document of 283 pages covers many aspects of reverse logistics: from what RL consists of to how it is applied in different industries. Their study was both theoretical and empirical as it was based on many previous papers and on an important survey was carried out among different US companies operating in different industries (Tibben-Lembke and Rogers, 1998).

Obviously, not all papers written on the matter cover reverse logistics in such a general manner and many are more specialized within one area of the field. For example, Tibben-Lembke (2002) linked reverse logistics to product lifecycle, Kroon and Vrijens (1995) studied the case of recyclable containers, Daugherty et al. (2003) concentrated on information technology for reverse logistics and both De Koster et al. (2002) and Kokkinaki et al. (2002) focused on network design and product flow management.

Fleischmann et al. (1997) considered the robustness issue of RL networks and many authors such as Ferrer and Whybark (2000) or Prallinski and Kocabasoglu (2006) discussed the costs of recovering products and how this can be reduced through to use of optimal locations (Pokharel and Mutha, 2009). In addition, authors such as Knemeyer et al. (2002), Tibben-Lembke and Rogers (2002) and De Brito and De Koster (2003) discussed the different strategies to use when implementing a reverse logistics network such as location facilities and proximity to the disposal sites.

Many authors presented linear models for reverse logistics activities. Kroon and Vrijens (1995), Ammons et al. (1997), Spengler et al. (1997), Barros et al. (1998), Krikke et al. (1999) and Fleischmann et al. (2001) have presented mixed-integer linear programming model on facility locations (Pourmohammadi et al., 2008). Other authors presented different quantitative models such as Demirel and Grökçen (2008) who presented a mixed-integer model for remanufacturing. Quinglong et al. (2008) presented a joint inventory model for the reverse supply chain whereas Fleischmann (2004) presented a joint recovery and inventory model. Zhou el al. (2005) discussed an algorithm approach to reverse logistics optimization. Moreover, other authors concentrated on outsourcing of reverse logistics such as Guojin (2006), Meade and Sarkis (2002), Meyer (1999), Bowman (2006) or Pagell et al. (2007). Finally, some authors have studied the implications of the WEEE Directive and reverse logistics in Europe such as James (2006) and Dickson (2005).
The list of articles on reverse logistics is quite long and most activities of the reverse logistics process were covered by one or many studies. Many industries were also analyzed such as the computer industry by Marcotte et al. (2008), Danda et al. (2005), Kwan Tan et al. (2006), Knemeyer et al. (2002), Fleischmann (2004), and Lee and Dong (2007). In addition, Daugherty et al. (2003) and Kumar and Yamaoka (2007) covered the automobile industry. Some authors concentrated on only one particular company such as Clendenin (1997), De Brito et al. (2003) and Fleischmann (2004) whom all presented the case of Xerox.

As one can see, and this is only a brief summary of some of the literature published on reverse logistics. Finally, reverse logistics is gaining momentum and since 2006 the Reverse Logistics Association publishes the Reverse Logistics Magazine, which is a bi-monthly publication read by over 65 000 readers worldwide (Reverse Logistics Magazine, 2009).

2. Reverse Logistics Challenges

When a company decides, for various reasons, to create and implement a reverse logistics networks, certain difficulties will have to be overcome. The goal of this section is to present the different possible challenges one can face when working with reverse logistics. These challenges will be supported with examples from different theoretical studies and cases. No matter the industry for which the RL system is created for, it is important for one to understand what the difficulties of operating a reverse network can be. This is even more relevant as one shall be aware of these challenges before one can attempt to create a reverse flow for a particular industry such for as the mobile phone industry. Therefore, the elements presented in this section will be used as the foundations and as the key components that will be taken into consideration for the creation of a possible network design for the recovery of mobile phones.

Guide et al. (2000) suggested that reverse logistics systems have the following seven challenges to be aware of:

- The uncertain timing and quantity of returns
- The need to balance demands with returns
- The need to disassemble the returned products
- The uncertainty in materials recovered from returned items
- The requirement for a reverse logistics network
- The complication of material matching restrictions
- The problems of routings materials undergoing repairs/remanufacturing operations and highly variable processing times.
The major challenges of reverse logistics, as one can see, are either general or activity-based. Therefore, this section will first present the general challenges of reverse logistics that can be encountered in most industries and then, the challenges existing in the different specific activities/areas, will be presented. This section will be concluded by presenting the possible integration of reverse networks to the forward networks as well as the outsourcing possibilities of RL as outsourcing can be used as a solution to some of the challenges presented in this section.

2.1 General Challenges

2.1.1 Decision Making Challenges
The first general challenge present in reverse logistics concerns the overall decision-making process. Most manufacturers are facing key problems and decisions have to be made regarding, for example, where to locate the facilities, what level of qualities to accept, how to coordinate the different processes and activities, what incentives to create in order to encourage consumers to return their products ect. “Therefore, RL operations and the supply chains they support are significantly more complex than traditional manufacturing supply chains. So, just as companies develop efficient logistics processes for new goods, they must do the same for returned goods, understanding that the processes may be quite different from those defined for forward distribution” (Srivastava, 2008).

According to Kwan Tan and Kumar (2006), the creation of a reverse process leads to asking and answering four key questions:

1. What are the conditions under which one should consider employing reverse logistics?
2. What types of reverse logistics processes should be prescribed to each item or for each group of items?
3. Where would the ideal location be to execute the repair or scrap and whether this should be done locally or centrally?
4. What would be the optimal pricing for the remanufactured parts compared and in order to compete against new parts?

In addition, other decisions have to be constantly made in a reverse flow for each single product entering the system. These decisions can be shown in the figure below:
As presented here, many decisions have to be made when implementing a reverse logistics systems as well as every time a product is returned. As it will be discussed later on in this paper, information systems can help automate some of the decisions that have to be made when products go through the system in question.

2.1.2 Costs
An important issue of reverse logistics is the costs. Creating such a reverse process is costly and it can be quite hard to assign the costs to the relevant activities. Reverse logistics costs can be divided into 3 main costs categories (Kwan Tan and Kumar, 2006):

1. Units costs
   a. Transportation costs per unit
   b. Customs cost per unit (when product travels across borders, if allowed)
   c. Acquisition costs
   d. Handling costs
2. Variable costs (depending on the returns’ quality)
   a. Repair costs
   b. Reuse costs
   c. Disposal costs
   d. Recycle costs
3. Variable costs (depending on the storage time)
   a. Storage costs
   b. Freight costs

Although reverse logistics costs can easily be separated into different categories, it can be
quite hard to identify the exact cost of each activity or to assign the exact costs to each return product. This is due, in part, to the fact that these activities receive only a limited amount of attention from the management team (Glodbsy and Closs, 2000). This is also attributable to the fact that return products can vary greatly in models, brands and conditions. In addition, “different cost structures and revenue recovery are associated with the different disposition strategies” (Skinner et al., 2008). Therefore, tracing costs back to each returned device or component can be a great challenge in RL.

Finally, in order to get a summarized overview of the different costs in reverse logistics compared to forward logistics; Tibben-Lembke and Rogers (2002) created a comparative analysis of the different costs encountered in RL:

<table>
<thead>
<tr>
<th>Costs</th>
<th>Reverse logistics costs compared to forward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Greater as goods are not all the same and supplies can be hard to forecast</td>
</tr>
<tr>
<td>Inventory holding costs</td>
<td>Lower as goods are of lesser value and can therefore be stocked less carefully</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>Much lower</td>
</tr>
<tr>
<td>Collection</td>
<td>Much higher due to the standardization difficulties</td>
</tr>
<tr>
<td>Sorting, quality diagnosis</td>
<td>Much higher as products differ in their conditions</td>
</tr>
<tr>
<td>Handling</td>
<td>Much higher as products differ in their conditions</td>
</tr>
<tr>
<td>Repairing/remanufacturing/repackaging</td>
<td>Significant for RL, non-existent in forward logistics</td>
</tr>
<tr>
<td>Change from book value</td>
<td>Significant for RL, non-existent in forward logistics</td>
</tr>
</tbody>
</table>

Adapted: Tibben-Lembke and Rogers, 2002.

2.2 Collection Challenges

The collection process starts as the items or products have to be moved from the end-user (private or business) to another location, such as collection centers or returned to the retailers. From that collection point, products will be sent on to the appropriate facility. The collection process poses a basic and complex problem: the uncertainty of supply.

2.2.1 Supply and Forecasting

Reverse logistics is characterized by one major constraint: supply. Supply in recovery networks is an uncertain and hard to forecast variable as collectors, remanufacturers and recyclers can hardly predict the quantity as well as the quality of the products that will be returned. Both these uncertainties (quantity and quality) are essential elements to take into considerations when implementing the reverse network. For example, high quality product might require better transportation which can lead to higher transportation costs, where as lower quality products might require more extensive remanufacturing which could increase
the processes’ costs (Fleischmann et al., 1997). Moreover, supply uncertainty means also that one cannot always predict ahead what processes and activities will be required for each returned products. Will it be repairing, remanufacturing or recycling? Therefore, supply has a huge impact on the recovery network, its costs and the processes through which the return goods will go through.

In addition, the uncertainty regarding the number of returned products creates complications when it comes to scheduling the different processes and planning efficiently the transportation required. In reverse logistics, where the products are pushed back into the supply chain, the forecasting tasks can be hard to accomplish (Kumar and Yamaoka, 2007). If the returns are greater than expected, one might not have sufficient storage space or sufficient equipment to process all products quickly. The opposite situation can occur where too few products are returned. Therefore, the success of an efficient reverse networks is “highly dependent on ensuring sufficient volumes of input materials” (Knemeyer et al., 2002).

In most industries, such as the automobile industry, returns fall into two different categories: planned and unplanned returns. Planned returns are usually estimated based on sales. For example, in the automobile industry, 15% to 20% of the sales of spare parts will be returned (Daugherty et al., 2003). On the other hand, unexpected returns are hard to forecast as they can be due to poor sales, incorrect or damaged shipments. Companies have to sustain a certain level of flexibility to be able to handle these unanticipated returns. According to Marcotte et al. (2008) and their research on the recovery of computers in Canada, companies approach this issue in two different ways: “some facilities do not try to attenuate them and therefore have to learn to thrive through complexity. Others are taking strategic approaches to attenuate complexity, mostly by prioritizing stabilizing and risk reducing business relationships or by focusing on specific potential supplies” (Marcotte et al., 2008).

