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Revenue Management for Multiple Product Recovery Options: a Triangulation Approach

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by

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Abstract

In recent times large numbers of end-of-use/end-of-life returns have been the result of the increasing pressure from environmental legislations, particularly the directive on Waste Electrical and Electronic Equipment (WEEE) in the European Union. These returns incur acquisition costs and take-back operation costs regarded as a sunk cost by many industries. Thus, returned/recovered product valuation and marketing issues become crucial factors for survival and profitability of many firms in various sectors in today's competitive world.

The research undertaken is relevant as pricing and revenue management for recovered products. Indeed, this theme is considered as a niche research and the fifth phase (prices and markets) of the evolution of closed loop supply chain research. Hence, it has been noted as one of the most critical research areas in quantitative modelling for reverse logistics and closed loop supply chain management studies. The research area is in its early stage because it can be seen that only a handful of articles have been published in peer-reviewed international journals, exploring a pricing and marketing decision of recovered products. Hence, there are significant opportunities to conduct pricing and revenue management research in reverse logistics, particularly with regard to multiple recovery options.

The primary objective of this research work is to formulate three pricing models by using a non-linear programming approach to determine optimal profit-maximising acquisition prices and selling prices, together with UK-based case studies in the mobile phone and computer recycling businesses. Moreover, this research aims to formulate two simulation

models based on these case companies by investigating the impact of the uncertainty element in terms of return quantity and reprocessing time on firm's profit. The triangulation approach is employed, specifically the multilevel model comprising case studies, questionnaire survey, and empirical quantitative models in order to address the principal research questions i.e. "What are optimal acquisition prices of received mobile phones and optimal selling prices of reprocessed handsets?", "What are optimal selling prices of reprocessed computers?", and based on the total profit, "What if the model's parameters change?"

The contribution of this research covers the generation of pricing and simulation models that are suitable for the recycled mobile phone and computer sector. The literature review discovers that the research on this subject lacks considerations of multiple recovery options, return rate and demand rate as exponential functions, recovery capacity limitation, product substitution policy, the element of uncertainty in terms of return quantity and reprocessing time, and multiple time periods. Hence, this research fulfils six main research gaps in academic literature as follows. First, this study takes multiple recovery options into account. Second, return and demand rate are modelled as an exponential function. Third, pricing and simulation models cope with a limit to recovery capacity. Fourth, models with product substitution policy are investigated. Fifth, the element of uncertainty in terms of return quantity and reprocessing time is added into proposed models. Finally, this study proposes models with multiple time periods.

The results from this research work support current pricing and revenue management research and most importantly, the results generated from these proposed models can enhance managers' decision making in recovery operations and reverse logistics.

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Publications

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Conference Paper

Chanintrakul, P., Coronado-Mondragon, A.E. and Lalwani, C.S. (2008). 'Revenue Management for Multi-Recovery Options Operations: a Pricing Model'. *2008 International Conference of Production and Operation management (ICPOM'08)*. Xiamen, PR China, December 2008.

Chanintrakul, P., Coronado-Mondragon, A.E. and Lalwani, C.S. (2009). 'Revenue Management for Multi-Recovery Options Operations with Product Substitution in the Mobile Phone Recycling Industry: A pricing model'. *the 14th Logistics Research Network Annual Conference*. Cardiff, UK, September 2009.

Chanintrakul, P., Coronado-Mondragon, A.E. and Lalwani, C.S. (2009). 'Revenue Management for Multi-Recovery Options Operations in the Computer Recycling Industry: a Pricing Model'. *the 1st International Conference on Logistics and Transport 2009 (ICLT 2009)*. Chiang Mai, Thailand, December 2009.

Chanintrakul, P., Coronado-Mondragon, A.E. and Lalwani, C.S. (2010). 'Reverse Logistics of the Mobile Phone Industry in Thailand'. *the 15th Logistics Research Network Annual Conference*. Harrogate, UK, September 2010.

Chanintrakul, P., Coronado-Mondragon, A.E. and Lalwani, C.S. (2011). 'Revenue Management for Multiple Recovery Options in the Computer Recycling Industry: a Simulation Model'. *the 16th Logistics Research Network Annual Conference*. Southampton, UK, September 2011.

Contents

List of Figures

List of Tables

Summary of Key Abbreviations

- *WEEE* = Waste Electrical and Electronic Equipment
- *EEE* = Electrical and Electronic Equipment
- *RoHS* = Restriction of Hazardous Substances
- *ANOVA* = Analysis of Variance
- *Model Type:* EC = econometric model, NLP = nonlinear programming model, QN = queueing network model, SM = simulation model, ST = stochastic model, STDP = stochastic dynamic programming model
- *Recovery system:* MD = market-driven system, WS = waste stream system
- *Period:* S = single-period, M = multi-period
- *Total costs:* 1 = acquisition cost or compensation cost, 2 = handling cost including collection, cleaning, grading and/or sorting cost, 3 = recovery cost, 4 = replaced equipment cost, 5 = transportation cost, 6= backorder cost, 7 = holding cost, 8 = disposal cost
- *Return/Demand Rate:* LF =linear function, NLF = nonlinear function
- *Decision Variable:* AP = acquisition prices, SP = selling prices, OT = other decision variables
- *Uncertainty:* DU= demand uncertainty, RPTU = reprocessing time uncertainty, RU = return uncertainty, SPU = sale price uncertainty, YU = yield uncertainty
- *G/S Duty = Grading and sorting duty*: SPs = suppliers, RA = recovery actor, P = perfect grading and sorting

- *Recovery Actor:* OEM = original equipment manufacturer, 3PL = third party company
- *Recovery Option:* S = single recovery option, T = two recovery options, M = multiple recovery options
- *Recovery Method:* 1 = direct resale, 2 = Repair, 3 = Refurbishing, 4 = Remanufacturing, 5 = Recycling
- *Market:* MM = monopoly market, OM = oligopoly market, PM = primary market, SM = secondary market

Chapter 1: Introduction

1.1 Background

Research in reverse logistics has gained considerable attention from both academia and industry driven by three key factors i.e. economics, rigid environmental legislation, and corporate citizenship (De Brito and Dekker, 2004). In terms of economics, a reverse logistics programme can be used as a strategic weapon in order to bring direct benefits to companies i.e. significant cost reduction and a potential profit source (Rogers and Tibben-Lembke, 1999). Moreover, the programme can provide firms with a wide range of indirect benefits i.e. market and brand protection, entering new markets, and improved customer relationship by offering an extra service to customers (Flapper et al., 2005).

In accordance with environmental legislation, implementation of a reverse logistics programme helps organisations to cope with current and future regulations. It has becoming increasingly significant since several countries, particularly in the European Union, have continued to launch various environmental regulations such as packaging regulation, recycling quotas, and original equipment manufacturer (OEM) take-back responsibility (Thierry et al., 1995; Carter and Ellram, 1998; Dowlatshahi, 2000; Bernon et al., 2004; De Brito and Dekker, 2004; and Kumar and Putnam, 2008). Furthermore, good corporate citizenship is also one of the most imperative factors when firms decide to start their reverse logistics programme, either accepting returns or in recovery (Rogers and Tibben-Lembke, 1999).

It is found that several books and hundreds of articles, published in peer-reviewed international journals, have been published since the term 'reverse distribution channels' was introduced in academic literature during the seventies by Guiltinan and Nwokoye (1975) and Ginter and Starling (1978). In the early nineties, the Council of Logistics Management (Stock, 1992) presented the first official definition of reverse logistics introduced as:

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

In academic research, quantitative modelling is considered to be one of the major research approaches in the context of reverse logistics and closed loop supply chain management (De Brito and Dekker, 2004). Dekker et al. (2004) highlighted that the quantitative modelling approach has been long used as a dominant tool to support decision making in both open loop and closed loop supply chain management. More importantly, quantitative modelling contributes to a better understanding of the interactions, dynamics, and underlying trades-offs of the open loop/closed loop supply chain process, and thereby enables managers consciously to take these factors into account when making decisions. Based on this research approach, researchers have worked on reverse logistics and closed loop supply chain management including reverse logistics network design, valuation of recoverable inventories, value of information, and so on.

1.1.1 Current Context and Problems

In today's competitive world many firms, in various sectors, might not be able to sustain their competitive advantage or even be able to survive in their business if they did not construct appropriate value-added recovery systems and make profitability from returns because the volume of reverse logistics activities is large. For example, the size of reverse logistics costs is approximately a half percent of the total U.S. Gross Domestic Product (GDP) and reverse logistics costs accounted for approximately $35 billion in 1997 (Rogers and Tibben-Lembke, 1999). The results from a survey of US catalogue companies with average annual sales volume of $33 million reported reverse logistics costs account for 9.49% of their total logistics costs (Daugherty et al., 2001).

It can be seen that customer returns incur acquisition costs and take-back operations costs that are considered as a sunk cost by many companies. In addition, due to take-back legislations such as the Waste Electrical and Electronic Equipment (WEEE) Directive in the European Union (EU), and as a demonstration of corporate citizenship (social and environmental issues), firms have been encountering a variety of return types from customers such as B2C commercial returns (reimbursement guarantees), warranty returns, service returns (repairs, spare parts), end-of-use returns, and end-of-life returns (De Brito and Dekker, 2004). On the other hand, pricing and revenue management has become a crucial issue concerning profitability for several recovery players who consider returns to be a potential profit source.

Hence, this research work investigates pricing and revenue management in reverse logistics. It is considered to be one of the most critical themes of quantitative models for reverse logistics, since such issues are considered as a niche research area and the fifth phase (prices and markets) of the evolution of closed loop supply chain research[1] (Guide Jr. and Van Wassenhove, 2005 and 2009). Moreover, Mitra (2007) argued that there is a need for more investigation on pricing and revenue management in reverse logistics since it has not been extensively addressed in academic literature to date. Sasikumara and Kannan (2008) also highlighted that it has become imperative to conduct research on the subject of recovered products; however, it has so far not gained sufficient attention.

Altogether this research work identifies six main research gaps in academic literature as follows: first, this study takes multiple recovery options into account. Second, return and demand rate are assumed to be an exponential function. Third, pricing and simulation models deal with a limit to recovery capacity. Fourth, product substitution policy is taken into account. Fifth, the element of uncertainty in terms of return quantity and reprocessing time is added into proposed models. Finally, this study proposes simulation models with multiple time periods.

[1] The five phases of the evolution of closed loop supply chain research are: the first phase: the golden age of remanufacturing as a technical problem; the second phase: from remanufacturing to valuing the reverse logistics process; the third phase: coordinating the reverse supply chain, the fourth phase: closing the loop; and the fifth phase: prices and markets (Guide Jr. and Van Wassenhove, 2009).

1.2 Research Objectives and Research Questions

Main objectives for this research are as follows:

- To formulate a pricing model using a non-linear programming approach to determine optimal profit-maximising acquisition prices and selling prices based on the impact of the multiple recovery options;

- To formulate two pricing models by using a non-linear programming approach to determine optimal profit-maximising selling prices based on the impact of the multiple recovery options; and

- To extend the study of the pricing models by formulating two simulation models to deal with the element of uncertainty in terms of return quantity and reprocessing time. More precisely, these proposed simulation models aim to investigate the revenue management impact of a multiple recovery options system by carrying out "what-if" assessments. In accordance with the research objectives, research questions addressed in this thesis are as follows.

RQ.1: What are optimal acquisition prices of received mobile phones and optimal selling prices of reprocessed handsets?"

This research question relates to the first research objective. To answer this question, a pricing model is formulated using a nonlinear programming approach to calculate optimal profit-maximising acquisition prices of received mobile phones and optimal selling prices of reprocessed handsets. This is carried out using a case company in the mobile phone recycling business which has implemented a market-driven system and a multiple recovery options operation.

This mobile phone recycling company motivates end-users to return end-of-use and/or end-of-life handsets to the firm by offering cash paid for a specified level of used handsets quality. After that, these used mobile phones are reprocessed. Selected recovery approaches and operating costs depend on quality levels of the handsets. Then, reprocessed mobile phones are redistributed and resold in a secondary market. Selling prices of these recovered phones are influenced by acquisition prices and recovery costs.

RQ.2: "What are optimal selling prices of reprocessed computers?"

This research question is relevant to the second research objective. To address this question, this study formulates two pricing models by using a non-linear programming approach to determine optimal profit-maximising selling prices. This is conducted using a case company in the computer recycling business which has applied a waste stream system and a multiple recovery options operation.

In accordance with the WEEE Directives, an old computer is considered as a type of waste electrical and electronic equipment and end-users are unable to put used computers in their bin. Hence, this company provides a service of computer recycling to end-users for the sustainable recovery of old computers. The company collects these computers from end-users. After that, the computers are reprocessed and selected recovery options rely on the computers' quality level. Then, reprocessed computers are resold and setting of selling prices of these reprocessed computers is affected by recovery costs.

RQ.3: based on the total profit, “What if the model's parameters change?”

This research question relates to the third research objective. The proposed pricing models are a deterministic system and are formulated by the use of a nonlinear programming approach. Moreover, Oakshott (1997) mentioned that most mathematical models cannot (efficiently) deal with the element of uncertainty and Greasley (2004) suggested that a simulation model can efficiently tackle risk and uncertainty. Hence, two simulation models are proposed in order to extend the study of the pricing models to deal with the element of uncertainty in terms of return quantity and reprocessing time by assuming a return rate represents an exponential distribution and reprocessing time performs a normal distribution.

Greasley (2004) advised that a simulation model can be used to answer ‘what if?’ type questions. Thus, this form of research question is applied in this study in order to investigate the revenue management impact of a multiple recovery options operation when changing a value of the models’ parameters.

1.3 Proposed Approach

Due to the importance of recovery systems for the electronics sector, this research explores the pricing and revenue management in reverse logistics by using both a real case company in the mobile phone recycling business and a real case company in the computer recycling business. The methodology adopted to achieve the research objectives for this work is the triangulation approach, more specifically the multilevel model. Namely, this study uses mixed research methods combining case studies, a questionnaire survey and empirical quantitative models as the research strategy. This research begins with two UK case companies in the recycled mobile phone sector and in the recycled computer sector followed by the questionnaire survey developed from the case companies. After that, data collected from two sources including the results from two case companies and the results from the questionnaire survey are employed to formulate the pricing models and the simulation models.

The contribution of this research work covers the generation of pricing models and simulation models that are suitable for the recycled mobile phone sector and the recycled computer sector. Moreover, this research work also contributes to the optimal pricing decisions based on the impact of the multiple recovery options; the impact of pricing models' parameters on the optimal acquisition prices, optimal selling prices and the total profit via the sensitive analysis; and the impact of the element of uncertainty in terms of return quantity and reprocessing time on the total profit by carrying out "what-if" assessments.

1.4 Organisation of the Thesis

The remainder of the thesis is organised as follows.

Chapter 2 discusses a review of the current literature on reverse logistics. It includes a primary background of reverse logistics and closed loop supply chain management i.e. a definition of reverse logistics, driving forces behind reverse logistics, reasons for product returns, actors in reverse logistics, reverse logistics process, and quantitative models for reverse logistics. More specifically, this chapter presents a comprehensive review of the literature on pricing and revenue management in reverse logistics, and identifies future research gaps and opportunities in this field. This chapter concludes with the research gaps that are addressed in this research work.

Chapter 3 presents the research methodology applied in this research work. A good and consistent research design amongst research philosophy, research approach, research strategy, a data collection and analysis method, and a time horizon are discussed. Specifically, a triangulation approach based on the multi-level model employed in this study is highlighted. The selected research methods including case studies, questionnaire survey, a nonlinear programming approach, and a simulation model are also discussed.

Chapter 4 demonstrates the general information regarding the Waste Electrical and Electronic Equipment (WEEE) Directive and the Restriction of Hazardous Substances (RoHS) Directive related to the WEEE recycling business. More importantly, this chapter also illustrates two case companies engaged in the mobile phone recycling business and the computer recycling business which have implemented multiple recovery options operations for the reverse logistics programme in practice. These case companies are used to develop a questionnaire survey presented in chapter 5, to formulate the pricing models illustrated in chapter 6, and to construct the simulation models demonstrated in chapter 7.

Chapter 5 presents the data analysis outputs of the survey data collected by using a questionnaire in accordance with behaviours and opinions of respondents, regarding the recycled mobile phone sector and the recycled computer sector. Three main statistical techniques have been used in this research including descriptive statistics, the one-way ANOVA technique, and factor analysis. Some of the statistical outputs will be used for validation in the pricing model demonstrated in chapter 6 and for 'what-if' assessments in the simulation models illustrated in chapter 7.

Chapter 6 presents three pricing models by using a non-linear programming approach to determine optimal profit-maximising acquisition prices and selling prices in the context of the mobile phone recycling industry, and to calculate optimal profit-maximising selling prices in the context of the computer recycling industry. These models aim to investigate the revenue management impact of the multiple recovery options operations.

Chapter 7 provides two simulation models to extend the study of the pricing models highlighted in chapter 6 of this thesis in order to cope with the element of uncertainty in terms of return quantity and reprocessing time. These simulation models are formulated by using a real case company in the mobile phone recycling business and a real case company in the computer recycling business. The 'what-if' assessments are carried out by the models' parameters, and the results from the questionnaire survey demonstrated in chapter 5.

Chapter 8 includes discussion and draws conclusions of this thesis and attempts to provide answers to the research questions. This chapter also highlights the limitations of the study and identifies future research opportunities. Figure 1.1 shows the organisation of the thesis.

The next chapter covers a primary background of reverse logistics and closed loop supply chain management. Moreover, a comprehensive review of the literature on pricing and revenue management in reverse logistics are presented and future research gaps and opportunities on this research area are identified.

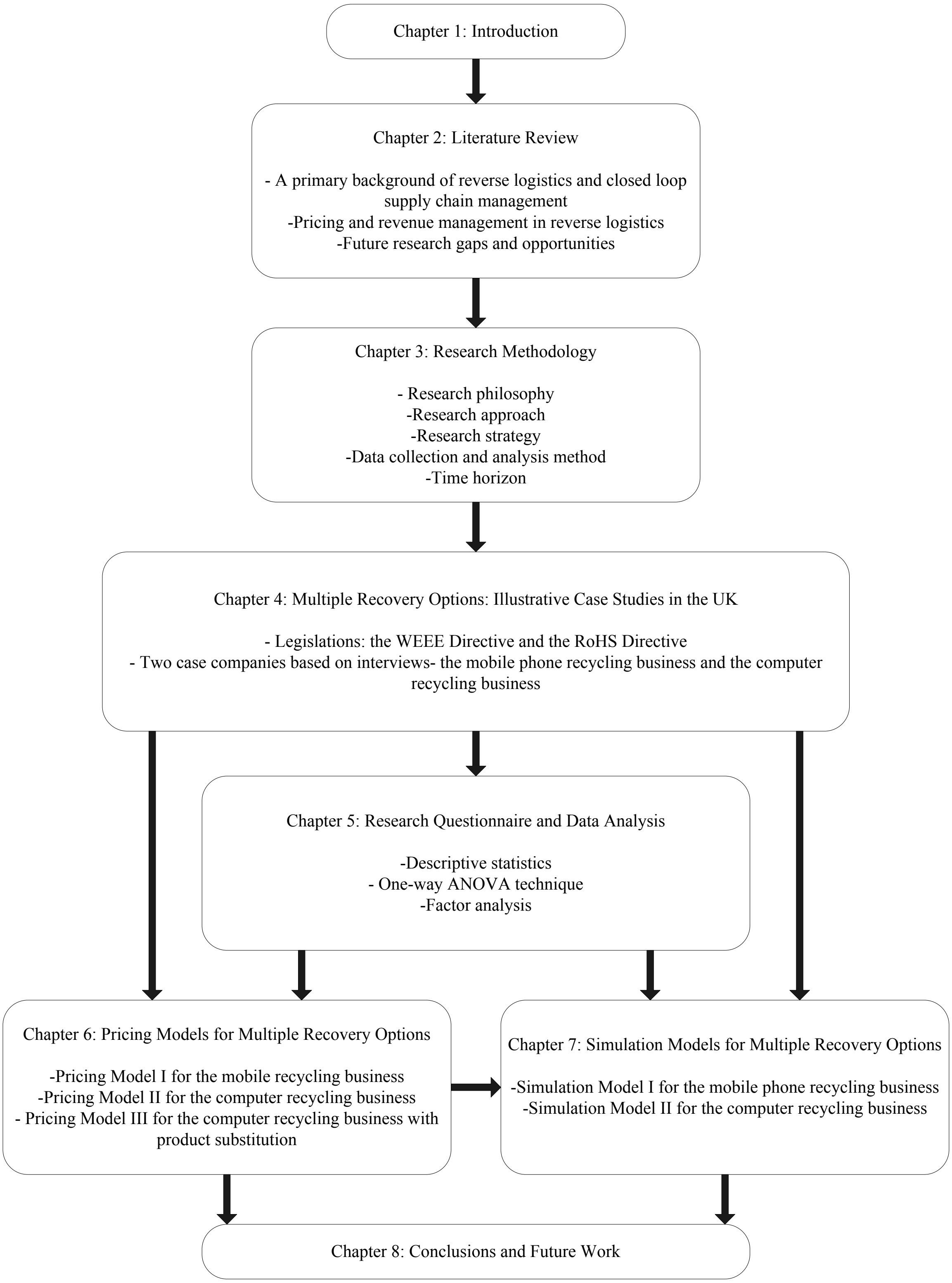

Figure 1.1: Organisation of the Thesis

Chapter 2: Literature Review

2.1 Introduction

In the last decade, interest in reverse logistics has rapidly grown in both academia and business driven by three main factors i.e. economics, rigid environmental legislation, and corporate citizenship (De Brito and Dekker, 2004). Pertinent to the literature dealing with reverse logistics, it is found that several textbooks and hundreds of articles published in peer-reviewed international journals have been published since the term ‘reverse distribution channels’ was introduced in the academic literature during the seventies by Guiltinan and Nwokoye (1975) and Ginter and Starling (1978).

Current overviews of reverse logistics can be classified into three main approaches including quantitative modelling, case studies, and theory building (De Brito and Dekker, 2004). Dekker et al. (2004) and Dyckhoff et al. (2004) provided an overview of reverse logistics quantitative models to support decision making. De Brito et al. (2003) and Flapper et al. (2005) introduced the element of a reverse logistics case studies approach in the area. The foundations of reverse logistics theory are proposed in many academic works (Stock, 1992; Kopicki et al., 1993; Stock, 1998; Rogers and Tibben-Lembke, 1999; Guide Jr. and Van Wassenhove, 2003; and Blumberg, 2005).

It is found that the volume of reverse logistics activities is large. For example, the size of reverse logistics costs is approximately a half percent of the total U.S. Gross Domestic Product (GDP) and reverse logistics costs accounted for approximately $35 billion in 1997 (Rogers and Tibben-Lembke, 1999). The results from a survey of US catalogue companies with average annual sales volume of $33 million reported reverse logistics costs account for 9.49% of their total logistics costs (Daugherty et al., 2001).

Moreover, Bernon and Cullen (2007) highlighted that total sales in the UK retail sector amounted to £230.5 billion and the results from their survey shows that returns of most of the participating firms are estimated to be between 1 and 5%. This implies that an average cost of goods being returned is £5.75 billion. Hence, several companies in many sectors that previously did not pay much attention to the management and understanding of reverse logistics have seriously taken reverse logistics into account such as BMW, Volkswagen, General Motors, Ford, Chrysler, IBM UK, DEC, Philips, and so on (Thierry et al., 1995).

This chapter provides a background of reverse logistics and closed loop supply chain management. In particular, this chapter presents a comprehensive review of the literature and identifies new issues for future research on pricing and revenue management in reverse logistics. The remainder of the chapter is organised as follows: section 2.2 presents a definition of reverse logistics; section 2.3 discusses driving forces behind reverse logistics; section 2.4 describes reasons for product returns; section 2.5 demonstrates actors in reverse logistics; section 2.6 depicts reverse logistics processes; section 2.7 presents quantitative models for reverse logistics; section 2.8 reviews pricing and revenue management in reverse logistics and identifies new issues for future research; section 2.9 highlights the research gaps; and section 2.10 provides the chapter conclusion.

2.2 Definition of Reverse Logistics

The conception of Reverse Logistics was developed during the 1990's, particularly, during the early nineties. The Council of Logistics Management (Stock, 1992) presented the first official definition of reverse logistics introduced as:

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

The previous definition only concentrates on the context of hazardous waste recovery and green logistics. Kopicki et al. (1993) gave the explanation of reverse logistics in line with Stock (1992); however, the author provided more comprehensive characterisations encompassing the element of hazardous or non-hazardous waste recovery, both material flow and information flow, and the direction of reverse logistics flow. Kopicki et al. (1993, p.3) mentioned that reverse logistics is

"*A broad term referring the logistics management skills and activities involved in reducing, managing, and disposal of hazardous or non-hazardous waste from packaging and products. It includes reverse distribution which causes goods and information to flow in the opposite direction of normal logistics activities*"

The European Working Group on Reverse Logistics (REVLOG) presented a new perspective on the definition of reverse logistics in that REVLOG took a sustainable (environmentally friendly) aspect into account. REVLOG (1998) stated that reverse logistics is "*all logistics activities to collect, disassemble and process used products, product parts, and/or materials in order to ensure a sustainable (environmentally friendly) recovery.*"

Another reverse logistics description is given by Rogers & Tibben-Lembke (1999). The authors have developed the definition of reverse logistics relevant to The Council of Logistics Management's definition of forward logistics. More precisely, the authors have pointed out that reverse logistics include all of the logistics activities, but these activities operate in reverse. Hence, Rogers and Tibben-Lembke (1999, p.2) defined reverse logistics as:

"*the process of planning, implementing, and controlling the efficient 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.*"

More importantly, the aforementioned definition also took a closed loop system into account that is "*the flows from the point of consumption to the point of origin*". During the early part of the 20th century, another meaning given by Fleischmann (2001) was described analogously to Rogers and Tibben-Lembke (1999)'s definition. Fleischmann (2001, p.6) introduced reserves logistics as:

"*the process of planning, implementing, and controlling the efficient, effective inbound flow and storage of secondary goods and related information opposite to the traditional supply chain direction for the purpose of recovering value or proper disposal.*"

Most recently, Blumberg (2005, p.12) has mentioned that "*Reverse logistics is the process found either as a subset of closed loop systems or standing alone. This includes full coordination and control, physical pickup and delivery of material, parts and products from the field to processing and recycling or disposition, and subsequent returns back to the field where appropriate*."

The above definition is relatively comprehensive in that the author pointed out both a closed loop system and an open loop system, and also mentioned the recovery process. Hence, this definition is used in this thesis.

In summary, the definition of reverse logistics has changed over time and it is found that each of these definitions is proposed based on a different viewpoint. Stock (1992) and Kopicki et al. (1993) emphasised the element of waste management viewpoint and put reverse logistics in the context of green logistics. By contrast, the definitions given by Rogers and Tibben-Lembke (1999) and Fleischmann (2001) focus on the process of planning, implementing, controlling, and the reverse logistics goal. In terms of the flow direction, Kopicki et al. (1993) and Fleischmann (2001) pointed out the sense of the flow direction opposed to traditional logistics; by contrast, Rogers and Tibben-Lembke (1999) stressed the flow from the point of consumption to the point of origin that is a closed loop system.

In terms of types of flow, most of the proposed definitions (Stock, 1992; Kopicki et al., 1993; REVLOG, 1998; and Blumberg, 2005) only took material flow into account. On the other hand, Rogers and Tibben-Lembke (1999) and Fleischmann (2001) highlighted the element of material flow and information flow. As there are three principle types of flow in reverse logistics - material flow, information flow and financial flow, it could be more comprehensive if a definition includes all of these types of flow. More importantly, only Blumberg (2005) took the element of an open loop system and a closed loop system into account, and REVLOG (1998) introduced the element of a sustainable (environmentally friendly) aspect into the definition.

2.3 Driving Forces behind Reverse Logistics

In the reverse logistics literature, a number of authors have pointed out various driving forces as summarised in Table 2.1. The structure of Table 2.1 concludes that a majority of the references classified the driving forces into three main aspects: economics (direct and indirect gains), environmental legislation, and corporate citizenship as shown in Figure 2.1.

Table 2.1: Driving Forces for Reverse Logistics

Authors	Driving Forces
Thierry et al. (1995)	Cost reduction, a reduction in the environmental impact, green marketing (image), and legislation
Carter and Ellram (1998)	Regulations, customers, policy entrepreneurs, and the uncertainty in the input sector
Stock (1998)	Cost reduction/revenues, legal requirement, and social responsibility
REVLOG (1998)	Environmental laws, economic benefits, and the growing environmental consciousness of consumers
Blumberg (1999)	Economic value of recovered product and the legal requirements of the "Green Laws"
Rogers and Tibben-Lembke (1999)	Strategic weapon, competitive reasons, return policy changes, good corporate citizenship, clean channel, protect margin, legal disposal issues, and recapture value and recover assets
Dowlatshahi (2000)	Economic, environmental, and legislative reasons
Guide Jr. et al. (2000)	Economic reasons (cost reduction and potential profit source), environmentally responsible pressures from customers, and government regulations
De Brito and Dekker (2004)	Economics, legislation, corporate citizenship
Flapper et al. (2005)	Profit (direct and indirect business economic reasons), people (environmental producer responsibility), and planet (environmental regulations)
Bernon and Cullen (2007)	Forecast accuracy and demand variability linked to purchasing policies, high on-shelf availability, liberal returns policies, legislative factors, new product introductions, logistics trade-offs, customer no-faults found, and cash flow management practices
Meade et al. (2007)	Environmental factors (regulatory issues, market and customer pressures, and ethical motivations to improve environmental performance), and business factors (direct and indirect economic benefits)
Kumar and Putnam (2008)	Environmental regulations, societal reasons, limited raw material resources, and market competition

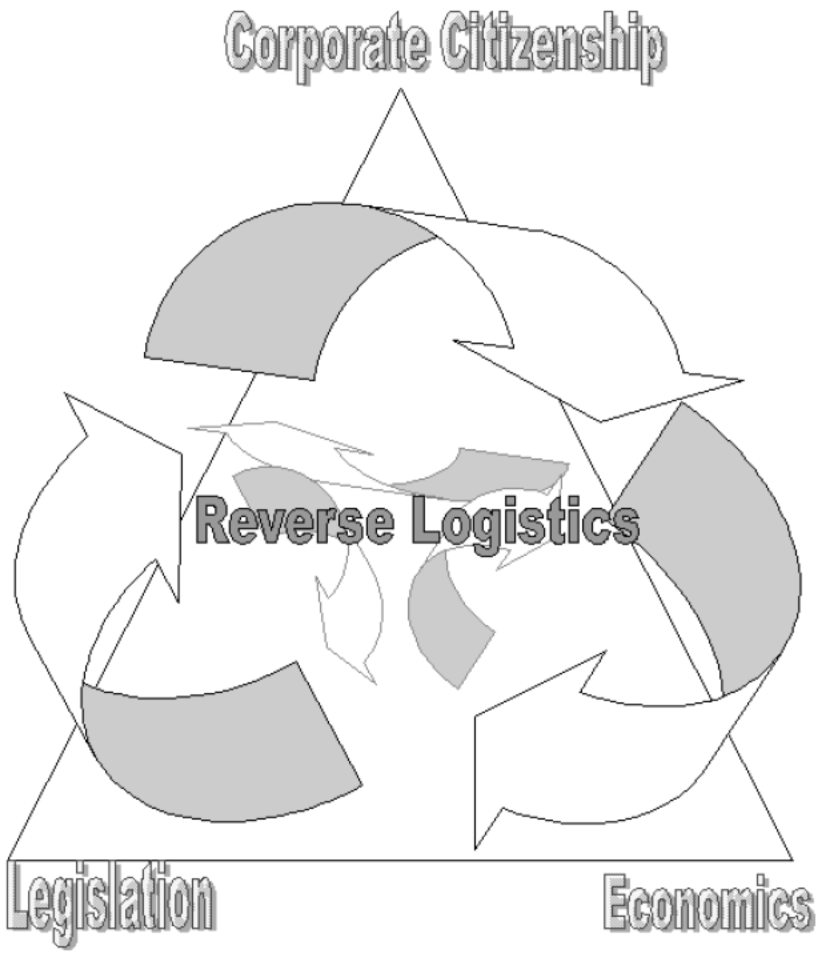

Figure 2.1: Driving Forces for Reverse Logistics (De Brito and Dekker, 2004)

2.3.1 Economics

Several firms in many business sectors implement a reverse logistics programme since it provides both direct and indirect benefits as follows:

Direct Benefits

Rogers and Tibben-Lembke (1999) mentioned that several companies have implemented reverse logistics as their strategic weapon. Firms obtain a large portion of their bottom-line profits including significant cost reduction and a potential profit source. Using the online survey in the recent study of cost reduction, Jack et al. (2010) found that reverse logistics capabilities have a significant impact on return cost savings for the retail sector. Carter and Ellram (1998) documented that AT&T Network Systems Division had saved nearly $100 millions in 19 months due to a reverse logistics programme for its telephone switching equipment. Dowlatshahi (2000) argued that industries that implement remanufacturing operations can save 40 to 60 percent of the cost of manufacturing a completely new product.

In terms of a potential profit source, Guide Jr. et al. (2000) mentioned that several industries in the United States have implemented recovery operations systems for a number of products including; copiers, automobile parts, computers, office furniture, mass transit, aviation equipment, and tyres. These operations systems are both environmentally friendly and profitable. In particular, total annual sales of recovered products are in excess of $53 billion. Moreover, Guide Jr. et al. (2005) pointed out that the profitability of ReCellular Inc., one of the leading US traders of used and remanufactured mobile phones, depends on its acquisition process, future market demand, and the selling prices for remanufactured mobile phones. Furthermore, Souza (2009) highlighted that the volume of the current global market for recovered mobile phones is $240 million.