Some companies have explained to researchers how they cope and deal with supply uncertainties. For example, Kodak recycles its single-used cameras and create new ones with the returned ones. The challenge for Kodak is to forecast the supply in order to create the appropriate balance between new parts and remanufactured parts when making new single-use cameras. Kodak’s forecasting technique is to estimate the future return products based on sale information and the average life-expectancy of the product. This technique has been employed for some years and has greatly reduced their inventory costs (Fleischmann, 2004). It has been shown, through other researches, that most companies will use the same technique
as Kodak, based on sales and lifecycle variables, to forecast the possible returns. In addition, different authors have also created theoretical models to forecast supplies based on those variables. For example, Buchanan and Adab (1998) created a model which assumed that for each period, the number of returns are defined by a stochastic fraction of the number of products in the market and by a predefined product sojourn period onto the market (Fleischmann, 2004).

Besides the supply quantity, quality and timing uncertainties, one last uncertainty exists regarding supply, which is the mix of returned products one might receive (Jahre and Flygansvær, 2002). For example, if a recycler-remanufacturer concentrates only on mobile phone, one will receive various shipments of mobile phone, but they might vary in types, sizes, brands, models, components ect. These characteristics have to be taken into account when setting up the reverse network as it can affect the coordination of the different activities and an efficient flexible system has to be put in place to support the varied incoming goods.

2.2.2 Incentives
In order to ensure that an adequate amount of goods are returned, manufacturers and recyclers have to create incentives to motivate customers to return their product when these have reached the end of their life cycle. For example, in the bottle industry, consumers get their deposit reimbursed once the bottles have been returned (Goldsby and Closs, 2000). Another example, which could be more relevant and used in the mobile phone industry, is the case of IBM Japan. As the makers of electrical devices in Japan are required to recycle their own products, IBM Japan encourages its customers to return their old computers and depending on the product’s age and condition, the consumer receives a credit (Rogers and Tibben-Lembke, 1998).

Major companies and websites have also started to create incentives for customers to return and recycle their old products. e-bay launched its Rethink Initiative, which gives advice, tools and profitable opportunities to consumers to recycle, resale and return their electronic equipments (e-bay, 2009). The company’s aim is to reduce e-waste through different partnerships as well as to create new sales opportunities for products that can still be used. Like in the case of e-bay’s initiative and in many other cases, the incentives put in place are reminders to the customers of their legal and moral environmental responsibility, which seems to be the method to encourage people to return their products other than money incentives (Breen, 2006).
2.2.3 Gatekeeping

Gatekeeping is an important procedure of the collection process. This activity consists of doing a basic screening of the return merchandise and determine if the return items are valid and if one can let them enter the reverse logistics network (Rogers et al., 2002). Many manufacturers and companies have created acceptable return standards in order to ease the sorting and testing process, which usually takes place later on in the reverse process. For companies dealing with returns due to warranty or return policies, good gate keeping is essential in order to make sure the products returned are allowed to be returned. For example, Dell does not allow any computer to be sent back before the customer has spoken to a customer service representative with whom most common problems have been eliminated (Moore, 2005). Additionally, gatekeeping’s lack of success can lead to tensions between the different supply chain partners, the customers and can also result in lost revenues and/or higher costs.

2.2.4 Location Challenges

The other most important challenge to initiate, launch and establish the recovery network, beside supply uncertainties, is location allocation. As supply is uncertain and varying, one needs to make the initial point of the recovery network as accessible as possible. The strategic decision of deciding on the number and the location of the recovery facilities is crucial and, in most cases, geographical location and forecasted volumes of returns are the most important decision variables for choosing the appropriate location (Fleischmann, 2004). In order to understand the allocation difficulties and find guidelines, some authors have tried to adapt forward logistics mixed-integer linear programming (MILP) models for facility location for the reverse networks, but many believe that MILP models might not be flexible enough to allow one to create a proper model that can support the diversity present in a recovery network as product supply, quality and timing are uncertain (Fleischmann, 2004).

As stated before, in order to make returns easy for the customers, the return facilities have to be properly located. In general, products are collected in collection centers that are regionally located so customers and retailers can easily access them (Lee and Chan, 2009). Moreover, many RL networks also allow customers to return goods directly to the retailers. Retailers then send the returned products, in batches, to the local collection center(s). This fact needs to be taken into account when creating these collection centers so they can support the inbound quantity of products received from both the customers and the retailers in the area. In other
words, if many people in the local population as well as many retailers are present in the area, the return center shall be capable of handling a large quantity of returns.

Finally, an important reverse logistics trend that has become more popular over the recent years is the creation and the use of centralized return centers (CRCs), which collect all types of products and materials. These various goods are sorted at the CRC and sent on to the appropriate facilities to be processed. These centers are mainly used as they are less costly and offer other advantages. Many CRCs have specialized sorting employees who can determine the condition of the product and what can be repaired or recycled quickly (Meyer, 1999). Furthermore, such return centers are subject to bigger volumes and can more easily send steady volumes of products and materials to the appropriate facilities. For one to decide how to set up the recovery network, the locations of the facilities and which partners to have are crucial decisions part of the reverse logistics network creation.

2.2.5 Transportation

Many recovery networks have a collection point (regionally located), which differ from the processing facility. That is often done so it is easier for consumers and retailers to bring back their goods (as mentioned in the previous sub-section), but this makes the recovery network one step more complex as transportation has to be arranged between the two points. Often, in the case of used goods, all products are not the same, do not have the same shape, and to use transportation efficiently can become a complex challenge.

In reverse logistics, many transportation routes are served by third party providers specializing in delivery services only. If that is the case, companies operating a reverse network shall find a provider that will meet their needs and expectations. As RL’s supply is uncertain, such transportation might have to be done with a high level of flexibility. Toshiba, for example, created a partnership with UPS for the returns of their laptops as UPS offers the flexibility Toshiba needed. (Moore, 2005).

In addition, transportation costs in recovery networks are, on average, higher per item than it is in a forward network. This is due to the fact that the shipments are often smaller. Tibben-Lembke and Rogers (2002) exemplify this with a retailer store that would receive full truckloads of new products weekly, but would return only a few pallets of aged products with the outgoing truck. As shown in this example, RL transportation often cannot use the full truck capacity as products returned might vary in quantity, model, size, state and therefore,
standardized transportation pallets or boxes might not exist. Because of this, some cube capacity might be lost. As transportation costs can be quite high, such an activity can determine the economic viability of a particular product recovery (Fleischmann, 2004). Finally, some authors have also raised the issue of additional transportation and how this can be conflicting with the environmental advantages of product recovery. Therefore, if one attempts to create such a network for environmental reasons, one shall also think of the environmental impact of the recovery network itself and use transportation efficiently to avoid public criticism.

2.3 Testing and Sorting Challenges
Once the products have been collected, they are transported to the disassembly facility where they will be tested and sorted. As explained earlier, supplies in recovery networks, are not standardized and the quality of each collected item can vary greatly. Although gatekeeping is usually carried out before hand in the recovery process, testing and sorting is a more thorough activity, which will reveal the exact state of the product in question (Rogers et al., 2002). The main challenge of testing and sorting is to create standardized procedures that can be applied to all items collected so the control process is constant and reliable. Testing and sorting operations are essential, as this assessment will allow one to know which of the products’ components are reusable, remanufacturable, recyclable or should be disposed.

Another challenge of the testing and sorting process is to create codes and labels to identify each possible product models entering the system and to identify their respective quality state and conditions. By doing so, the information system put in place can follow the products through out the network and guide them, and their components, through the right processing sequence.

Companies operating reverse logistics networks take testing challenges seriously. For example, IBM has an engineering division which is responsible of creating and controlling the different tests that are done to certify the quality of the return material and assess which components can be reused, which one need to be remanufactured and which one should be recycled. In this case, the remanufacturing process is fully dependent on the testing process, which is carried out in order to analyze the extent of the transformations required. This has to be done using tight control measures to ensure the constant quality of all remanufactured components, as these will be used in remanufactured computers - IBM’s reputation could be harmed if their testing process failed. Finally, in the case of IBM, certain machines are tested
as a whole and certain are disassembled so their components can be tested individually. This decision is made based on the computer, its components and their possible reselling opportunities (Fleischmann, 2004).

### 2.4 Disassembling Challenges

As it was presented in Section 1 of this thesis, RL includes many disposition activities (repair, remanufacture, recycle), which can all be preceded by the disassembly of the product.

When a product is taken apart in a recovery network, many different challenges will arise. First, most products were not made to be easily taken apart and it might be difficult to quickly disassemble the product without harming its exterior shell or its components. Studies have shown that less than 30% of all products are designed having in mind disassembly options or recycling of the components as a possible post lifecycle option (Pagell et al., 2007). This is an important challenge to overcome and it is taken seriously in certain industries, such as the automobile industry, where remanufacturing parts is a common activity. Therefore, automakers pay a great deal of attention to the disassembly possibilities of the cars they make in order to facilitate this process (Tibben-Lembke, 2002). As reverse logistics becomes more present in today’s business world, other industries will have to follow the car industry and create products that permit easy disassembly. This process has already started as some companies have become aware that the decisions made during the development phase of a product will have a direct impact on the reverse logistics possibilities and their related costs.

Another challenge of disassembly is to create an automated or semi-automated process that will allow taking apart products that are similar but that may vary in model and types. Disassembly automation\(^5\) of similar products has become a new engineering challenge in order to reduce costs in reverse logistics networks (Kopacek, 2008).

An additional challenge of disassembly is to determine to which extent a product or component should be disassembled. For certain products, the extent of the disassembly will have to be decided beforehand by calculating the disassembly costs versus the remanufacturing costs or recycling costs of the possible recovered materials and components. This will be done in order to find the optimal way to use the available resources, minimize the costs and maximize the outputs and profits (Fleischmann et al., 1997). For those reasons,

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\(^5\) An example of automatic disassembly is the Multi Life Cycle Center, which strives to automate the disassembly process of mobile phones. Such a system will be discussed in greater details in Section 4, as reverse logistics initiatives taken in the mobile phone industry are examined.
disassembly has to be set, in most cases in a 3 steps semi-standardized process where products are disassembled, components are then tested and are sorted out either to go on to the next activity or to be disassembled even more if need be.

In order to deal with the complexity of disassembly in the reverse logistics networks, many authors have proposed models to try to automate the decision process and the disassembly sequence. For example, Johnson and Wang (1995) presented a model in which the disassembly is done in a particular order. Parts with a higher value are taken apart first and the process continues in a decreasing value order until the marginal benefits outweighs the marginal costs of disassembly (Fleischmann et al., 1997). This makes sense, but it might be harder to accomplish when the products being collected vary in types, shapes, models and manufacturers. Other authors have suggested that preselected elements of the products should be taken a part first and then, if necessary or relevant, future disassembly steps can be taken to extract other components. In addition, some authors also take into consideration another important variable when it comes to disassembly, and a variable one should not forget: the lead time of extracting the possible components (Soto Zuluaga, 2006). Lead time fluctuations will influence greatly the chosen disassembly process as greater lead times increases the disassembly costs and decreases possible marginal benefits.

After taking apart a product, the different components and materials will be sent on, depending on their state, reselling options and benefit margins, to the appropriate activity, which can be repair, remanufacture, recycle or disposal.

2.5 Remanufacturing and Repairing Challenges
Although components that will have to be repaired or remanufactured will be sorted, the challenge here is that these similar components might not be in the same state and the remanufacturing or repairing that has to be done on each of them might differ. According to Fleischmann et al. (1997), remanufacturing and repairing can be the most complex process in a reverse logistics networks as individual repairs and remanufacturing can hardly be standardized and the coordination between the different repairing activities can be hard to balance in an efficient way. The full extent to which a product or component should be remanufactured can only be assessed once the product has been thoroughly tested and disassembled. Unlike manufacturing, where the sequence is clear and standardized, remanufacturing and repairing steps will depend on the component’s disposition, and therefore, standardization can be quite hard to implement. In addition, the remanufacturing
and repairing processes will be influenced and challenged by the market to which the component/product will be delivered too as the standards can vary from market to market.

2.6 Recycling Challenges
Like remanufacturing and repairing, recycling also deals with overcoming the challenge created by receiving components or materials that are different from one another as they might come from different products, different manufacturers or different product models. When recycling products, one needs to choose which recycling option will be the most valuable for the firm and for the products/components being recycled.

The two recycling options one can choose from are recycling without disassembly and recycling with disassembly (Pagell et al., 2007). Recycling without disassembly is to crush collected products and components that will be recycled, altogether and then the crushed materials will be sorted by type (e.g. metals, plastics, glass etc.). Such a recycling technique has advantages if the system put in place works efficiently as it operates quickly. For example, Micro Metallics Corporation recycles monitors for Hewlett Packard. The company uses a mechanic crusher, which is capable of separating, after the crush, the different materials present in the monitors (Pagell et al., 2007). This allows the company to recycle different monitor types and models without having to change the procedure or without having to disassemble the monitors prior to the crushing process. On the other hand, the main disadvantage of this type of recycling is that it has a lower recovery rate than recycling with disassembly as materials are often contaminated (mixed with other materials) or have a limited commercial use and lower value. Moreover, such a recycling system prohibits from learning from the recycling procedure as the products or components are not disassembled and manufacturers cannot learn from the after-life product (Pagell et al., 2007).

The second recycling option is to recycle with disassembly. This recycling method is more time consuming and can be more costly but offers a higher recovery rate (Pagell et al., 2007). In the computer industry, approximately 15% of the computers and their respective parts cannot be reused or remanufactured (Marcotte et al., 2008). Therefore, computers are taken fully apart and parts are separated into containers depending on their composition of materials and will be sent on to be recycled. A recycling with disassembly example can be Sony, which works in collaboration with a recycling company in Minnesota and together collect 600 tons of Sony products per year. These products are taken apart first and sorted out before being recycled. To recycle these products, Sony spends about 80 cents per pound of recycled
products, but the benefits of this task are important. *Sony* learns about its own designs recovery and recyclable capacities and by doing so can gain a competitive advantage and make products that are easier and cheaper to recycle in order to meet legislative standards, increase its environmental value in the eyes of the customers as well as reduce their own reverse logistics costs in the longer run (Pagell *et al.*, 2007). Another example is *WeRecycle – IT Asset Recovery and Recycling Solutions*. This company, operating in the United States, focuses on IT asset recovery and recycles, with disassembly, all IT equipments that cannot be remanufactured. The company chose this method in order to provide a recycling solution that is as environmentally responsible as possible (WeRecycle, 2009). By recycling with disassembly, the company lowers the materials’ contamination risks as well as diminishing the dangers of including, in the recycling process, non-recyclable and/or hazardous materials/chemicals and therefore creating unusable and dangerous recycled materials that have to be disposed of in the end.

Finally it is important to mention that one shall take into consideration which market the recycle goods will go to before choosing the recycling strategy. Standards in the different markets might be different and therefore, this will demand different recycling process and influence the choice of recycling method and/or partners.

### 2.7 Disposal Challenges

The main challenge of disposal is to dispose of a product, its components or raw material in a secure manner. Many products that are returned today, including electronic ones contain hazardous material and chemicals. Disposing of certain elements can be costly due to the material composition, legislations and high disposal lead times. Therefore, the best disposition techniques and methods should be analyzed before one chooses the procedure the company will employ or if the company should simply outsource this process to a specialized provider.

### 2.8 Inventory Management and Information System Challenges

Lowering inventory costs through minimizing holding time as well as in-transit inventory are objectives of inventory management in both reverse and forward logistics. According to Tibben-Lembke and Rogers (2002), the inventory costs of reverse logistics can be divided into the same broad categories as in forward logistics, but the cost attached to each activity

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6 An illustration of *WeRecycle*’s recycling process can be found in Appendix 2 – *The Recycling Process.*
will vary. For example, handling costs in reverse logistics will be greater than in forward logistics as RL requires extra labor and/or equipment in order to identify, sort, test and determine the optimal disposition strategy of each product/component received. In addition, holding costs are normally calculated as a percentage of the product’s value in forward logistics, but in the case of reverse logistics, as the products’ values can be quite low, this technique of calculation of holding costs cannot be applied.

Another challenge of inventory control in reverse logistics is the complex identification process of the returned products and components as they differ in models, brands, years of fabrication, etc, and, in many cases, their identification barcodes and serial numbers might have deteriorated or disappeared during their lifetime (Soto Zualaga, 2006). For these reasons, the inventory system has to be flexible enough to deal with the identification difficulties and all products and components have to be recorded unto the system so one can have a complete overview of the inventory present in the network. In addition, not only do the products have to be recorded but their quality level have to be assessed and attached to the products and/or components in the system to ease the inventory management, to allow real-time tracking and to forecast the potential outputs. The common ERP systems designed for the forward flow are not created to oversee an inventory which can be in different conditions and therefore, reverse logistics requires information systems capable of sustaining the dynamic and uncertain aspects of the reverse flow (Martin, 2006).

In order to ease the reverse logistics process, the integration of one or many information systems capable of tracking the different products, their different components and conditions are essential. Depending on the items recovered, such a system might have to be fully customized to satisfy the reverse networks needs and be compatible with the different business partners involved in the network. Unfortunately, many companies operating reverse logistics systems find that the softwares available lack in control possibilities as software companies and system designers have not yet any RL expertise nor do they know about the differences that exist between reverse and forward networks (Wikner and Tang, 2008).

As stated above, in order to sustain the inventory control of a reverse logistics process, an information system has to be implemented. Such a system can solve different problems and benefit the reverse flow by increasing the speed and efficiency of the stream as well as increasing the visibility of the inventory within the system. Most of the systems used in
reverse logistics networks are RFID-based\(^7\). These systems can scan the returned goods and their components as well as display the product’s information such as serial number, model number, manufactured dates etc (Lee and Chan, 2009).

Many companies have recognized the importance of inventory management and information systems in reverse logistics. For example, Global Assets Recovery Services (GARS) assist IBM in the creation of a database linking all IBM components across the company’s different divisions. By implementing such a system, the inventory of spare parts is visible and employees can order quickly the parts they need. In addition, one of GARS most important task is to assign the appropriate process to the returned components and products whether it is remanufacturing, repairing or recycling. GARS uses a hierarchy system to choose the possible options based on the state of the product, its remanufactured value and its remanufacturing costs in order to seek the most beneficial option for each product and component (Fleischmann, 2004). Dell is also implementing a similar technique for asset recovery backed up by a information system allowing tight inventory control and automatic process sequence decisions (Ferguson, 2000).

In the study done by Marcotte et al. (2008) concerning the computer industry in Canada, it was discovered that inventory management was control in the same way by all reverse logistics providers studied. The process is as follow: the received computers are identified by a bar code, codified and a bill of material is created. Along the process, all components’ bar codes are scanned so each unit is traceable through the system. By using such a technique, it allows the facility to know, in real-time, the exact status of the inventory and to find specific components when needed. The components’ quality and state are also codified so that the current condition as well as the upcoming operation(s) to be done on the component, whether it is remanufacturing, repairing or recycling, are registered in the system. Such steps and techniques are also present in most reverse logistics systems as real-time information on stock levels, routing and inventory status are essential to support and control the reverse logistics process.

**2.9 Integration of Reverse Logistics with the Forward Supply Chain**
The last challenge of reverse logistics is to decide whether the network should be integrated to

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\(^7\) RFID: Radio Frequency Identification Technology. Emerging information communication technology that has many advantages such as being contact less, allowing back tracing, alerts in case of process deviations, it can document the processes and can help reduce the handling efforts. RFID requires reading stations through which each product passes and is identified (Kopacek, 2008).
the forward network, if it should be separated or outsourced.

In general terms, reverse networks can either be open-loop systems where products are returned to other parties than the original manufacturer or they can be part of closed-loop systems in which the products are returned to the original manufacturer. An example of a open-loop system can be shown through *Intercon Solutions Inc.* which is one of the largest American recycler of electronics. The company collects the goods from larger businesses as well as from the government and recycle a wide range of products from photocopiers to modems and computers (Qinlong *et al.*, 2008).

Integration is a challenge as reverse logistics, is not simply forward logistics going backwards and different practice have to be put in place. Integrating reverse logistics to the forward flow is not an easy task and it can easily reduce an organization’s profit by up to 30% (Martin, 2006). Many articles also revealed that keeping both system separated is better unless the company builds the appropriate expertise to create a closed-loop system. For companies which decide to create such a system, the key is to, according to Martin (2006), allow for dynamic decision making to be done easily and for the functions to be integrated on both tactical and operational horizons. The tactical level of the operations is to forecast the incoming supply and optimize the return flow whereas the operational level is responsible of operating the processes and activities and adapt to possible changes. By creating an integrated system that can sustain dynamic decision making on those levels, a company can succeed at creating a closed-loop system.

Any companies which decides to create a closed-loop will do so in order to gain a competitive advantage and to gain full control of their product before and after lifecycle as well as controlling the services offered to the customers. If a manufacturer recovers its old and defective products in an efficient manner, it can remanufacture parts and components and lower down its overall manufacturing costs. Examples of closed-loop systems are the *Kodak’s* single-use cameras recycling programme as the cameras are returned to *Kodak*. *Xerox* also uses a closed-loop system when it comes to its photocopiers as the company retake its old photocopiers when installing new ones and remanufactures parts of the old photocopiers machines and uses them in new models (Fleischmann, 2004). *Canon* has been operating two similar closed-loop systems for photocopier machines, one in the UK and one in the USA (Fleischmann, 2004).
In order to create an efficient closed-loop, firms must decide which activities and processes will exist in the integrated system to create synergy and efficiency, as well as how information will be communicated between both flows (Demirel and Gökçen, 2008). Such a closed-loop system and its different activities can be visualized by the model below:

![Figure 2.2 – Closed-Loop Supply Chain](image)

Adapted from Wikner and Tang, 2008.