Indirect Benefits

Flapper et al. (2005) pointed out that the reverse logistics programme can provide companies with a wide range of indirect benefits as follows:

- Market and brand protection e.g., the Whirlpool case (Deneijer and Flapper, 2005),

- Entering new markets e.g., the Mercedes-Benz case (Driesch et al., 2005) and the ReCellular Inc. case (Guide Jr. et al., 2005), and
- Improved customer relationship by offering an extra service to customers e.g., the Whirlpool case (Deneijer and Flapper, 2005), the L'Oreal case (Kuik et al., 2005), the HP case (Davey et al., 2005), the Wehkamp case (De Koster and Zuidema, 2005), and the Mercedes-Benz case (Driesch et al., 2005).

2.3.2 Environmental Legislation

Companies implement a reverse logistics programme to cope with current and future legislation since several countries, particularly in the European Union, have increasingly launched various environmental regulations such as packaging regulation, recycling quotas, and original equipment manufacturer (OEM) take-back responsibility (Thierry et al., 1995; Carter and Ellram, 1998; Dowlatshahi, 2000; Bernon et al., 2004; De Brito and Dekker, 2004; and Kumar and Putnam, 2008). Three examples of environmental regulations are as follows:

- Due to Dutch packaging regulations that are in line with the European Union's Packaging and Waste directive (94/62/EC) such as Convenant III (1/1/2003), Convenant II (end of 1997), and Convenant I (1991), Heineken is obligated to take back 90% of its bottles (Van Dalen et al.,2005).

- Due to The Landfill Directive of 1999, a prohibition on the landfilling of whole tyres starting in 2003 and shredded tyres in 2006, and The End of Life Vehicle (ELV) Direction of 2000, OEMs take-back responsibility of all ELV, RetreadCo set up operations in France, Germany, Belgium, and Luxemburg to retread tyres of several vehicle types including passenger cars, van, heavy trucks, and earthmovers and produces retread rubber for export (Debo and Van Wassenhove, 2005).

- The UK's Waste Electrical and Electronic Equipment (WEEE) Directive came into force in January 2007. The three main objectives of the WEEE directive are 1) to reduce the amount of WEEE being produced, 2) to encourage everyone to reuse, recycle and recover it, 3) to improve the environmental performance of businesses that manufacture, supply, use, recycle and recover electrical and electronic equipment (The Environment Agency, 2009). Hence, the WEEE regulations impact on an importer, a manufacturer, a retailer, and a user of new electrical or electronic equipment. These actors are legally obligated to ensure that a certain amount of electronic waste or (WEEE) is collected for reuse and recycling.

2.2.3 Corporate Citizenship

For altruistic reasons, good corporate citizenship is also one of the most imperative factors why various firms have started their reverse logistics programme in accepting returns or in recovery (Rogers and Tibben-Lembke, 1999). To put it another way, corporate citizenship has been considered to be a major principle in forcing a company to take corporate social responsibility by engaging in a reverse logistics programme (De Brito and Dekker, 2004).

The Kenneth Cole Productions, a shoe manufacturer and retailer, and Nike are good examples of this (Rogers and Tibben-Lembke, 1999). The Kenneth Cole retailer provides a 20 percent discount on a new pair of Kenneth Cole shoes to customers who return old shoes to their stores during February. The company then donates these shoes to people in need. For a second example, Nike also persuades customers to return old shoes to their stores, and then these shoes are sent back and shredded at a Nike factory. After that, Nike gives the shredded material for the making of basketball courts and also Nike provides financial support to construct and maintain these courts.

2.4 Reasons for Product Returns

Rogers et al. (2002) and De Brito and Dekker (2004) discussed a number of reasons for product returns based on different perspectives. Rogers et al. (2002) classified reasons for returns into five groups including customer returns, marketing returns, asset returns product recalls, and environmental returns as listed in Table 2.2.

Table 2.2: Five Reasons for Returns (Rogers et al., 2002)

Types of Returns	Description
Consumer returns	Customer returns are generally the largest class of returns. The principle reasons for customer returns include buyers' change of mind or defect, liberal return policies, and warranty returns.
Marketing returns	The key reasons for marketing returns consist of slow sales, quality issues, the need to reposition inventory, close-out returns, buy-outs, job-outs, surplus, and overruns.
Asset returns	Asset returns comprise the recapture and repositioning of an asset due to reuse/cost reduction and friendly environment.
Product recalls	The key reasons for product recalls include safety and quality issues. Generally, product recalls can be voluntary or mandated.
Environmental returns	Environmental returns consist of disposal of hazardous waste and are enforced by environmental regulations.

In a further classification, in accordance with the usual supply chain hierarchy, De Brito and Dekker (2004) classified return reasons more systematically into three main categories: manufacturing returns, distribution returns, and customer returns as shown in Table 2.3.

Table 2.3: Three Reasons for Returns (De Brito and Dekker, 2004)

Types of Returns	Description
Manufacturing returns	Manufacturing returns are defined as components or products that must be recovered in the production phase. The key reasons for manufacturing returns include rework, raw material surplus, quality-control returns, and production leftovers/by-products.
Distribution returns	Distribution returns mean those returns that are introduced during the distribution phase. Several main reasons for distribution returns are product recalls, B2B commercial return (e.g. unsold products or wrong/damaged deliveries), stock adjustments, and functional returns (e.g. distribution items, carriers, packaging).
Customer returns	Customer returns are those returns started when the final customer has received the product. A variety of reasons for customer returns include B2C commercial returns (reimbursement guarantees), warranty returns, service returns (repair, spare parts), end-of-use returns, and end-of-life returns.

2.5 Actors in Reverse Logistics

A number of authors (Guiltinan and Nwokoye, 1975; Pohlen and Farris, 1992; Stock, 1998; Rogers and Tibben-Lembke, 1999; De Brito et al., 2003; and De Brito and Dekker, 2004) identified the various parties involved in the reverse logistics process. However, De Brito and Dekker (2004) presented the most comprehensive classification of actors in the reverse logistics programme. The authors classified players in reverse logistics into three main groups as follows: 1) forward supply chain actors (supplier, manufacturer, wholesaler, and retailer); 2) specialised reverse chain players (such as jobbers, recycling specialists, etc.); and 3) opportunistic players (such as charity organisations).

2.6 Reverse Logistics Process

A number of the references (Thierry et al., 1995; Blumberg, 1999; Rogers and Tibben-Lembke, 1999; Krumwiede and Sheu, 2002; De Brito and Dekker, 2004; Blumberg, 2005; Prahinski and Kocabasoglu, 2006; Meade et al., 2007; Sasikumara and Kannan, 2008; Srivastava, 2008; and Souza, 2009) presented a variety of reverse logistics processes; however, these processes are relatively similar. It can be concluded that the reverse logistics process consists of four main procedures as follows: first, there is collection. Next, there is the combination of inspection/selection/sorting processes. Third, there is recovery. Recovery can be classified into two options based on returns' quality; direct recovery (re-sale/ re-use/re-distribution) and process recovery (repair, refurbishing, remanufacturing, parts retrieval (cannibalisation), recycling, incineration, and (proper) disposal. Finally, there is redistribution. Figure 2.2 shows the reverse logistics process.

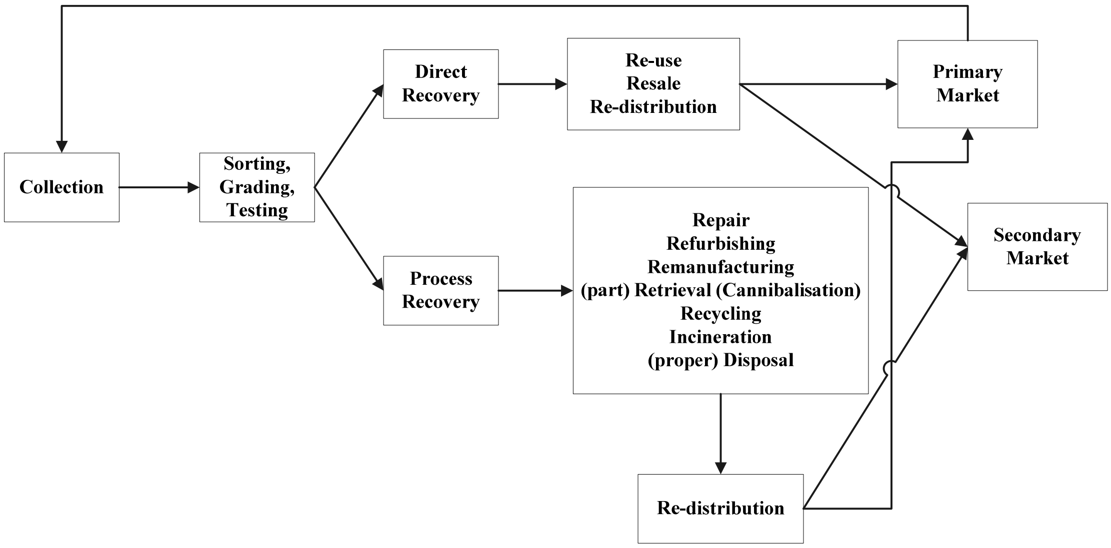

Figure 2.2: The Reverse Logistics Process (adapted from De Brito and Dekker (2004))

Moreover, Thierry et al. (1995) also summarised different characteristics of the product recovery options, and main dissimilarities between these recovery methods as illustrated in Table 2.4.

Table 2.4: Comparison between Product Recovery Options (Thierry et al., 1995)

	Level of Disassembly	Quality Requirement	Resulting Product
Repair	To product level	Restore product to working order	Some parts fixed or replaced by spares
Refurbishing	To module level	Inspect all critical modules and upgrade to specified quality level	Some modules repaired/ replaced; potential upgrade
Remanufacturing	To part level	Inspect all modules and parts and upgrade to as new quality	Used and new modules /parts combined into new product; potential upgrade
Cannibalisation	Selective retrieval of parts	Depends on process in which parts are reused	Some parts reused; remaining Product recycled/disposed of
Recycling	To material level	High for production of original parts; less for other parts	Material reused to produce new parts

2.7 Quantitative Models for Reverse Logistics

One of the major research approaches in reverse logistics and closed loop supply chain management is quantitative modelling. Dekker et al. (2004) have mentioned that the quantitative modelling approach has been long used as a dominant tool to support decision making in both open loop and closed loop supply chain management. More importantly, quantitative modelling contributes to a better understanding of the interactions, dynamics, and underlying trades-offs of the open loop/closed loop supply chain processes, and thereby enables managers consciously to take these factors into account when making decisions.

Based on quantitative models, the list of major research areas of reverse logistics and closed loop supply chain management are categorised by Dekker et al. (2004) as shown in Table 2.5. The list of main themes are benchmarked and developed from the key research areas of quantitative models for traditional supply chain management highlighted by Tayur et al. (1998) and Simchi-Levi et al. (2002). However, pricing and revenue management research for recovered products has not been paid attention by Dekker et al. (2004).

Recently, Guide Jr. and Van Wassenhove (2009) introduced a comprehensive overview of the evolution of closed loop supply chain research over the past 15 years using five phases to describe this evolution. More importantly, pricing and revenue management have been highlighted as a new research area and the fifth phase of the evolution of this research area. Hence, this study has included this subject as one of the most important research areas in quantitative models for reverse logistics. The structure of Table 2.5 consists of two dimensions – functional areas and types of decisions. The first dimension refers to the areas of distribution management, product planning and inventory control, and the inter-organizational scope of a supply chain. The second dimension is the usual distinction between long-term strategic decisions and short-term tactical and operational decisions.

Table 2.5: Quantitative Models for Reverse Logistics (Dekker et al. 2004)

Strategic	Tactical/operational
Distribution Area:	
Reverse logistics network design Reusable packaging	Product return forecasting Collection and distribution routing Return handling
Inventory and Production Area:	
Valuation of recoverable inventories Product design for reusability	Lot sizing in product recovery operations Safety stocks in product recovery systems Dynamic control of product recovery operations Production planning for product recovery Remanufacturing operations Production planning for bulk recycling
Supply Chain Scope Area:	
Closed loop supply chain coordination and contracts Long-term performance development Environmental performance Collaborative recycling network design	Pricing and Revenue management* Value of information Product acquisition

(* = new research area)

However, some categories in reverse logistics research are combined as there are some overlaps among research areas; for example, reverse logistics network design and reusable packaging; reverse logistics network design and collaborative recycling network design; production planning for product recovery and production planning for bulk recycling; and so on. In addition, a product design for reusability issue is discarded because it is related to material science and thus beyond the scope of business and management studies. The major research areas in reverse logistics and closed loop supply chain management are highlighted in Table 2.6.

Table 2.6: The Major Areas of Reverse Logistics and Closed Loop Supply Chain Management Research (adapted from Dekker et al. (2004))

Research Area	Strategic or Tactical/Operational	Major Issues
Distribution	Reverse logistics network design	The infrastructure for collection and reprocessing returned products
	Product return forecasting	The forecasting of products returns
	Collection and distribution routing	The corresponding transportation operations
	Return handling	The internal logistics issues such as the impact of product returns on facility layout and internal transportation
Inventory and Production	Valuation of recoverable inventories	How to assign holding costs to inventories of product returns
	Lot sizing in product recovery operations	Lot sizing such as the economic order quantity (EOQ) model and the discrete time, dynamic lot sizing problem
	Safety stocks in product recovery systems	Stochastic inventory control for product recovery management
	Dynamic control of product recovery operations	Competitive strategy, selection of recovery processes, investments in remanufacturing technology, product life cycle decisions, and production planning under seasonal demand
	Production planning for product recovery	Generic concepts such as MRP approaches, disassembly strategies, and production planning in the case of rework
Supply Chain Scope	Closed loop supply chain coordination and contracts	Interaction between multiple decision makers in the reverse chain
	Long-term performance development	How System Dynamics (SD) can be employed to assist long-term strategies by means of quantifying the anticipated effects of alternative strategic choices
	Environmental performance	Eco-eco closed-loop supply chain optimisation model and Life-Cycle Analysis (LCA)
	Pricing and Revenue management	A means for matching returns and demand in an optimal way such as revenue management, the coordination of pricing decisions with operations, and so on
	Value of information	The impact of misinformation considering product return forecasting, value of information sharing, and the value of stochastic information

2.8 Pricing and Revenue Management in Reverse Logistics

Pricing and revenue management research is one of the most critical research areas in reverse logistics since such issues are considered to be a niche research area and the fifth phase (prices and markets) of the evolution of closed loop supply chain research (Guide Jr. and Van Wassenhove, 2005 and 2009). Moreover, Mitra (2007) argued that there is need for more investigation on pricing and revenue management in reverse logistics since it has not been extensively addressed in the academic literature so far. Sasikumara and Kannan (2008) also highlighted that it is imperative to conduct research in this subject for recovered products; however, it has not gained sufficient attention. Guide Jr. and Van Wassenhove (2001) proposed a framework for economic value analysis of the potential profitability of product recovery based on product acquisition management.

Moreover, authors also classified types of product recovery system for acquiring used product from end users for reuse into two major systems: the waste stream system and the market-driven system. A waste stream system is a system in which a manufacturer is responsible for collection and product recovery operations of its end-of-life products in order to reduce the amount of products discarded in landfills. A number of European recycling companies under the waste stream approach are controlled by recent environmental regulations. More importantly, firms often receive a large number of returns that seem to be old and have poor quality; as a result, their recovery operations system is complex and costly and firms must take the element of cost reduction into account.

On the other hand, a market-driven system is a system in which recovery companies encourage end-users to return end-of-life products to them by offering financial incentives such as deposit systems, credit toward a new unit, or cash paid for a specified level of quality. The market-driven approach considers recovery products to be a potential profit source because these products can be resold. In addition, the firms are able to control the level of quality of returned products; so, the market-driven operations system is much simpler and cheaper than the waste stream operations system.

Based on the framework presented by Guide Jr. and Van Wassenhove (2001), it found seven articles related to pricing and revenue management in reverse logistics and closed loop supply chain management research during the period 2003-2009 (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Vorasayan and Ryan, 2006; Mitra, 2007; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009)[2]. These papers proposed a number of pricing models applied in different industrial and product sectors such as recovery of mobile phones (Guide Jr. et al., 2003; and Mitra, 2007), remanufactured parts of the end-of-life vehicles (ELVs) (Bakal and Akcali, 2006; Qu and Williams, 2008), and refurbished personal computers (Vorasayan and Ryan, 2006).

Furthermore, several particular issues have been addressed such as the effect of random yield in terms of value of information on pricing decisions (Bakal and Akcali, 2006), the effect on demands for new and refurbished products in the same markets on the refurbishing decisions (Vorasayan and Ryan, 2006), and acquisition pricing decisions

[2] Please note that this review does not include the articles (Majumder and Groenevelt, 2001; Savaskan et al., 2004; Debo et al., 2005; Heese et al., 2005, Ray et al.; 2005, Ferrer and Swaminathan, 2006;Savaskan and Van Wassenhove, 2006; Karakayali et al.; 2007; Webster and Mitra; 2007; Mitra and Webster, 2008; Qiaolun et al., 2008; Ferrer and Swaminathan, 2010; Aras et al., 2011; and Shi et al., 2011) that also address optimal pricing decisions. However, these papers are mainly relevant to the other research area, coordination in closed loop supply chains in terms of competition of market structure for recovered products, incentive alignment, and functional coordination.

based on a geometric Brownian motion (GBM) for the selling price of remanufactured products (Liang et al., 2009).

To evaluate these pricing models, the applied modelling approach and assumptions will be identified i.e. recovery system, time period, product life cycle, capacity constraint, operations cost, return/demand rate, decision variable, the element of uncertainty, grading and sorting duty, recovery actor, recovery option, recovery method, product substitution policy, and market issues. Table 2.7 illustrates a summary of reviewed papers on pricing and revenue management in reverse logistics. With this systematic approach, it gives the ability to review the recent research articles and identify issues for future research.

From Table 2.7, it can be seen that a variety of model types were proposed such as an econometric model (Guide Jr. et al., 2003), a stochastic model (Bakal and Akcali, 2006; Liang et al., 2009), a queueing network model (Vorasayan and Ryan, 2006), a nonlinear programming model (Mitra, 2007; Qu and Williams, 2008), and a stochastic dynamic programming model (Xiang et al., 2009). Nearly all of the proposed models (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Mitra, 2007; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009) apply to the market-driven system.

Table 2.7: Summary of Reviewed Papers of Pricing and Revenue Management in Reverse Logistics

Author(s)	Model Type	Recovery System	Period	Product Life Cycle	Capacity Constraint	Operations costs	Return /Demand Rate	Decision Variable	Uncertainty	G/S duty	Recovery Actor	Recovery Option	Recovery Method	Product Substitution Policy	Market Issue
Guide Jr. et al. (2003)	EC	MD	S			1,3	NLF	AP, SP		SPs, P	3PL	S	4		MM, SM
Bakal and Akcali (2006)	ST	MD	S			1,2,3,5	LF	AP, SP	YU	RA, P	3PL	T	4,5		MM, SM
Vorasayan and Ryan (2006)	QN	WS	S			2,3,5,6, 7		SP, OT		RA, P	OEM	S	3		MM, PM
Mitra (2007)	NLP	MD	S		x	8	LF	SP		SPs, P	3PL	T	3,4		MM, PM, SM
Qu and Williams (2008)	NLP	MD	M			1,2,3,5	-	AS,OT		RA,P	3PL	S	5		MM,SM
Liang et al. (2009)	ST	MD	M			1,2,3		AP	SPU	RA, P	3PL	S	4		OM, SM
Xiang et al. (2009)	STDP	MD	S			1,2,3,8	LF,NLF	AP, SP	YU,DU	RA	3PL	S	4		MM, SM

Moreover, most of the papers (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Vorasayan and Ryan, 2006; Mitra, 2007; and Xiang et al., 2009) incorporated a single time period into their models. Significantly, only Mitra (2007) took capacity limitation into account, and none of the papers considered product life cycle issues. In terms of objective function, all papers utilised profit maximization as a single objective. Thus, future studies should take multiple time periods, capacity limitation, product life cycle, and the two-or multi-objective model into account.

With respect to operations costs, a wide range of costs were taken into their models including acquisition costs and recovery costs (Guide Jr. et al., 2003); acquisition cost, handling cost, recovery cost and transportation cost (Bakal and Akcali, 2006; Qu and Williams, 2008); handling cost, recovery cost, transportation cost, backorder cost and holding cost (Vorasayan and Ryan, 2006); disposal cost (Mitra, 2007); acquisition cost, handling cost, and recovery cost (Liang et al., 2009); and acquisition cost, handling cost, recovery cost, and disposal cost (Xiang et al., 2009). Guide Jr. et al. (2003) defined the return rate and the demand rate as a twice differentiable function; Bakal and Akcali (2006) assumed that both of the rates were a linear function; Mitra (2007) also assumed the demand rate to be a linear function and Xiang et al. (2009) identified the return rate as a linear function and the demand rate to be a constant-elasticity function.

Guide Jr. et al. (2003), Bakal and Akcali (2006), and Xiang et al. (2009) assumed that the return rate is an increasing function of an acquisition price and the demand rate is a decreasing function of selling price. In addition, Mitra (2007) defined the demand rate as a decreasing function of selling price and availability or supply of recovered items. Qu and Williams (2008) also identified that return rate is an increasing function of acquisition price.

Talluri and Van Ryzin (2005) argued that there are four main types of common demand functions as follows: 1) linear demand, 2) log-linear (exponential) demand, 3) constant-elasticity demand, and 4) logit demand. In future studies, it would be interesting to assume that return rates (function) and demand rates (function) represent a log-linear (exponential) function or a logit function.

In terms of decision variables, various decision variables were calculated i.e. acquisition price and selling price (Guide Jr. et al., 2003; Bakal and Akcali, 2006; and Xiang et al., 2009); selling price and procurement lot sizing (Vorasayan and Ryan, 2006), selling price (Mitra, 2007); acquisition price, inventory of returns, weight of returns, and weight of output material (Qu and Williams, 2008); and acquisition price (Liang et al., 2009). Moreover, only three articles addressed the element of uncertainty i.e. recovery yield uncertainty (Bakal and Akcali, 2006), selling price uncertainty (Liang et al., 2009), and recovery yield uncertainty and demand uncertainty (Xiang et al., 2009). Hence, further studies should include more investigation of the element of uncertainty in terms of return, demand, recovery yield, reprocess time, and/or selling price.

Regarding grading and sorting issues, nearly all models assumed that grading and sorting are perfect, and the duty is carried out by suppliers (Guide Jr. et al., 2003; and Mitra, 2007) or recovery actors (Bakal and Akcali, 2006; Vorasayan and Ryan, 2006; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009) i.e. Original Equipment Manufacturer (OEM) or 3PL refurbisher/ remanufacturer. However, grading and sorting quality classes are imperfect in real situations (Guide Jr. et al., 2003).

On the topic of reverse logistics frameworks, Thierry et al. (1995) and De Brito and Dekker (2004) argued that there are two main types of recovery depending on quality of returned items: direct recovery and reprocessing recovery. *Direct recovery* is used for closed as-good-as-new quality class such as reuse, resale, and redistribution. *Reprocessing recovery* is used for as-is quality grade that demands more action at different levels, such as repair (product level), refurbishing (module level), remanufacturing (component level), retrieval/cannibalisation (selective part level), recycling (material level), and incineration (energy level).

Moreover, multiple recovery options of returned items have been used in real world situations, particularly in the electrical and electronic equipment industry i.e. CopyMagic, a multinational copier manufacturer (Thierry et al., 1995), IBM (Fleischmann et al., 2004), a Japanese producer of refrigerators (Bloemhof-Ruwaard et al., 2004), Safeway, a former UK leading grocery retailer (Bernon and Cullen, 2007), and Envirofone.com, the UK's number one online mobile phone recycling company, (Envirofone.com, 2008).

In light of the recovery issue, most papers explored only one recovery option i.e. refurbishing (Vorasayan and Ryan, 2006), remanufacturing (Guide Jr. et al., 2003; Liang et al., 2009; and Xiang et al., 2009), or recycling (Qu and Williams, 2008). Only two articles highlighted two recovery options including remanufacturing and recycling (Bakal and Akcali, 2006) and refurbishing and remanufacturing (Mitra, 2007). Therefore, it would be interesting to further explore multiple recovery options.

On recovered product quality, most of the papers considered a single product quality class (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Vorasayan and Ryan, 2006; Liang et al., 2009; and Xiang et al., 2009). By contrast, only Mitra (2007) addressed two product quality classes; however, the author assumed that the demands of each product class are independent due to the price-quality differentials. Nevertheless, some research in lot sizing decisions (Robotis et al., 2005) and hybrid inventory control (Inderfurth, 2004; and Bayindir et al., 2007) considered a product substitution policy due to out-of-stock problems such as product downward substitution, one-way substitution (Inderfurth, 2004; and Robotis et al., 2005), or perfect substitution, two-way substitution (Bayindir et al., 2007). Further pricing models taking product substitution policy into account may offer interesting research opportunities.

Focusing on marketing issues, Talluri and Van Ryzin (2005) classified level of competition, one of a pricing model's key assumptions, into three main types: monopoly, oligopoly, and perfect-competition market. The description of these market assumptions is presented in Table 2.8. Nearly all references (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Vorasayan and Ryan, 2006; Mitra, 2007; Qu and Williams, 2008; and Xiang et al., 2009) addressed a monopoly market. Moreover, there are three market types for recovered products, which have been considered in previous studies: secondary market for remanufactured products (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009), primary market for new products and refurbished products (Vorasayan and Ryan, 2006), and primary market for remanufactured products and secondary market for refurbished products (Mitra, 2007).

Table 2.8: Description of Market Assumptions (Talluri and Van Ryzin, 2005)

Type of market assumption	Description
Monopoly market	The demand a firm faces is assumed to depend only on its own price and not on the price of its competitors. Thus, the model does not explicitly consider the competitive reaction to a price change. This assumption is primarily for tractability and is not always realistic.
Oligopoly market	The equilibrium price response of competitors is explicitly modelled and computed. This assumption may result in a poor predictor of firms' actual price response. These potential modelling errors together with the increased complexity of analysing oligopoly models the difficulty in collecting competitor data to estimate the models accurately. As a result, these models are less popular in practice.
Perfect-competition market	Many competing firms supply an identical commodity. The output of each firm is assumed to be small relative to the market size, and this, combined with the fact that each firm is offering identical commodities means that a firm cannot influence market price. Despite the importance of perfect-competition models in economic theory, the assumption that the firm has no pricing power means that the results are not useful for price-based revenue management.

2.9 Research Gaps

After reviewing the academic literature on pricing and revenue management research in the field of reverse logistics, it has been decided that the setting of this research work is different from the setting of the previous studies in the following considerations:

First, most of the proposed models investigated only one recovery option (Guide Jr. et al., 2003; Vorasayan and Ryan, 2006; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009) and only two articles considered two recovery options (Bakal and Akcali, 2006; and Mitra, 2007). By contrast, in order to capture more complex and real-life situations, this study explores multiple recovery options which are generally employed in the waste electrical and electronic equipment recycling industry (Thierry et al., 1995; Fleischmann et al., 2004; Bloemhof-Ruwaard et al., 2004; Bernon and Cullen, 2007; and Envirofone.com, 2008).

Second, only one article has considered a limit to recovery capacity (Mitra, 2007); on the other hand, this thesis takes more investigation of recovery operations capacity into account. Third, the previous research assumed the return rate and/or the demand rate as a twice differentiable function (Guide Jr. et al., 2003), a linear function (Bakal and Akcali, 2006; Mitra, 2007; and Xiang et al., 2009), and a constant-elasticity function (Xiang et al., 2009) while, in this research work, a return rate and a demand rate are modelled to be an exponential function.

Fourth, none of the papers took a product substitution policy into account, whereas the proposed models in this study consider this policy to be one of the most important assumptions. Fifth, in the previous studies, the element of uncertainty i.e. recovery yield uncertainty (Bakal and Akcali, 2006), selling price uncertainty (Liang et al., 2009), and recovery yield uncertainty and demand uncertainty (Xiang et al., 2009) were considered. On the other hand, this study highlights the element of uncertainty in terms of return quantity and reprocessing time. Finally, most of the proposed models (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Vorasayan and Ryan, 2006; Mitra, 2007; and Xiang et al., 2009) considered single-period condition while, this thesis proposes models with multiple time periods.

However, a few research gaps have not been addressed in this thesis. These include the following aspects: first, all the previous studies lack considerations of multi-objective models and the element of product life cycle. Hence, future studies should include models with multiple objectives and product life cycle issues. Second, a return rate and/or a demand rate assumed as a logit function have not been given attention. Hence, future studies should define the rates to be a logit function. Third, nearly all the papers (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Vorasayan and Ryan, 2006; Mitra, 2007; Qu and Williams, 2008; and Xiang et al., 2009) coped with a monopoly market. Thus, more investigation of oligopoly markets should be carried out.

2.10 Conclusion

Research in reverse logistics has gained more attention from both academia and business driven by several factors such as economics, rigid environmental legislation, and corporate citizenship. This chapter presents the overview of reverse logistics and closed loop supply chain management i.e. the definition of reverse logistics, driving forces behind reverse logistics, reasons for product returns, actors in reverse logistics, reverse logistics process, and quantitative models for reverse logistics.

This chapter presents a comprehensive review of the literature published in peer-reviewed international journals on pricing and revenue management in reverse logistics during the period 2003-2009 relevant to this research. More importantly, it also identifies gaps and future research opportunities in the field of this subject. This research work addresses the following aspects, which are different from the existing literature: multiple recovery options, more investigation of recovery operations capacity, return rate and demand rate as an exponential function, product substitution policy, the element of uncertainty in terms of return quantity and reprocess time, and multiple time periods.

As mentioned in section 1.2, the main objective of this study is to formulate pricing models using a non-linear programming approach to determine optimal profit-maximising prices based on the impact of the multiple recovery options. Moreover, this research work aims to extend the study of the pricing models by formulating two simulation models to deal with the element of uncertainty in terms of return quantity and reprocessing time. In accordance with these research objectives, the main research questions of this research are – "What are optimal acquisition prices of received mobile phones and optimal selling prices of reprocessed handsets?", "What are optimal selling prices of reprocessed computers?", and based on the total profit, "What if the model's parameters change?"

The objectives and the research questions are able to explore a pricing and marketing decision for recovered products in the recycled mobile phone and computer sectors. More importantly, this research is to fill in the aforementioned research gaps on pricing and revenue management in reverse logistics operations, particularly with regard to multiple recovery options. The next chapter illustrates research methodology applied in this study.

Chapter 3: Research Methodology

3.1 Introduction

This chapter presents the research methodology applied to this research work. Research methodology refers to "*the procedural framework within which the research is conducted. It describes an approach to a problem that can be put into practice in research programme or process*" (Remenyi et al., 1998, p.28). In other words, Teddlie and Tashakkori (2009, p.21) defined research methodology as "*a general approach to scientific inquiry involving preferences for broad components of the research process*". This means that a good and consistent research design among research philosophy, research approach, research strategy, data collection and analysis method, and the time horizon is crucial in order to achieve research objectives

The structure of this chapter is organised in accordance with the research 'onion' proposed by Saunders et al. (2007) as shown in Figure 3.1. Hence, the remainder of this chapter includes the following sections; section 3.2 presents research philosophy; section 3.3 demonstrates research approach; section 3.4 covers research strategy, data collection method and data analysis technique; section 3.5 highlights time horizons; and section 3.6 provides the chapter conclusion.

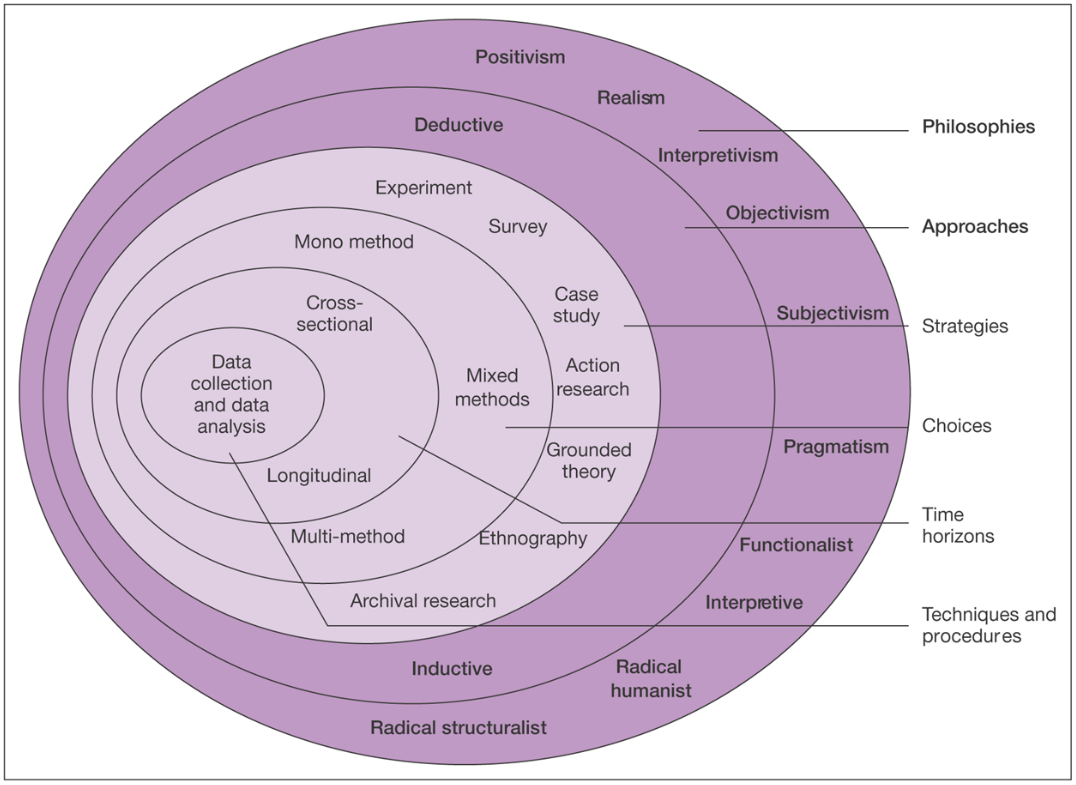

Figure 3.1: The Research 'Onion' (Saunders et al., 2007, p.102)

3.2 Research Philosophy

Research philosophy or research paradigm refers to a "*framework that guides how research should be conducted, based on people's philosophies and their assumptions about the world and the nature of knowledge"* (Collis and Hussey, 2009, p.55). The selected research strategy and methods will be underpinned by these assumptions. This implies that a researcher must select an appropriate research methodology with careful consideration of the research paradigm.