As one can see from the figure shown above, the forward flow is represented by the full lines whereas the reverse flow is shown through the dotted lines. Once customers have used the products, they return it to the manufacturer and depending on the products’ state, the products are either resold, repaired, remanufactured, recycled or disposed of. Finally, as one can see in the figure above, depending on the reverse logistics process the products will go through, they will re-enter the forward flows at different steps of the forward sequence.

Finally, it is also important to add that many activities present in the reverse flow will affect and have an impact on the forward flow. Examples of these activities that can be affected are storage and transportation as both activities will have to be shared between the two streams (Lee and Dong, 2007). Additionally, closed-loop systems might have many joint facilities for their flows. When facilities are both part of the forward and reverse process, the activities carried out in both flows, their locations and the storage space have to be decided strategically so both system can benefit from the location and allocation of the various resources.

### 2.10 Joint partners and outsourcing

In many cases, companies will decide to create partnerships with business partners that can provide some of the activities and processes present in the reverse flow and, by doing so,
create a semi-closed-loop network. By choosing this alternative, companies that do not have the expertise required to carry out efficient reverse logistics can outsource part of the process to firms that are specialized in that procedure and therefore reduce the risks of implementing a reverse flow. “Third-party providers have a broader view of how reverse logistics works because they work with multiple firms and industries, and they can leverage their knowledge and software to benefit everybody. And these providers can offer economies of scale, because they can typically process returns of many customers in their centralized return centers” (Meyer, 1999). An example of this possible partnership is Toshiba America which outsourced the transportation of returned products to UPS in order to ease this process and build stronger customer loyalty (Moore, 2005). By doing so, Toshiba hopes to increase its customer satisfaction as well as gaining better inventory visibility as UPS’s information system is synced with Toshiba’s information system. Toshiba is not the only company using UPS as a reverse logistics partner. Sony Ericsson Brazil paired up with UPS Supply Chain Solutions which is responsible for all of Sony Ericsson post sales operations, from transportation (forward and reverse), testing, repairing and handling warranty for the 140 Sony Ericsson retailers of Brazil (Bowman, 2006).

Additionally, in order to create strong partnerships, trust between partners has to be built and this is usually done through long-term alliances in which strategies are discussed and decisions are made in collaboration to define common goals and share risks between the collaborators (Li and Olorunniwo, 2008). By outsourcing part or the full reverse process, firms can save many expenditures. For example, Kmart, an American retail store, saves between 5$ to 6$ million per 1$ billion in sales through the outsourcing of its reverse logistics activities (Meade and Sarkis, 2002). Kmart took on the decision of outsourcing its reverse logistics as the company recognized that this business area was not one of their core competency and that outsourcing it could improve their strategic advantages as well as improving their customer service. Different surveys have shown that firms, like Kmart, doubt their skills to implement reverse logistics network. When 311 managers of logistics were surveyed, 34% admitted that the firm they were working for had insufficient systems for conducting reverse logistics activities (Meyer, 1999).

One of the difficult tasks of creating alliances or outsourcing the entire reverse flow is the strategic decision of choosing the right partners and service suppliers. Many factors affect the decision making process and the various activities that have to be carried out in the reverse
flow often serve as decision criteria. Companies will rank the activities importance and the expectations they have form each in order to find one or many suppliers that can meet those criteria at an acceptable cost. Other factors will also play an important role in the decision process such as the location of the supplier and its reputation (Meade and Sarkis, 2002).

Another important challenge that presents itself when outsourcing reverse logistics is to protect the firms assets and intellectual property as the supplier of reverse logistics will have an exclusive inside look at the companies products, their components and technology. If the manufacturer uses any secret designs or special techniques, using a third-party can jeopardize this competitive advantage if loyalty and trust are not built (Pagell et al., 2007). Finally, a last risk of outsourcing the reverse logistics process is linked to reputation. If the RL supplier does not handle the return products in a responsible and ethical manner, this could affect the manufacturer and its reputation.

2.11 Overview of the Main Challenges:
As many challenges we presented in this section, a brief overview of these difficulties can be summarized into the following points:

- Calculate and control the costs
- Forecast incoming supply
- Create incentives for customers to return their products
- Choose the location of the collection centers and the processing facilities
- Optimize transportation routes
- Have efficient gatekeeping
- Deciding the operation steps sequence of the system
- Choosing the appropriate processing activity for the product and components
- Optimize the system so it can handle efficiently the different products and their varied conditions
- Reduce processing lead time
- Implementation of an information system capable of processing the different inputs
- Handle storage capacities and limitations
- Decide whether the reverse logistics system should be integrated with the forward flow
- Choice of partners and outsourcing possibilities and build trustworthy relationships

3. The Mobile Phone Industry
As stated in the introduction of this thesis, the goal of this paper is to present the concept of reverse logistics and its challenges, which was done over the last two sections and, using the concepts brought forward in those sections, to present a reverse logistics model for the mobile phone industry. This present section will briefly introduce the mobile phone industry and its characteristics, within a product recovery context, whereas the next section will present the
characteristics of reverse logistics for the mobile phone industry as well as presenting a RL model for this industry.

3.1 General Characteristics
The mobile phone started as an expensive niche product 20 years ago (Carral and Kajanto, 2008). Today, it’s penetration rate has reached over 100% in many western European countries and its penetration, in emerging economies, is on the rise as some of the major players aim at these new markets by promoting cheaper phones. It was estimated that already in 2003, 476 million units had been sold worldwide (Kopacek, 2008). Today’s market is mainly divided among six major manufacturers – Nokia, Motorola, Samsung, Siemens, Sony Ericsson and LG Electronics, which control approximately 75% of the global mobile phone market (Mace, 2007).

One of the mobile phones’ distinct characteristics is the pace at which new models enter the market and the rate at which consumers replace their handsets for a newer models. The average lifetime of a cell phone is down and recently it was shown that 90% of the new mobile phones have a lifetime of 1 year (Chan and Chan, 2008). Some customers disposed of their mobile phone properly by returning them to retailers or recycling sites, but many keep them at home for years after they have stopped using it or simply throw them in the trash (Halldorsson, 2008). Sony Ericsson (2009) estimates that only 7% of all mobile phones are being recycled at this point. It was estimated that already in 2005, in the USA only, over 130 million mobile phones were retired – kept in people’s home (Environmental Protection Agency, 2009). Over the past 4 years this number as grown to almost 1 billion (CollectiveGood, 2009). This is not just the case in North America, in Sweden it is estimated that the number of unused cell phones kept in people’s house has now reached over 15 millions (Deutsche Welle, 2009). In other words, for each person living in Sweden, there are 1.5 mobile phones stored in a drawer somewhere. This is far from being ideal as mobile phones contain hazardous materials such as lead, mercury and arsenic and many of their materials can be recycled such as copper, nickel and titanium (Halldorsson, 2008). In addition, recycling mobile phones can help reduce e-waste, it can save energy, reduce greenhouse gas emissions, save natural resources and chemicals. Recycling 1 million mobile phones can reduce the greenhouse emissions to the equivalent of taking 33 cars off the roads for 1 year (Environmental Protection Agency, 2009).
3.2 Mobile Phones Components and Materials
Many components and materials are remanufacturable or recyclable in a mobile phone. *Nokia*, for example, states that 80% of any of their device is recyclable. Many materials can be found in their mobile phones such as plastics, aluminium, cobalt, copper, nickel, iron, silver and gold (Keong, 2008). Mobile phones’ circuit boards, LCD modules and camera’s contain precious metals and in total, one ton of mobile phones contain 1kg of silver and 300grams of gold (Deutsche Welle, 2009). In addition, many components and modules such as chips, circuit boards, antennas, data modems and cameras can be reused or remanufactured and these can become spare parts for mobile phone repair centers, can be used for making cheaper models of mobile phones as well as being used in other industries (ReCellular, 2009). The plastic casing of the mobile phones can be recycled either to build new casings or to make traffic cones, fences, car bumpers ect. (Environmental Protection Agency, 2009). Each mobile phone on the market contains a battery, which contains hazardous components. Cobalt can be collected from batteries for other usage and the rest of the battery has to be disposed safely to lower environmental contamination risks.

4. Creation and Design of Reverse Flows in the Mobile Phone Industry
As explained in the previous section, among the many industries where reverse logistics has become a necessity, the mobile phone industry faces an important problem. Due to legislations and environmental concerns, mobile phone companies and providers have started to implement recovery networks in order to recycle and remanufacture their “out of date” products. Unlike other industries such as the personal computer industry or the automobile industry, the reverse logistics process of the mobile phone industry has not been extensively studied and models explaining the possible recovery networks and their required activities for this industry have not been abundantly created. The aim of this section will be to study, analyze and understand the different reverse logistics characteristics of the mobile phone industry and to present a possible design for the recovery, recycling and remanufacturing of mobile phones. This model will be based on the different reverse logistics characteristics of the mobile phone industry presented in this section. It will also be based on other industries such as the computer industry and their implemented reverse logistics systems as well as on the information presented in *Section 1* and *Section 2* of this thesis.

4.1 Brief Literature on Reverse Logistics Related to Mobile Phone Industry
Before discussing the mobile phone reverse flow characteristics, it is important to have a brief
overview of the different studies that have been published on the subject in order to depict to which extent this industry, in the reverse logistics context, has been studied. After long and extensive research through databases and Internet, one can conclude that the literature on mobile phone recovery networks is quite narrow, which contrasts with the RL literature available on other industries.

The few cases that discuss the mobile phone industry are usually geographically based such as the studied by Chan and Chan (2008) which solely focuses on reverse logistics systems for the mobile industry in Hong Kong. The research conclusions are based on a survey which was mailed to mobile phone companies in the Hong Kong area and the targeted respondents were occupying different supply chain positions, from manufacturers to service providers. Their results show that mobile phones have a short life cycle, 3 to 6 months, in Hong Kong and that the motivations to carry out reverse logistics activities in the mobile phone industry in Hong Kong are either done to capture value/recover assets, to use reverse logistics as a strategic weapon or to show good corporate citizenship. In addition, their study showed which proportion of the mobile phones were assigned to the following activities:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remanufactured/Refurbished</td>
<td>32.6%</td>
</tr>
<tr>
<td>Recycled</td>
<td>23.1%</td>
</tr>
<tr>
<td>Resold as is</td>
<td>21.5%</td>
</tr>
<tr>
<td>Repackaged and sold as new</td>
<td>9.5%</td>
</tr>
<tr>
<td>Sold at outlet store</td>
<td>6.8%</td>
</tr>
<tr>
<td>Landfill</td>
<td>6.5%</td>
</tr>
</tbody>
</table>

Source: Chan and Chan, 2008

Another author who discusses recovery networks specifically for the mobile phone is Canning (2006) who concentrates her research on the UK and two particular activities in the reverse flow: reusing and recycling. The research aims at analyzing the impacts of the WEEE Directive on the mobile phone industry and to give a descriptive overview of a trial network set by a company recovering mobile phones in the UK. Finally, other authors have covered the topic in different ways, Bowman (2006) discusses briefly Sony Ericsson’s challenges of creating reverse networks and Hanafi et al. (2008) discuss collection strategies for end-of-life products and present a case study on the mobile phone collection in Australia. Beside these few authors, not much research focus on the mobile phone industry in a reverse logistics context.
4.2 Reverse Flow Characteristics of the Mobile Phone Industry

Many characteristics have to be taken into account when creating a reverse logistics systems specifically for the mobile phone industry. What are the actors present in such a system? What will be the motivators leading companies to implement this reverse flow? Which activities will be required in order to create a complete and efficient process? These questions are important to be asked, as their answers will have an overall impact on the system put in place. In addition to answering these questions, different initiatives taken by different manufacturers as well as third parties will be presented in order to exemplify those characteristics and present what is already being done within the industry. These different characteristics and initiatives will serve as another fundamental premise necessary to create the model presented later on in this section.

4.2.1 Reverse Logistics Motivators and Drivers for the Mobile Phone Industry

The first important characteristics of the mobile phone reverse flow are the different elements that influence manufacturers as well as third parties to recover these devices. As presented in Section 1 of this thesis, there are many possible motivators that lead companies to create reverse logistics systems. The Global Supply Chain Forum groups returns into five different categories: consumer returns, marketing returns, asset returns, product recalls and environmental returns (Rogers et al., 2002). Mobile phones can be returned for all of the reasons mentioned above. As a consumer return if the phone is defective, it can be a marketing return if the phone did not sell as well as planned, an asset recovery if the manufacturer wants to recuperate part of the phone, a product recall if a phone is discovered with a defect or can lead to potential danger. Mobile phones can also be environmental returns and enter the reverse networks due to legislation such as the WEEE Directive in Europe as manufacturer are obliged to recycle their equipment.

It seems, according to the research done in order to write this thesis, that at this point in time, most mobile phones reverse logistics networks are created for two of these reasons: asset recovery and environmental legislations. Each cell phone contains many components that can be reused, remanufactured or recycled. The purpose of recovering mobile phone is, in this case, to recapture as much value from each returned device’s components and sell them to secondary and/or original markets. Moreover, raw materials can be recycled and used in the same and/or different industries. In addition, creating effective reverse logistics systems for the mobile phone industry can help reduce the costs of repairing defective phones as returned components can be remanufactured and used by repair services and improve the industry’s
profits (Chan and Chan, 2008).

The second important motivator to create reverse flows in the mobile phone industry, at this point in time, is influenced by environmental legislations and companies wanting to help the environment and/or improve their reputation through good corporate citizenship. In addition, more and more customers are adopting environmentally friendly behaviors and many are now aware that hazardous materials and chemicals are found in mobile phones. These consumers now seek ways to recycle their device. Therefore, manufacturers such as Nokia, Samsung, LG, Motorola and Sony Ericsson started advertising and creating ways for their customers to send their old device back to the manufacturer. By doing so, manufacturers help the environment, respect the legislations put in place and improve their good corporate citizenship (Pagell et al., 2007).

How do these motivations will influence a possible recovery network in the mobile phone industry? As the manufacturers and RL providers will seek to ease the return process from the mobile phone users, the recovery network will include many collection points and incentives so consumers can easily return their device. In addition, as most reverse logistics networks for mobile phones aim at recovering assets, the activities present in the reverse flow will take this important motivator into consideration and, in order to recover as many components as possible, it will include extensive testing and disassembly to ensure to maximize the quantity of recuperated parts from each device\(^8\).

4.2.2 Reverse Logistics Actors in the Mobile Phone Industry
The actors involved in a reverse logistics systems for the mobile phone industry are many of the actors present in the forward supply chain; suppliers, manufacturers, retailers and customers. In addition, other players might arise, such as specialized reverse logistics suppliers. In the reverse logistics network for the mobile phone industry, the actor with the highest importance is the customer, as without its return initiative, the process cannot be initiated. Possible incentives to encourage customers to return their old phones will be discussed when the model for the mobile phone industry is presented and collection challenges are discussed.

4.2.3 Reverse Logistics Activities for the Mobile Phone Industry
The activities involved in the reverse logistics system for the mobile phone industry are very

\(^8\) More information on these activities will be given in the presentation and explanation of the model for the recovery of mobile phones.
similar to the ones in most other industries and are the same, as the one required in other electronic devices industries. These basic activities were previously presented and can be summarized as follow: goods shall be collected, tested, sorted, disassembled or sent on to be reused right way, remanufactured, repaired, recycled or disposed. The specific steps in each activity that is required to carry out an efficient recovery network, as well as their challenges will be discussed in greater details when the model is presented.

4.2.4 Initiatives Taken by some Mobile Phone Manufacturers
To better understand the different characteristics of a reverse logistics system for the mobile phone industry, it is important to have an overview of what different companies are doing to recover mobile phones at this point in time. These companies can either be manufacturers of mobile phones as well as firms specializing in the remanufacturing and recycling of mobile phones.

Many mobile phones manufacturers have started recovering their products in order to recuperate precious metals, remanufacture components and recycle certain materials (Environmental Protection Agency, 2009). To start with, Motorola has included on all its products sold in Europe the label (shown the introduction), and documentation in accordance to the WEEE Directive, which guides consumers not to throw away their products but to dispose of them in conformity to the directive. In addition, Motorola as well as most manufacturers have started take-back campaigns encouraging consumers to bring back or send back their old devices. Between 2004 and 2007, Motorola recovered 7500 metric tons of equipment through this program (Motorola, 2009). Motorola as well as Nokia, Sony Ericsson and LG now offer, in the United States, to send prepaid envelopes so consumers can send back their mobile phones, free of charge, to the manufacturer or to a partner collector/recycler. Motorola has enlarged this coverage and now provides prepaid packaging boxes and envelopes also in many European countries such as Austria, Belgium, Estonia, France, Ireland, the Netherlands, Norway, Poland, Spain, Switzerland and the United Kingdom (Motorola, 2009).

Sony Ericsson, as stated above, also promotes different ways to recover their products. Prepaid envelopes as well as detailed information on their website for customers to be able to easily send back their device. The company guides customers through a 6-steps process to ensure that all personal data was deleted and that the battery is emptied before sending the product back (Sony Ericsson, 2009). So far, this efficient service is only offered in the USA,
but with the implementation of the *WEEE Directive* in the different EU countries, *Sony Ericsson* will offer this service across Europe soon. In addition, *Sony Ericsson* explains on its website the aim of the take-back program which consists of “optimizing the amount of material that can reasonably be re-used or recycled. The remaining material will be disposed of in an environmental conscious manner in accordance with applicable laws and regulations. This warranty is valid globally, independent of the original sales location or the selected Sony Ericsson collection point location. This is our way to show Sony Ericsson supports individual producer responsibility (IPR)” (Sony Ericsson, 2009).

*Samsung* also implemented take back program similar to the one created by *Motorola* and *Sony Ericsson* (Samsung, 2009). *LG* offers, just like in the case of *Sony Ericsson* and *Samsung*, detailed information on its website concerning the different steps to take before using the prepaid envelope such as discharging the battery. In addition, *LG Electronics* created 392 mobile phone drop-off points in the USA only, in order to expand the accessibility to the take-back channels to all their customers (LG Electronics, 2009). *Nokia* offers the same take-back programs as stated above. In addition, the company has started to install automated kiosks in Asia where people can go and drop off their phones for recycling and remanufacturing purposes (Keong, 2008). The service offered is user-friendly and customers have to follow the instructions on a screen as well as give some information concerning their phones in order for the automated system to label the devices and help the pre-sorting process.

As one can see, manufacturers offer many incentives in order to initiate the recovery process and have customers send in their old device. That being said, one can also notice that manufacturers do not disclose, at this point in time, their internal reverse logistics process and only advertize on their incentive initiatives. Little is known concerning the procedure the return products go through when sent back to one of the major manufacturer. Is the rest of the process outsourced? Are components remanufactured and reused by the manufacturers? Ect.

### 4.2.5 Initiatives Taken by Third Parties

Manufacturers are not the only one recovering old mobile phone devices and many third parties are also present in this market, either as collaborating partners to one or many of the main manufacturers or as specialized mobile phone reverse logistics firms. In order to illustrate both cases, one-third party that operates in partnership with manufacturers as well as one that acts on its own will be briefly discussed. Unlike the very restricted information given
by the manufacturers concerning their reverse logistics networks, third parties offer a better
insight into their recovery process and the activities they carry out.

*Anovo* is a European leading provider of logistics, maintenance services, customization, after-
sales services, technical support, repair services, spare parts management and testing for
telecommunication and multimedia products in Europe (Anovo, 2009). Over the past few
years, the company signed different contracts with mobile phones carriers and manufacturers
across Europe. For example, *Anovo Madrid* is responsible of the mobile phones return flows
for *Telefonica*, the leading telephone operator in Spain. *Anovo*’s responsibilities include the
testing and screening of more than 75 000 devices every month after which the different
mobile phones will be redirected to the right manufacturer or they will be repaired in *Anovo*’s
repaired center. *Telefonica* is not the only one to have chosen *Anovo*. *Nokia* has also chosen
the company to implement a logistics platform in the United Kingdom in order to centralize
the returns of all of *Nokia*’s, under warranties, mobile phones. *Anovo*’s responsibility
includes screening and testing before sending the devices to the appropriate repair center.
*Nokia* “has chosen ANOVO for its competence in reverse logistics that helps to reduce
turnaround time while improving customer experience” (Anovo, 2008).

While different mobile phone manufacturers hire *Anovo*, other companies operate without
building these exclusivity contracts. A great example of this is *ReCellular*, an American
company, which was establish in Michigan in 1991 that specializes in the recovery of mobile
phones. *ReCellular* is the world’s largest recycler and reseller of used mobile phones
(ReCellular, 2009). The company remanufactures all brands and models of cell phones and
resells them onto the market to individuals and companies (ReCellular, 2009).
As it was explained previously, mobile phones are replaced at a faster rate every year and this can be witnessed by ReCellular’s processing activities, which are shown in the graph above. It can be seen that the number of phones the company collected has increased rapidly over the past few years. In 2008, ReCellular processed 5.5 million mobile phones. The firm observed that almost all returned products were less than 4 years old and 80% of them were still functional. In the end, of the 5.5 million mobile phones collected, half of the collected devices were reconditioned whereas the other half were recycled into 1.2 million pounds of materials (ReCellular, 2009).