Morgan and Smircich (1980, p.492) provided "*a rough typology for thinking about the various views that different social scientists hold about human beings and their world*" as demonstrated in Table 3.1. The continuum starts at the extreme positivist end and concludes at the extreme interpretivist end. Moreover, Guba and Lincoln (2005) stressed that research paradigms consist of three fundamental beliefs i.e. ontology[3], epistemology[4], and methodology[5]. There are two extreme research paradigms i.e. positivism and interpretivism.

Table 3.1: Principle Assumptions on a Continuum of Paradigms in Social Science (Adapted from Morgan and Smircich, 1980, p.492)

	Positivism ←					→ Interpretivism
Ontology	Reality as concrete structure	Reality as a concrete process	Reality as a contextual field of information	Reality as a symbolic discourse	Reality as a social construction	Reality as a projection of human imagination
Epistemology	To construct a positivistic science	To construct system, process and change	To map contexts	To understand patterns of symbols discourse	To understand how social reality is created	To obtain phenomenolo-gical insight, revelation
Research methods	Lab experiments and surveys	Historical analysis	Contextual analysis of Gestalten	Symbolic analysis	Hermeneutic	Exploration of pure subjectivity

[3] Ontology means "*philosophy assumptions about the nature of reality*" (Easterby-Smith et al., 2008, p.60).

[4] Epistemology refers to "*the study of the criteria by which we can know what does and does not constitute warranted, or scientific, or knowledge*" (Johnson and Duberley, 2000, p.2).

[5] Methodology is "*the theory of how research should be undertaken*" (Saunders et al., 2007, p.3).

Positivism has been predominant in logistics research (Mentzer and Kahn, 1995). Remenyi et al. (1998, p.32) stressed that a positivist "*is working with an observable social reality and that the end product of such research can be the derivation of laws or law-like generalisations similar to those produced by the physical and natural scientists*." On the other hand, interpretivism refers to "*a theoretical point of view that advocates the study of direct experience taken at face value; and one which sees behaviour as determined by the phenomena of experience rather than by external, objective and physically described reality"* (Remenyi et al., 1998, p.34).

Mangan et al. (2004) pointed out the research paradigm underlying triangulation or mixed research methods is between the two extreme ends of research paradigms. This implies that this research is underpinned by the research philosophy that is between positivism and interpretivism due to the fact that triangulation is also employed in this study. Specifically, the triangulation design in this study is the multi-level model. It uses the integration of all results from mixed research methods including two quantitative methods (quantitative models and questionnaire survey) and one qualitative method (case study) to answer the research questions. This means that this research is conducted based on scientific perspective; as a result, the research paradigm underpinning this research is located closer to the positivist rather than the interpretivist end.

3.3 Research Approach

There are two main research approaches i.e. deductive approach (testing theory) and inductive approach (building theory).

Deductive approach refers to "*a study in which a conceptual and theoretical structure is developed and then tested by empirical observation; thus particular instances are deduced from general inferences*" (Collis and Hussey, 2009, p.8). In contrast, an Inductive approach is "*research approach involving in the development of a theory as a result of the observation of empirical data"* (Saunders et al., 2007, p.599). This research employs both the deductive approach and the inductive approach; however, deductive reasoning is mostly used in this study.

3.4 Research Strategy, Data Collection Method, and Data Analysis Technique

Easterby-Smith et al. (2008) highlighted that there are several factors affecting research design and one of these factors that influences the way research is conducted and analysed is the research philosophy. In particular, it is considered to be the foundation of the selection of research strategies. This implies that the design of research strategies must be consistent with the philosophical position in order to answer the research questions. A number of research strategies can be classified according to their philosophical bases, or quantitative or qualitative methods as listed in Table 3.2. However, Mangan et al. (2004) pointed out that some of these can be used with either of the paradigms. Moreover, different research strategies are suitable to be used for relevant situations as highlighted in Table 3.3.

Table 3.2: Research Strategies used in the Positivism and Interpretivism Paradigms (adapted from Remenyi et al., 1998; Mangan et al. 2004; Collis and Hussey, 2009)

Positivism	Interpretivism
Cross-sectional studies Experimental studies Longitudinal studies Surveys Models and simulation	Hermeneutics Ethnography Participative enquiry Action research Case studies Grounded theory Feminist, gender, and ethnicity studies

Table 3.3: Relevant Situations for Different Research Strategies (Oakshott, 1997; Yin, 2003)

Strategy	Form of Research Question	Requires Control of Behavioral Event	Focuses on Contemporary Events
Experiment	how, why?	Yes	Yes
Surveys	who, what, where, how many, how much	No	Yes
Archival analysis	who, what, where, how many, how much	No	Yes/No
History	how, why?	No	No
Case study	how, why?	No	Yes
Models and simulation	what if, what	No	Yes
	how many		

After carefully considering all the research strategies, models and simulation (quantitative modelling) are the most suitable method to answer the main research questions of this research – "What are optimal acquisition prices of received mobile phones and optimal selling prices of reprocessed handsets?", "What are optimal selling prices of reprocessed computers?", and based on the total profit, "What if the model's parameters change?". Betrand and Fransoo (2002, p.242) defined quantitative models as "*a set of variables that* *vary over a specific domain, while quantitative and causal relationships have been defined between these variables.*" Moreover, the authors classified quantitative model-based operations research into two distinct types i.e. axiomatic quantitative research and empirical model-based quantitative research.

Axiomatic Quantitative Research

Axiomatic quantitative research is primarily driven by the idealised model itself (Betrand and Fransoo, 2002). To put it in another way, axiomatic modelling approaches are formulated based on an artificial reconstruction of object reality (Meredith et al., 1989). Namely, a researcher attempts to recast the object reality, determined from his own belief concerning the object reality, into a defined model that is more appropriate for generating solutions within the defined model and experimentation (Meredith et al., 1989).

Betrand and Fransoo (2002) stressed that axiomatic quantitative research has been very productive and researchers have generated a vast body of model-based knowledge over the last 50 years. However, the major disadvantage of this research method is that construct validity has been generally missing (O'Leary-Kelly and Vokurka, 1998). Furthermore, Ackoff (1979) also highlighted that there is a weak connection between results and analysis of axiomatic quantitative research and real-life operational problems. Hence, many of models and solutions could not contribute any benefits to practitioners in order to solve the problems they struggled with.

Empirical Model-Driven Quantitative Research

On the other hand, empirical model-driven quantitative research is "*concerned with either testing the (construct) validity of the scientific models used in quantitative theoretical research, or with testing the usability and performance of the problem solutions obtained from quantitative theoretical research, in real-life operational processes*" (Betrand and Fransoo, 2002, p.257). Due to the changing nature of operations management research, a mission of conducting research should contribute to both academia and practitioners who are one of the major customers of the established knowledge (Handfield and Melnyk, 1998; Melnyk and Handfield, 1998). This implies that conducting quantitative model-based empirical research has a potential to make a contribution to a scientific discipline and also to fulfil a managerial relevance requirement.

In addition, Bertrand and Fransoo (2002) also stressed that this model type would be able to validate empirically axiomatic quantitative models in real-life operational processes. With regard to the disadvantages of this model type, the authors highlighted that it is time consuming and costly to collect all the required data to check all the underlying model assumptions. As a result, the assumptions are seldom checked. Even though quantitative model-based empirical research in logistics and supply chain studies is still in its infancy, this model type is becoming increasingly more important over time (Reiner, 2005).

After carefully considering the advantage(s) and disadvantage(s) of these distinct quantitative model types, it has been decided that this study would employ quantitative model-based empirical research to answer the main research questions. In addition, this research also uses a methodological and data triangulation approach as discussed below:

3.4.1 Triangulation Approach

All quantitative and qualitative research methods have their own distinctive limitations or weaknesses and using only a single research method to conduct research may cause bias issues (Creswell, 2008). Hence, it would seem to be useful to use mixed research methods in the same empirical study in order to overcome the potential bias and also enhance the validity and the reliability of the research findings. Furthermore, the combination of the quantitative and qualitative research methods will provide opportunities for methodological triangulation (Gill and Johnson, 2010).

The trend in the use of combined research has been increasing since the early 1980's and particularly in business and management studies, methodological triangulation using quantitative and qualitative research methods, is popular (Bryman and Bell, 2007). More importantly, there is the increase in the use of methodological triangulation in logistics research, and many of the articles have employed two or more methods in the same study (Frankel et al., 2005).

Triangulation refers to "*the use of multiple sources of data, different research methods, and/or more than one researcher to investigate the same phenomenon in a study*" (Collis and Hussey, 2009, p.89). Sekaran and Bougie (2010) identified four different types of triangulation:

- Methodological triangulation where both quantitative and qualitative methods of data collection and analysis are used;

- Data triangulation where data are collected from several sources and/or at different times;
- Researcher triangulation where different researchers independently collect and/or analyse the data; and
- Theory triangulation where multiple theories and/or perspectives are used to interpret and explain the data.

Methodological triangulation and data triangulation are used in this research. Namely, this study uses the mixed research methods combining case studies, questionnaire survey and empirical quantitative models as the research strategy in order to investigate the phenomenon of interest and to answer the research questions.

Creswell and Plano Clark (2007) classified the triangulation design into five main types: a one-phase model, the convergence model, the data transformation model, the validating quantitative data and the multilevel model. The multilevel model is employed to achieve the research objectives for this study. In this model type, a researcher uses different quantitative and qualitative methods in order to address multiple levels within a system. Quantitative and qualitative data from these different levels are analysed and the results from each level are integrated in order to provide one overall interpretation, or to answer the same question or related questions (Teddlie and Tashakkori, 2009).

This research begins at level one collecting data from case studies in the UK. Next, at level two, the questionnaire survey is developed from two case companies in the UK. Finally, at level three, required data collected from two sources including the results from two case companies in the UK and the results from the questionnaire survey are employed to formulate the nonlinear programming models and the simulation models in order to accomplish the research objectives. Figure 3.2 illustrates the triangulation design: the multilevel model of this study and Table 3.4 demonstrates an overview of the steps of the research process.

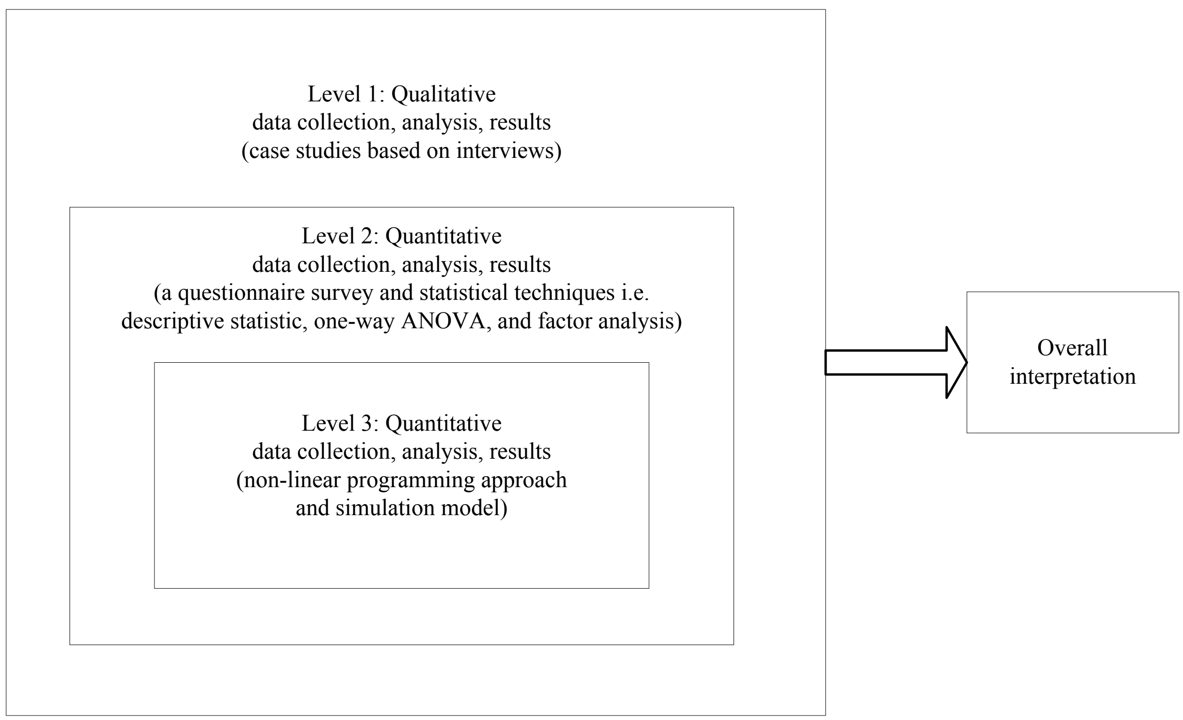

Figure 3.2: The Triangulation Design: the Multilevel Model of This Study (adapted from Creswell and Plano Clark, 2007, p.64)

Table 3.4: An Overview of the Steps of the Research Process

Phase	Research Strategy, Data Collection Method, and Data Analysis Technique	Output
Phase 1 (Induction)	- Case studies based on interviews - Interviews with the CEO of a top European mobile phone recycling company and the owner of a small and local computer recycling company	- Portraits of the reverse logistics programme in practice, particularly with regard to multiple recovery options, in recycled mobile phone and computer sectors.
Phase 2 (Deduction)	- A questionnaire survey developed from the data collected from the case companies - Development and pilot testing of the questionnaire - A self-administered delivery and collection questionnaire, as the questionnaire administration method (a total of 500 student s and staff at the University of Hull as respondents). - Data analysis techniques i.e. descriptive statistics, one-way ANOVA technique, and factor analysis.	- Outputs in accordance with behaviours and opinions of respondents, regarding the mobile phone and computer recycling businesses. - The importance of the research finding is used for data triangulation.
Phase 3 (Deduction)	- Three pricing models and two simulations models are formulated, using the results from the case companies and the questionnaire survey - All the proposed pricing models represent a deterministic system. - The simulation models aim to extend the study of the pricing models and deal with the element of uncertainty in terms of return quantity and reprocessing time by assuming that a return rate performs exponential distribution, and reprocessing time performs normal distribution.	- The optimal profit-maximising prices - The impact of the pricing models' parameters on the optimal prices and total profit carried out by the sensitive analysis. - The revenue management impact of the multiple recovery options system affected by the models' parameters and the results from the questionnaire survey carried out by the The "what-if" assessments

3.4.2 Case Study

A case study refers to "*an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident*" (Yin, 2003, p.13). A case study may be located in a positivist paradigm or an interpretivist paradigm or between these two extreme ends (Remenyi et al., 1998; Easterby-Smith et al., 2008; Collis and Hussey, 2009). A case study is considered to be a highly and well-established research strategy and the use of a case study has been rapidly grown in business and management research (Remenyi et al., 1998).

Specifically, small amounts of logistics research have been carried out with case study methodology; however, the use of this methodology tends to be increasing (Craighead et al., 2007). The principal advantages of case studies are that they are a powerful technique to generate answers to who, why, and how questions and their improvement of understanding of the context of the research (Remenyi et al., 1998). On the other hand, the drawbacks of this methodology include difficulties of negotiation and access to a suitable case, the time-consuming research strategy, decision complexity of the study scope, and difficulties in understanding the events at a single point in time without historical and future knowledge (Collis and Hussey, 2009).

Selection of Case Companies

This research focuses on the mobile phone recycling business and the computer recycling business in the UK for the following reasons.

First, during the review of the academic literature on recovery and reverse logistics, it was found that multiple recovery options of end-of-use items have been applied in the recycled electrical and electronic equipment sector. For example, CopyMagic, a multinational copier manufacturer, applies four recovery options including repair, remanufacturing, cannibalisation and recycling (Thierry et al., 1995). IBM also uses four recovery options: reuse, repair, remanufacturing, and recycling (Fleischmann et al., 2004).

Another example is a Japanese producer of refrigerators which also employs four recovery options: repair, retrieval, remanufacturing, and recycling (Bloemhof-Ruwaard et al., 2004). Safeway, a former UK leading grocery retailer, implemented three recovery options: resale, refurbishing, and repair for electrical and electronic products returns (Bernon and Cullen, 2007). Envirofone.com, the UK's number one online mobile phone recycling company, uses four recovery options, comprising direct resale, repair, refurbishing, and recycling (Envirofone.com, 2008).

Second, a number of environmental regulations have been increasingly launched, particularly in the European Union (Thierry et al., 1995; Carter and Ellram, 1998; Dowlatshahi, 2000; Bernon et al., 2004; De Brito and Dekker, 2004; and Kumar and Putnam, 2008). Specially, The UK’s Waste Electrical and Electronic Equipment (WEEE) Directive came into force in January 2007 (The Environment Agency, 2009). As a result, Electrical and Electronic Equipment industries in the UK are under pressure from this new environmental policy in that they have to deal with large numbers of end-of-use/end-of-life returns and an increase in take-back operation costs. It would be fruitful if WEEE recycling companies in the UK could set up appropriate value-added recovery operations and make profitability from these returns in order to survive in their business.

Third, the economic volume of the recycled mobile phone and recycled computer sectors in the UK are large. To begin with the mobile phone recycling industry, it is estimated that over 77% of the UK population have at least one mobile phone and over 15 million UK people are replacing their handsets each year (the Mid Sussex District Council, 2011). Moreover, a UK consumer group reported that in the UK 85 million end-of-use mobile phones have been discarded rather than traded in for cash and the results from a survey of 853 UK people indicated that 68% of the sample had kept one or more old handsets that they did not use (BBC News, 2010).

With regard to the computer recycling industry, Mintel International Group Ltd. (2008) reported that the estimated sales volume in the UK market for desktop and laptop/portable personal computers was 4.2 million units in 2008 and volume sales of computers will continuously increase by around 68% from 2008-2013. In particular, around 7 million units will be being sold by 2013. However, an estimated number of 1.5 million computers in the UK end up on landfill sites every year, generating around one million tonnes of waste. Therefore, many computer recycling companies have started services to reduce, and reuse this waste left by computers and other computer peripherals (BBC News, 2007). Moreover, according to the Department of Trade and Industry (2000), the UK market for refurbished computers has increased by 500% since 1999. Hence, there are great opportunities for both industries to make a profit from recovered products and also reduce a number of environmental problems.

Data Collection Method for Case Study

In this research, one case company in the recycled mobile phone sector and one case company in the recycled computer sector in the UK are used to demonstrate how these companies deal in practice with reverse logistics programmes. In particular, the issues relate to multiple recovery options operations. Yin (2003) highlighted that there are six main sources of evidence that are commonly used in doing case studies: documentation, archival records, interviews, direct observation, participant-observation, and physical artefacts. Due to gaining access and data availability, the methodology employed in this research includes the use of structured interviews, documentation (e.g. a company report, company websites, presentation slides, etc.), and direct observation to conduct the case studies.

All interviews had an average duration of approximately two hours, were tape-recorded and carefully transcribed. An interview protocol is illustrated in Appendix A and all the questions were asked. Table 3.5 shows the details of each interview.

Table 3.5: The Detail of Each Interview

Company	Interviewee	Nature of the Company
A	CEO	A top European mobile phone recycling company
B	Owner	A small and local computer recycling company

3.4.3 Survey

Ghauri and Grønhaug (2002, p.93) defined a survey as "*a method of data collection that utilises questionnaires or interview techniques for recording the verbal behaviour of respondent.*" A survey strategy is strictly underpinned by the positivism paradigm (Remenyi et al., 1998) and it is usually connected with the deductive approach (Gill and Johnson, 2010). This strategy is a popular and common research strategy in business and management studies (Saunders et al., 2007) and particularly, survey research is generally used in logistics research (Craighead et al., 2007).

Furthermore, it has also been considered as an effective tool to obtain opinions, attitudes, descriptions, and cause-and-effect relationships (Ghauri and Grønhaug 2002). The key advantage of collecting data through survey is that a researcher can collect a large amount of data from a large population at a reasonable cost, and within a reasonable time (Collis and Hussey, 2009) whereas, the main disadvantages are that there is a limit to the number of questions, and the respondent rate depends on the goodwill of the respondents (Saunders et al., 2007).

Data Collection Method for Survey

This subsection introduces the important aspects related to questionnaire data collection technique including population and sample, questionnaire design and pilot study, and questionnaire administration and response rate.

- **Population and Sample**

It would be not viable to consider people who are living in the UK as the population in this study due to budget restrictions, time constraints, and more-quickly-available results. Furthermore, the results from an annual survey conducted by Endsleigh Insurance of 1,000 students and young people about to start university reported that of their most important possessions the top three items were laptops, mobile phones, and clothes (BBC News, 2008). Moreover, the results from market research indicated that 91% of students have their own computer with them at university, with laptops favoured over desktops (Mintel International Group Ltd., 2010). Hence, students and staff at the University of Hull were taken as 'the population' in this research.

The current figure for the University's population is approximately 22,500 (The University of Hull, 2010). In addition, there is a need to use sampling techniques in order to select a sample representing the entire population. Collis and Hussey (2009) mentioned that there are two major classifications of sampling techniques including random sampling methods and non-random sampling methods.

Kvanli et al. (2003) indicated that the major advantage of using the first set of methods is that the sample results can be used in order to estimate statistically the characteristics of the population from the sample. On the other hand, the main advantages of using the second set of methods include three following considerations: first, data collection is easier. Second, non-random sampling methods are usually less expensive and take less time than random sampling methods and data from a non-random sample may provide sufficient information for further analysis. Finally, non-random sampling data can be used in order to prepare a later sample based on random sampling.

Moreover, Saunders et al. (2007) also mentioned that non-random sampling techniques may be appropriate when the researcher has limited resources and cannot identify a sampling frame. As there were resource limitations in terms of time and funds, self-selection sampling, a non-random sampling technique, has been used in this research. This method is appropriate when respondents make a decision as to whether they will take part in the research by themselves (Saunders et al., 2007).

Regarding suitable sample size, Collis and Hussey (2009) have suggested that samples of larger size are more likely to be representative of the entire population than smaller sample size. De Vaus (1996) presented the formula to calculate the minimum sample size required from different sizes of population. Based on the proposed formula, the entire population in this research is approximately 22,500, assuming data are collected from all cases in the sample; as a result, the actual sample size should be 378 cases at the 95 per cent confidence level.

- **Questionnaire Design and Pilot Study**

The questionnaire was designed in order to seek behaviours and opinions of respondents regarding the mobile phone recycling business and the computer recycling business (shown in Appendix B). The questions were constructed by adapting questions used in other questionnaires, and also developing the researcher's own questions. The questionnaire includes several question types i.e. list questions, category questions, rating questions, and quantity questions. The questionnaire is divided into two sections within three pages. The first section deals with the mobile phone recycling business and the second section deals with the computer recycling business.

Each section consists of two question classifications. The first consists of the questions that aim to describe behaviours of the respondents regarding their old mobile phone and their old computer. The second consists of the questions that aim to examine opinions of the respondents in accordance with companies' strategies and it is constructed by using rating questions. Saunders et al. (2007) pointed out that the Likert-style rating scale is the most frequently-used in rating questions in order to investigate how strongly the respondents agree or disagree with several statements, and the Likert-style rating scale is usually on a four-, five-, six-, or seven-point rating scale.

This research has used a five- point rating scale from very unimportant (scored one) to very important (scored five) for the following reasons. Firstly, a five- or seven-point rating scale may produce slightly higher mean scores relative to the highest possible attainable score compared to that produced from a ten-point scale, and this difference was statistically significant (Dawes, 2008). Secondly, a five-point rating scale provides several advantages. These include that a scale with a neutral midpoint increases measurement reliability and provides a practical option for respondents who do not know, or do not have an opinion about a given statement (Weems and Onwuegbuzie, 2001). Without a middle position, respondents are forced to artificially create opinions (De Vaus, 1996). Finally, with a five-point rating scale, it is simpler for the respondents to read out all the scale descriptors compared with a seven-point rating scale, and respondents can respond accurately to a five-point rating scale.

In terms of a pilot study, two academics from the University of Hull Logistics Institute, five Ph.D. students from the University of Hull Business School, and three native speakers were involved in the pilot tests. A number of suggestions e.g. question design, the order and flow of the questions, the layout of the questions, and language from the pilot study were taken into account in order to redesign and improve the questionnaire. Hence, the questionnaire was carefully developed through all the design procedures so that the response rate, validity, and reliability of the questionnaire could be maximised.

- **Questionnaire Administration and Response Rate**

Saunders et al. (2007) mentioned that there are three ways of collecting data from a survey, and these include questionnaire, structured observation, and structured interviews. Nevertheless, Ghauri and Grønhaug (2002) emphasised that the questionnaire is considered to be the most popular data collection method through survey research in business and management. Regarding the method of administering questionnaires and the amount of available respondents contact, Saunders et al. (2007) have classified questionnaires into two main types including self-administered questionnaires (i.e. internet-mediated, postal, and delivery and collection questionnaires) and interview-administered questionnaires (i.e. telephone and structured interview questionnaires) as illustrated in Figure 3.3.

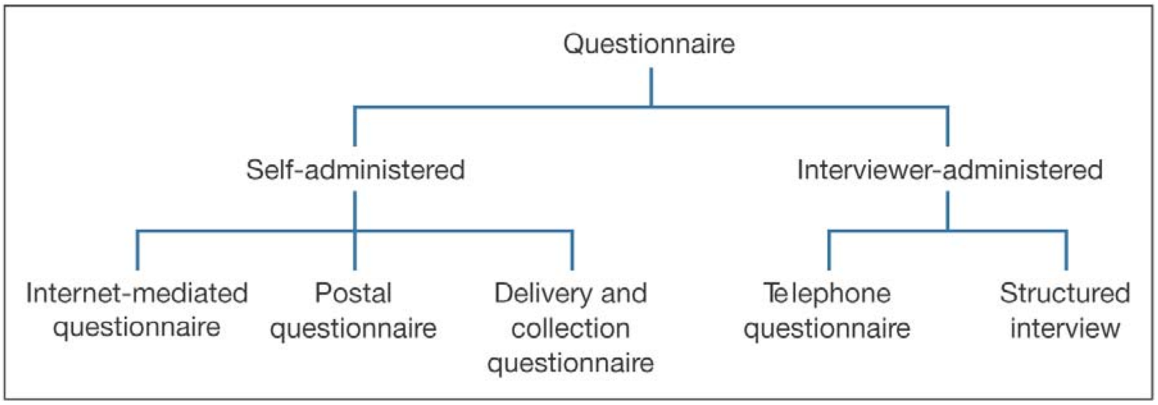

Figure 3.3: Types of Questionnaire (Saunders et al., 2007, p.357)

This research used a self-administered delivery and collection questionnaire, as the questionnaire administration method. Questionnaires are delivered by hand to each respondent and are collected later. Sekaran and Bougie (2010) stressed that this method has three major advantages as follows. Firstly, all the completed questionnaires can be collected within a short period of time. Secondly, a researcher can answer any questions from respondents on the spot and also can enhance respondent participation. Thirdly, it is less expensive and time-consuming than conducting interviews; also it requires less skill to administer a questionnaire than to carry out an interview.

At the end of October 2009, the questionnaires, with a cover letter, were delivered to 500 students and staff at the University of Hull. Importantly, all the respondents related to this research because nowadays students and staff at the University use and/or have their own mobile phone and computer.

For the students, the questionnaires were delivered at the cafeteria in the Student Union at lunch time, and took between five and ten minutes to complete. After that, the questionnaires were collected; it took three days to collect about four hundred copies of the questionnaire. For the members of staff, about one hundred copies of the questionnaire were delivered and those questionnaires were collected within four days. In terms of the response rate, out of the total number of 500 possible respondents, 80 were either not returned, or were returned uncompleted, or only partially-completed. The number of returned and usable questionnaires was, therefore, 420. Hence, the response rate of this study was 84.00%.

Data Analysis Technique for Survey

Three main statistics techniques have been used in this study i.e. descriptive statistics, one-way analysis of variance (ANOVA) technique, and factor analysis.

- **Descriptive Statistics**

Tabachnick and Fidell (2007, p.7) mentioned that "*descriptive statistics describe samples of subjects in terms of variables or combinations of variables.*" Descriptive statistics aim to reduce and summarise a large set of data to one or more single numbers (Saunders et al. 2007; Easterby-Smith et al., 2008). Kvanli et al. (2003) highlighted that descriptive statistics consist of four main measure types i.e. measures of central tendency, measures of dispersion, measures of position, and measures of shape. In this study, descriptive statistics are used in order to provide descriptive general information of respondent behaviours regarding the recycled mobile phone sector and the recycled computer sector.

- **One-Way Analysis of Variance (ANOVA)**

Pallant (2007) has pointed out that there are two major statistical techniques to access differences between groups. These statistical techniques are parametric and non- parametric techniques. Bryman and Cramer (2005), Pallant (2007) and Field (2009) mentioned that, when using the parametric tests, there are a number of key assumptions that must be satisfied and these assumptions are normally distributed data, homogeneity of variance, interval or ratio data, and independence of observations. On the other hand, non-parametric techniques do not make assumptions about the distribution of the data; as a result, these tests are sometimes known as distribution-free tests. Moreover, it has been suggested that non-parametric tests can be used with nominal and ordinal data (Pallant, 2007).

More importantly, non-parametric techniques are less powerful than parametric tests because non-parametric statistics may fail to detect differences between groups that actually exist (Pallant, 2007; Field, 2009). Consequently, parametric techniques were used to detect differences between groups in this study. In accordance with parametric techniques, Pallant (2007) and Burns and Burns (2008) mentioned there are two techniques are used to test for significant differences between groups, and these are analysis of variance (ANOVA) techniques and T-tests.

It is advised that ANOVA techniques are used when one compares two or more groups; by contrast, T-tests are used when comparing only two groups. More importantly, it is suggested that conducting multiple T-tests to compare all possible pairs of mean increases the probability of making a Type I error (Kvanli et al., 2003; Burns and Burns, 2008; Field, 2009). In other words; the ANOVA test provides inflated rates of Type I errors.

As a result, an ANOVA technique, specifically, a one-way ANOVA technique, was used to detect whether there was a difference between groups because this study has only one independent factor (i.e. strategy). There are three major assumptions of ANOVA (Kvanli et al., 2003; Burns and Burns, 2008; Field, 2009) and these are

- Normality. It is assumed that the samples from the populations perform a normal distribution.
- Homogeneity of variance. It is expected that all the normal populations have a similarity of variance.
- Independence of observations. It is suggested that the observations must be independent from each population.

- **Factor Analysis**

Hair et al. (2006, p. 104) defined Factor Analysis as ''*an interdependent technique whose primary purpose is to define the underlying structure among the variables in the analysis*." The Factor Analysis technique primarily aims to reduce a large number of observed variables to a smaller number of factors (Tabachnick and Fidell, 2007) and these factors are a highly correlated set of variables representing the underlying dimensions that account for the original set of observed variables. In this research work, Factor Analysis is employed in order to group and reduce a large number of variables (sub-strategies) into a smaller set of variables (a strategy).

Exploratory Factor Analysis (EFA) versus Confirmatory Factor Analysis (CFA)

Pallant (2007) stressed that Factor Analysis can be classified into two main techniques in the literature. These are Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). Tabachnick and Fidell (2007) have pointed out that EFA aims to describe and summarise by grouping highly correlated variables together. Hair et al. (2006) also said that EFA is a highly powerful technique that is used to group correlated variables in order to reduce a number of variables and introduce a new factor that represents each group of variables. The researcher often uses EFA in the early stages of research in order to consolidate variables and generate hypotheses about the underlying process.

By contrast, Pallant (2007) argues that CFA is a much more complex and sophisticated technique and the researcher often uses it in the advanced stages of the research process in order to test hypotheses or theories regarding the structure underlying a set of variables. Moreover, a researcher often uses CFA for structural equation modelling (Tabachnick and Fidell, 2007). Hence, Exploratory Factor Analysis (EFA) is selected for use in this analysis because the purpose of this study is to reduce a number of variables and to create a new composite measurement that represents these variables.

Principle Component Analysis (PCA) versus Factor Analysis (FA)

Pallant (2007) stressed the term ‘factor analysis’ consists of two different techniques and these include the terms ‘principle component analysis (PCA)’ and ‘factor analysis (FA)’. The purpose of both is to produce a new and smaller set of variables from an original and large set of correlated variables. Hair et al. (2006) indicated that there are two main criteria to select one method over the other. These include the aims of the factor analysis and the amount of prior knowledge about the variance in the variables. In terms of the factor analysis objectives, PCA is most appropriate when the primary purpose is data reduction. On the other hand, FA aims to identify a set of latent dimensions or constructs the underlying structure of correlation among the original variables.