As a company specializing in reverse logistics for mobile phones only, and being one of the very few doing so to this day, it is particularly interesting, especially as this section of the thesis focuses on the reverse logistics systems for the mobile phone industry, to learn how the company operates its different reverse logistics activities and the process sequence. That being said, it is important to mention that ReCellular does not disassemble the collected phones and upon inspection, these are either sent to be recycled (without disassembly) or to be reconditioned. None of the phones’ inner components are taken apart to be remanufactured individually and to be sold on to original or secondary markets. Therefore, one can conclude that ReCellular focuses on asset recovery, but that the company’s point of view on what assets are can be defined as the phone as a whole and not any of its individual inner components. In addition, the company does not use recycling with disassembly and therefore does not focus on high quality-uncontaminated recuperation of materials.
From the information provided on their website as well as their production line video, one can conclude that their operation process sequence is as follow:

**Figure 4.2 – ReCellular Reverse Logistics Process**

Adapted from ReCellular, 2009.

As one can see ReCellular as a define and precise process sequence to recover and operate its reverse logistics system for mobile phones and the recovered products can be either recycled (as a whole) or remanufactured (as a whole). From the recycling, done without disassembly, the recuperated materials are sorted and sold to different raw materials suppliers. As for the reconditioned phones, they are sold on in large quantities to businesses or to individuals through regular sales or their online auctions (ReCellular, 2009).

In addition to the two companies presented above, trials and experimental reverse logistics systems for the mobile phone industry are also being created and tested. For example, the Vienna University of Technology and the Austrian Society for System Engineering and Automation have put in place a pilot plant, the Multi Life Cycle Center, to test semi-automated handling of wired boards and mobile phones disassembly and recycling. Such systems are created and tested before being put into practice in larger operating facilities. These semi-automated systems are designed to be capable of identifying products and their components.
In addition, these systems are also capable of erasing the data saved on the phones and have automatic disassembly capabilities (Kopacek, 2008). The semi-automated disassembly line implemented at the Multi Life Cycle Center can disassemble phones into the following fractions: batteries, plastics parts, rubber (keys), metals (screws and others), circuit boards and liquid crystal displays (Kopacek, 2008). Such a disassembly process is divided into different steps: the first being a vision system that identifies re-usable and toxic parts. This is executed with the help of an information system in which a database of shapes and labels is found so the disassembly system can identify the components automatically. The second step consists of a de-soldering station operated via a laser in which hazardous and valuable components are de-soldered and taken apart using a robotic gripper. For components that were identified as not soldered, they are sent on to a heating removal station. Toxic parts are sent on to be disposed whereas all reusable parts are sent on to be reused, remanufactured or repaired. Non-toxic items that are not reusable are sent on to the recycling facility.

At this point in time, this system is being tested until optimization goals will be achieved before it can be implemented in operating mobile phones’ recovery networks. This technology is becoming essential with the increasing amount of returned products and the implementation of legislations such as the WEEE Directive. By reaching a certain level of efficiency, the plant and its creators hope to optimize the reverse logistics process and create a competitive system for recovering and handling electrical and electronic equipment waste.

4.3 Suggested Design of Reverse Flows for the Mobile Phone Industry

4.3.1 The Model and its Creation Process

The aim of this thesis was to first present the broad concept of reverse logistics and to bring forward, through out different theories, authors and examples, the different challenges involved in the creation of recovery networks. The second objective of this paper was to finally present a possible reverse logistics sytem for the mobile phone industry based on the industry’s characteristics which include short product life-cycle and that many old devices are kept in people’s home or simply thrown in the trash.

In order to create such a model, the theory and examples brought forward in the previous sections, as well as all the articles read throught out this exercise were used during the reflection-analysis-construction process required to conceptualize an adequate model. In
addition to the theories presented and studied, other models\textsuperscript{9} were used as influence and background information to construct a model as realistic as possible. Moreover, in order to create the model, first were reviewed Kwan Tan and Kumar’s (2006) four main key questions, which were previously presented in \textit{Section two} of this thesis. In addition to these four key questions, the following questions had to be asked to assure that the model would cover all possible aspects of the needed reverse logistics systems for the mobile phone industry:

- What are the conditions under which a reverse logistics model would be employed in the mobile phone industry?
- What are the objectives of the model?
- What are the systems possible sources of inputs and the possible outputs?
- How will the inputs be collected and to whom will the outputs be sold to?
- What are the different possible sequences for the material flow and what are the essential processes required?
- What are the challenges of each activity/process?
- What type of recycling will be carried out?
- What level of flexibility will be required?
- What information has to be communicated and from where to where?
- What are the control measures?

Along with these various questions, many of the different challenges of reverse logistics presented in \textit{Section two} had to be taken into consideration when creating the model in question. As a reminder, according to Guide \textit{et al.} (2000), there are seven challenges present in reverse logistics:

- The uncertain timing and quantity of returns
- The need to balance demands with returns
- The need to disassemble the returned products
- The uncertainty in materials recovered from returned items
- The requirement for a reverse logistics network
- The complication of material matching restrictions
- The problems of stochastic routings for materials for repair and remanufacturing operations and highly variable processing times.

The model created for the mobile phone industry can be visualized through the following figure:

\textsuperscript{9} The models presented in \textit{Appendix 1} were examined for the model construction. Other models, not presented in this thesis, were also scrutinized, their visual representations can be found in \textit{Appendix 3}.
In short, the model shows the following sequence: mobile phones are either sent back by the customers to the retailers or manufacturers or brought directly by the customers, the retailers and manufacturers to the collection point(s). A gatekeeping system has to be put in place to ensure that only eligible products enter the system. From the collection center(s), the products are sent on the primary testing and sorting where personal data will be removed from the phones as well as an assessment of their individual condition will be done. Based on this assessment, the phones will either be re-sold right away, sent to be repaired/remanufactured as a whole or sent on to the appropriate disassembly line where materials and components will be extracted. After the disassembly is done, components will be re-tested in order to decide which process they should be forwarded to. This second testing/sorting is done in order to assess the individual components’ state and to decide what is the best way to recover value from these individual assets whether it is recycling, remanufacturing/repairing or disposal. Once the components and materials have been remanufactured/repaired or recycled, they will be sold to the appropriate supplier.
4.3.2 The Model’s Assumptions and Limitations
The model presented above was created to illustrate how a reverse logistics system would work in the mobile phone industry and which steps as well as processes are essential when recovering these devices. The objective of the model is to recuperate mobile phones so they can be, and/or their components, remanufactured, repaired, recycled and/or properly disposed. In other words, the main objective of this system is to respect new or coming legislations and to maximize asset recovery. In the system presented above, inputs are the mobile phones whereas there is an assorted diversity of outputs. Unlike it was shown in the case of ReCellular, the system presented here allows phones to be disassembled and for the individual components to be remanufactured and repaired. Therefore, the system presented above produces the following different outputs:

- Remanufactured, repaired and/or reusable mobile phones
- Remanufactured, repaired and/or reusable singular components
- Recycled materials from non-reusable mobile phones and components

The reason why the constructed model allows for disassembly and for individual components to be remanufactured, repaired, reused or recycled (unlike the case of ReCellular) is based on the assumption that the main objective of a retrieval network for mobile phones is to recover as many assets as possible and respect new legislations, which request to lower the production of fully new products and components. By allowing such disassembly and rework to be done on single components, one can seek to maximize the asset recovery and respect those regulations. In addition, this leads the model to incorporate recycling with disassembly and, as explained in Section two of this paper, this type of recycling offers a better rate of material recovery. Through this type of recycling, materials are less contaminated and therefore offer a higher quality, higher revenues and a lesser quantity has to be disposed of due to contamination. This low dispose rate is necessary as the model created also seeks to minimize disposal in order to comply with legislations such as the WEEE Directive. Therefore, this type of recycling is also done in accordance with the objective of the model and consequently, this is a more ecologically sustainable alternative for the industry (WeRecycle, 2009).

Costs associated with the recovery of mobile phones and the required activities are only briefly taken into account for the presented model and are only discussed in a general manner. This is the case as the information concerning this aspect of reverse logistics is lacking and

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10 This objective was chosen in accordance with the literature found on the recovery of most electronic goods as well as according to Canning (2006) and Chan and Chan (2008) findings regarding recovery networks for mobile phones.
costs are conditional to many external variables. For example, workers wages, costs of technology and transportation costs can vary from one country to another. As this model is not geographically based and could be implemented anywhere, the precise costs encountered by each activity of the system are excluded in order to leave the model as universal as possible at this point in time. That being said, when implementing such a recovery systems, costs of implementation as well as all costs required to carry out the different processes have to be estimated and taken into account in order to create a system that will be as efficient and as cost effective as possible.

Finally, in the illustration presented beforehand, each box represents an essential step of the recovery of mobile phones and arrows represent the different flows and the process sequence options. Ultimately, for the detailed presentation of the model that will follow over the next few pages, it will be assumed that the different processes presented in the illustration are done "in-house" by a singular company. That being said, it’s important to know that one reverse logistics company could decide to outsource one or many of the activities required in the recovery network if one believes another firm as a better expertise or offer competitive prices.

4.3.3 The Collection Process
The first step of the model presented is the collection of the mobile phones. Goods are collected from the consumers, retailers and manufacturers and enter the reverse logistics system. The collection points can vary from retailers to centralized return centers that also collect other goods. If the recovery system for mobile phones has strict requirement, gatekeeping has to be done to assure that only eligible phones (or eligible brands) are entering the reverse logistics network. When entering the collection center, the phones should be scanned and registered into the system so goods are traceable through out the reverse logistics network. In addition, scanning all products entering the system allows the identification of the materials and components that constitute the phones and therefore, enables to have a real-time overview of the different constituent present in the system. This also allows better control of the inventory from the get go. Such scanning process can be done at the collection centers or once the products have reached the disassembly facilities. In most of the cases used as background information for the construction of this model, such scanning occurred at the disassembly facilities and collection centers did not have a great overview of the received products. In order to increase the efficiency of the system and gain better control over it, it would be a good idea to scan returned products and have them registered within the system from the collection centers to allow better coordination between the processes and better
inventory management from the get go.

Obviously, many challenges will be present at the collection step of the reverse logistics systems illustrated above. These, although not shown in the visual representation of the model, have to be taken into consideration. First of all, the supply uncertainty is an important challenge to be dealt with. Forecasting can mostly be done based on sales and the average life cycle of the products. Based on these variables one can try to forecast the returns in order to create and implement a recovery network for mobile phones capable of processing the quantity of phones that will be returned. This is important as one does not want to create a system either too big or too small, as either option will create unnecessary costs and profit loss. In addition, as many mobile phones are retired and waiting to be returned, one has to take this variable into consideration when forecasting the incoming supply. This variable can be significantly affected by incentives put in place by manufacturers and retailers to have customer bring back their old device.