In accordance with the prior knowledge about the variance in the variables, PCA is most appropriate when specific and error variance are relatively small compared with proportion of the total variance. In contrast, it is suggested that FA is most suitable when the researcher knows little about the amount of specific and error variance, and there is a need to eliminate this variance.

Moreover, Tabachnick and Fidell (2007) also argued that the selection between PCA and FA depends on the fit between the models, the data sets, and the goals of the research. PCA represents better choice when there is a need for an empirical summary of the data set. On the other hand, FA is a preferable choice when there is a need for a theoretical solution uncontaminated by unique and error variability and the research is based on an underlying construct to produce scores on observed variables. Hence, principal component analysis (PCA) is selected for this data analysis because the main objective of this study is data reduction.

3.4.4 Nonlinear Programming Approach and Simulation Model

Quantitative models based on empirical data (i.e. mathematical and simulation models) are used to calculate optimal acquisition prices and optimal selling prices in this study. Craighead et al. (2007) stressed that there is a significant increase in the amount of logistics research that has been conducted with mathematical and simulation modelling. Quantitative models are underpinned by the positivism paradigm (Johnson and Duberley, 2000; Reiner, 2005) and these frequently use deduction as a research approach (Spens and Kovács, 2006).

Pidd (1998) identified four main types of models used in business and management studies. These are a scale model, a logical model, a mathematical model and a simulation model. In addition, Oakshott (1997) classified mathematical models into two major techniques: deterministic models (e.g. linear programming models, integer programming models, and nonlinear programming models) and stochastic models (e.g. queuing models and Markov chain). This researcher selected three techniques for candidates to answer the research questions: a nonlinear programming model, a stochastic model, and a simulation model. Advantages and disadvantages of each model are discussed as follows:

A nonlinear programming approach is a technique for solving optimisation (either maximisation or minimisation) problems where the objective function and a set of constraints are nonlinear (Hillier and Lieberman, 2005). Like other deterministic models, the advantage of this approach is that it is usually much simpler to solve and provides more stable optimal outputs than a stochastic model (Oakshott, 1997). On the other hand, its disadvantage is that "*most mathematical models cannot satisfactorily cope with dynamic or* *transient effects"* (Pidd, 1998, p.8). This implies that a non-linear programming approach cannot (efficiently) address uncertainty in the variables or parameters being measured (Oakshott, 1997).

A stochastic model or a probabilistic model can be defined as "*a model in which at least one uncontrollable input is uncertain and subject to variation"* (Anderson et al., 2005, p.20). Sengupta (1982) argued that the main advantage of a stochastic model is that it can provide optimal decision making under risk and uncertainty; whereas its disadvantages are unstable outputs due to random values of parameters and huge computational effort (Kolbin, 1977). In addition, it permits only certain distributions; hence it cannot deal with many types of problem (Pidd, 1998).

A simulation model is a model that uses a computer programme to simulate the operation of an entire process or system over a period of time and under several scenarios (Hillier and Lieberman, 2005). It is one of the most widely used quantitative models to support decision making in business and management research. Moreover, this model has been successfully applied in a wide range of application such as new product development, airline overbooking, inventory policy, traffic flow, and waiting lines (Anderson et al., 2005).

A simulation model has a number of advantages. For example, a simulation model can efficiently tackle risk and uncertainty (Greasley, 2004). It can also be used to study complex (real world) systems, and to answer 'what if?' type questions. It can be used in the design of new systems, and to provide people with a better understanding of a system (Oakshott, 1997). Its disadvantages are that data collection and simulation model development will use a significant amount of resources in terms of time and cost (Greasley, 2004); and simulation software packages are expensive (Oakshott, 1997).

This research represents an innovative approach for pricing decision making based on the revenue management impact of multiple recovery options operations and it can be seen that a nonlinear programming approach (a simpler mathematical model compared with a stochastic model, an unstable output and huge computational effort model) can be used to answer the main questions of this research work – "What are optimal acquisition prices of received mobile phones and optimal selling prices of reprocessed handsets?" and "What are optimal selling prices of reprocessed computers?" However, a nonlinear programming approach cannot (efficiently) deal with the element of uncertainty. Hence, a simulation model is also employed in order to deal with uncertainty and to address another principle research question based on the total profit, "What if the model's parameters changes?"

Selection of a Computer Software Package for a Nonlinear Programming Approach

There are a number of software packages that can calculate outputs of nonlinear programming model such as LINGO, MPL, CPLEX, GAMS and etc. Table 3.6 highlights key features of the optimisation modelling software. The LINGO software package is used in this research for the following reasons. Firstly, the software package can formulate linear, nonlinear and integer problems quickly in a highly readable form. Second, it is a powerful solver for a variety of mathematical models such as linear programming, nonlinear programming, quadratic programming, and integer programming. Finally, its solver performance is fast and robust as well as being cheap- only $25 for the student package (Lindo System, Inc., 2008).

Table 3.6: Key Features of the Optimisation Modelling Software (Maximal Software Inc., 2008; GAMS Development Corporation, 2011; IBM Corporation, 2011; Lindo System Inc., 2011)

	LINGO	MPL	CPLEX	GAMS
Model type	Linear, nonlinear, integer programming model, and etc.			
Problem size	Small-large (250-unrestricted constraints)	Large (2.1 billion constraints)	Very large and real-world	Very large and real-world
Language	Modelling language	Algebraic modelling language	C Programming language	Algebraic modelling language
Solver performance	Powerful	Robust and stable	Flexible and high	High
Cost of software ($)	25-1,195 * 195-4,995**	89.99	8,240	640* 3,200**

(* = Academic prices, ** = Commercial prices)

Selection of a Simulation Software Package

Greasley (2004) and Kelton et al. (2007) classified simulation software packages into three main categories as follows:

- General Purpose Languages including computer languages such as FORTRAN, C, C++. These packages are highly customizable and flexible; on the other hand, the disadvantage of general purpose languages is that development is time consuming.

- Simulation Languages including SIMAN, SIMSCRIPT, SLAM and GPSS. These software packages can build a simulation model much more quickly than using general purpose languages; their drawbacks are the cost of software purchasing and the time needed to learn the simulation language.

- Visual Interactive Modelling (VIM) Systems including ARENA, WITNESS, SIMUL8, and SIMFACTORY. These packages are indeed very easy to use, and reduce the need to code simulation model due to the use of graphic symbols or icons. A VIM system is the most appropriate simulation software package for most business application, although the cost of the software package can be high.

After comparing the advantages, disadvantages, and availability of simulation software packages, the SIMUL8 software package is used in this research. SIMUL8 is one of the most powerful simulation software packages and it is very easy to use (SIMUL8 Corporation, 2001).

3.4.5 Research Strategy Applied to Achieve Each Research Objective

Objective 1: to formulate a pricing model using a non-linear programming approach to determine optimal profit-maximising acquisition prices and selling prices based on the impact of the multiple recovery options

The mixed research methods, combining a case study and an empirical quantitative model, are employed as to achieve this objective. This research begins at level one collecting data from a top European case company in the mobile phone recycling business to portray how the business deals in practice with reverse logistics programmes in accordance with a multiple recovery options operation. Data collection methods applied to conduct this case company include structured interview with the CEO, documentation (e.g. a company report, company websites, presentation slides, etc.), and direct observation. Next, at level two, required data collected from the case company are employed to formulate a pricing model using a non-linear programming approach to determine optimal profit-maximising acquisition prices of received mobile phones and selling prices of recovered handsets. As mentioned in section 3.4.4, this study uses a nonlinear programming approach because it is a simpler mathematical model compared with a stochastic model and can be used to accomplish this objective

Objective 2: to formulate two pricing models by using a non-linear programming approach to determine optimal profit-maximising selling prices based on the impact of the multiple recovery options

The methodology employed to complete Objective 2 includes the use of the mixed research methods combining a case study, a questionnaire survey and an empirical quantitative model. This study consists of three main steps as follows: at phase one, required data is collected from a UK-based computer recycling company by the use of structured interview with the owner, documentation (e.g. a company magazine, company websites, internal document, etc.), and direct observation. The study of this case company aims to demonstrate how the industry copes in practice with reverse logistics programmes with regards to multiple recovery options operations.

At phase two, the results from the case company are used to develop the questionnaire survey. The outputs of this survey in accordance with behaviours and opinions of respondents regarding the recycled computer sector, are used in order to validate the main assumption of one of the proposed pricing models which is the dependent demand assumption.

At phase three, two pricing models are formulated by using the results from the case company, the results from the questionnaire survey, and a non-linear programming approach to determine optimal profit-maximising selling prices of reprocessed computers. As highlighted in section 3.4.4, it is decided to use a nonlinear programming approach because it is a simpler mathematical model compared with a stochastic model that can be employed to generate the outputs.

Objective 3: to extend the study of the pricing models by formulating two simulation models to deal with the element of uncertainty in terms of return quantity and reprocessing time. More precisely, these proposed simulation models aim to investigate the revenue management impact of multiple recovery option systems by carrying out "what-if" assessments.

To accomplish this research objective, this research work uses the mixed research methods combining a case study, a questionnaire survey and an empirical quantitative model as the research strategy. The research process consists of three main procedures as follows. This research begins at level one collecting data from UK-based case companies in the mobile phone recycling industry and the computer recycling industry to illustrate how these companies deal in practice with reverse logistics programmes. In particular, the issues relate to multiple recovery options systems.

Next, at level two, the outputs collected from these case companies are employed to develop the questionnaire survey. This survey aims to seek behaviours and opinions of respondents regarding the recycled mobile phone and the recycled computer sector.

Finally, at level three, required data collected from two sources including the results from two case companies in the UK and the results from the questionnaire survey are employed to formulate the simulation models and to carry out "what-if" assessments. As discussed in section 3.4.4, the simulation model is used in this study for three main reasons as follows:

First, a nonlinear programming approach cannot efficiently deal with the element of uncertainty. Second, a stochastic model can cope with a system under risk and uncertainty; however, it provides unstable outputs due to random values of parameters and huge computational effort. Third, a simulation model can efficiently tackle the element of risk and uncertainty. These simulation models deal with the element of uncertainty of return quantity and reprocessing time by assuming that a return rate performs an exponential distribution and reprocessing time represents a normal distribution.

3.5 Time Horizons

Time horizon is one of major issues that must be addressed in research design and specifically, researchers have to decide whether research will be cross-sectional or longitudinal (Saunders et al., 2007).

The cross-sectional or snapshot study refers to "*a methodology used to investigate variables or a group of subjects in different contexts over the same period of time*" (Collis and Hussey, 2009, p.77). The study will collect the data just once, perhaps over a period of days, weeks, or months, in order to find an answer to a research question (Sekaran and Bougie, 2010). Collis and Hussey (2009) highlighted that cross-sectional studies are often used to collect data from a large number of organisations or people and it is suitable to conduct these studies when there are both time and resource limitations. More importantly, the survey methods are frequently employed within the context of cross-sectional research (Bryman and Bell, 2007; Easterby-Smith et al., 2008). However, Saunders et al. (2007) argued that the cross-sectional design is sometimes conducted through many case studies based on interviews at a single point in time.

On the other hand, longitudinal study can be defined as a study of phenomena conducted over a long period of time (Remenyi et al. 1998). Blaikie (2000) stressed that this study is referred to as before-and-after design and aims to investigate the changes of a similar population or group over a substantial period of time. Moreover, it can be carried out within a positivism or an interpretivism methodology (Collis and Hussey, 2009). The main advantage of longitudinal research is that a number of points in time offer the capacity to study medium- to long-term trends and this type of research also allows the researcher to obtain useful insights into practices and policies (Remenyi et al. 1998).

However, conducting a longitudinal methodology is time-consuming and expensive (Collis and Hussey, 2009; Sekaran and Bougie, 2010). Hence, business and management researchers employ longitudinal design relatively less often (Bryman and Bell, 2007). This research is associated with a cross-sectional study due to the fact that all required data will be collected through a survey and structured interviews at one point in time.

3.6 Conclusion

This chapter presents the research methodology applied in this research work. A good and consistent research design amongst research philosophy, research approach, research strategy, a data collection and analysis method, and a time horizon are discussed. The research paradigm underpinning this study is between positivist and interpretivist; however, it is located closer to the former. This research is conducted based on both deductive and inductive reasoning; nevertheless, deduction is predominant in this study.

Mixed research methods or triangulation based on the multi-level model are employed as research strategy, data collection method, and data analysis method in order to achieve the research objectives. These selected research methods include case studies, a questionnaire survey, a nonlinear programming approach, and a simulation model. A cross-sectional study is employed as the time horizon in this study. The next chapter presents two case companies in the UK which have implemented multiple recovery options operations in their reverse logistics programmes. These companies are in the recycled mobile phone and the recycled computer sectors.

Chapter 4: Multiple Recovery Options: Illustrative Case Companies in the UK

4.1 Introduction

This chapter presents the current regulations related to the electrical and electronic equipment (EEE) recycling industry and illustrates two case companies which have implemented multiple recovery options operations. These case companies are used to develop a questionnaire survey presented in chapter 5, and are used to formulate the pricing models demonstrated in chapter 6 and the simulation models illustrated in chapter 7.

The remainder of this chapter is organised into four additional sections as follows: section 4.2 discusses two major pieces of legislation related to the electrical and electronic equipment (EEE) recycling business, including the Waste Electrical and Electronic Equipment (WEEE) Directive and the Restriction of Hazardous Substances (RoHS) Directive; section 4.3 presents the case of company A, the mobile phone recycling business; section 4.4 illustrates the case of company B, the computer recycling business; and section 4.5 provides the chapter conclusion.

4.2 Legislations: the WEEE Directive and the RoHS Directive

As a result of the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive, several electrical and electronic equipment (EEE) recycling firms took the opportunity to make a profit from recovering EEE by collecting, reprocessing, reselling, and redistributing end-of-life EEE to markets. However, when the companies place the recovered EEE onto the market, they have to comply with the Restriction of Hazardous Substances (RoHS) Directive. These regulations are presented as follows:

4.2.1 The Waste Electrical and Electronic Equipment (WEEE) Directive

NetRegs (2009a) has mentioned that electrical and electronic waste is one of the most enormous types of waste in the UK because it has been found that approximately 1.8 million tonnes of the waste are produced every year. More importantly, much of this waste contains hazardous substances such as polychlorinated biphenyls (PCBs), ozone depleting substances (ODS) (e.g. fridges and freezers), asbestos, cadmium, lead, and cathode ray tubes (e.g. televisions and computer CRT monitors).

As a result, the Government has paid more attention to electrical and electronic waste, and has also implemented the WEEE Directive that came into force in January 2007. The WEEE directive aims to reduce the amount of this waste being produced by donating or selling EEE in working condition, to be reused, to encourage reuse, recycle, and recover it, and to improve the environmental performance of businesses that manufacture, supply, use, recycle and recover electrical and electronic equipment (The Environment Agency, 2009).

Businesses Affected by the WEEE Directive

Several forward and reverse logistics actors have to comply with the WEEE Regulations such as EEE manufacturers, importers, distributors, retailers, WEEE generators, and collectors who collect waste from customers for treatment or disposal, operators of waste treatment facilities, reprocessors (who repair, refurbish, recycle, dismantle, and/or dispose of WEEE), and WEEE exporters (NetRegs, 2009a). In particular, the companies participating in this study are a mobile phone recycling business considered a WEEE reprocessor and exporter, and a computer recycling business considered a WEEE reprocessor.

In terms of the repairing, refurbishing and reselling WEEE business, a company must apply for an environmental permit (England and Wales), pollution prevention and control (PPC) permit, a waste management licence (Northern Ireland and Scotland) or an exemption from an environmental regulator. The firms' premises are inspected by an environmental regulator subject to certain restrictions. The recycling business has to pay a fee for registration and needs to renew its registration every year, which will include a reduced renewal fee. In addition, the firm must be an authorised treatment facility (ATF) or approved authorised treatment facility (AATF). More importantly, the recycling business has to recover WEEE according to the guidance on best available treatment, recovery and recycling techniques (BATRRT).

With regard to a WEEE exporter, a firm must export only safely recovered or recycled WEEE to the receiving country. Alternatively, when exporting WEEE for treatment or reprocessing the company must ensure that the overseas facility processes to standards similar to an ATF or AATF, and in accordance with any permit needed in that country. Furthermore, the exporter has to comply with legislation on the shipment of waste both in the UK and in the destination country.

WEEE Classification

There are two principle classification schemes for electronic and electrical equipment (EEE) as follows:

- **Type of Product Classification**

The Environment Agency (2009) highlighted that the WEEE Directive classifies electronic and electrical equipment (EEE) with a voltage of up to 1000 volts for alternating current, or up to 1500 volts for direct current, into 10 main categories as follows:

- Large household appliances (Category 1)
- Small household appliances (Category 2)
- IT and Telecommunications equipment (Category 3)
- Consumer equipment (Category 4)
- Lighting equipment (Category 5)
- Electrical and electronic tools (Category 6)
- Toys, leisure and sports equipment (Category 7)
- Medical devices (Category 8)
- Monitoring and control instruments (Category 9), and
- Automatic dispensers (Category 10)

Specifically, products included in WEEE category 3: IT and Telecommunications equipment, are personal computers (CPU, mouse, screen and keyboard), laptop computers (CPU, mouse, screen and keyboard), printers, copying equipment, facsimile, telephones, cordless telephones, cellular telephones, and so on. Therefore, the products (mobile phones and personal computers) of the firms participating in this study fall under Category 3: IT and Telecommunications equipment.

- **'Historic' and 'Future' WEEE**

NetRegs (2009a) argued that the WEEE Directive also divides WEEE products into two main classes depending on when they were placed onto the UK market as follows:

- 'Historic WEEE' is defined as a WEEE product placed onto the market before 13th August 2005. A 'Historic WEEE' owner has to pay for disposal when discarding EEE unless he replaces it with equivalent EEE bought from the same store. This is called 'in-store take-back scheme'.
- 'Future WEEE' is defined as a WEEE product placed onto the market after 13th August 2005. A 'Future WEEE' owner can dispose of it at designated collection facilities (DCFs) free of charge. This is called 'distributor take-back scheme'.

4.2.2 The Restriction of Hazardous Substances (RoHS) Directive

NetRegs (2009b) mentioned that a tremendous amount of WEEE has been produced due to the rapid growth of new EEE technology. More importantly, much of WEEE comprises harmful substances that damage human health and the environment, and it is difficult to recycle or dispose of this waste. As a result, the UK Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive came into force on 1st February 2008. The present regulations replace the previous RoHS regulations that came into force on 1st July 2006 (Department for Business Innovation & Skills, 2009).

NetRegs (2009b) argued that the Directive aims to limit the amount of hazardous substances including lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyl (PBB), and polybrominated diphenyl ether (PBDE) that can be used in new EEE placed on the market anywhere in the European Union (EU). The maximum concentration value for lead, mercury, hexavalent chromium, PBB, and PBDE is 0.1% or 1000ppm by weight of homogeneous material, and for cadmium is 0.01% or 100 ppm by weight of homogeneous material. In terms of actors affected by the RoHS Directive, there are three major businesses including EEE manufacturers or importers, EEE exporters who ship it to other EU member states, Norway, Liechtenstein or Iceland, and EEE businesses who rebrand other manufacturers' EEE as their own.

According to EEE covered by the RoHS Directive, Department for Business Innovation & Skills (2009) mentioned that the RoHS regulations cover eight of the ten categories of the WEEE Directive which have a voltage of up to 1000 volts for alternating current, or 1500 volts for direct current. The regulations do not include the two categories of the WEEE

Directive that are medical devices (Category 8) and monitoring and control instruments (Category 9). The RoHS regulations apply specifically to the reuse of EEE that has been placed on the EU market since 1st July 2006. Therefore the recycling industries participating in this study have to comply with these regulations.

4.3 Company A: Mobile Phone Recycling Business

The mobile phone recycling business which has implemented a market-driven system has become an important industry for two main reasons: an economic aspect, and an environmental aspect, as follows:

Firstly, in terms of the economic aspect, there are about 80 million unused mobile phones left in the drawers of homes throughout the UK every year, due to upgrade offers made by mobile network providers. Several online mobile phone recycling companies have taken the opportunity to make a profit from the unwanted phones by offering owners as much as £150 for the handsets. The phones can be sold via a website by entering the model of the phone; the website then shows what price companies are willing to pay for it. After that, the phone recycling operators will provide a freepost envelope for the owners to use to post the phones to them. Companies will pay cash for the handsets based on their model and quality, after a grading, sorting, and testing procedure (Simpson, 2009).

Secondly, in relation to the environmental aspect, the recycling of mobile phones is crucial due to the fact that end-of-life mobile phones are currently considered as one of the world's largest contributors to waste electrical and electronic equipment, particularly handsets and their accessories, such as the battery, which is the most hazardous part, which contain ten of the most harmful substances, i.e. cadmium, rhodium, palladium, beryllium, lead, nickel, mercury, manganese, lithium, zinc, arsenic, and copper. Inappropriate disposal of unwanted mobile phones can damage the environment as there is the risk of these toxic substances leaking into the surrounding environment. It is therefore very important that professional mobile phone recycling companies recover and dispose of these mobile phones in an appropriate and environmentally-friendly way (Corporate Mobile Recycling Ltd, 2007).

Company A participating in this study was founded in England in 2001 by a group of experienced professionals. Since the beginning of 2002 the firm has become one of the top European mobile phone recycling corporations and has expanded its operations from the UK into Continental Europe. In addition, the firm has been assessed against over 20 widely-accepted standards, bodies and guidelines relevant to sustainable development, such as the UN Global Compact, ISO 14001, EEG (European Renewable Energy Law), European Emissions Trading Scheme (ETS), European Waste Electrical and Electronic Equipment Directive (WEEE Directive), Restriction of Hazardous Substances Directive (RoHS Directive) etc. It has cooperation agreements with leading national and international partners, and was initially set up to make a profit from recovered mobile phones affected by the European Waste Electrical and Electronic Equipment (WEEE) Directive.

Currently the firm has two main offices, one located in London, UK and the other located in Munich, Germany, with the two sites employing less than 100 workers. The firm provides a wide range of products and services to customers, such as recovered mobile phones, a WEEE recycling service, stock procurement management for new mobile phones or 14-day warranty mobile phones, an environmental consulting service, and a data management system service. However the primary concern of the firm is still the recovered end-of-life mobile phones.

Currently, Company A recovers more than one million mobile phones, comprising between 3,000 to 5,000 phone models each year. The firm recovered about 1.4 million end-of-use and end-of-life mobile phones in 2008, with the forecast number of expected reprocessed mobile phones in 2009 being in the order of 2.2 million as the company was about to sign new contracts with new business partners with the expectation of getting more phones from online suppliers. The remainder of this subsection is as follows: unwanted mobile phone recovery process, suppliers, collection procedure, grading, sorting, and testing procedure and marketing issues.

4.3.1 Unwanted Mobile Phone Recovery Process

The end-of-use mobile phone recovery process of Company A consists of four main procedures, the same as the normal reverse logistics process proposed by Thierry et al. (1995), Rogers and Tibben-Lembke (1999), and De Brito and Dekker, (2004). The process is as follows: firstly, the company collects old mobile phones from its suppliers. Next, the mobile phones are graded, sorted, and tested, and the firm then classifies them in terms of their quality and technology (or age). Next come the multiple recovery options operations. The firm sends the phones for direct recovery (direct resale) or process recovery (repair, refurbishment, recycling and disposal) depending on the quality of the items. Finally, the firm redistributes and resells the reusable handsets to a secondary market and then sells the non-reusable cell phones to recyclers. Figure 4.1 demonstrates the recovery process of Company A.

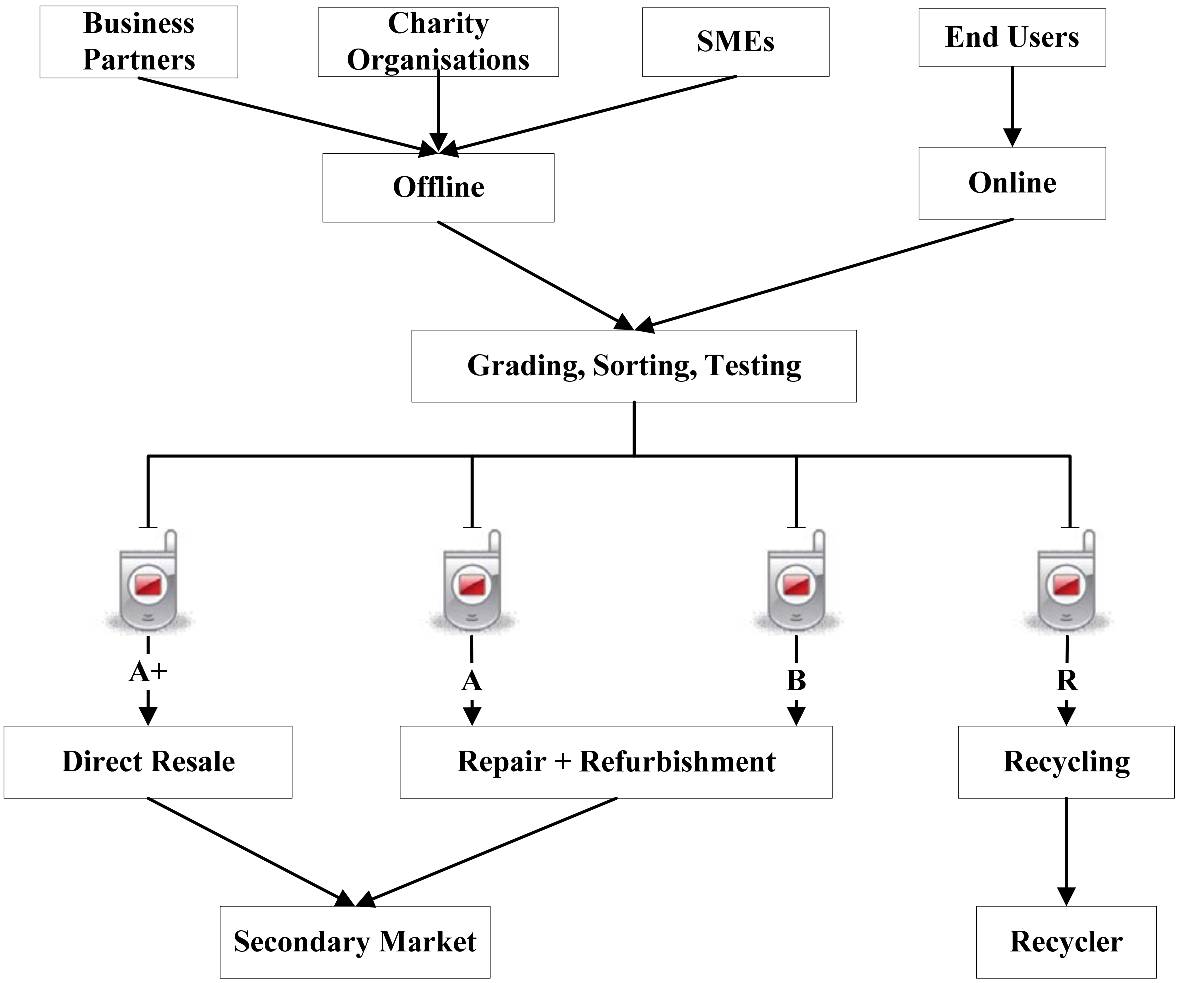

Figure 4.1: The Recovery Process of Company A

The phones contain precious metals such as gold, silver, platinum and copper; therefore the recyclers extract these precious metals from the non-reusable cell phones by way of a recycling and extracting process. After that, they resell the metals to a market. However the company operates these reverse logistics activities either in-house and/or by utilising a third party by distributing most of the tested and recoverable handsets to a repair and refurbishment operator in Hong Kong. Table 4.1 shows the reverse logistics activities of Company A operated by the firm or a third party.

Table 4.1: The Reverse Logistics Activities of Company A Operated by the Firm or a Third Party

Activities	In-House	Third Party
1. Collection of old mobile phones	-	100%
2. Sorting, Grading, and Testing	100%	-
3. Direct Resale	100%	-
4. Repair	10%	90%
5. Refurbishment	10%	90%
6. Recycling	-	100%
7. Disposal	-	100%
8. Transportation of recovery items	-	100%

4.3.2 Suppliers

Company A collects unused mobile phones from a variety of suppliers and from several countries throughout Europe. For example, the UK office collects the phones from the UK, Ireland, Portugal, Iceland, Norway, the Netherlands, Belgium and Spain. The Germany office collects handsets from Germany, Austria, Croatia, Bosnia Herzegovina and the Republic of Serbia. With regard to the supplier classification, the company categorises its suppliers into two main groups: the offline suppliers (i.e. business partners, charity partners, and small and medium enterprises) and the online suppliers (end users).

The firm's primary supplier since 2001 has been the business partners. However, the firm has changed their procurement policy so that currently it is paying more attention to small and medium enterprises and the online suppliers (end users), because they are potential sources of used mobile phones, particularly the online suppliers (end users). Figures 4.2 and 4.3 show the percentage of the number of old mobile phones received from each supplier in 2008 and 2009 respectively. Next, the offline suppliers and the online suppliers will be highlighted in more detail.

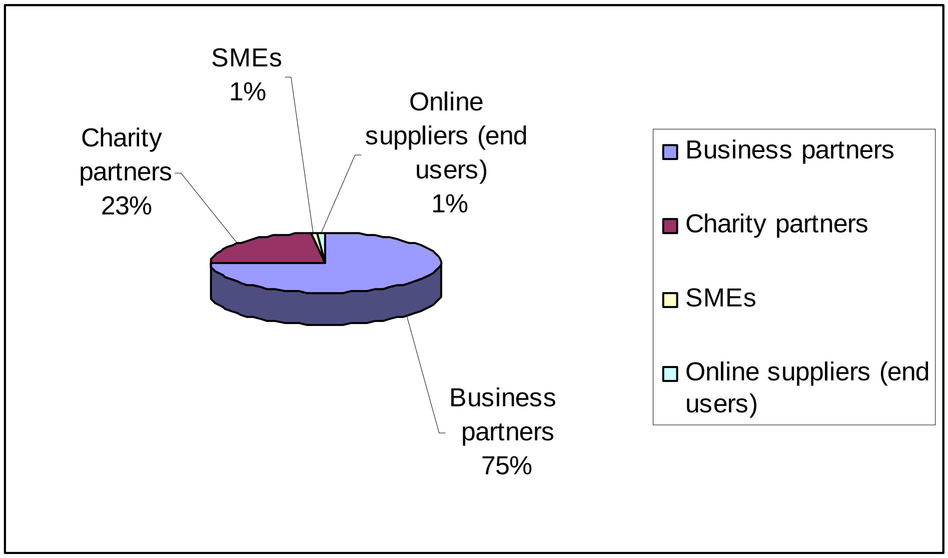

Figure 4.2: Percentage of Old Mobile Phones Received from Each Supplier in 2008

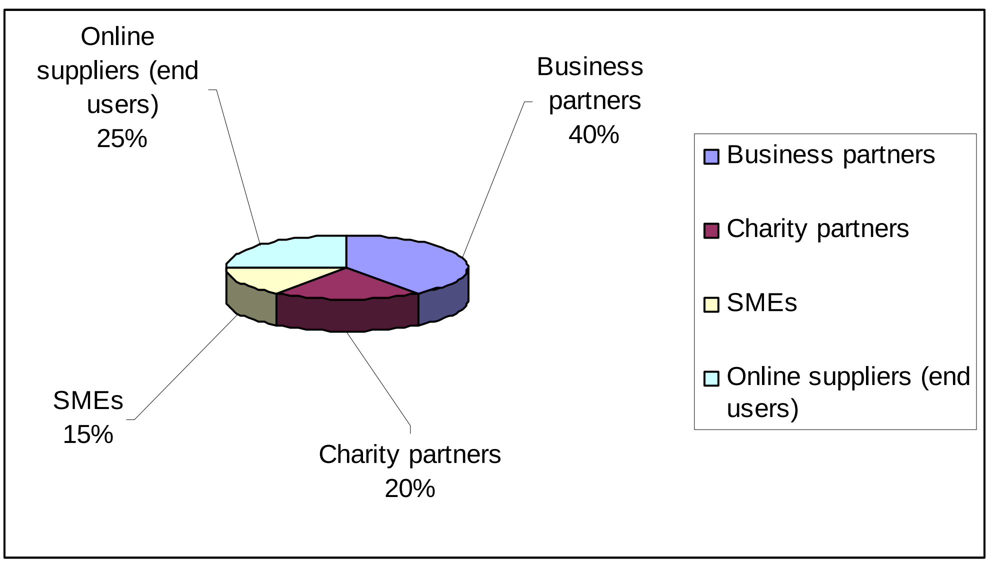

Figure 4.3: Percentage of Old Mobile Phones Received from Each Supplier in 2009

The Offline Suppliers

Company A has divided the offline suppliers into three main types i.e. business partners, charity partners, and small and medium enterprises, as follows:

- **Business Partners**

The corporation has established cooperation agreements with several business partners in Europe i.e. several big retail supermarkets and a number of mobile phone network providers. The offline suppliers subcontract the firm for the mobile phone recovery process, and they receive some incentives from the company. The offline suppliers or their customers send unwanted handsets to the mobile recycling company.

A good example of a big retail supermarket is one of the biggest of its kind in the UK. It has introduced an online mobile recycling programme in order to build its green image, to set up corporate responsibility, to support its royalty scheme and to make some profit from the programme. The retail supermarket's mobile customers and other networks' customers can trade their old mobile phones via the supermarket's mobile recycle website. After that, the supermarket sends a freepost envelope to customers who then post the phone to the mobile recycling company. If the old mobile phone is functional, the customers can earn rewards of up to £70 through either mobile airtime, or a gift card. Moreover, the customers can also receive 200 Clubcard points, or choose to donate £2 to the retail supermarket's charity.