In addition to forecasting the incoming inputs, inducements have to be put in place to assure that the devices will be returned. *Motorola* estimates that a minimum of 55% of old phones are stored in drawers (Canning, 2006). These motives have to be put in place so consumers are aware of the recycling possibilities for their mobile phone(s) as well as the advantages created from returning one’s old device. Incentives can include environmental behavior awareness motives as well as money rewards such as cash vouchers or credit for a new phone.

As Canning (2006) stated, “*consumer participation in phone retrieval requires that firms both offer incentives to persuade the end customer to return phones which no longer have a useful purpose and also inform/educate consumers of the significance of electronic waste (and their contribution to schemes designed to reduce waste levels)*”. Such information can be communicated through campaigns, in store literature and retailer staffs informing new and old consumers on the matter. Incentives as well as education are essential to create a good reverse logistics system for mobile phone industry as such a recovery system cannot be efficient if the supply is low or intermittent. The quantity of inducement, information given out and advertisements created to encourage people to bring back their current and old phones will affect the forecasting variables and through statistical methods, one could estimate how each campaign or incentive will affect the return rates in order to create a more efficient forecast and anticipate the incoming supply.

Additionally, as explained in *Section two*, the location of the collection points can highly
affect the rate of return. Allowing points of sales (retailers) to become points of return eases the collection process and consumers do not have to search for a recycling center. The retailers can also act as gatekeepers, ensuring that the return products respect the requirements put in place by the recovery network. Furthermore, recovery locations, other than retailers, have to be located so the consumers are able, without difficulty, to return their products, if one does not want to create unnecessary supply barriers. Moreover, initiatives done in the US by most of the major mobile phone manufacturers are examples to follow as consumers can order a prepaid envelope and therefore, easily return their device(s). This initiatives, as well as proper location of the collection points also helps forecasting supply and reduce its uncertainty.

From the collection centers the goods have to be transported to the disassembly facility. As transportation is a costly activity, this should be done in an efficient way. Products should be loaded unto trucks and only be sent on once the transportation capacity has reached an optimal level, if possible. That being said, in some cases, if the disassembly facility is running out of supply, smaller loads might be required to be sent on to the facility. In addition, storage capacity has to be taken into consideration, both at the collection centers as well as the disassembly facility. If too many loads reach the disassembly facility at once, storage capacity could be exceeded. Therefore, constant flow of information have to be communicated between the collection centers as well as the disassembly facility to create optimal coordination and lower down, as much as possible, the transportation and inventory costs.

Finally, as Tibben-Lembke and Rogers (2002) pointed out, technology products such as mobile phones and their components have such a short lifecycle that their value decreases very quickly. Therefore, in a recovery network for the mobile phone industry, it is important that the returned products be sent on to the next step regularly so extra value is not loss as the products wait, for a too long time, in the collection centers and their components become worthless as their resell value declines over time.

4.3.4 Testing, Sorting and Disassembly
As shown in Figure 4.3, the mobiles phones are transported from the collection center to the disassembly facilities where they are first tested and sorted. If the products have not yet been scanned and entered into the information system at the collection centers, they will be at this point in time. For example, at the Multi Life Cycle Center products are automatically
identifies and sorted for further treatment. Such automation process is ideal for primary sorting as it increases the efficiency of the system (Kopacek, 2008). All mobile phones come with a model number and a serial code, which can be used for this scanning. If, for some reasons, the labels have disappeared, manual identification will be required or an automated process, such as the Multi Life Cycle Center will have to be implemented so returned products without codes can be identified quickly.

Primary testing and sorting is a very important and essential step in a mobile phone recovery network, as each device has to be assessed for its quality and functionality level so phones can be sorted out and forwarded to the appropriate process. As shown in the illustration of the model, there are three possible paths the primary testing can push the product unto: to be resold as is, to be repaired/remanufactured as a whole or to be disassembled. Many variables will be taken into account to determine which of the before mentioned step the product should be sent to:

<table>
<thead>
<tr>
<th>Factors</th>
<th>Questions to be asked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior conditions</td>
<td>Any scratches? Any missing parts?</td>
</tr>
<tr>
<td>Functions</td>
<td>Can the phone receive and make a call? Is the display working? Is the keypad working?</td>
</tr>
<tr>
<td>Value</td>
<td>What is the phone’s reselling value (as a whole) versus the value of its components if disassembled</td>
</tr>
<tr>
<td>Costs</td>
<td>Phone’s disassembly costs Phone’s repairing/remanufacturing costs</td>
</tr>
</tbody>
</table>

Based on these decision criteria, the phones will be sent on to the appropriate process. This decision making process can be assisted by an information system capable of computing and analyzing these variables for each product entering the system.

Derived from the variables presented above, phones will be resold directly, repaired, remanufactured or disassembled. For the phones that should be disassembled, before this is done, each phone’s battery has to be taken out, which is usually done manually or through a semi-automated machine capable of taken batteries out of different models of mobile phones. Batteries are sorted per type and will have to be disposed properly as they contain hazardous chemicals. Most phones, except for newer generations with touch screens, have the following

\[11\] The use of information systems will be discussed in greater details when the other characteristics of the system are discussed in Section 4.3.6.
components that can be disassembled: plastic parts, keypad, metals (screws), circuit boards and display. When it comes to touchscreen phones, keyboards are not present and instead a much larger screen has to be taken apart. In either case, such a process, ideally, should be as automated as possible.

The major challenge of disassembly is due to the various models of phones returned as well as their different condition and state which makes the automation of the process hard to achieve. Companies operating disassembly lines have to find ways to automate this process as much as possible to save on labor costs as well as making this process as efficient as possible. Creating automated processes for reverse logistics is a hard engineering challenge and can be quite costly to achieve. Semi-automated systems for the reverse logistics of the mobile phone industry have been constructed and a good example of such a disassembly semi-automated process line is the one created at the Multi Life Cycle Center presented earlier in this paper. As it was explained, such a system is capable of identifying and automatically disassembling products. Therefore, the recovery network system should be implemented with a Multi Life Cycle Center system or with a system similar to it to ensure an efficient disassembly process.

Additionally, some reverse logistics system for the mobile phone industry might choose extra criteria to value the disassembly possibilities and to which extent products should be disassembled. As it was discussed in Section 2, Johnson and Wang (1995) presented a disassembly model in which the process is started by extracting the components with the highest value until the remaining components marginal benefits do not outweigh the disassembly costs. These remaining components are then sent on to be recycled. This disassembly decision technique could also be taken into consideration for the mobile phone industry, but one should remain aware that, as models and quality levels vary, it might make it harder to assess the components’ real value required to se this method efficiently.

4.3.5 Second Sorting/Testing, Repairing, Remanufacturing, Recycling and Disposal
In the case of the phones that were sent on the be disassembled, after the components have been taken apart, a second round of testing and sorting has to be done in order to test the individual components functionality and assess their quality as the first round only assessed the phone as a whole. This is also done in case the first assessed condition was inaccurate or influenced by defective modules, which were present in the phone making a particular component not fully functional in the first place. This is also done to establish a high control
levels in order to ensure that the components and materials are sent on to the accurate subsequent process and by doing so one can aim to maximize asset recovery. In addition, for this second testing and sorting process to be efficient, a system has to be put in place to judge/decide which process would be the most profitable for the component according to different decision variables. These variables are, for example, the demand by the different possible suppliers, the costs of recycling versus repairing and remanufacturing and which process for the component leads to higher benefits for the reverse logistics company. Based on these variables, the appropriate decision concerning what to do with the component or material will be taken. Such a decision making system can be implemented through an information system in which the different characteristics of the component, its quality, functionality level, the different costs and the demand variables are entered. Then, this system can decide where each component should be sent based on a variables analysis that determines the optimal marginal benefit option for each module. In order to create such an analysis and choose the optimal process sequence, many variables have to be taken into account during the second testing phase and the sorting out of the components. Such variables can be summarized in the following table:

<table>
<thead>
<tr>
<th>Activities</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reusable</td>
<td>• Is the component directly reusable?</td>
</tr>
<tr>
<td></td>
<td>• Suppliers’ current bid price for reusable non-repaired component</td>
</tr>
<tr>
<td>Repairing</td>
<td>• Repairing costs of the component to meet suppliers requirements</td>
</tr>
<tr>
<td></td>
<td>• Suppliers’ current demand for the repaired component</td>
</tr>
<tr>
<td></td>
<td>• Suppliers’ current bid price for the repaired component</td>
</tr>
<tr>
<td>Remanufacturing</td>
<td>• Remanufacturing costs of the component to meet supplier’s requirements</td>
</tr>
<tr>
<td></td>
<td>• Suppliers’ current demand for the remanufactured component</td>
</tr>
<tr>
<td></td>
<td>• Suppliers’ current bid price for the remanufactured component</td>
</tr>
<tr>
<td>Recycling</td>
<td>• Recycling costs of the materials</td>
</tr>
<tr>
<td></td>
<td>• Suppliers’ current demand for recycled materials</td>
</tr>
<tr>
<td></td>
<td>• Suppliers’ bid current bid price for the recycled materials</td>
</tr>
<tr>
<td>Disposal</td>
<td>• Disposal costs</td>
</tr>
</tbody>
</table>

If certain components can be reused as is, they will then be sent on to the appropriate supplier, whether it is an original market supplier or to secondary markets for new usage. Components that can be remanufactured or repaired, depending on their condition and state, as well as depending on the industry standards and the suppliers demand, will be repaired or remanufactured. It is important to mention that the difference between repairing and remanufacturing is significant. Repairing centers or departments require lower capital investments in order to repair the products and components, but skills and labor are highly
required. On the other hand, remanufacturing divisions or centers require higher capital investment as they are more technology-based than skills-based (Srivastava, 2008).

All non-reusable, non-repairable, nor remanufacturable components or components that repair/remanufacture costs outweigh their selling opportunities should be sent on to the recycling process. The recycling process will take on those components as well as recycling materials and recycle them into raw materials that can be sold on to original suppliers of the mobile phone industry as well as secondary market suppliers so the recycled material can be used in other industries.

Whether repaired, remanufactured and recycled components and materials are sold on to original or secondary market suppliers will depend on the demand, the bidding price set by the suppliers or based on contracts that could have been created beforehand with different suppliers. Components and materials that cannot be recycled or repaired/remanufactured will be sent on to the disposal site/facility. Disposal has to be done according to environmental standards so hazardous components that can be found in mobile phones and in their batteries are disposed in an environmentally friendly manner.

Overall, all processing options are motivated by possible profit earnings or by uncovering the less costly procedure. Therefore, the system put in place will have to compare all possible options, according to the variables presented beforehand, and find the best course of action for each component.