A good illustration of a mobile phone network provider is one of the leading mobile phone network providers in the UK. The company has started a programme of trading-in old mobile phones for recycling in order to create a royalty brand scheme and to construct social responsibility. The mobile phone network provider's customers or other networks' customers can trade in used mobile phones via the company's trade-in website. The rest of the process is the same as in the case of the retail supermarket; however, if the phone is in working condition, the network provider gives the customer rewards of up to £100 in free network provider airtime, or donation of 25%, 50%, 75% or 100% of the customer’s phone's value to charity. Even if the phone is not working any more, the mobile phone network provider will donate £5 to charity on the customer's behalf.

- **Charity Partners**

Company A has cooperation agreements with over 220 communities, civil societies and charities in the UK, Germany and Austria, such as the British Heart Foundation, Christian Aid UK, the National Blind Children's Society, Misshandlung von Jugendlichen, HELP eV Bonn, SOS-Kinderdorf and others. These organisations have set up a mobile phone recycling programme to raise money for their organisations and also to protect the environment at the same time. Moreover, the firm has paid more than £10 million to these charity partners since 2001 when the company was formed. Normally, the company sends a courier to collect used mobile phones from a charity branch; otherwise, old mobile phones can be posted to the recycler by the charity's freepost recycling envelope. After that, the firm will pay cash and kind donations to the charity.

- **Small and Medium Enterprises (SMEs)**

Company A also purchases used mobile phones from small and medium enterprises that have at least 12 mobile phones to trade in. The SMEs can make a phone call or send an email to the mobile phone recycling business to receive offered prices and to arrange the courier collection. The firm offers various benefits to the SMEs, such as highly competitive quotations, free courier collections, prompt payment to their account and a free electronic environmental report to meet the WEEE Directive.

The Online Suppliers (End Users)

Company A started its online mobile phone trade-in programme in 2008 by creating its own website. This was due to the fact that online marketing is a huge potential source of old mobile phones. The company bought about 140,000 phones from end users via the website in 2008, and the forecast number of expected trade-in phones is about 500,000 phones in 2009.

The trade-in procedure for old mobile phones via the website is as follows: firstly, a mobile phone owner checks his/her old mobile phone model and its offered price from the website. The website provides a list of mobile phone models consisting of over 300 mobile phone models. Next, if the end user agrees with the quotation, he/she will fill in the online form to sell his mobile phone. Then, the company will send him/her a freepost pre-addressed padded envelope. After that, the end user puts his/her mobile phone in the envelope and sends it back to the firm. The postal return service takes between one to three days to arrive at the company address.

The firm then sends a confirmation email when they have received the phone. Next, the mobile phone is tested to check whether it is in working condition and to see if it has been stolen. If the phone is functional, the firm will pay the end user money as per the offered price. If it is non-functional, the company will pay about 40% of the value of the same working model. All end users receive payment within 22 days of receipt of phone(s) and the money is transferred directly into a bank account, the details of which were provided by the end user when registering the phone online.

4.3.3 Collection Procedure

Company A employs five collection schemes to collect used mobile phones from its suppliers, depending on collection cost, type of supplier, or the country as follows: the first collection method is that end users send old mobile phones directly to the company via the freepost envelope as shown in Figure 4.4.

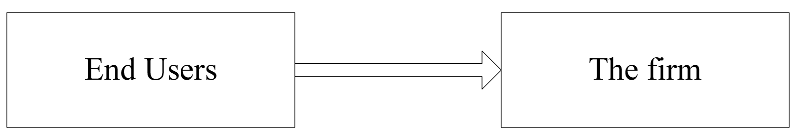

Figure 4.4: Collection Approach I of Company A

The second scheme is that end users post old mobile phones to a central collection point, after which a courier collects and delivers the phones to the company as illustrated in Figure 4.5.

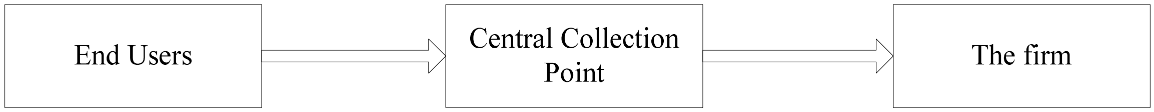

Figure 4.5: Collection Approach II of Company A

The third approach is that end users post old mobile phones to business or charity partners and then the firm arranges a courier to collect the phones from the partners as demonstrated in Figure 4.6

Figure 4.6: Collection Approach III of Company A

The fourth policy is that end users drop off old mobile phones at business or charity partners; otherwise, they sell the phones to SMEs. Next, the business arranges a courier to collect the phones from the partners or the SMEs as demonstrated in Figure 4.7.

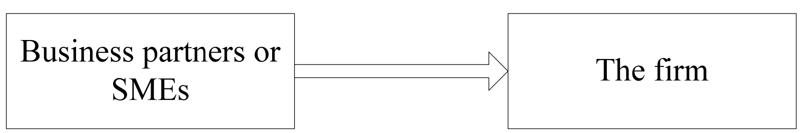

Figure 4.7: Collection Approach IV of Company A

The fifth strategy is that the firm arranges a courier, named courier I to collect used mobile phones from business partners, and then courier I delivers the phones to a central collection point. After that, an amount of the used mobile phones is shipped to the company in the UK by a courier, named courier II as shown in Figure 4.8. This approach is applied for the old mobile phones collected from Norway, because Norway is not one of the European Union countries. The company has to pay a charge per shipment when it imports electrical and electronic equipment from outside the European Union.

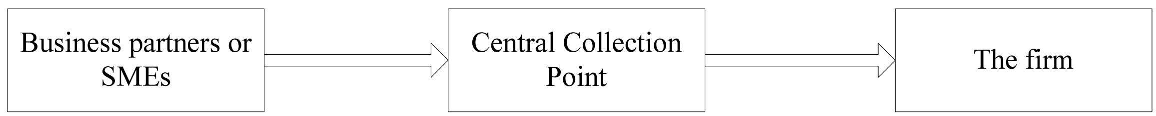

Figure 4.8: Collection Approach V of Company A

4.3.4 Grading, Sorting and Testing Procedure

The procedure for received mobile phones including grading, sorting and testing is as follows: firstly, a worker enters customers' reference numbers into the firm's database system. Next, the worker checks each mobile phone's IMEI (Unique reference number) by using a scanner in order to trace whether the mobile phone has been stolen, and to check whether the handset's model matches with the trade-in model. If a stolen mobile has been sent in, the system raises the alarm and the firm sends a report to the police for further investigation.

After that, the received handsets are graded, sorted and tested by a technician. In terms of technology (or average age of the handsets) and quality, the phones are classified into three main technology classes (or average age of the handsets): high end (1-2 years old), mid range (2-4 years old), and low end (more than 4 years old) and into four main quality classes: A+, A, B, R. In addition, the company also defines a functional phone as a mobile phone having turn on, a clear working LCD screen and no water damage, and defines a non-functional phone as a mobile phone that will no longer switch on, the LCD screen is broken or cracked, or has suffered water damage. The description of the mobile phone technology classes and quality (or an average age of the handsets) is shown in Table 4.2 and Table 4.3 respectively.

Table 4.2: Description of the Mobile Phone Technology (or Average Age of the Handsets) Classes (Kelkoo, 2009)

Technology (or age) Class	Definition
High end (1-2 years old)	Smart phones include operating systems like Symbian to turn a phone into something closer to a laptop computer and full mobile internet access to reach your e-mail, video phone calls, and video services like TV and sporting clips (ex. Sony Ericsson X1, Nokia N95, and Apple iPhone)
Mid range (2-4 years old)	Mobile phones include digital cameras, video recorder, full-colour screens, multimedia messaging, built-in radios and/or MP3 players. (ex. Sony Ericsson W980i, Nokia N78, and Samsung SGH U900 Soul)
Low end (4 + years old)	The simplest phone can be used to make calls, access voicemail, send text messages and other simple functions (ex. Sony Ericsson T250i, Samsung SGH J700, and Nokia 6300)

Table 4.3: Description of Each Mobile Phone Quality Classes

Quality Class	Description
A+	A functional phone can be direct resold to a secondary market without a need of process recovery
A	A non-functional phone needs to be repaired
B	A non-functional phone needs to be refurbished.
R	A non-functional phone is beyond an economic process recovery and it will be sold to a third-party recycler.

Figure 4.9 displays the percentage of the number of received mobile phones classified in terms of their technology (or average age) in 2008; Figure 4.10 shows the percentage of the number of received mobile phones classified in terms of their quality in 2008; and Figure 4.11 represents the expected percentage of the number of received mobile phones classified in terms of their quality in 2009.

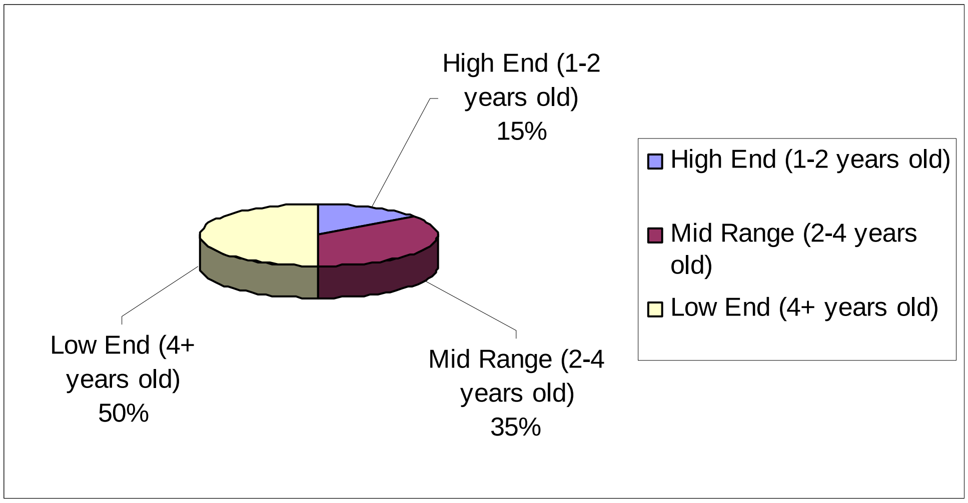

Figure 4.9: Percentage of Received Mobile Phones Classified in Terms of Technology (or Average Age) in 2008

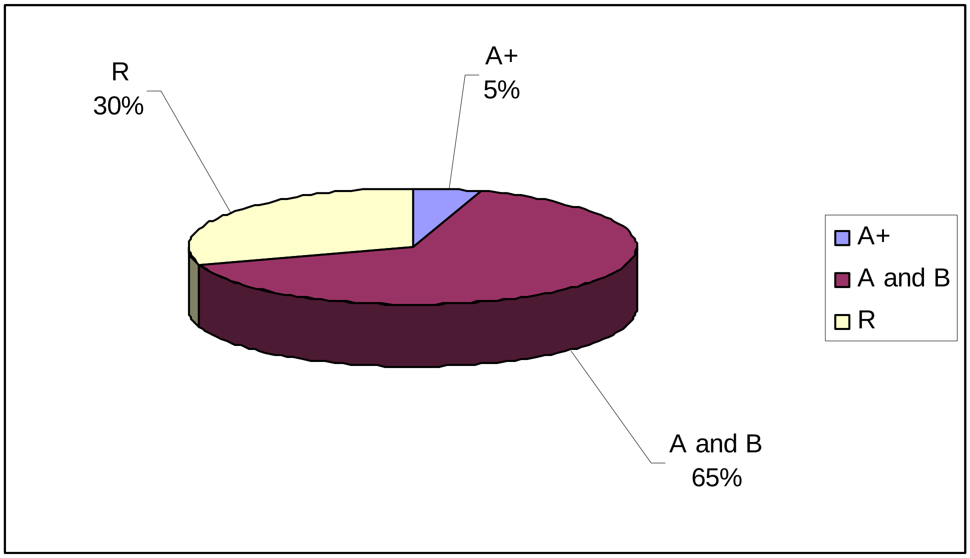

Figure 4.10: Percentage of Received Mobile Phones Classified in Terms of Their Quality in 2008

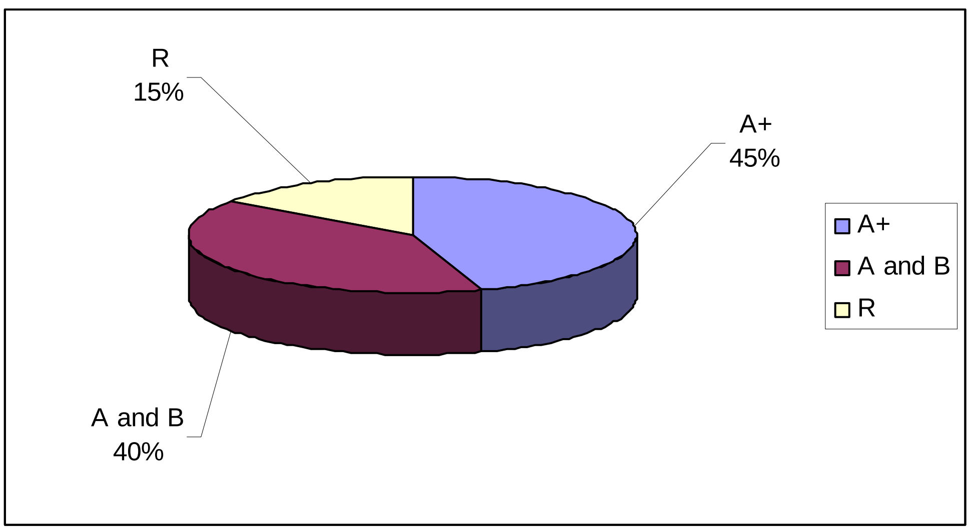

Figure 4.11: Expected Percentage of Received Mobile Phones Classified in Terms of Their Quality in 2009

4.3.5 Market Issues

After the recovery process, Company A ships the recovered mobile phones to secondary markets fortnightly because acquisition prices of old mobile phones and selling prices of recovered mobile phones fluctuate considerably. The major secondary market of the firm is represented by undeveloped countries, especially in Asia, Africa, and Eastern Europe, since people in these countries cannot afford new technology mobile phones. The main markets in Asia are China, the United Arab Emirates, Thailand, Vietnam, Sri Lanka, the Islamic Republic of Pakistan and Bangladesh, whilst the main markets in Africa are Kenya, Nigeria and the People's Democratic Republic of Algeria. Figure 4.12 shows the percentage of the number of recovered mobile phones sent to each continental secondary market.

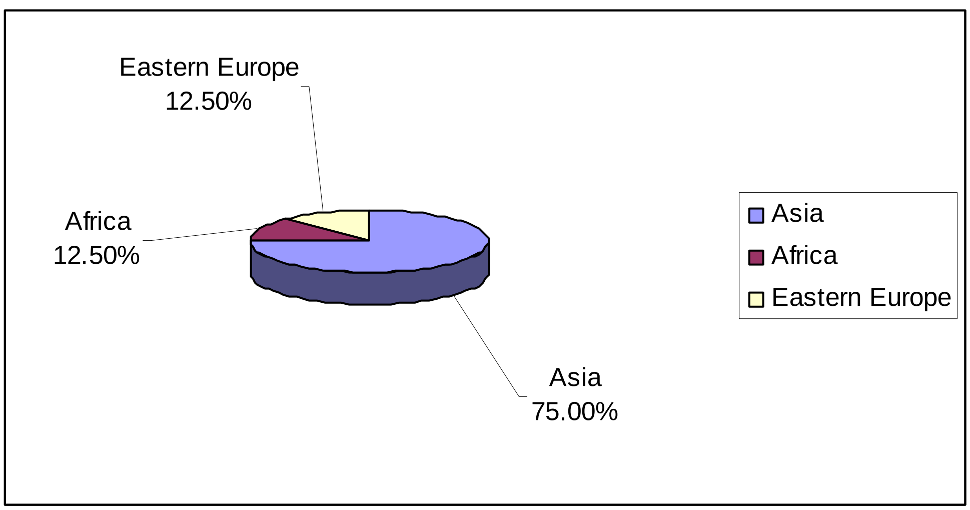

Figure 4.12: Percentage of Recovered Mobile Phones Sent to Each Continental Secondary Market

Company A has also attempted to open new secondary markets, namely India and Russia, because these countries have a tremendous number of inhabitants. In 2010, the estimated total population in India is about 1,173 million people, the second largest population in the world. The estimated total population in Russia is about 139 million people, the ninth largest population in the world (Central Intelligence Agency, 2010). Currently, however, the company is facing some difficulties in these markets due to federal regulations and political problems.

In terms of income, the main revenue of the company is from the repaired and refurbished mobile phones of the high-end and mid-range classes. With regard to the company's competitors, the firm classifies its main rivals into two main groups including offline businesses such as Regenesis plc, SHP Solutions, Recellular Inc., and Redeem plc, and online businesses such as Mazuma Mobile Limited and Envirofone.com.

4.4 Company B: Computer Recycling Business

In accordance with EU directives, the UK Government implemented the WEEE Directives in January 2007, and an old computer is also a type of waste electrical and electronic equipment. For example, CRT monitors contain 4lb of lead in the screen to protect users from radiation, and the base units contain a battery which makes them hazardous, so people cannot put redundant computers in their bin. There are several computer recycling companies providing this service to local communities, either free or for a small charge, for the sustainable recovery of old computers as illustrated in this study.

Company B participating in this study is a seven-year-old business located in a small village in West Yorkshire, UK. It is a small enterprise carrying out running repairs to, and refurbishment and recycling of, used computers. The firm has implemented a waste stream system. The owner decided to run the business for two main reasons: firstly, he had expertise in the area of computer repair and refurbishment, and he also taught computer repair and refurbishment in a college for ten years. Secondly, the owner wanted to create employment opportunities for people in his local area, and to bring social and economic regeneration to his community by retraining long-term unemployed people and training volunteers and high school students. People from those groups work alongside technicians preparing computers for resale in the computer workshop and dismantling computers and sorting the components in the recycling warehouse.

Since the company was established the business has achieved profitability and social responsibility. For example, the estimated turnover of the company was more than 0.25 million pounds during the most recent year, even though the firm is only a small business in a small town. Moreover, the company has also won several awards for its service to the community and for its relentless work in keeping hazardous waste out of landfills over the last seven years, such as the Award for Excellence in Recycling 2008, West Yorkshire Environmental Business Awards 2007 (Social Enterprise Category), District Business Awards 2006 (Business and the Environment), etc.

Furthermore, the company has also achieved several credentials, including as a Microsoft Authorised Refurbisher, ICER (Industry Council for Electronics Recycling) accreditation, member of the WEEE Recycling Network, member of the Regional Electronics Initiative (REI) in Yorkshire and the Humber, member of the Community Recycling Network (CRN-

UK), member of the Best Practice Network, member of the Chartered Institute of Water and Environmental Management (CIWEM), Waste Carriers, Transporters, Dealers & Brokers Exemption, Paragraph 40 waste management exemption, and Brigantia registered computer experts.

Currently, the company employs eight workers comprising four technicians, two general repair staff, and two warehouse staff who sanitise hard drives, cannibalise old computers and collect old computers in the local area. The firm provides a wide range of products and services to customers, such as brand new and refurbished computers, computer accessories and components, and computer repair and recycling services. However, the main profit sources of the company are from brand new and refurbished computers. The remainder of this subsection is as follows: end-of-use and end-of-life computer recovery process, suppliers, the collection procedure, the grading, sorting and testing procedure, recovery operations and marketing issues.

4.4.1 End-of-use and End-of-life Computer Recovery Process

The old computer recycling process of the firm consists of four main procedures, the same as the normal reverse logistics process proposed by Thierry et al. (1995), Rogers and Tibben-Lembke (1999) and De Brito and Dekker, (2004), as follows: first, the company collects used computers from its suppliers. Next, the computers are graded, sorted and tested, and the firm classifies them in terms of their quality and age. Next, there are multiple recovery options operations. The firm sends them for direct recovery (direct resale) or process recovery (repair, refurbishment, cannibalisation, recycling and disposal) depending on the items' quality. Finally, the firm redistributes and resells them to a market.

Nearly all of these reverse logistics activities are operated in-house. Figure 4.13 demonstrates the recovery process of the firm and Table 4.4 shows the reverse logistics activities operated by the firm or a third party.

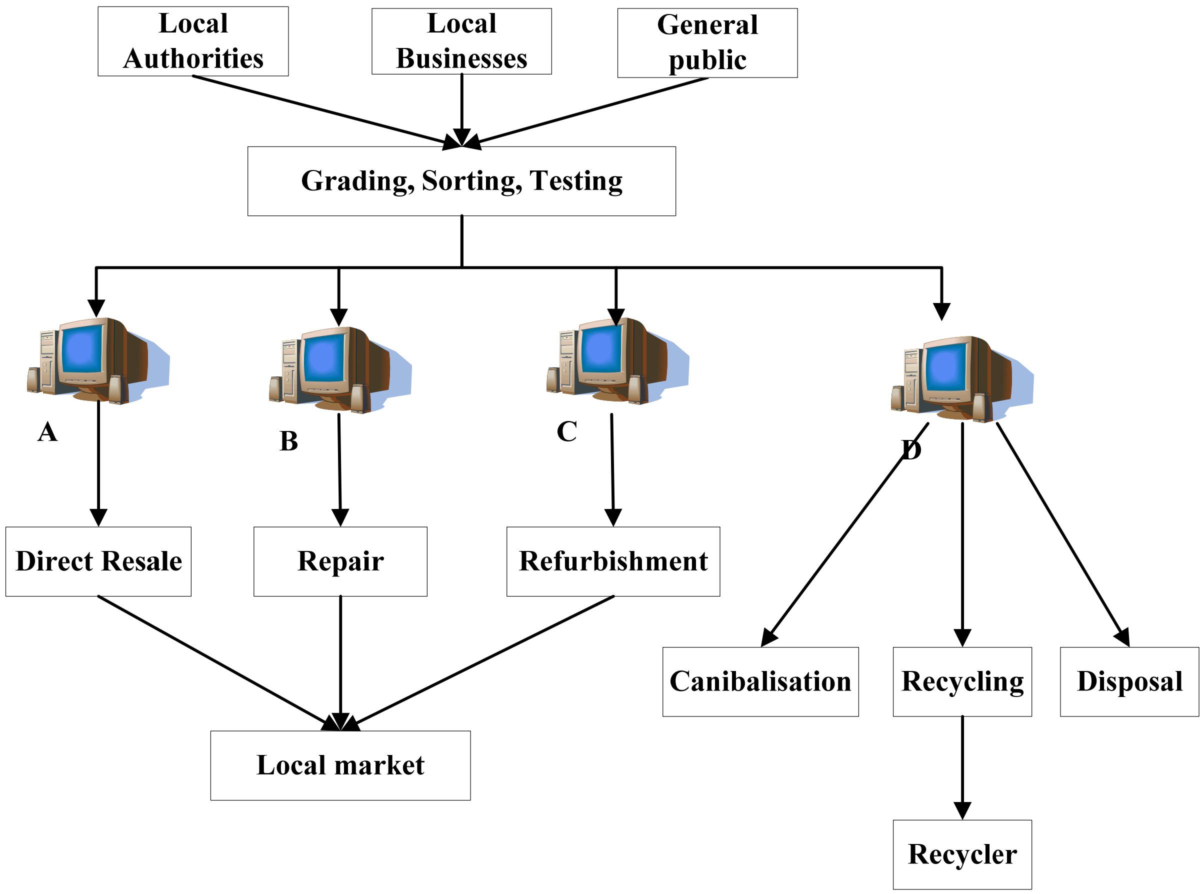

Figure 4.13: The Recovery Process of Company B

Table 4.4: The Reverse Logistics Activities of Company B Operated by the Firm or a Third Party

Activities	In-House	Third Party
1. Collection of old computers	x	
2. Sorting, Grading and Testing	x	
3. Direct Resale	x	
4. Repair	x	
5. Refurbishment	x	
6. Remanufacturing	x	
7. Cannibalisation	x	
8. Recycling	x	x
9. Disposal	x	
10. Transportation of recovery items	x	x

4.4.2 Suppliers

Company B collects redundant computers for recovery from a wide range of local suppliers classified into three main types as follows:

- Local Authorities i.e. housing stock transfer organisation, Fire and Rescue service, Ambulance Services, National Health Service (NHS) and Primary Care Trusts (PCTs);
- Businesses throughout the area; and
- General public.

4.4.3 Collection Procedure

The company employs two collection methods to collect used computers from its suppliers. The first collection method is that suppliers can drop off the computers at the company's facility free of charge. The second collection approach is that the firm sends a van to collect them from suppliers, and the company may charge the businesses and general public a small fee to cover transport costs. However, the majority of received computers are collected by the former method.

4.4.4 Grading, Sorting and Testing Procedure

The procedure of grading, sorting and testing received computers is as follows: first, to keep the customer's personal or corporate information secure, the company uses a commercial software package to sanitise all hard drives, effectively overwriting every sector of a drive with zeros and ones. If any drives are not to be reused, they are physically destroyed. After that, the computers are graded, sorted and tested by a technician. The computers can be classified into four main quality classes: A, B, C, and D. The description of each computer class is shown in Table 4.5.

Table 4.5: Description of Each Computer Class

Quality Class	Description
A	A functional computer can be direct resold to a market without need for process recovery
B	A non-functional computer needs to be repaired
C	A non-functional computer needs to be refurbished.
D	A non-functional computer cannot be repaired or refurbished and it will be cannibalised, recycled and disposed of

Figure 4.14 shows the percentage of the number of received computers classified in terms of their quality in 2008 and Figure 4.15 displays the percentage of the number of received computers classified in terms of their age in 2008.

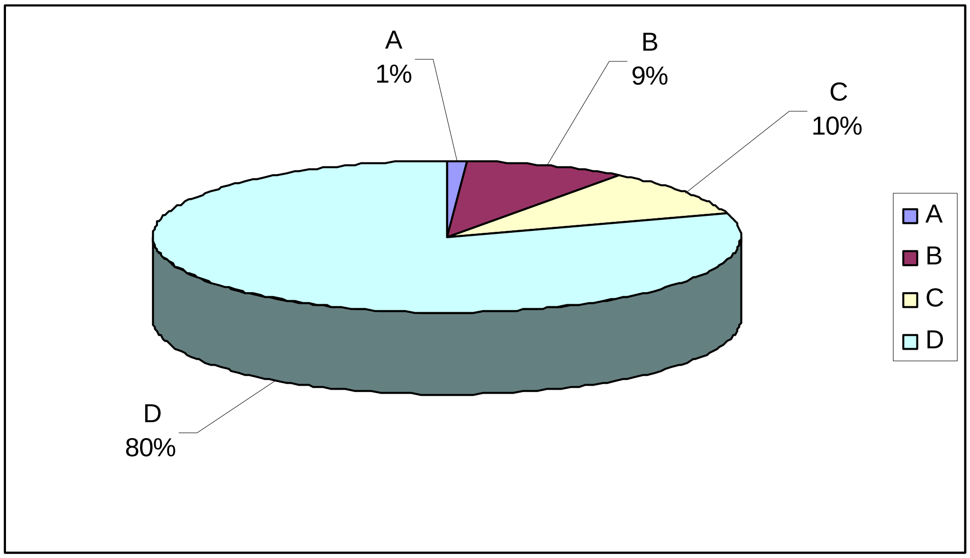

Figure 4.14: Percentage of Received Computers Classified in Terms of Their Quality in 2008

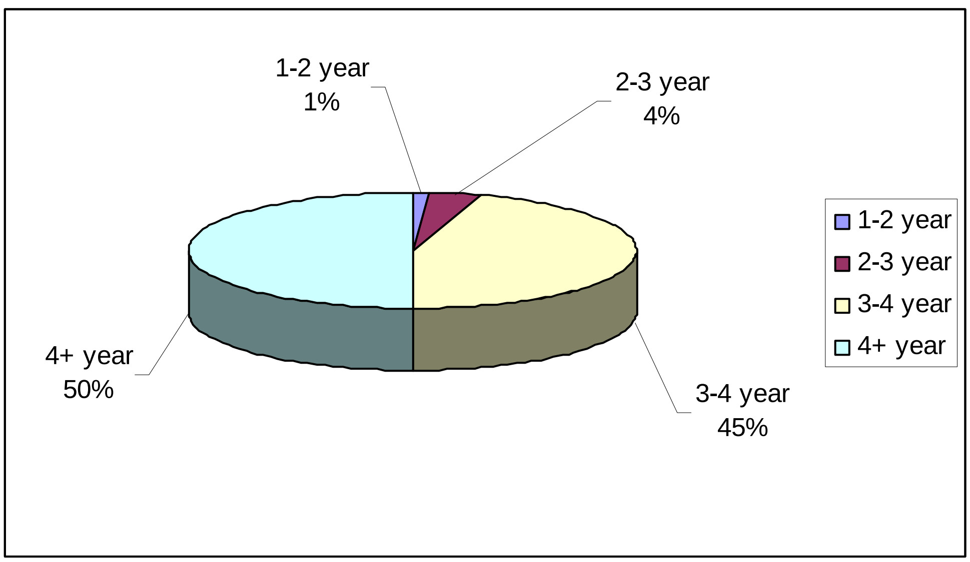

Figure 4.15: Percentage of Received Computers Classified in Terms of Their Age in 2008

4.4.5 Recovery Operations

Currently, the company's maximum capacity of all recovery operations is about 3,000 units per week; however the capacity can be expanded since the firm can recruit more workers. The company employs several recovery options including direct resell, repair, refurbishment, cannibalisation, recycling and disposal. The detail of some recovery methods are discussed as follows:

- **Repair**

Old computers are restored to working order. Computer repair involves the fixing and/or replacement of broken parts using spares. Generally, the company replaces the mouse and keyboard on old computers.

- **Refurbishment**

Old computers are brought to the specified quality. They are disassembled into modules, and all modules and parts are carefully inspected, and fixed or replaced. Outdated modules/parts are replaced with technologically superior ones. Generally, the firm replaces the DVD-RW drive and/or FTF screen on old computers.

- **Cannibalisation**

Most old computers cannot be repaired or refurbished. Only reusable parts are retrieved for spares to carry out repair and/and refurbishment.

- **Recycling**

Most old computers cannot be repaired or refurbished; however they contain several valuable parts/materials as shown in Table 4.6 so the firm dismantles them and separates the valuable parts/materials. After that, the firm sells them to a recycler.

Table 4.6: Valuable Parts/Materials of a Used Computer and Their Selling Prices

Part(s)/Material(s)	£/ton
Circuit board	2,500
Microchip	35,000-60,000
Ferrous metal/steel case	60-70
Aluminium	120
Cable/Wire	600

4.4.6 Market Issues

Company B classifies the recovered computers into six main categories based on their specification as shown in Table 4.7, and their picture as shown in Figures 4.16, 4.17, 4.18, 4.19, 4.20, and 4.21. The company sells customers the recovered computers with a three-month repair or replacement warranty, and take-back service of the end-of-life recovered computers.

Table 4.7: The Specification, Recovery Method, Selling Price and Average Age of Each Recovered Computer Class

Computer type	Description	Recovery method	Price (£)	Age (year)
I	Pentium 1000 processor, 128+Mb RAM, 10+Gb Hard Drive, CD-Rom, keyboard and mouse, 17" CRT monitor and Windows 98.	Direct resell	39	6
II	Broadband Ready Silver HP/Compaq or Black Dell System with Pentium 1600, 17" CRT monitor, keyboard and mouse,and Windows XP.	Repair	75	5
III	Broadband Ready Black Dell or Silver Compaq system with Pentium 2000 or above, 17" CRT monitor, matching keyboard and mouse and Windows XP	Repair	99	4
IV	NEC Pentium 2600 processor, 512+Mb RAM,40+Gb Hard Drive, TFT Screen, keyboard and mouse and Windows XP.	Refurbishment	125	3
V	NEC Pentium 2800 processor, 512+Mb RAM, 40+Gb Hard Drive, DVD-Rewriter, TFT Screen, keyboard and mouse and Windows XP.	Refurbishment	150	3
VI	PENTIUM 2800 processor, 512+Mb RAM, 40+Gb Hard Drive, DVD-Rewriter, TFT Screen, keyboard and mouse, new case, and Windows XP.	Refurbishment	175	3

Figure 4.16: Recovered Computer Type I

Figure 4.17: Recovered Computer Type II

Figure 4.18: Recovered Computer Type III

Figure 4.19: Recovered Computer Type IV

Figure 4.20: Recovered Computer Type V

Figure 4.21: Recovered Computer Type VI

The company's main customers are the local general public at the low-end of the pay scale. In addition, its principle market channel is its own shop, and its minor market channels are its website and the UK eBay website. The company's main competitors are 20 members of the Regional Electronics Initiative (REI) in Yorkshire and the Humber.

4.5 Conclusion

This chapter provides general information on the WEEE Directive and the RoHS Directive related to the WEEE recycling business e.g. the Directive objectives, the businesses bound by the Directive, the Directive EEE classification and so on. More importantly, this chapter also illustrates two case companies engaged in the mobile phone recycling business and the computer recycling business which have implemented multiple recovery options operations for the reverse logistics programme in practice. Company A in the recycled mobile phone sector is relevant as an international, efficient and sustainable organisation which works in re-use, reprocess, and recycling, in order to make a profit from unwanted mobile phone and also to protect all people and environments.

On the other hand, Company B in the recycled computer sector is relevant as a community-based, not-for-profit and co-operative waste management organisation which works in reduction, re-use, and recycling in order to tackle the UK's growing waste problem in a practical and effective way. Each case company provides the company background, its recovery process, its suppliers, the collection procedure, the grading, sorting and testing procedure and the market issues. These case companies are used to develop a questionnaire survey presented in chapter 5; and are used to formulate the pricing models illustrated in chapter 6 and the simulation models demonstrated in chapter 7.