4.3.6 Other Processes and Characteristics of the Model
In addition, other processes and characteristics are present throughout the model, which are not represented by a singular activity box in Figure 4.3. These characteristics include overall costs, information systems and inventory control processes, which will have to be decided upon in order to make the system as efficient as possible. These are also required in order to maintain a tight control over the entire reverse logistics network.

Recovery networks for any type of products will be costly and this is also the case for recovery networks created for the mobile phone. Government funding, selling back remanufactured and repaired components as well as recycled materials are the possible way to recover the different costs of the reverse logistics system. These costs are present at each step.
of the process and include different fixed and variables costs such as implementation costs, maintenance costs, labor costs, machinery costs, transportation costs, inventory costs, operation costs, decision costs etc. Any firm operating a reverse logistics network will try to minimize these costs as much as possible in order to create a viable system. In some countries, labor costs, in reverse logistics networks, are cut down by employing long-term unemployed people and handicapped people to carry out the un-skilled work tasks as these employees can be funded up to 85% by the government as part as social and labor market integration programs (Kopacek, 2008). Transportation costs have to be taken into account when the different recovery locations are chosen as each extra transportation kilometer will increase the overall costs. In addition, carrying un-full truckloads will also increase the transportation costs and therefore, these have to be reduced to a minimum. Collection costs include gatekeeping, pre-sorting and storing the products until they are sent on to the disassembly facility. Operation costs include fixed costs such as the equipment and technology used as well as variable costs dependent on the volume of devices that enter the system and depending on which process each component goes through. Overall, operation costs will be highly related to the materials that enter the system and the processes under which the components have to go through. Moreover, storage costs can be quite high if the devices have to be stored while waiting to be processed or shipped to suppliers.

Many recovery networks dealing with electronic equipment uses RFID (Radio Frequency Identification) (Kopacek, 2008). As explained previously, such technology has many advantages, it can back trace, alert in case of process deviations, document the processes and helps reduce the handling efforts. RFID requires reading stations where each device goes through and is identified. This type of technology seems to be the most appropriate for the mobile phone industry and could allow the identification process to be done in an automated way. In addition, in order to maintain a good control over the reverse process, and as it was discussed before, an information system has to be put in place in order to be able to have a constant accurate overview of the different mobile phones and models within the recovery network. Such information system has to be capable of identifying and recording the different models entering the system as well as their components, their respective state and, once decided, which process the products or components will go through in order to allow better inventory management and real-time monitoring. As previously discussed, such a system can also be used to ease the decisional process required to determine which operation each component will be sent to. Additionally, this decision process should be automated as much
as possible to increase the efficiency of the network and reduce the assessment’s lead time. As briefly explained before, in order to automate this decision, the information system should be capable, using different variables such as the different costs, the bidding price of the suppliers, the demands and the current condition of the component, to evaluate which process offers the best benefits for each single component. This information system should also choose to whom the component should be sold in order to identify which standards the component should meet. The system should make such decisions by calculating the highest revenue/benefit option versus the incurred costs. By implementing such a system, not only would the reverse logistic company have a real time overview of the inventory, but it would also increase the process efficiency and reduce the decision process workload.

Reverse logistics networks require an important and constant cooperation between the different partners present in the system and the information systems, ideally, should be compatible to optimize the communication between all parties. These different parties include retailers, manufacturers, suppliers, recyclers, disposers, collectors ect. As the reverse logistics system for mobile phone can be operated by one or many operators, communication between the different parties is essential in order to optimize the efficiency of each process as well as forecasting the demand and making sure the flow between the processes is as smooth as possible.

4.3.7 Integration of a Reverse Logistics System with the Forward Supply Chain in the Case of the Mobile Phone Industry
The model created for the mobile phone industry and illustrated in Figure 4.3, only considered the recovery network as a distinct process of the forward supply chain, but mobile phone manufacturers could decide to implement a reverse flow parallel to their forward flow. To do so requires high coordination and great planning so the different process can complement each other. But why would a manufacturer want to integrate the two flows together? Manufacturers, by doing so, can save money as they can use some of the returned mobile phones components to repair broken phones and to create new and cheaper phone models. In addition they can recycle certain materials from the returned phones and save on the expenses incurred by buying new materials such as plastic or different types of metals necessary to make new phones. Finally, by integrating both processes, manufacturers can also have an information system in which new and old devices and their components are registered and therefore have an optimal control over their supply chain, their inventory and their total costs.
4.3.8 Conclusions of the Model
This model, created for the mobile phone industry, displayed the different processes required to carry out an efficient recovery network for these devices. The model and its description have also shown that many challenges and different strategic decisions have to be made when creating and implementing such a network. Incentives have to be put in place for supplies to be collected in a non-intermittent manner and to assure the good functioning of the network. Supplies have to be forecasted using different variables, but stocks remain difficult to predict as they vary in model types, manufactured dates, quantities and quality levels. In addition, it was shown that the different processes required in the reverse flow demand high levels of automation in order to increase the efficiency and reduce lead times. It was also demonstrated that the testing steps are critical processes in a recovery network that aims to recover as much asset value as possible. As a matter of fact, in the presented model, two testing phases were included. This was done as the objective of the model is to maximize asset recovery and those two testing/sorting steps ensure tight control measures as well as leading products and components to the appropriate succeeding operation. By ensuring that each component, based on many variables, is forwarded to the appropriate process, one can seek to find the optimal option for each module in the system, maximize the benefits and lower the costs. In addition, it was discussed and explained that such a network should employ recycling with disassembly in order to maximize the asset recovery and reduce disposal rate. Additionally, information systems that can track products, their components and their processing sequence have to be implemented in order to allow suitable inventory control and real-time monitoring of the inventory. Finally, it was discussed how these information systems can also be implemented in order to assist the decision making process required to select which subsequent activity each product and component should be submitted to.

To conclude the presentation of the created model, one last point has to be disclosed. As this model is not based on a current firm operating a reverse logistics network for the recovery of mobile phones, the constructed model had to be evaluated and modified, where needed, in order to assess its validity and sustainability. In order to do so, a comparative analysis was done by juxtaposing the theories used to construct the present thesis, different quantitative models, integer and mixed-integer linear programming studies as well as general and industry specific reverse logistics models in order to compare and evaluate the designed model for the mobile phone industry, its viability, its legitimacy, and review its overall quality.
Conclusion
This thesis investigated one of the supply chain management disciplines: reverse logistics. As shown in this paper, RL is an important business area and, due to many factors such as environmental concerns, legislations and customer demands, firms have started to invest time and efforts in order to build efficient reverse flows to gain competitive advantages and respect new environmental laws. Additionally, as it was shown throughout this thesis, RL is a complex field and presents many challenges, which have to be overcome when businesses implement reverse flows. These challenges are still complex as RL remains a new business area and expertise, in this domain, is still being built.

In addition to the depiction of the reverse logistics field and its different challenges, the mobile phone industry, in a RL context, was examined and a reverse network was created for this industry. The mobile phone industry was chosen for two reasons: there is an excessive amount of mobile phones waiting to be returned in most developed countries of the world and this industry has not been extensively studied in a reverse logistics context. The model was created, its objective was defined and its operational sequence was explained in details. Through this description, all required activities as well as their challenges were displayed. It can be concluded, from this model, that reverse flows for the mobile phone industry can be created and that their implementation will necessitate great investments and intelligent planning in order to make these flows as efficient as possible. Forecasting techniques have to be created and defined to predict incoming supplies and incentives have to be put in place to encourage customers to return their devices. In addition, it was concluded that a high level of automation of the processes is essential in order to create an efficient network and that the use of information systems with high flexibility capacities is mandatory in order to deal with the varied forms of inputs and their various states. Finally, as stated before hand, the model was constructed based on theories and through a reflection-comparative process by juxtaposing different models from different industries and authors. That being said, the validity of the model was tested through these comparative analyses as this model has yet to be implemented.

Although the concept of reverse logistics and studies on this particular field have been conducted for almost 20 years, many facets and characteristics of the field remain to be examined. Such investigations could converge towards many business areas. For example, studies focusing on product development could explore product design and their affect of the
reverse logistics possibilities or how companies can design products made for reverse flows. Additionally, reverse logistics costs remain an unclear area of this discipline, as costs are hard to allocate to the returned products and the different processes. Therefore, studies on cost drivers and within the field of management accounting could be carried out to create possible models to help assign the different costs of RL properly. Finally, models and studies investigating reverse logistics networks dealing with multiple products are rare as most studies focus on a one-product flow. Therefore, this area of RL remains to be investigated thoroughly.

To conclude, reverse logistics is gaining momentum in today’s environmental context and it can easily be anticipated that, with the implementation of environmental laws, this business field will gain in popularity and more studies, theories and experts will emerge.
Bibliography


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Appendices

Appendix 1 - The Main Reverse Logistics Models

Figure A1.1 - Framework Reverse Distribution

Source: Fleischmann et al., 1997.

Figure A1.2 - Product Flow in Supply Chain and Recovery Chain

Source: Kokkinaki et al., 2002.
**Figure A1.3 - Supply Chain that Accounts for Reverse Flows**

Source: Pagell et al., 2007.

**Figure A1.4 - The Reverse Logistics Network**

Figure A1.5 - Computer Products Recovery Operations


Figure A1.6 - Non-used products packaging and waste

Figure A1.7 - Constituents of Reverse Logistics

- Recycling
- Remanufacturing
- Refurbishing
- Disposal
- Reusable container

Reverse distribution

- Remplacement products
- Repair under warranty
- Product return

Green logistics
- Substitute materials
- Reuse material
- Reduce

- Save resources
- Design for environment
- Improve productivity
- Eliminate waste

Source: Marcotte et al., 2008

1. Lambert and Roppel, 2003
2. Rogers and Tibben-Lembke, 1998

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Figure A1.8 - Content Categories for an RL System

**INPUTS**
- Used products
- New parts/modules

**STRUCTURE AND PROCESSES**
- Processing
- Remanufacturing
- Inspection
- Consolidation

**DRIVERS**

**OUTPUTS**
- Recycled material, spare parts
- Remanufactured products
- Waste disposal

Appendix 2 – The Recycling Process

Figure A2.1 – WeRecycle Recycling Process

Appendix 3 – Other Models Reviewed for the Creation of the Suggested Reverse Logistics Model for the Mobile Phone Industry

Figure A3.1 - Cardiff Methodology for Supply Chain Design

Source: Kumar and Yamaoka, 2007.
Figure A3.2 – Refurbishing/Recycling Facility Process for the Computer Industry

Figure A3.3 – A Supply Chain that Accounts for Reverse Flows

Source: Marcotte et al., 2008.

Source: Pagell et al., 2007.
Figure A3.4 – Flow of Materials and Finances in the Swiss e-waste Management System

Source: Khetriwala et al., 2009.