Moreover, attempts have been made to investigate reverse logistics programmes in the computer sector and the mobile phone sector in Thailand (see Appendix C) in order to formulate a pricing model and a simulation model for multiple recovery options in the Thai context. It is found that the two participating mobile phone companies have implemented multiple recovery options operations. However, the individuals interviewed could not give the cost parameters of the reverse logistics operations since these data are confidential and also difficult to estimate. Hence, a pricing model and a simulation for multiple recovery options operations based on the Thai mobile phone sector could not be formulated. The next chapter presents research questionnaire and data analysis.

Chapter 5: Research Questionnaire and Data Analysis

5.1 Introduction

This chapter presents and interprets the data analysis outputs of the survey data collected through the use of the questionnaire. Three main statistical techniques have been used in this research including descriptive statistics, one-way ANOVA technique and factor analysis. This questionnaire survey is developed from two case companies, Company A (the mobile phone recycling business) and Company B (the computer recycling business) illustrated in chapter 4 of this thesis. It aims to look for behaviours and opinions of respondents with regard to the mobile phone recycling business and the computer recycling business.

The remainder of this chapter is organised as follows: section 5.2 introduces data analysis for the mobile phone recycling business; section 5.3 presents data analysis for the computer recycling business; and section 5.4 provides the chapter conclusion.

5.2 Data Analysis for the Mobile Phone Recycling Business

In this section, the important aspects related to data analysis for the mobile phone recycling industry are presented i.e. general information of respondent behaviours, strategies used by the mobile phone recycling company, and One-Way Analysis of Variance (ANOVA).

5.2.1 General Information of Respondent Behaviours

It can be seen from Figure 5.1 that the majority of the respondents (59.67%) change a mobile phone once every one to two years because several mobile network providers offer a variety of handsets with an 18- or 24-month tariff contract. Customers tend to change their old phone for a new one at the end of a contract.

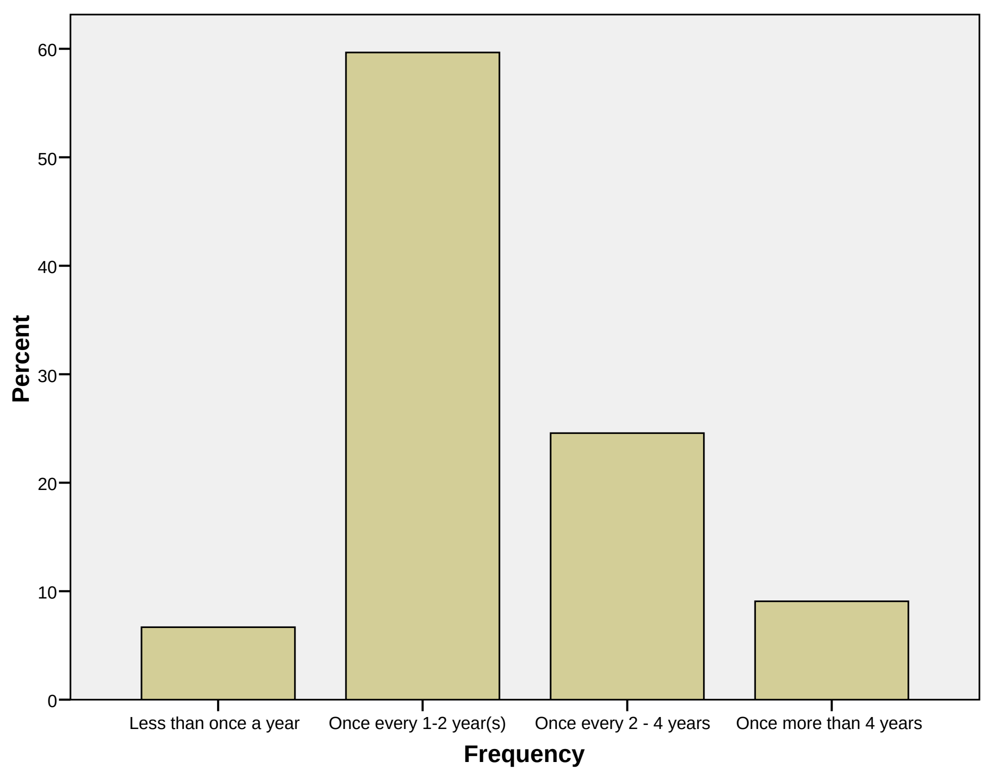

Figure 5.1: Frequency with Which a Mobile Phone is Changed

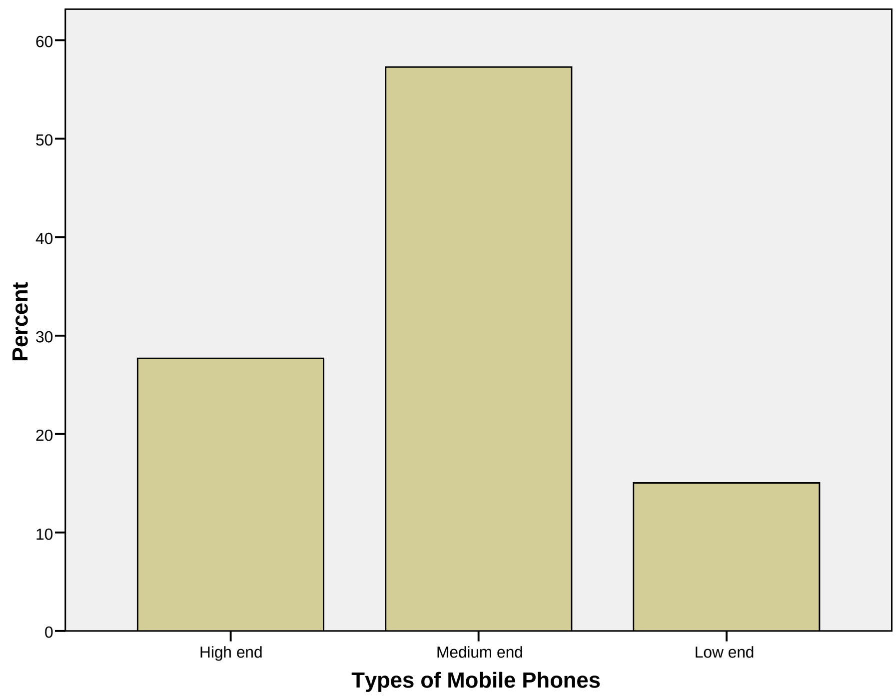

Figure 5.2: Graph Showing Distribution of Mobile Phone Types

From Figure 5.2, it can be seen that 27.68, 57.28 and 15.04 % of the sample used high-end, mid-range and low-end mobile phone types, respectively. A majority of the sample used high-end and mid-range handsets, since most of respondents were students in the University who tended to use lightweight, slim handsets incorporating the latest in communication technology; they also had a strong feel for current fashions.

Table 5.1: What People Did with Their Old Mobile Phone

Methods	Frequency	Percentage (%)
Left it in a drawer	227	54.05
Donated it to a charity shop	18	4.29
Sold it via a mobile phone recycling company website	51	12.14
Sold it via a big retail supermarket or a mobile network provider	3	0.71
Sold it via a high street second hand shop	9	2.14
Gave it to a family member, a friend, or someone	58	13.81
Other	54	12.86
Total	420	100.00

As can be seen from Table 5.1, 54.05 % of the sample left their old mobile phones in a drawer; by contrast, only 15.00 % (63 cases) of the sample sold their handset via a mobile phone recycling company website, a big retail supermarket or a mobile phone network provider, or a high street second-hand shop. Hence it may be suggested that a mobile phone recycling company website should launch a number of strategies in order to persuade customers to trade in handsets to its website because there is a potential source of old mobile phones ‘left in drawers’.

According to the statistics gathered here, there may be as many as 80 million mobile phones that are no longer used, left in the drawers of homes throughout the UK every year due to upgrade offers made by mobile phone network providers (Simpson, 2009). Tables 5.2, 5.3, and 5.4 show the selling prices of each mobile phone technology class when the sample sold their handset via any channel.

Table 5.2: Selling Price Range of High-end, Old Mobile Phones in Working and Non-Working Condition

Working Condition			Non-Working Condition		
Selling Price (£)	**Frequency**	**Percentage (%)**	**Selling Price (£)**	**Frequency**	**Percentage (%)**
10.00	1	7.69	9.47	1	25.00
30.00	1	7.69	10.00	1	25.00
36.00	1	7.69	15.00	1	25.00
40.00	1	7.69	19.00	1	25.00
50.00	1	7.69	**Total**	4	100.00
52.00	1	7.69			
53.00	1	7.69			
60.00	2	15.38			
90.00	1	7.69			
108.00	1	7.69			
120.00	1	7.69			
136.00	1	7.69			
Total	13	100.00			

Table 5.3: Selling Price Range of Mid-Range, Old Mobile Phones in Working and Non-Working Condition

Working Condition			Non-Working Condition		
Selling Price (£)	Frequency	Percentage (%)	Selling Price (£)	Frequency	Percentage (%)
1.00	1	5.00	0.00	1	16.67
2.70	1	5.00	5.00	1	16.67
8.00	1	5.00	10.00	1	16.67
9.00	1	5.00	13.00	1	16.67
10.00	1	5.00	20.00	1	16.67
20.00	1	5.00	30.00	1	16.67
22.00	1	5.00	**Total**	6	100.00
23.00	1	5.00			
30.00	1	5.00			
32.00	1	5.00			
35.00	1	5.00			
40.00	1	5.00			
45.00	1	5.00			
47.00	1	5.00			
50.00	1	5.00			
55.00	1	5.00			
60.00	1	5.00			
65.00	1	5.00			
70.00	1	5.00			
130.00	1	5.00			
Total	20	100.00			

Table 5.4: Selling Price Range of Low-end, Old Mobile Phones in Working Condition

Selling Price (£)	Frequency	Percentage (%)
19.00	1	33.33
35.00	1	33.33
42.00	1	33.33
Total	3	100.00

5.2.2 Strategies Used by the Mobile Phone Recycling Company

This study used the questionnaire to seek customers' opinions in relation to a mobile phone recycling company's strategies. The handset recycling firm (Company A) participating in this study uses several strategies to persuade customers to trade-in the phone on its website. These strategies include Strategy 1: more extensive mobile phone model list including the customer's phone; Strategy 2: higher offer price; Strategy 3: faster payment process; Strategy 4: alternative payment options such as a gift voucher, mobile phone airtime, and charity donation; Strategy 5: a wide range of collection methods such as a free post envelope, free courier collections, and a drop-off centre; Strategy 6: friendly and professional customer service; Strategy 7: corporate citizenship such as a cash donation to a charity; and Strategy 8: green image such as helping the environment by recycling old mobile phones.

Table 5.5 shows the descriptive statistics outputs of the strategies. From table 5.5, it is found that the respondents consider the following strategies: Strategy 2: higher offer price as ranked 1; Strategy 6: friendly and professional customer service as ranked 2; Strategy 3: faster payment process as ranked 3; Strategy 5: a wide range of collection methods as ranked 4; Strategy 1: more extensive mobile phone model as ranked 5; Strategy 8: green image as ranked 6; Strategy 7: corporate citizenship as ranked 7; and Strategy 4: alternative payment options as ranked 8.

Table 5.5: Descriptive Outputs of the Mobile Phone Recycling Firm's Strategies

Strategy	Very Unimportant	Unimportant	Neutral	Important	Very important	N	Rank	Mean	S.D.	Actual Range	
										Min	Max
2. Higher offer price	0	1.40%	9.80%	32.40%	56.40%	420	1	4.400	0.727	2	5
6. Friendly and professional customer service	0	1.70%	17.90%	45.20%	35.20%	420	2	4.140	0.761	2	5
3. Faster payment process	0.20%	3.10%	23.40%	43.10%	30.10%	418	3	4.000	0.827	1	5
5. A wide range of collection methods	0.20%	5.70%	17.50%	54.50%	22.00%	418	4	3.920	0.801	1	5
1. More extensive mobile phone model	1.00%	5.50%	28.20%	45.30%	20.00%	419	5	3.780	0.861	1	5
8. Green image	2.90%	9.30%	26.70%	44.00%	17.10%	420	6	3.630	0.967	1	5
7. Corporate citizenship	1.70%	12.90%	45.20%	33.80%	6.40%	420	7	3.300	0.836	1	5
4. Alternative payment options	4.50%	30.60%	38.30%	22.50%	4.10%	418	8	2.910	0.932	1	5

5.2.3 One-Way Analysis of Variance (ANOVA)

A one-way ANOVA technique was used to detect whether there was difference among mean scores of the strategies. There are three major assumptions of ANOVA (Kvanli et al., 2003; Burns and Burns, 2008; Field, 2009) i.e. normality, homogeneity of variance, and independence of observations. Next, the data will be tested based on these assumptions.

Tests of Normality

It is generally accepted that the Kolmogorov-Smirnov test and Shapiro-Wilk test are used to check whether the sample is normally distributed (Pallant, 2007; Field, 2009). If the test is non-significant (Sig. value ≥ 0.05), it indicates that the distribution of the sample is not significantly different from a normal distribution. However, if the test is significant (Sig. values < 0.05), it means that the distribution is non-normal (Field, 2009). The outputs of normality tests for all the mobile phone recycling firm's strategies are shown in Table 5.6.

Table 5.6: Tests of Normality for All the Mobile Phone Recycling Firm's Strategies

Strategy	Kolmogorov-Smirnov (a)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
1. More extensive mobile phone model	0.255	419	0.000	0.867	419	0.000
2. Higher offer price	0.345	420	0.000	0.730	420	0.000
3. Faster payment process	0.233	418	0.000	0.847	418	0.000
4. Alternative payment options	0.196	418	0.000	0.896	418	0.000
5. A wide range of collection methods	0.304	418	0.000	0.831	418	0.000
6. Friendly and professional customer service	0.232	420	0.000	0.821	420	0.000
7. Corporate citizenship	0.240	420	0.000	0.877	420	0.000
8. Green image	0.260	420	0.000	0.878	420	0.000

(a = Lilliefors Significance Correction)

From Table 5.6, it can be seen that all variables have a non-normal distribution because all significant values are zero (Sig. values < 0.05). In other words, the assumption of normality is violated. However Hair et al. (2006) and Tabachnick and Fidell, (2007) have argued when using large sample sizes (e.g. more than 200 cases), the detrimental effects of non-normality may be insignificant. Hence, with the sample size of 420 replicates in this study, the violation of the normality assumption should not cause any major problems.

Homogeneity of Variance

Pallant (2007) have mentioned that the assumption of homogeneity of variance can be checked by using Levene's test for homogeneity of variance. This technique tests whether the variance in replicates is the same for each group. If the significant value is greater than 0.05, it indicates that this assumption is not violated. However, if the significant value is less than 0.05, it means that this assumption is violated.

Table 5.7: Tests of Homogeneity of Variance

Test of Homogeneity of Variances

Rate

Levene Statistic	df1	df2	Sig.
9.245	7	3345	.000

As can be seen from Table 5.7, significant values are zero (Sig values < 0.05); as a result, the variances for all groups are not equal and the assumption of homogeneity of variance is violated. However, Kvanli et al. (2003), Pallant (2007) and Field (2009) argued that when sample sizes are reasonably equal, The F-test used in the ANOVA procedure for testing means is only slightly affected; in other words, ANOVA is fairly robust to violations of this assumption. Hence, with nearly equal sample sizes (a range of 418 to 420 replicates) in this study, it can be concluded that ANOVA is fairly robust to violations of this assumption.

Independence of Observations

Each observation in this study is not influenced by any other observation; as a result, the observations are independent of one another.

ANOVA Outputs

Table 5.8: ANOVA Outputs

ANOVA

Rate

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	685.166	7	97.881	137.943	.000
Within Groups	2373.519	3345	.710		
Total	3058.685	3352			

Pallant (2007) has mentioned that if the significant value is less than 0.05, it indicates that there is significant difference in the variation among groups. From table 5.8, it can be seen that significant value is less than 0.05; consequently, it can be concluded that there is significant difference among mean scores of the strategies.

Post hoc Tests

After rejecting the ANOVA null hypothesis that informs us that the population means are different, there is a need for further analysis to find out which of the groups differ (Kvanli et al., 2003; Burns and Burns, 2008; Field, 2009). To answer this question, it is suggested that a post hoc analysis may be used in order to identify where statistical differences lie among the groups. There are several major post hoc tests i.e. Tukey's Honestly Significant Difference (HSD), Scheffe, Bonferroni, and the Games-Howell procedure. It is recommended that this study should use the Tukey's HSD procedure because it is more powerful when a number of samples are similar in size, and that is the case in this study. Table 5.9 shows outputs from Tukey's HSD post hoc tests and Figure 5.3 illustrates means plots of the strategies.

From Table 5.5, it can be seen that the sample means of the strategies, in order, are Strategy 2 (Mean = 4.400, SD =0.727), Strategy 6 (Mean = 4.140, SD =0.761), Strategy 3 (Mean = 4.000, SD =0.827), Strategy 5 (Mean = 3.920, SD =0.801), Strategy 1 (Mean = 3.780, SD =0.861), Strategy 8 (Mean = 3.630, SD =0.967), Strategy 7 (Mean = 3.300, SD =0.836) and Strategy 4(Mean = 2.910, SD =0.932), respectively.

More importantly, based on the outputs from Table 5.9, post hoc comparisons using the Tukey HSD tests indicate that the means for Strategy 2 are significantly different from all the other strategies. There is no evidence of a difference between the Strategy 6 and Strategy 3 populations, between the Strategy 3 and Strategy 5 populations, between the Strategy 5 and Strategy 1 populations, or between the Strategy 1 and Strategy 8 populations. There is evidence of a difference among the Strategy 8, Strategy 7 and

Strategy 4 populations. Hence, the company should use Strategy 2: higher offer price as an order-winner.

Table 5.9: Outputs from Tukey's *Post hoc* Tests

(I) Strategy	(J) Strategy	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Strategy 1	Strategy 2	-0.658*	0.058	0.000	-0.834	-0.481
	Strategy 3	-0.217*	0.058	0.005	-0.394	-0.041
	Strategy 4	0.871*	0.058	0.000	0.695	1.048
	Strategy 5	-0.143	0.058	0.215	-0.320	0.034
	Strategy 6	-0.360*	0.058	0.000	-0.536	-0.184
	Strategy 7	0.476*	0.058	0.000	0.299	0.652
	Strategy 8	0.147	0.058	0.183	-0.029	0.323
Strategy 2	Strategy 1	0.658*	0.058	0.000	0.481	0.834
	Strategy 3	0.440*	0.058	0.000	0.264	0.617
	Strategy 4	1.529*	0.058	0.000	1.353	1.706
	Strategy 5	0.515*	0.058	0.000	0.338	0.691
	Strategy 6	0.298*	0.058	0.000	0.121	0.474
	Strategy 7	1.133*	0.058	0.000	0.957	1.310
	Strategy 8	0.805*	0.058	0.000	0.628	0.981
Strategy 3	Strategy 1	0.217*	0.058	0.005	0.041	0.394
	Strategy 2	-0.440*	0.058	0.000	-0.617	-0.264
	Strategy 4	1.089*	0.058	0.000	0.912	1.265
	Strategy 5	0.074	0.058	0.909	-0.103	0.251
	Strategy 6	-0.143	0.058	0.216	-0.319	0.034
	Strategy 7	0.693*	0.058	0.000	0.516	0.869
	Strategy 8	0.364*	0.058	0.000	0.188	0.541
Strategy 4	Strategy 1	-0.871*	0.058	0.000	-1.048	-0.695
	Strategy 2	-1.529*	0.058	0.000	-1.706	-1.353
	Strategy 3	-1.089*	0.058	0.000	-1.265	-0.912
	Strategy 5	-1.014*	0.058	0.000	-1.191	-0.838
	Strategy 6	-1.231*	0.058	0.000	-1.408	-1.055
	Strategy 7	-0.396*	0.058	0.000	-0.572	-0.219
	Strategy 8	-0.724*	0.058	0.000	-0.901	-0.548
Strategy 5	Strategy 1	0.143	0.058	0.215	-0.034	0.320
	Strategy 2	-0.515*	0.058	0.000	-0.691	-0.338
	Strategy 3	-0.074	0.058	0.909	-0.251	0.103
	Strategy 4	1.014*	0.058	0.000	0.838	1.191
	Strategy 6	-0.217*	0.058	0.005	-0.394	-0.041
	Strategy 7	0.619*	0.058	0.000	0.442	0.795
	Strategy 8	0.290*	0.058	0.000	0.114	0.467
Strategy 6	Strategy 1	0.360*	0.058	0.000	0.184	0.536
	Strategy 2	-0.298*	0.058	0.000	-0.474	-0.121
	Strategy 3	0.143	0.058	0.216	-0.034	0.319
	Strategy 4	1.231*	0.058	0.000	1.055	1.408
	Strategy 5	0.217*	0.058	0.005	0.041	0.394
	Strategy 7	0.836*	0.058	0.000	0.659	1.012
	Strategy 8	0.507*	0.058	0.000	0.331	0.683

(* = The mean difference is significant at the 0.05 level)

Table 5.9: Outputs from Tukey's *Post hoc* Tests (Continued)

(I) Strategy	(J) Strategy	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Strategy 7	Strategy 1	-0.476*	0.058	0.000	-0.652	-0.299
	Strategy 2	-1.133*	0.058	0.000	-1.310	-0.957
	Strategy 3	-0.693*	0.058	0.000	-0.869	-0.516
	Strategy 4	0.396*	0.058	0.000	0.219	0.572
	Strategy 5	-0.619*	0.058	0.000	-0.795	-0.442
	Strategy 6	-0.836*	0.058	0.000	-1.012	-0.659
	Strategy 8	-0.329*	0.058	0.000	-0.505	-0.152
Strategy 8	Strategy 1	-0.147	0.058	0.183	-0.323	0.029
	Strategy 2	-0.805*	0.058	0.000	-0.981	-0.628
	Strategy 3	-0.364*	0.058	0.000	-0.541	-0.188
	Strategy 4	0.724*	0.058	0.000	0.548	0.901
	Strategy 5	-0.290*	0.058	0.000	-0.467	-0.114
	Strategy 6	-0.507*	0.058	0.000	-0.683	-0.331
	Strategy 7	0.329*	0.058	0.000	0.152	0.505

(* = The mean difference is significant at the 0.05 level)

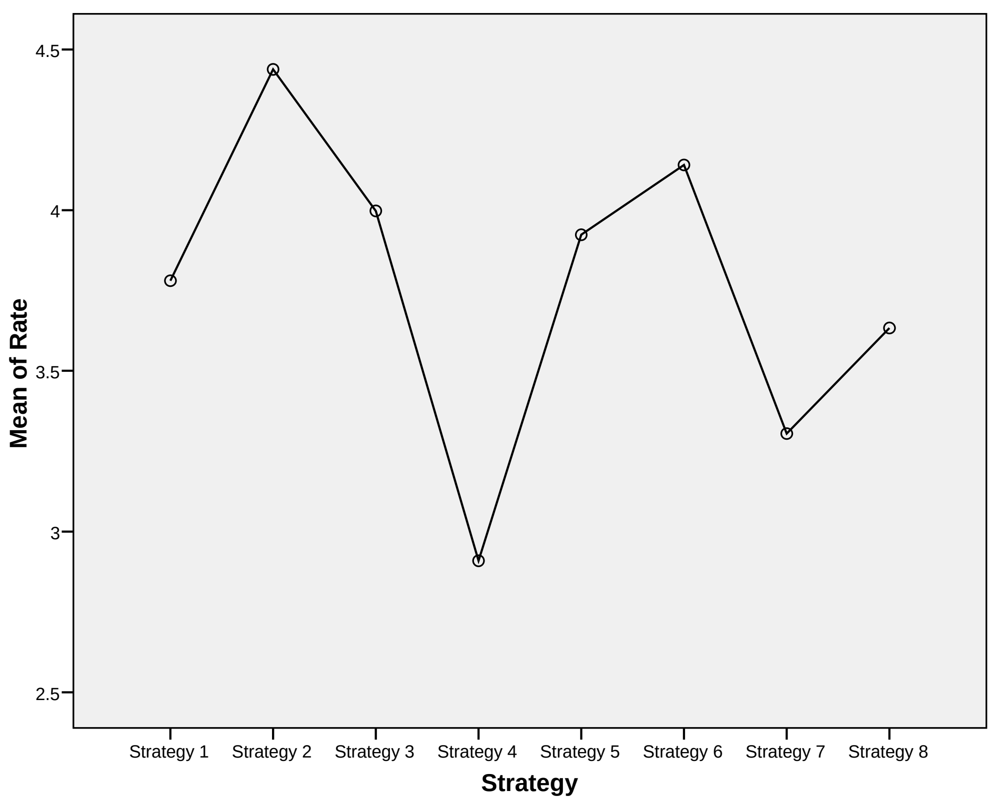

Figure 5.3: Means Plots of the Strategies

5.3 Data Analysis for the Computer Recycling Business

This section provides the significant issues in accordance with data analysis for the computer recycling industry i.e. general information of respondent behaviours, strategies used by the computer recycling company, factor analysis and One-Way Analysis of Variance (ANOVA).

5.3.1 General Information: Respondent Behaviours

Based on the survey outputs with the sample size of 420 cases, it is found that 96.19 % of the sample has their own computer. In terms of computer types, 15.21 %, 70.07 % and 14.71 % of their computers are a desk top, a laptop and both of these types respectively, as shown in Figure 5.4. It can be seen that most of the computers are laptops, possibly because nearly all of the respondents are students. They are likely to use a laptop as it is more portable than a desktop. Moreover, 6.23 % of all the respondents who have a computer mentioned that it was their first computer.

From Table 5.10, it can be shown that 19.14 %, 29.11 %, 21.29 %, 12.40 % of the sample change their computer once every 2 years, once every 3 years, once every 4 years and once every 5 years, respectively.

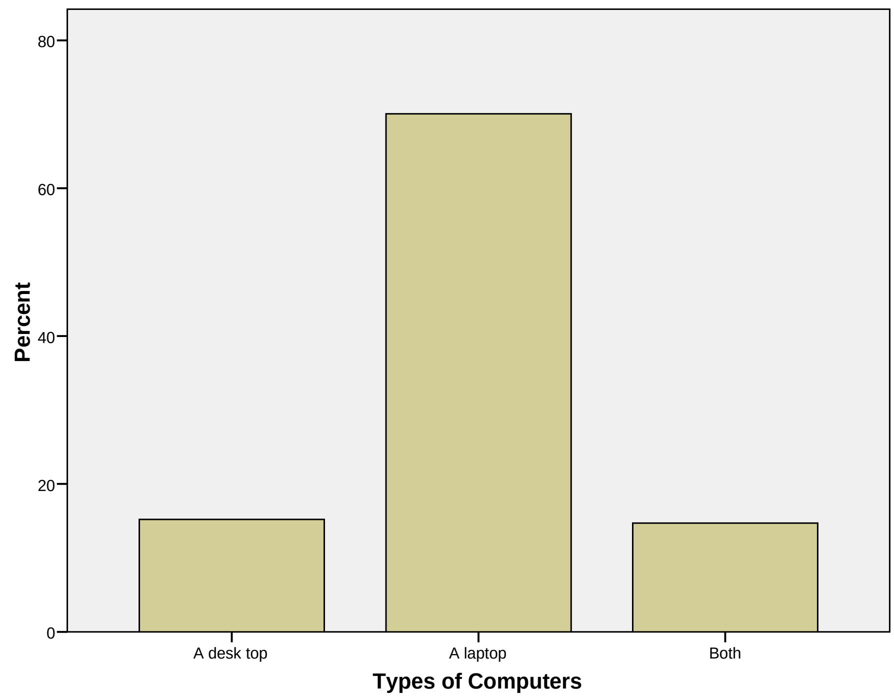

Figure 5.4: Types of Computers

Table 5.10: Frequency with Which a Computer is Changed

Year	Frequency	Percentage (%)
Less than once a year	8	2.16
Once a year	11	2.96
Once every 2 years	71	19.14
Once every 3 years	108	29.11
Once every 4 years	79	21.29
Once every 5 years	46	12.40
Once every 6 years	17	4.58
Once more than 6 years	31	8.36
Total	371	100.00

Table 5.11: What People Did with Their Old Computer

Methods	Frequency	Percentage (%)
Donated it to a charity shop	29	7.97
Sold it via a high street second hand shop	33	9.07
Gave it to a computer recycling company	29	7.97
Gave it to a family member, a friend, or someone	89	24.45
Left it at home	114	31.32
Other	70	19.23
Total	364	100.00

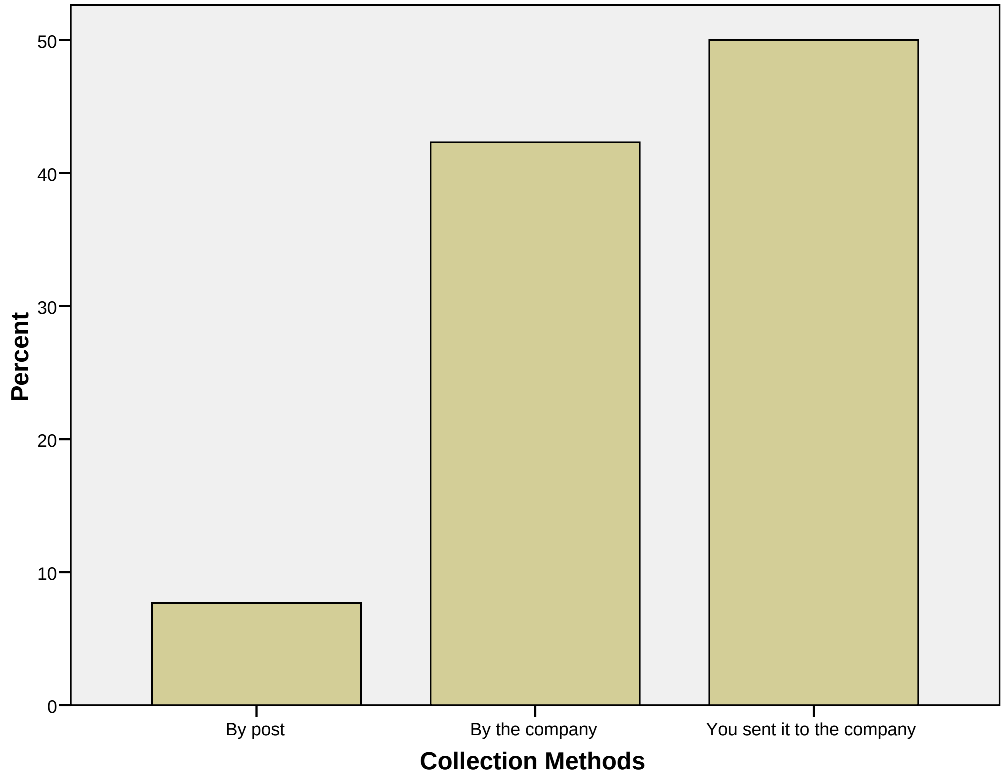

Figure 5.5: Collection Methods

From Table 5.11, it can be seen that 24.45% of the respondents gave their old computers to a family member, a friend, or someone else, and that 31.32% left them at home. On the other hand, only 7.97 % of the sample gave them to a computer recycling company, and it can be seen from Figure 5.5 that these were collected by post (7.69 %) by the company (42.31%) or by being sent to the company by the owner (50.00 %).

Table 5.12: How Long the Sample Used Their Old Computer

Year	Frequency	Percentage (%)
Less than a year	11	3.02
1-2 years	73	20.05
2-3 years	88	24.18
3-4 years	77	21.15
4-5 years	58	15.93
More than 5 years	57	15.66
Total	364	100.00

Table 5.13: Price of Respondents' Old Computer

Price	Frequency	Percentage (%)
Less than £300	38	10.64
£300-£400	103	28.85
£400-£500	58	16.25
£500-£600	59	16.53
£600-£700	51	14.29
More than £700	48	13.45
Total	357	100.00

From Table 5.12, it can be seen that 3.02 %, 20.05%, 24.18%, 21.15%, 15.93%, and 15.66% of the sample used their old computer for less than a year, between 1 to 2 years, between 2 to 3 years, between 3 to 4 years, between 4 to 5 years and more than 5 years, respectively. From Table 5.13, it can be concluded that 10.64%, 28.85%, 16.25%, 16.53%, 14.29% and 13.45% of the sample paid less than £300, between £300 to £400, between £400 to £500, between £500 to £600, between £600 to £700 and more than £700, respectively, for their computer.

Moreover, it is also found that 75.90 % of the sample would consider product substitute when the desired computer specification of a repaired or refurbished computer is not available.

5.3.2 Strategies Used by the Computer Recycling Company

This research used the questionnaire to seek customers' opinions in relation to the computer recycling company's strategies. The computer recycling firm (Company B) participating in this study uses several strategies, and is likely to implement a few of them to persuade customers to send their old computer to it. These strategies include Strategy 1: free collection service; Strategy 2: offering cash back; Strategy 3: special discount for buying a new computer or computer accessories; Strategy 4: corporate citizenship (including Strategy 4.1: free computer repair training for the long-term unemployed or high school students; Strategy 4.2: donation of refurbished computer into the community; Strategy 4.3: a cash donation to a charity) and Strategy 5: green image such as helping the environment by recycling old computers. The descriptive statistics outputs of the strategies are shown in Table 5.14.

From table 5.14, it can be seen that the respondents rate the strategies as follows: Strategy 1: free collection service as ranked 1; Strategy 2: offering cash back as ranked 2; Strategy 3: special discount for buying a new computer or computer accessories as ranked 3; Strategy 5: green image as ranked 4; Strategy 4.3: a cash donation to a charity as ranked 5; Strategy 4.2: donation of refurbished computer into the community as ranked 6; and Strategy 4.1: free computer repair training for the long-term unemployed or high school students as ranked 7. Next, Factor Analysis is employed in order to group and reduce a large number of variables (Strategies 4.1, 4.2, and 4.3) into a smaller set of variables (Strategy 4).

Table 5.14: Descriptive Outputs of the Computer Recycling Firm's Strategies

Strategy	Very Unimportant	Unimportant	Neutral	Important	Very important	N	Rank	Mean	S.D.	Actual Range	
										Min	Max
1. Free collection service	0	0.50%	8.60%	40.10%	50.80%	419	1	4.410	0.666	2	5
2. Offering cash back	0	2.40%	11.20%	40.10%	46.30%	419	2	4.300	0.762	2	5
3. Special discount for buying a new computer or computer accessories	0	2.10%	20.30%	49.40%	28.20%	419	3	4.040	0.755	2	5
5. Green image	2.40%	6.50%	29.90%	43.80%	17.50%	418	4	3.670	0.918	1	5
4. Corporate citizenship											
4.3 A cash donation to a charity	1.40%	9.50%	41.30%	39.60%	8.10%	419	5	3.430	0.829	1	5
4.2 Donation of refurbished computer into the community	1.00%	11.00%	41.30%	38.20%	8.60%	419	6	3.420	0.833	1	5
4.1 Free computer repair training for the long-term unemployed or high school students	3.30%	14.40%	38.50%	31.30%	12.40%	418	7	3.350	0.983	1	5

5.3.3 Factor Analysis

Before using one-way ANOVA technique to detect whether there are differences among the strategies applied and whether they are likely to be implemented by the computer recycling company, there is a need to group and reduce a large number of variables into a smaller set of variables by using Factor Analysis. Specifically, it would be more manageable prior to using one-way ANOVA that Strategy 4.1: free computer repair training for the long-term unemployed or high school students; Strategy 4.2: donation of refurbished computer into the community and Strategy 4.3: a cash donation to a charity are grouped and reduced into one factor in order to represent Strategy 4: corporate citizenship.

Assessment of the Suitability of the Data for Factor Analysis

Pallant (2007) indicated that the researcher has to be concerned with two main issues to determine whether the specific data set is suitable for factor analysis. These issues are measured variables and sample size. In terms of measured variables, it is important that there are a suitable number of measured variables from the domain of interest included in the analysis to cover important common factors. Otherwise, spurious common factors might emerge or true common factors might be obscured. More importantly, it is also suggested that at least three to five measured variables should be included in the analysis in order to represent a proposed factor (Fabrigar et al., 1999). Hair et al. (2006) highlighted that factor analysis is more appropriate when measured variables are metric; by contrast, non-metric variables are problematic.

In terms of sample size, a large sample size is more preferable to a smaller one, since in large samples the correlation coefficients among measured variables are more reliable (Pallant, 2007). Specifically, a preferable sample size is at least 300 cases for factor analysis (Tabachnick and Fidell, 2007). By contrast, Hair et al. (2006) suggested that a minimum sample size is 50 observations and it is more preferable if a sample size is 100 observations or larger.

This research contains a sample size of 418 and 419 observations and the number of measured variables included in factor analysis is three. These variables are Strategy 4.1: free computer repair training for the long-term unemployed or high school students, Strategy 4.2: donation of refurbished computer into the community and Strategy 4.3: a cash donation to a charity. Thus, this research has an adequate number of measured variables and a sufficient sample size.

Factor Analysis Assumptions

Field (2009) indicated that before conducting factor analysis, there are three major assumptions that need to be addressed. These are sample size, correlation between variables and normality.

Sample Size

In terms of sample size, Tabachnick and Fidell (2007, p.613) agreed that "*it is comforting to have at least 300 cases for factor analysis*." Alternatively, Field (2009) has suggested that the Kaiser-Meyer measure of sampling adequacy (KMO) can be used to test whether a sample size is sufficient. Values in the KMO statistics vary between 0 and 1. A value of 0 means it is inappropriate to use factor analysis, due to diffusion in the pattern of correlations. By contrast, a value of 1 indicates that factor analysis is appropriate for use because the patterns of correlations are relatively compact. Tabachnick and Fidell (2007) suggested that a value of 0.6 is the minimum value suitable for a good factor analysis.

This study contains a sample size of 418 and 419 observations and from Table 5.15, it can be seen that the KMO index is 0.603. Therefore this research has an adequate sample size.

Table 5.15: KMO and Bartlett's Test

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.603
Bartlett's Test of Sphericity	Approx. Chi-Square	323.522
	df	3
	Sig.	.000

Correlation between Variables

One of the principle issues to be addressed when conducting a factor analysis concerned with the strength of the intercorrelation among the variables (Pallant, 2007). Field (2009) indicated that the correlations among variables can be analysed by creating the correlation matrix. If the value of the correlations is greater than 0.30, factor analysis is appropriate. Alternatively, Hair et al. (2006) advised that the Bartlett's test of Sphericity can also be used as a statistical test for the presence of correlations among variables. Pallant (2007) argued that if the Sig. value is 0.05 or smaller, it indicates that the correlations among variables are significantly different from zero.

From Table 5.16, it can be seen that the outputs of the correlations are greater than 0.30, and it is shown from Table 5.15 that the Sig. value of the Bartlett's test of Sphericity is zero. Hence, it can be concluded that the correlations among variables are significant enough to make a meaningful factor analysis.

Table 5.16: Correlation Matrix

		Strategy 4.1	Strategy 4.2	Strategy 4.3
Correlation	Strategy 4.1	1.000	0.391	0.319
	Strategy 4.2	0.391	1.000	0.674
	Strategy 4.3	0.319	0.674	1.000

Tests of Normality

Table 5.17: Tests of Normality for All the Computer Recycling Firm's Strategies

	Kolmogorov-Smirnov (a)			**Shapiro-Wilk**		
Strategy	**Statistic**	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
4.1 Free computer repair training for the long-term unemployed or high school students	0.202	418	0.000	0.903	418	0.000
4.2 Donation of refurbished computer into the community	0.227	419	0.000	0.876	419	0.000
4.3 A Cash donation to a charity	0.230	419	0.000	0.872	419	0.000

(a = Lilliefors Significance Correction)

From Table 5.17, it can be seen that all variables have a non-normal distribution because all significant values are zero (Sig. values < 0.05). In other words, the assumption of normality is violated. However, Hair et al. (2006) and Tabachnick and Fidell, (2007) have argued when using large sample sizes (e.g. more than 200 cases), the violation of this assumption may be insignificant. Hence with the sample size of 418 and 419 replicates in this study, the violation of the normality assumption should not cause any major problems.

Factor Analysis Outputs

Field (2009) mentioned that there are three main techniques from SPSS outputs that can be used to make a decision concerning the number of retaining factors. These are Kaiser's criterion, scree plots and communality. In terms of Kaiser's criterion, Pallant (2007) highlighted that it is one of the most generally used to decide a number of retaining factors by using eigenvalue rule. Using this rule, retaining factors should have an eigenvalue of 1.00 or more. With regard to a scree plot, it is suggested that a scree plot is used to find a point at which the shape of the curve changes direction and becomes horizontal, and all retaining factors should be above the elbow or break in the plot (Pallant, 2007).

Regarding communality, Field (2009) suggested that it is used in order to test whether the outputs from Kaiser's criterion are accurate. When the sample size is more than 250 cases and the average communality is greater than 0.6, it indicates that this criterion is accurate. From table 5.18, it can be seen that only one factor has an eigenvalue of 1.942 and Figure 5.6 shows that only one factor is above the elbow or break in the scree plot. Moreover, from table 5.19, the average of the communalities is 0.647 which is greater than 0.6. Hence it could be concluded that there is only one retaining factor based on factor analysis outputs.

Table 5.18 : Total Variance Explained

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.942	64.740	64.740	1.942	64.740	64.740
2	.738	24.584	89.325			
3	.320	10.675	100.000			

Extraction Method: Principal Component Analysis.

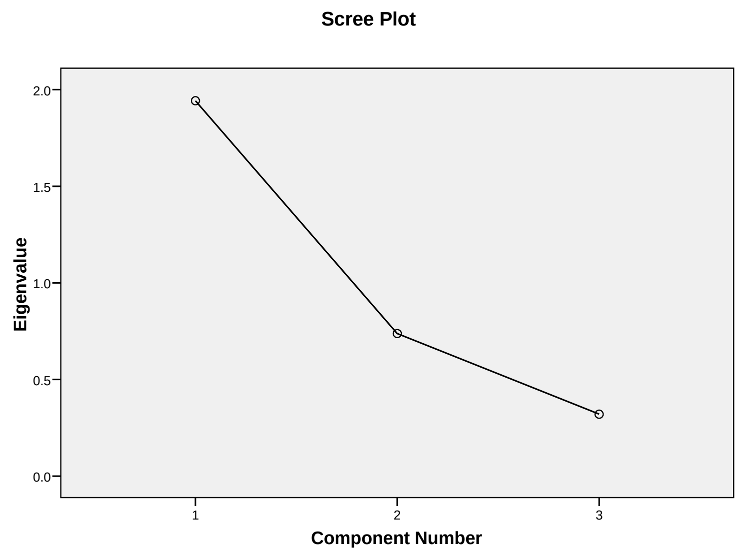

Figure 5.6: Scree Plot

Table 5.19: Communalities

Communalities

	Initial	Extraction
Q14_4.1	1.000	.430
Q14_4.2	1.000	.781
Q14_4.3	1.000	.730

Extraction Method: Principal Component Analysis.

Table 5.20: Component Matrix

	Component
	1
Strategy 4.1	0.884
Strategy 4.2	0.855
Strategy 4.3	0.656

Extraction Method: Principal Component Analysis (one component extracted)

Reliability Analysis

After using factor analysis, it is important that reliability analysis is conducted in order to measure the degree of consistency between multiple measurements of a variable (Field, 2009). Hair et al. (2006) suggested that the test-retest technique, one form of reliability analysis, should be used to measure consistency between the samples for an individual at two different points in time by using Cronbach's alpha, the most common measure of scale reliability. The outputs of reliability analysis are shown in Table 5.21 and Table 5.22.

Field (2009) suggested that if the values of the column named Corrected Item-Total Correlation are above 0.30, it indicates that there are the correlations between each items and the total score of the questionnaire. Moreover, the reference also advised that a value of Cronbach's alpha in the range of 0.70 to 0.80 means good reliability. From Table 5.21 and Table 5.22, the outputs of reliability analysis show that the values of Corrected Item- Total Correlation are above 0.30 and the value of Cronbach's alpha is 0.707; thus, the results are reliable.

Table 5.21: Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Strategy 4.1	6.856	2.315	0.388	0.158	0.805
Strategy 4.2	6.785	2.174	0.640	0.489	0.478
Strategy 4.3	6.775	2.304	0.577	0.458	0.557

Table 5.22: Reliability Statistics

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.707	.720	3

5.3.4 One-Way Analysis of Variance (ANOVA)

After conducting factor analysis, there is only one retaining factor; therefore, it is decided to average the scores of Strategy 4.1: free computer repair training for the long-term unemployed or high school students, Strategy 4.2: donation of refurbished computer into the community and Strategy 4.3: a cash donation to a charity, in order to represent the new scores of Strategy 4: corporate citizenship. The average of the new scores can be found by adding them up in each case and dividing by the number of measured variables, which is three. Table 5.23 shows new descriptive outputs of the computer recycling firm’s strategies after conducting factor analysis. The new scores of Strategy 4: corporate citizenship are used further for the ANOVA technique.

Table 5.23: New Descriptive Outputs of the Computer Recycling Firm's Strategies after Conducting Factor Analysis

Strategy	N	Rank	Mean	S.D.	Actual Range	
					Min	Max
1. Free collection service	419	1	4.410	0.666	2	5
2. Offering cash back	419	2	4.300	0.762	2	5
3. Special discount for buying a new computer or computer accessories	419	3	4.040	0.755	2	5
5. Green image	418	4	3.670	0.918	1	5
4. Corporate citizenship	418	5	3.403	0.703	1	5

There are three major assumptions of ANOVA (Kvanli et al., 2003; Burns and Burns, 2008; Field, 2009) i.e. normality, homogeneity of variance and independence of observations. Next, the data will be tested based on these assumptions.

Tests of Normality

The outputs of normality tests for all the computer recycling firm's strategies are shown in Table 5.24.

Table 5.24: Tests of Normality for all the Computer Recycling Firm's Strategies

Strategy	Kolmogorov-Smirnov (a)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
1. Free collection service	0.319	419	0.000	0.750	419	0.000
2. Offering cash back	0.283	419	0.000	0.779	419	0.000
3. Special discount for buying a new computer or computer accessories	0.257	419	0.000	0.833	419	0.000
4. Corporate citizenship	0.128	418	0.000	0.969	418	0.000
5. Green image	0.251	418	0.000	0.873	418	0.000

(a = Lilliefors Significance Correction)

From Table 5.24, it can be seen that all variables represent a non-normal distribution because all significant values are zero (Sig. values < 0.05). In other words, the assumption of normality is violated. However, Hair et al. (2006) and Tabachnick and Fidell, (2007) have argued, when using large sample sizes of more than 200 cases the detrimental effects of non-normality may be negligible.. Hence, with the sample size of 418 and 419 replicates in this analysis, the violation of the normality assumption should not cause any major problems.

Homogeneity of Variance

As can be seen from Table 5.25, significant values are zero (Sig values < 0.05); as a result, the variances for all groups are not equal and the assumption of homogeneity of variance is violated. However, Kvanli et al. (2003), Pallant (2007) and Field (2009) stressed that when sample sizes are reasonably equal The F-test used in the ANOVA procedure for testing means is only slightly affected; in other words, ANOVA is fairly robust to violations of this assumption. Hence, with nearly equal sample sizes (a range of 418 to 419 replicates) in this study, ANOVA is fairly robust to violations of this assumption.

Table 5.25: Tests of Homogeneity of Variance

Test of Homogeneity of Variances

Rate

Levene Statistic	df1	df2	Sig.
15.088	4	2088	.000

Independence of Observations

Each observation in this study is not influenced by any other observation; as a result, the observations are independent of one another.

ANOVA Outputs

Table 5.26: ANOVA Outputs

ANOVA

Rate

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	301.447	4	75.362	128.540	.000
Within Groups	1224.168	2088	.586		
Total	1525.614	2092			

Pallant (2007) mentioned that if the significant value is less than 0.05, this indicates that there is significant difference in the variation among groups. From table 5.26, it can be seen that significant value is less than 0.05; it can be concluded that there is significant difference among mean scores of the strategies.

***Post hoc* Tests**

After rejecting the ANOVA null hypothesis that informs us that the population means are different, this study used Tukey's HSD post hoc tests to find out which the groups differ since a number of cases were nearly similar. Table 5.27 shows outputs from Tukey's HSD post hoc tests and Figure 5.7 illustrates the means plots of the strategies.

Table 5.27: Outputs from Tukey's *Post hoc* Tests

(I) Strategy	(J) Strategy	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Strategy 1	Strategy 2	0.110	0.053	0.231	-0.035	0.254
	Strategy 3	0.377*	0.053	0.000	0.233	0.522
	Strategy 4	1.010*	0.053	0.000	0.866	1.155
	Strategy 5	0.738*	0.053	0.000	0.594	0.883
Strategy 2	Strategy 1	-0.110	0.053	0.231	-0.254	0.035
	Strategy 3	0.267*	0.053	0.000	0.123	0.412
	Strategy 4	0.900*	0.053	0.000	0.756	1.045
	Strategy 5	0.628*	0.053	0.000	0.484	0.773
Strategy 3	Strategy 1	-0.377*	0.053	0.000	-0.522	-0.233
	Strategy 2	-0.267*	0.053	0.000	-0.412	-0.123
	Strategy 4	0.633*	0.053	0.000	0.489	0.778
	Strategy 5	0.361*	0.053	0.000	0.217	0.506
Strategy 4	Strategy 1	-1.010*	0.053	0.000	-1.155	-0.866
	Strategy 2	-0.900*	0.053	0.000	-1.045	-0.756
	Strategy 3	-0.633*	0.053	0.000	-0.778	-0.489
	Strategy 5	-0.272*	0.053	0.000	-0.417	-0.127
Strategy 5	Strategy 1	-0.738*	0.053	0.000	-0.883	-0.594
	Strategy 2	-0.628*	0.053	0.000	-0.773	-0.484
	Strategy 3	-0.361*	0.053	0.000	-0.506	-0.217
	Strategy 4	0.272*	0.053	0.000	0.127	0.417

(* = The mean difference is significant at the 0.05 level)

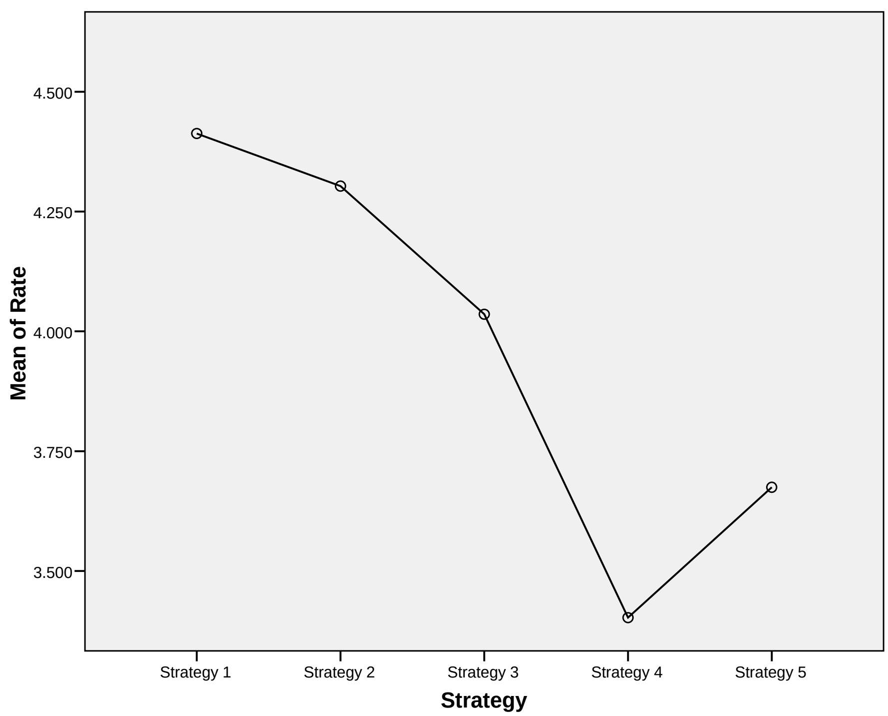

Figure 5.7: Means Plots of the Strategies

From Table 5.23, it can be seen that the sample means of the strategies, in order, are Strategy 1 (Mean = 4.410, SD =0.666), Strategy 2 (Mean = 4.300, SD =0.762), Strategy 3 (Mean = 4.040, SD =0.755), Strategy 5 (Mean = 3.670, SD =0.918) and Strategy 4 (Mean = 3.403, SD =0.703), respectively.

More importantly, based on the outputs from Table 5.27, post hoc comparisons using the Tukey HSD tests indicate there is no evidence of a difference between the Strategy 1 and Strategy 2 populations; however, the means for Strategy 1 and Strategy 2 are significantly different from all the other strategies. There is evidence of a difference among the Strategy 3, Strategy 5 and Strategy 4 populations. Hence, it is strongly suggested the company should use Strategy 1: free collection service and Strategy 2 offering cash back as order-winners.

5.4 Conclusion

This chapter presents the data analysis outputs of the survey data collected by using a questionnaire in accordance with behaviours and opinions of respondents, regarding the recycled mobile phone sector and the recycled computer sector. Three main statistical techniques have been used in this research including descriptive statistics, the one-way ANOVA technique and factor analysis.

The data analysis outputs from the mobile phone recycling industry include the frequency with which a mobile phone is changed, respondents' mobile phone types, things that people did with their old handsets, and the selling price ranges of old mobile phones. More importantly, it was found that the business should use Strategy 2: a higher offer price as an order-winner with which to persuade potential customers to trade-in their old phones to its website.

On other hand, the data analysis outputs from the computer recycling industry include respondents' computer types, the frequency with which they changed their computer, things people did with their old computers, and so on. Specifically, it was found that Strategy 1: a free collection service and Strategy 2: offering cash back, should be used as order-winners and to persuade users to send their old computers to the company. With regard to the managerial implications, the businesses can use the results in order to forecast the expected number of returns and the characteristics of returns; moreover, the industries can also apply the findings in order to introduce new tactical or strategic decisions to achieve their company goals and objectives.

In terms of the importance for the study, as mentioned in section 3.4.1, the questionnaire outputs are used for data triangulation in order to reduce the possibility of creating bias and also enhance the validity and the reliability of the research findings. Data collected from the case studies in the UK and the questionnaire survey are employed in order to formulate the pricing and simulation models and to conduct the sensitive analysis. More precisely, some of the outputs are used for assumption validation in Pricing Model III demonstrated in chapter 6 and for 'what-if' assessments in the simulation models illustrated in chapter 7. These outputs include the percentage of mobile phone types in the current market, the strategies applied as an order-winner, and respondents' opinions in accordance with production substitution of reprocessed computers.

The next chapter presents three pricing models. These models are formulated using a non-linear programming approach and two case companies, Company A (the mobile phone recycling business) and Company B (the computer recycling business) introduced in chapter 4 of this thesis.

Chapter 6: Pricing Models for Multiple Recovery Options

6.1 Introduction

This chapter presents the formulation of three pricing models by using a non-linear programming approach to determine optimal profit-maximising acquisition prices and selling prices using Company A from chapter 4 which is in the mobile phone recycling business and which has implemented a market-driven system, and to calculate optimal profit-maximising selling prices using Company B from chapter 4 which is in the computer recycling business and which has applied a waste stream system. All the proposed pricing models represent a deterministic system. This system is perfectly understood and a researcher can entirely predict its behaviour due to no randomness being involved (Pidd, 1998).

Altogether the proposed pricing models address four main academic contributions to the aforementioned research gaps as discussed in section 2.9. First, these price models are proposed in order to pioneer the pricing decision making based on the revenue management impact of multiple recovery options operations using two case companies in the mobile phone and computer recycling businesses. Second, this study assumes that the return rates and the demand rates are exponential functions and third, this work considers that there is a limit to recovery capacity. Finally, this research takes product substitution policy into account. The comparison between the proposed pricing models and the pricing models in previous research is shown in Table 6.1. The remainder of this chapter is built up as follows: Pricing Model I, Pricing Model II, Pricing Model III, and the chapter conclusion.

6.2 Pricing Model I for the Mobile Phone Recycling Business

This pricing model is formulated to determine optimal profit-maximising acquisition prices and selling prices using Company A introduced in chapter 4 (the mobile phone recycling industry) which has implemented a market-driven system. This pricing model deals with three main academic contributions as follows:

First, in previous works, only one recovery option (Guide Jr. et al., 2003; Vorasayan and Ryan, 2006; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009) and two recovery options (Bakal and Akcali, 2006; and Mitra, 2007) were investigated in order to determine optimal solutions. On the other hand, Pricing Model I explores multiple recovery options operation i.e. direct resale, repair and refurbishment, and recycling, which are employed by Company A (the mobile phone recycling industry).

Second, in the previous research, the return rate and/or the demand rate were defined as a twice differentiable function (Guide Jr. et al., 2003), a linear function (Bakal and Akcali, 2006; Mitra, 2007; and Xiang et al., 2009) and a constant-elasticity function (Xiang et al., 2009). By contrast, this pricing model assumes return and demand rate to be an exponential function.

Table 6.1: Comparison between the Proposed Pricing Models and the Pricing Models in the Previous Research

Author(s)	Model Type	Recovery System	Period	Product Life Cycle	Capacity Constraint	Operations costs	Return /Demand Rate	Decision Variable	Uncertainty	G/S duty	Recovery Actor	Recovery Option	Recovery Method	Product Substitution Policy	Market Issue
Guide Jr. et al. (2003)	EC	MD	S			1,3	NLF	AP, SP		SPs, P	3PL	S	4		MM, SM
Bakal & Akcali (2006)	ST	MD	S			1,2,3,5	LF	AP, SP	YU	RA, P	3PL	T	4,5		MM, SM
Vorasayan & Ryan (2006)	QN	WS	S			2,3,5,6, 7		SP, OT		RA, P	OEM	S	3		MM, PM
Mitra (2007)	NLP	MD	S		x	8	LF	SP		SPs, P	3PL	T	3,4		MM, PM, SM
Qu & Williams (2008)	NLP	MD	M			1,2,3,5	-	AS,OT		RA,P	3PL	S	5		MM,SM
Liang et al. (2009)	ST	MD	M			1,2,3		AP	SPU	RA, P	3PL	S	4		OM, SM
Xiang et al. (2009)	STDP	MD	S			1,2,3,8	LF,NLF	AP, SP	YU,DU	RA, P	3PL	S	4		MM, SM
Pricing Model I	NLP	MD	S			1,2,3,5	NLF	AP, SP		RA, P	3PL	M	1,2,3,5	x	MM, SM
Pricing Model II	NLP	WS	S		x	2,3,4	NLF	SP		RA, P	3PL	M	1,2,3		MM, SM
Pricing Model III	NLP	WS	S		x	2,3,4	NLF	SP		RA, P	3PL	M	1,2,3	x	MM, SM

Third, none of the proposed models considered a product substitution policy whereas in this study, this policy is taken into account as one of the most important assumptions. The remainder of this subsection is as follows: model's assumptions, model formulation, and results and sensitive analysis.

6.2.1 Model's Assumptions

This section provides the assumptions for the model which are listed below:

- The mobile phone recycling business buys old mobile phones from its suppliers and it offers the same acquisition prices to all suppliers.
- Grading, sorting and testing are done by the firm, and the duties are perfect (there is no misclassification that leads to defect).
- The firm pays more money for higher-grade old mobile phones (A+ grade) and it pays the same price for A grade and B grade mobile phones.
- Yields of all reprocessed products are perfect.
- The supply rate behaves as an increasing exponential function of acquisition price and the demand rate behaves as a decreasing exponential function of selling price.
- All of the received mobile phones can be reprocessed, and all of the reprocessed items can be resold.
- No capacity constraints, no fixed costs and monopoly market.
- The firm sells the recovered mobile phones to a secondary market, such as undeveloped countries. Customers prefer to buy reprocessed products rather than new items due to price differentiation and consumer affordability.

- The demands of direct resold mobile phones, and repaired and refurbished mobile phones are dependent because the company sells the recovered mobile phones at the same price, and there is not much difference in their quality. So, direct resold mobile phones and repaired and refurbished mobile phones can replace each other.
- The model is for a single period, and is not dependent on the product life cycle.
- The mobile phone recycling company sets the minimal acquisition price for each product class below which returns are not accepted, and sets the maximum price at which recovered products can be sold.
- All received mobile phones have the same handling costs.

6.2.2 Model Formulation

The decision variables, the parameters and the pricing model are introduced below:

- **Decision Variables**

S_1 = Selling price of recovery mobile phones including direct resold, repaired and refurbished mobile phones

S_2 = Selling price of recycled mobile phones

A_1 = Acquisition price of A+ grade mobile phones

A_2 = Acquisition price of A grade and B grade mobile phones

A_3 = Acquisition price of R grade mobile phones

- **Parameters**

D_1 = Demand of direct resold, and repaired and refurbished mobile phones $(D_1(S_1) = e^{f_1 - g_1 * s_1},\ f_1, g_1 > 0)$

D_2 = Demand of recycled mobile phones $(D_2(S_2) = e^{f_2 - g_2 * s_2},\ f_2, g_2 > 0)$

R_1 = Supply of A+ grade mobile phones $(R_1(A_1) = e^{a_1 + b_1 * A_1},\ a_1, b_1 > 0)$

R_2 = Supply of A grade and B grade mobile phones $(R_2(A_2) = e^{a_2 + b_2 * A_2},\ a_2, b_2 > 0)$

R_3 = Supply of R grade mobile phones $(R_3(A_3) = e^{a_3 + b_3 * A_3},\ a_3, b_3 > 0)$

β_i = the minimal acquisition price

γ_i = the maximum selling price

H = Handling costs including collection cost, and grading, sorting and testing cost

C = Repair and refurbishing operations cost

T = Transportation cost

Next, the pricing model can be formulated as shown in equation 6.1:

- **Objective**

Maximise F = Income – Acquisition Cost – Handling Costs – Recovery Cost – Transportation cost

$$= \sum S_i * R_i(A_i) - \sum A_i * R_i(A_i) - H * \sum R_i(A_i) - C * R_2(A_2) - T * \sum R_i(A_i) \quad (6.1)$$

- **Constraints**

$$R_1(A_1) + R_2(A_2) \geq D_1(S_1) \tag{6.2}$$

$$R_3(A_3) \geq D_3(S_3) \tag{6.3}$$

$$A_i \geq \beta_i \tag{6.4}$$

$$S_i \leq \gamma_i \tag{6.5}$$

$$S_i \geq A_i + H + C + T \tag{6.6}$$

$$S_i > 0 \tag{6.7}$$

$$A_i > 0 \tag{6.8}$$

Objective function (6.1) maximises the profit of the firm from recovered mobile phones sold in the secondary markets. Constraints (6.2) and (6.3) ensure that available recovered mobile phones are enough to cover their demand. Constraints (6.4) and (6.5) represent the minimal acquisition price of each product class, and the maximum selling price. Constraint (6.6) ensures that the firm will set a profitable selling price. Constraints (6.7) and (6.8) are sign restrictions.

6.2.3 Results and Sensitive Analysis

The return functions, the demand functions, the pricing models and the parameters have been formulated based on the data from the structured interview since the firm could not provide all required data for the analysis due to commercial reasons. Hence, the assumptions were made for the number of received mobile phones vs. acquisition prices and the number of recovery mobile phones vs. selling prices. In addition, it has been decided to formulate three pricing models for technology classes (or an average age) of received mobile phones: high-end (1-2 years old), mid-range (2-4 years old) and low-end (4+ years old) since the range of acquisition prices and the range of selling prices of each mobile phone class are markedly different, and these models provide more realistic optimal outputs. These models are on a fortnightly basis and deterministic.

The parameters of high-end (1-2 years old) class are as follows: H = £2.3/item, C = £1.5/item, T = £0.5/item, β_1 = £65, β_2 = £1, β_3 = £0.5, γ_1 = £100 and γ_2 = £3.5; the parameters of mid-range (2-4 years old) class are as follows: H = £2.3/item, C = £1.5/item, T = £0.5/item, β_1 = £10, β_2 = £1, β_3 = £0.5, γ_1 = £30 and γ_2 = £3.5; and the parameters of low-end (4+ years old) class are as follows: H = £2.3/item, C = £1.5/item, T = £0.5/item, β_1 = £4, β_2 = £1, β_3 = £0.5, γ_1 = £10.8 and γ_2 = £3.5.

LINGO version 11.0 was used to calculate the outputs. LINGO is one of the most powerful and comprehensive software packages designed to formulate and calculate outputs of linear, nonlinear and integer optimisation models (Lindo Systems Inc., 2008). Table 6.2 shows the initial outputs of Pricing Model I.

Table 6.2: The Initial Outputs of Pricing Model I

Product	Total Profit (£)	A_1 (£)	A_2 (£)	A_3 (£)	S_1 (£)	S_2(£)
High-end	197,033.30	65.00	1.97	0.80	100.00	3.50
Mid-range	95,200.25	10.00	2.72	1.22	15.50	3.50
Low-end	43,929.65	5.00	1.00	0.91	10.50	3.50
Total	336,163.20					

Moreover, during analysis changes were introduced to the cost parameters, including handling cost, repair and refurbishing operations cost and transportation cost. Table 6.3 shows some of the outputs of the changes of the cost parameters. Based on this experiment, it can be concluded that the increase and the decrease of the cost parameters have an impact on the total profit without any changes of the variables' optimal values. For example, when increasing the handling cost, repair and refurbishing operations cost and transportation cost by £ 1 per unit, it can be seen that the total profit of high-end, middle-end and low-end mobile phones decreases by 9.33%, 4.40% and 9.33% respectively, compared with the outputs from table 6.2.

Table 6.3: Some of the Outputs of the Cost Parameters Changes

Product	H (£/unit)	Total Profit (£)	C (£/unit)	Total Profit (£)	T (£/unit)	Total Profit (£)
High-end	3.30	193,942.50	2.50	195,277.90	1.50	193,942.50
Mid-range		82,130.65		84,405.54		82,130.65
Low-end		28,716.88		41,676.69		28,716.88
		304,790.03		321,360.13		304,790.03

Furthermore, it has been decided to alter the minimal acquisition prices of A+ grade mobile phones (β_1) and the maximum selling prices of direct resold and repaired and refurbished mobile phones (γ_1). Based on the results of the experiment, it is found that the increase and the decrease of the minimal acquisition prices and the maximum selling prices have an impact on the variables' optimal values and the total profit. Table 6.4 shows the outputs of the changes of the minimal acquisition prices of A+ grade mobile phones and Table 6.5 presents the outputs of the changes of the maximum selling prices of recovery mobile phones.

Table 6.4: The Outputs of the Changes of the Minimal Acquisition Prices of A+ Grade Mobile Phones

Product	β_1(£)	γ_1(£)	Total Profit (£)	A_1(£)	A_2(£)	A_3(£)	S_1(£)	S_2(£)
High-end	60.00	100.00	215,788.70	60.00	2.09	0.80	100.00	3.50
Mid-range	8.00	30.00	82,223.13	8.00	2.83	1.22	13.50	3.50
Low-end	2.00	10.80	53,702.53	5.30	1.30	0.91	10.80	3.50
			351,714.36					
Product	β_1(£)	γ_1(£)	Total Profit (£)	A_1 (£)	A_2 (£)	A_3 (£)	S_1 (£)	S_2(£)
High-end	70.00	100.00	170,503.70	70.00	1.79	0.80	100.00	3.50
Mid-range	12.00	30.00	101,092.40	12.00	2.59	1.22	17.50	3.50
Low-end	6.00	10.80	50,340.61	5.30	1.00	0.91	10.80	3.50
			321,936.71					

Based on the outputs from Table 6.4, when decreasing the minimal acquisition prices of A+ grade mobile phones of high-end, middle-end and low-end mobile phones by £5, £2 and £2 respectively, it can be seen that the variables' optimal values have changed to the new optimal value, and the total profit of high-end, middle-end and low-end mobile phones has increased by 9.50%, decreased by 13.63% and increased by 22.25% respectively, compared with the outputs from Table 6.2.

Moreover, when increasing the minimal acquisition prices of A+ grade mobile phones of high-end, middle-end and low-end mobile phones by £5, £2 and £2 respectively, it can be seen that the variables' optimal values have changed to the new optimal value, and the total profit of high-end, middle-end and low-end mobile phones has decreased by 13.46%, increased by 6.19 % and increased by 14.59 % respectively, compared with the outputs from Table 6.2.

Table 6.5: The Outputs of the Changes of the Maximum Selling Prices of Recovery Mobile Phones

Product	β_1(£)	γ_1(£)	Total Profit (£)	A_1(£)	A_2(£)	A_3(£)	S_1(£)	S_2(£)
High-end	65.00	95.00	214,421.90	65.00	2.13	0.80	95.00	3.50
Mid-range	10.00	28.00	95,200.25	10.00	2.72	1.22	15.50	3.50
Low-end	4.00	8.80	20,982.45	3.30	1.00	0.50	8.80	3.50
			330,604.60					
Product	β_1(£)	γ_1(£)	Total Profit (£)	A_1 (£)	A_2 (£)	A_3 (£)	S_1 (£)	S_2(£)
High-end	65.00	105.00	180,258.60	65.00	1.80	0.80	105.00	3.50
Mid-range	10.00	32.00	95,200.25	10.00	2.72	1.22	15.50	3.50
Low-end	4.00	12.80	43,929.65	5.00	1.00	0.91	10.50	3.50
			319,388.50					

Based on the outputs from Table 6.5, when decreasing the maximum selling prices of recovery mobile phones of high-end, middle-end and low-end mobile phones by £5, £2 and £2 respectively, it can be seen that the variables' optimal values of high-end and low-end mobile phones have changed to the new optimal value, and the total profit of high-end and low-end mobile phones has increased by 8.83% and decreased by 52.24 % respectively, compared with the outputs from Table 6.2. By contrast, the outputs of middle-end mobile phones have the same optimal outputs and the same total profit as the outputs from Table 6.2.

Moreover, when increasing the maximum selling prices of recovery mobile phones of high-end, middle-end and low-end mobile phones by £5, £2 and £2 respectively, it can be seen that only the variables' optimal values of high-end mobile phones have changed to the new optimal value, and the total profit of high-end mobile phones has decreased by 8.51 % compared with the outputs from Table 6.2. On the other hand, the outputs of middle-end and low-end mobile phones have the same optimal outputs and the same total profit as the outputs from Table 6.2.

6.3 Pricing Model II for the Computer Recycling Business

This pricing model is formulated to determine optimal profit-maximising selling prices using Company B introduced in chapter 4 (the computer recycling business) which has applied a waste stream system. This pricing model deals with three main academic contributions as follows:

First, all the papers investigated only one recovery option (Guide Jr. et al., 2003; Vorasayan and Ryan, 2006; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009) or two recovery options (Bakal and Akcali, 2006; and Mitra, 2007) while Pricing Model II explores multiple recovery options i.e. direct resale, repair and refurbishment, which are used in Company B introduced in chapter 4 (the computer recycling business).

Second, only one article has considered a limit to recovery capacity (Mitra, 2007) whereas this pricing model takes more investigation of recovery operations capacity into account. Third, the previous articles modelled the return rate and/or the demand rate as a twice differentiable function (Guide Jr. et al., 2003), a linear function (Bakal and Akcali, 2006; Mitra, 2007; and Xiang et al., 2009) and a constant-elasticity function (Xiang et al., 2009). On the other hand, in this pricing model, demand rate is assumed to be an exponential function. The remainder of this subsection is as follows: model's assumptions, model formulation and results and sensitive analysis.

6.3.1 Model's Assumptions

This section provides the assumptions for the model which are listed below:

- The number of received computers is unlimited.
- Grading, sorting and testing are done by the firm and the duties are perfect (there is no misclassification that leads to defect).
- Yields of all reprocessed computers are perfect.
- The demand rate behaves as a decreasing exponential function of selling price.
- All of the recoverable computers are reprocessed, and all of the reprocessed computers can be resold.
- No fixed costs and monopoly market
- The computer demands of each recovery option are independent, due to the differentials in terms of price, quality, age and specification.
- There is a limit to recovery capacity.
- The model is for a single period, and is not dependent on the product life cycle.
- The business sets the maximum price at which recovered products can be sold.

6.3.2 Model Formulation

The decision variables, the parameters and the pricing model are introduced below:

- **Decisions Variables**

S_1 = Selling price of direct resold computers

S_2 = Selling price of repaired computers

S_3 = Selling price of refurbished computers

- **Parameters**

D_1 = Demand of direct resold computers $(D_1(S_1) = e^{a_1 - b_1 * s_1},\ a_1, b_1 > 0)$

D_2 = Demand of repaired computers $(D_2(S_2) = e^{a_2 - b_2 * s_2},\ a_2, b_2 > 0)$

D_3 = Demand of refurbished computers $(D_3(S_3) = e^{a_3 - b_3 * s_3},\ a_3, b_3 > 0)$

MC = Maximum recovery capacity (units/year)

γ_i = the maximum selling price at which recovered computers can be sold(i = 1, 2, 3)

G = Grading, sorting and testing cost

P_i = Replaced part(s), spare(s) and/or equipment cost (i = 2, 3)

C_i = Operations cost (i = 1, 2, 3)

Next, the pricing model can be formulated as shown in equation 6.9:

- **Objective**

Maximise F = Income –Grading, Sorting, and Testing Cost –Recovery Cost – Replaced Part(s) Cost

$$= \sum S_i * D_i(S_i) - \sum G_i * D_i(S_i) - \sum C_i * D_i(S_i) - \sum P_i * D_i(S_i) \qquad (6.9)$$

- **Constraints**

$$\sum D_i(S_i) \leq MC \qquad (6.10)$$

$$S_i \leq \gamma_i \qquad (6.11)$$

$$S_i \geq G + C_i + P_i \qquad (6.12)$$

$$S_i > 0 \qquad (6.13)$$

Objective function (6.10) maximises the profit of the business from recovered computers sold in the local market. Constraint (6.10) is maximum recovery capacity and Constraint (6.11) ensures that the maximum selling price at which recovered products can be sold. Constraint (6.12) ensures that the firm will set a profitable selling price and Constraint (6.13) is sign restrictions.

6.3.3 Results and Sensitive Analysis

The demand functions, the pricing model and the parameters have been formulated, based on the data collected during the structured interview and secondary data of the number of recovery computers sold in the year 2008. This model is on an annual basis and deterministic. The number of direct resold computers, repaired computers and refurbished computers sold were 101, 548, 609 units, respectively.

The parameters are as follows: G = £3/item, C_1 = £3/item, C_2 = £6/item, C_3 = £3/item, P_1 = £0/item, P_2 = £5/item, P_3 = £77/item, MC = 1000 units/year, γ_1 = £39, γ_2 = £99 and γ_3 = £175. For the analysis, LINGO version 11.0 was used to calculate the outputs. LINGO is one of the most powerful and comprehensive software packages designed to formulate and calculate outputs of linear, nonlinear and integer optimisation models (Lindo Systems Inc., 2008). Table 6.6, Part A shows the initial outputs of this model.

Table 6.6: The Initial Outputs, the Outputs of the Cost Parameters Changes, the Outputs of Capacity Limitation Changes

Part				S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
A	initial outputs			15.52	99.00	138.56	39,298.40
B	G (£/item)			S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	2			15.06	99.00	138.10	40,292.41
	4			16.52	99.00	139.56	38,350.77
C	C_1 (£/item)	C_2 (£/item)	C_3 (£/item)	S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	2.00	5.00	2.00	15.06	99.00	138.10	40,292.41
	4.00	7.00	4.00	16.52	99.00	139.56	38,350.77
D	P_2 (£/item)			S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	4			15.52	99.00	139.56	39,544.81
	6			15.52	99.00	139.56	39,051.99
E	P_3 (£/item)			S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	57			17.07	99.00	120.10	45,210.45
	67			15.95	99.00	128.98	42,012.31
	87			15.52	99.00	148.56	37,027.50
	97			15.52	99.00	158.56	35,130.68
F	Capacity (units/year)			S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	800			19.32	99.00	142.35	38,987.77
	900			16.97	99.00	140.01	39,245.86
	1100			15.52	99.00	138.56	39,298.40
	1200			15.52	99.00	138.56	39,298.40

Table 6.7: The Outputs of the Changes of the Maximum Selling Prices of Recovery Computers

Part	$\gamma_{1(£)}$	$\gamma_{2(£)}$	$\gamma_{3(£)}$	S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
A	29	99	175	15.52	99.00	138.56	39,298.40
	49	99	175	15.52	99.00	138.56	39,298.40
B	39	89	175	15.52	89.00	138.56	38,373.51
	39	109	175	15.52	109.00	138.56	39,962.74
C	39	99	165	15.52	99.00	138.56	39,298.40
	39	99	185	15.52	99.00	138.56	39,298.40

Moreover, during analysis changes were introduced to the cost parameters including grading, sorting and testing cost, recovery operations cost and equipment cost; the outputs of these cost parameters changes are shown in Table 6.6, Part B, C, D and E, respectively. Based on this experiment, it can be concluded that the increase and the decrease of these cost parameters have an impact on the variables' optimal values and the total profit. For example, when decreasing the grading, sorting and testing cost and recovery operations cost by £ 1 per unit, it can be seen that the variables' optimal values change to the new optimal value and the total profit increases by 2.53% compared with the outputs from Table 6.6, Part A.

Furthermore, the limitation of operations capacity was addressed here. Based on the outputs of the experiment as illustrated in Table 6.6 Part F, it is found that the decrease of the capacity limitation has an impact on the variables' optimal values and the total profit. On the other hand, it can be seen that the increase of the capacity limitation does not have an impact on any optimal output of this model. For example, when decreasing the capacity limitation by 100 and 200 units/year, it can be concluded that the variables' optimal values change to the new optimal value and the total profit decreases by 0.13 % and 0.79 % respectively, compared with the outputs from Table 6.6 Part A. In addition, the results show that the optimal selling price of repaired computers was always £99.00, which is the maximum selling price.

More importantly, the maximum selling prices of each recovered computer type has been altered. Based on the results of the experiment as demonstrated in Table 6.7, particularly part B, it is found that only the increase and the decrease of the maximum selling prices of repaired computers have an impact on the variables' optimal values and the total profit. For example, when decreasing the maximum selling prices of these computers by £10, it can be seen that the variables' optimal values change to the new optimal value and the total profit decreases by 2.35% compared with the outputs from Table 6.6 Part A.

6.4 Pricing Model III for the Computer Recycling Business with Product Substitution

This pricing model is formulated to determine optimal profit-maximising selling prices using Company B presented in chapter 4 (the computer recycling business), which has applied a waste stream system. This pricing model deals with four main academic contributions as follows:

First, in the existing academic literature only one recovery option (Guide Jr. et al., 2003; Vorasayan and Ryan, 2006; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009) and two recovery options (Bakal and Akcali, 2006; and Mitra, 2007) were explored. On the other hand, Pricing Model III investigates multiple recovery options i.e. direct resale, repair and refurbishment, which are used in Company B introduced in chapter 4 (the computer recycling business).

Second, only Mitra (2007) took a limit to recovery capacity into account while this pricing model considers more investigation of recovery operations capacity. Third, the proposed pricing models assumed the return rate and/or the demand rate as a twice differentiable function (Guide Jr. et al., 2003), a linear function (Bakal and Akcali, 2006; Mitra, 2007; and Xiang et al., 2009) and a constant-elasticity function (Xiang et al., 2009). By contrast, in Pricing Model III, a demand rate is defined as an exponential function.

Fourth, a product substitution policy has not been given attention in the previous research; on the other hand, Pricing Model III consider this policy as one of the most important assumptions. The assumptions for Pricing Model III are the same as in Pricing Model II, except for the dependent demand assumption. In addition, this assumption is realistic because, according to the result from the questionnaire survey presented in chapter 5, it is found that 75.90 % of the sample would consider product substitute when the desired computer specification of a repaired or refurbished computer is not available. The remainder of this subsection is as follows: model's assumptions, model formulation and results and sensitive analysis.

6.4.1 Model's Assumptions

This section provides the assumptions for the model which are listed below:

- The number of received computers is unlimited.
- Grading, sorting and testing are done by the firm and the duties are perfect (there is no misclassification that leads to defect).
- Yields of all reprocessed computers are perfect.
- The demand rate decreases as an exponential function of selling price.
- All of the recoverable computers are reprocessed and all of the reprocessed computers can be resold.
- No fixed costs and monopoly market

- The computer demands of each recovery option are dependent because there is not much difference in their price, quality, age and specification. So repaired computers and refurbished computers can replace each other.
- There is a recovery capacity limitation
- The model is for a single period, and is not dependent on the product life cycle
- The business sets the maximum price at which recovered products can be sold.

6.4.2 Model Formulation

The decision variables, the parameters and the pricing model are introduced below:

- **Decision Variables**

S_1 = Selling price of direct resold computers

S_2 = Selling price of repaired computers

S_3 = Selling price of refurbished computers

- **Parameters**

D_1 = Demand for direct resold computers $(D_1(S_1) = e^{a_1 - b_1 * S_1},\ a_1, b_1 > 0)$

D_2 = Demand for repaired computers and refurbished computers

$(D_2(S_2, S_3) = e^{a_2 - b_2 * S_2 - c_2 * S_3},\ a_2, b_2, c_2 > 0)$

X_i = Percentage of repaired computers and refurbished computers (i = 2, 3)

MC = Maximum recovery capacity (units/year)

γ_i = the maximum selling price at which recovered computers can be sold(i = 1, 2, 3)

G = Grading, sorting and testing cost

P_i = Replaced part(s), spare(s), and/or equipment cost (i = 2, 3)

C_i = Operations cost (i = 1, 2, 3)

Next, the pricing model can be formulated as shown in equation 6.14.

- **Objective**

Maximise   F = Income –Grading, Sorting, and Testing Cost –Recovery Cost – Replaced Part(s) Cost

$$\begin{aligned} &= S_1 * D_1(S_1) + \sum_{i=2,3} X_i * S_i * D_2(S_2, S_3) - G * [D_1(S_1) + D_2(S_2, S_3)] \\ &\quad - [C_1 * D_1(S_1) + \sum_{i=2,3} X_i * C_i * D_2(S_2, S_3)] - \sum_{i=2,3} X_i * P_i * D_2(S_2, S_3) \end{aligned} \tag{6.14}$$

- **Constraints**

$$D_1(S_1) + D_2(S_2, S_3) \le MC \tag{6.15}$$

$$S_i \le \gamma_i \tag{6.16}$$

$$S_i \ge G + C_i + P_i \tag{6.17}$$

$$S_i > 0 \tag{6.18}$$

Objective function (6.14) maximises the profit of the company from recovered computers sold in the local market. Constraint (6.15) is maximum recovery capacity and Constraint (6.16) ensures that the maximum selling price at which recovered product can be sold. Constraint (6.17) ensures that the firm will set a profitable selling price and Constraint (6.18) is sign restrictions.

6.4.3 Results and Sensitive Analysis

The demand functions, the pricing model and the parameters have been formulated, based on the data collected during the structured interview and secondary data of a number of sold recovery computers in 2008. This model is on an annual basis and deterministic. The parameters are as follows: X_1 = 47%, X_2 = 53%, G = £3/item, C_1 = £3/item, C_2 = £6/item, C_3 = £3/item, P_1 = £0/item, P_2 = £5/item, P_3 = £77/item, MC = 1000 units/year, γ_1 = £39, γ_2 = £99 and γ_3 = £175. LINGO version 11.0 was used to calculate the outputs and the initial outputs of this model are shown in Table 6.8 Part A.

Table 6.8: The Initial Outputs, the Outputs of the Cost Parameters Changes, the Outputs of Capacity Limitation Changes

Part				S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
A	initial outputs			39.00	99.00	117.42	57,164.49
B	G (£/item)			S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	2			39.00	99.00	117.42	58,164.49
	4			16.52	99.00	117.42	56,164.49
C	C_1 (£/item)	C_2 (£/item)	C_3 (£/item)	S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	2.00	5.00	2.00	39.00	99.00	117.42	58,164.49
	4.00	7.00	4.00	39.00	99.00	117.42	56,164.49
D	P_2 (£/item)			S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	4			39.00	99.00	117.42	57,615.33
	6			39.00	99.00	117.42	56,713.66
E	P_3 (£/item)			S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	57			39.00	99.00	117.42	67,332.31
	67			39.00	99.00	117.42	62,248.40
	87			39.00	99.00	117.42	52,080.59
	97			39.00	99.00	117.42	46,996.68
F	Capacity (units/year)			S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
	800			39.00	99.00	126.41	49,145.01
	900			39.00	99.00	121.65	53,273.64
	1100			39.00	99.00	113.60	60,842.45
	1200			39.00	99.00	110.13	64,327.67

Table 6.9: The Outputs of the Changes of the Maximum Selling Prices of Recovery Computers

Part	$\gamma_{1(£)}$	$\gamma_{2(£)}$	$\gamma_{3(£)}$	S_1 (£)	S_2 (£)	S_3 (£)	Total Profit(£)
A	29	99	175	29.00	99.00	120.58	55,572.66
	49	99	175	49.00	99.00	116.37	57,427.18
B	39	89	175	39.00	89.00	120.50	54,220.40
	39	109	175	39.00	109.00	114.34	60,108.58
C	39	99	165	39.00	99.00	117.42	57,164.49
	39	99	185	39.00	99.00	117.42	57,164.49

Moreover, the cost parameters, including grading, sorting and testing cost, recovery operations cost, and equipment cost have been subject to variations as the outputs of these cost parameters changes shown in Table 6.8, Part B, C, D and E, respectively. Based on this experiment, it can be concluded that the increase and the decrease of these cost parameters have an impact on the total profit without any changes in the variables' optimal values. For example, when decreasing the grading, sorting and testing cost and recovery operations cost by £ 1 per unit, it can be seen that the total profit increases by 1.75 % compared with the outputs from Table 6.8 Part A.

Furthermore, the limitation of the operations capacity was addressed here. Based on the outputs of the experiment as illustrated in Table 6.8 Part F, it is found that the increase and the decrease of the capacity limitation have an impact on the variables' optimal values and the total profit. For example, when decreasing the capacity limitation by 100 and 200 units/year, it can be seen that the variables' optimal values change to the new optimal value. The new total profit is £49,145.01 and £53,273.64 decreasing by 14.03 % and 6.81 % respectively, compared with the outputs from Table 6.8 Part A.

More importantly, the maximum selling prices of each recovered computer type have been altered. Based on the results of the experiment as demonstrated in Table 6.9, particularly part C, it is found that only the increase and the decrease of the maximum selling prices of refurbished computers do not have an impact on any optimal output of this model. By contrast, it can be seen that the increase and the decrease of the maximum selling prices of direct resold and repaired computers have an impact on the variables' optimal values and the total profit. For example, when decreasing the maximum selling prices of repaired computers by £10, it is found that the variables' optimal values change to the new optimal value and the total profit decreases by 5.15 % compared with the outputs from Table 6.8 Part A.

Even more importantly, it was found that the solutions of Pricing Model III gave much higher total profit than Pricing Model II. The changes of the cost parameters of Pricing Model II had an impact on the variables' optimal values and the total profit; by contrast, the changes of the cost parameters of Pricing Model III had an impact on the total profit without any changes in the variables' optimal values. The changes of the capacity limitation of the Pricing Model III had an impact on the variables' optimal values and the total profit.

On the other hand, only the decrease of the capacity limitation of Pricing Model II had an impact on the variables' optimal values and the total profit, and the increase in the capacity limitation of Pricing Model II did not have an impact on any optimal output of this model. The results from Pricing Model II found that only the changes in the maximum selling prices of repaired computers had an impact on the variables' optimal values and the total profit whilst the results from Pricing Model III found that only the changes in the maximum selling prices of refurbished computers did not have an impact on any optimal output.

6.5 Conclusion

This chapter presents three pricing models by using a non-linear programming approach to determine optimal profit-maximising acquisition prices and selling prices in the context of the mobile phone recycling industry, and to calculate optimal profit-maximising selling prices in the context of the computer recycling industry. All the proposed pricing models are deterministic. These models aim to investigate the revenue management impact of the multiple recovery options operations. In addition, the proposed models deal with four main academic contributions including multiple recovery options operations, the exponential return and demand rates, recovery capacity limitation and product substitution.

In terms of models' output, the pricing models provide results that have the potential to support decision making based on pricing and revenue management for the recycled mobile phone recycling sector and the recycled computer sector, although the demand functions, the return functions and the parameter were estimated from the structured interview and limited secondary data. The use of an exponential function makes the best approximation for the demand rates and the return rates given the data that were available.

Moreover, the sensitive analysis was carried out in order to investigate the impact of the pricing models' parameters on the optimal prices and total profit. The parameters of Pricing Model I include the cost parameters (i.e. handling cost, repair and refurbishing operations cost, and transportation cost), the minimal acquisition prices of A+ grade mobile phones and the maximum selling prices of reusable mobile phones. On the other hand, the parameters of Pricing Model II and Pricing Model III include the cost parameters (i.e. grading, sorting and testing cost, recovery operations cost and equipment cost), the limitation of operations capacity and the maximum selling prices of each recovered computer type.

The next chapter presents two simulation models. These models are formulated using Company A from chapter 4 which is in the mobile phone recycling business and which has implemented a market-driven system, and using Company B from chapter 4 which is in the computer recycling business and which has applied a waste stream system.

Chapter 7: Simulation Models for Multiple Recovery Options

7.1 Introduction

As all the proposed pricing models presented in chapter 6 are deterministic, this chapter extends the study of the pricing models presented in chapter 6 by formulating two simulation models to deal with the element of uncertainty in terms of return quantity and reprocessing time by assuming return rate is exponentially distributed, and reprocessing time is normally distributed. Pidd (1998) highlighted that probability distributions are employed in such stochastic simulation models and these models are used to mimic a system which behaves stochastically. Moreover, stochastic simulation can be used to assess the impact of the element of uncertainty on a system's behaviour (Shalliker and Ricketts, 2008).

These simulation models are constructed based on Company A from chapter 4 which is in the mobile phone recycling business and which has implemented a market-driven system, and Company B from chapter 4 which is in the computer recycling business and which has applied a waste stream system. Overall, the proposed simulation models identify four main research gaps in academic literature as discussed in section 2.9. First, these simulation models are proposed in order to investigate the revenue management impact of multiple recovery options systems affected by the models' parameters and the results from the questionnaire survey demonstrated in chapter 5 by carrying out "what-if" assessments.

Second, simulation models with multiple periods are investigated. Third, this study takes the element of uncertainty in terms of return quantity and reprocessing time into account. Finally, this research considers product substitution policy. The comparison between the proposed simulation models and the pricing models presented in the previous research is demonstrated in Table 7.1. The remainder of this chapter is built up as follows: Simulation Model I, Simulation Model II and the chapter conclusion.

Table 7.1: Comparison between the Proposed Simulation Models and the Pricing Models Presented in the Previous Research

Author(s)	Model Type	Recovery System	Period	Product Life Cycle	Capacity Constraint	Operations costs	Return /Demand Rate	Decision Variable	Uncertainty	G/S duty	Recovery Actor	Recovery Option	Recovery Method	Product Substitution Policy	Market Issue
Guide Jr. et al. (2003)	EC	MD	S			1,3	NLF	AP, SP		SPs, P	3PL	S	4		MM, SM
Bakal & Akcali (2006)	ST	MD	S			1,2,3,5	LF	AP, SP	YU	RA, P	3PL	T	4,5		MM, SM
Vorasayan & Ryan (2006)	QN	WS	S			2,3,5,6, 7		SP, OT		RA, P	OEM	S	3		MM, PM
Mitra (2007)	NLP	MD	S		x	8	LF	SP		SPs, P	3PL	T	3,4		MM, PM, SM
Qu & Williams (2008)	NLP	MD	M			1,2,3,5	-	AS,OT		RA,P	3PL	S	5		MM,SM
Liang et al. (2009)	ST	MD	M			1,2,3		AP	SPU	RA, P	3PL	S	4		OM, SM
Xiang et al. (2009)	STDP	MD	S			1,2,3,8	LF,NLF	AP, SP	YU,DU	RA, P	3PL	S	4		MM, SM
Pricing Model I	NLP	MD	S			1,2,3,5	NLF	AP, SP		RA, P	3PL	M	1,2,3,5	x	MM, SM
Pricing Model II	NLP	WS	S		x	2,3,4	NLF	SP		RA, P	3PL	M	1,2,3		MM, SM
Pricing Model III	NLP	WS	S		x	2,3,4	NLF	SP		RA, P	3PL	M	1,2,3	x	MM, SM
Simulation Model I	SM	MD	M			1,2,3,5			RU, RPTU	RA, P	3PL	M	1,2,3,5	x	MM, SM
Simulation Model II	SM	WS	M			1,2,3,4			RU, RPTU	RA, P	3PL	M	1,2,3,5		MM, SM

7.2 Simulation Model I for the Mobile Phone Recycling Business

This simulation model is formulated to extend the study of Pricing Model I highlighted in section 6.2 by dealing with the element of uncertainty in terms of return quantity and reprocessing time. Namely, this simulation model assumes that return rate is exponentially distributed and reprocessing time is normally distributed. The proposed model aims to investigate the revenue management impact of a multiple recovery options system affected by the model's parameters and the results from the questionnaire survey demonstrated in chapter 5 by carrying out "what-if" assessments. This model is based on Company A introduced in chapter 4 (the mobile phone recycling industry), which has implemented a market-driven system. This simulation model deals with four main academic contributions as follows:

First, in the previous studies only one recovery option (Guide Jr. et al., 2003; Vorasayan and Ryan, 2006; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009) and two recovery options (Bakal and Akcali, 2006; and Mitra, 2007) were addressed. On the other hand, Simulation Model I explores multiple recovery options operation i.e. direct resale, repair and refurbishment, and recycling, which are employed in Company A (the mobile phone recycling industry). Second, in the existing literature, the element of uncertainty i.e. recovery yield uncertainty (Bakal and Akcali, 2006), selling price uncertainty (Liang et al., 2009), and recovery yield uncertainty and demand uncertainty (Xiang et al., 2009) were considered. On the other hand, this simulation model considers the element of uncertainty in terms of return quantity and reprocessing time.

Third, most of the proposed models (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Vorasayan and Ryan, 2006; Mitra, 2007; and Xiang et al., 2009) considered single-period condition while Simulation model I includes multiple time periods. Fourth, none of the proposed models considered a product substitution policy whereas in this simulation model, this policy is taken into account as one of the most important assumptions. The remainder of this subsection is as follows: model's assumptions, model formulation, and results and sensitive analysis.

7.2.1 Model's Assumptions

This section provides the assumptions for the model which are listed below:

- The mobile phone recycling business buys old mobile phones from its off-line and on-suppliers and it offers higher acquisition prices with an incentive for the off-line suppliers.
- Grading, sorting and testing are done by the firm, and the duties are perfect (there is no misclassification that leads to defect).
- The firm pays more money for higher-grade old mobile phones (A+ grade) and it pays the same price for A grade and B grade mobile phones.
- Yields of all reprocessed products are perfect.
- There is a limit to recovery capacity due to recovery processing time.
- No fixed costs, no travel time and monopoly market.

- The firm sells the recovered mobile phones to a secondary market, such as undeveloped countries. Customers prefer to buy reprocessed products rather than new items due to price differentiation and consumer affordability.
- The demands of direct resold mobile phones and repaired and refurbished mobile phones are dependent because the company sells the recovered mobile phones at the same price, and there is not much difference in their quality. So, direct resold mobile phones and repaired and refurbished mobile phones can be replace each other.
- The model is for a multi-period time scale and is not dependent on the product life cycle.
- All received mobile phones have the same handling costs.
- The characteristics of all the inspecting workstations are identical, and also the characteristics of all the repairing and refurbishing workstations are identical.
- Return rates are exponentially distributed, and repair and refurbishing processing time is normally distributed.
- Due to the ease of traceability, this study assumes that the reprocessing layout is cellular manufacturing.

7.2.2 Model Formulation

This research work uses the SIMUL8 simulation software package to formulate the simulation model. The software package is developed by the SIMUL8 Corporation. It is one of the most powerful simulation software packages available and is also user-friendly (SIMUL8 Corporation, 2001). Model construction is in accordance with the recovery process of Company A presented in subsection 4.3.1 of this thesis. Simulation Model I is illustrated in Figure 7.1 and the number of work stations for each procedure and storage capacity are listed in Table 7.2. The performance measurement of the system is the total profit as shown in equation 7.1.

$$\textit{Total profit} = \textit{Income} - \textit{Acquisition Cost} - \textit{Handling Costs} - \textit{Recovery Cost} - \textit{Transportation cost} \quad (7.1)$$

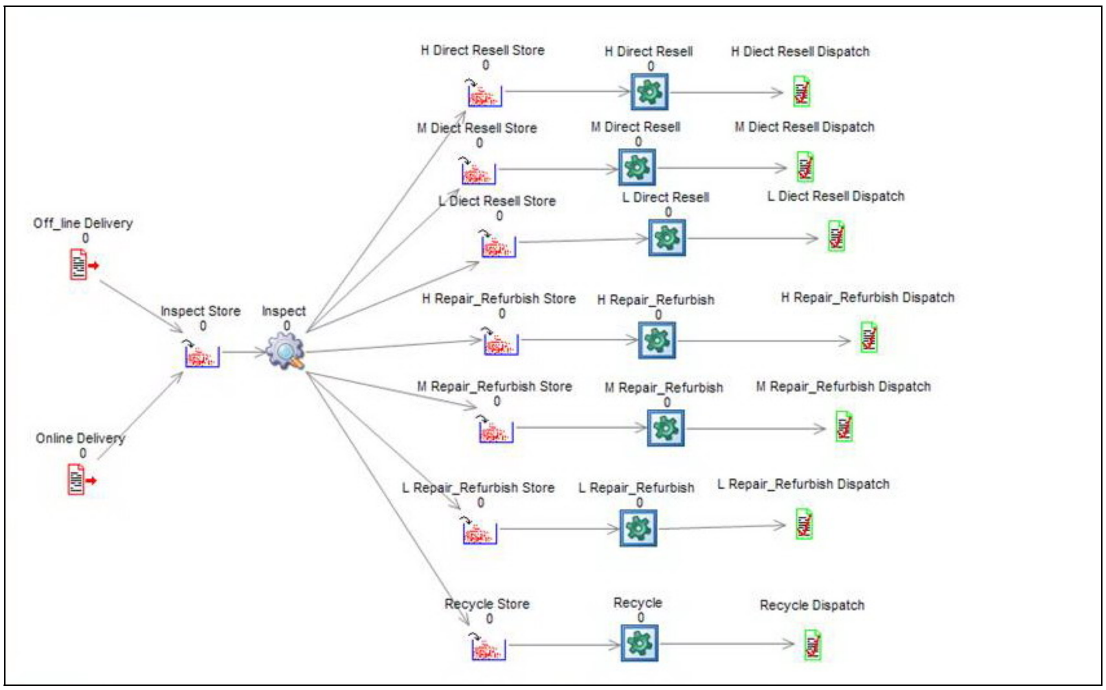

Figure 7.1: Simulation Model I

Table 7.2: Number of Workstations for Each Procedure and Storage Capacity

Workstation	No. of work centres
Inspect	140
High-end direct resale	1
Mid-range direct resale	1
Low-end direct resale	1
High-end repair and refurbish	10
Mid-range repair and refurbish	25
Low-end repair and refurbish	35
Recycle	1
Capacity of all storage	infinite

7.2.3 Results and Sensitive Analysis

The return rate of received mobile phones from each reverse channel, the inspecting time, the repairing and refurbishing time and other parameters are estimated, based on the data from the structured interview, since the firm could not provide all required data for the analysis due to commercial reasons. This model performs on a fortnightly basis. The parameters of the simulation model are listed in Tables 7.3 and 7.4.

Table 7.3: Parameters of the Simulation Model I

Total return (2009)	2.2M units/year
Offline return (75%)	1.65M units/year
Online return (25%)	0.55M units/year
Working time	80 hrs/ 2 weeks
Warm-up period	8 hrs.
Incentive cost for offline suppliers	1.2 pounds/unit
Collection Cost	1.5 pounds/unit
Labour Cost	6 pounds/hr.
Transportation cost	0.5 pound/unit

Table 7.4: Return Rate and Operating Times the Simulation Model I

	Distribution	**Mean (hr.)**	**units/batch**
Return rate			
Off-line	Exponential	0.1	79
On-line	Exponential	0.1	26
Operating time	**Distribution**	**Mean (hr.)**	**S.D.**
Inspect	Normal	0.130	0.0325
Direct resale	Fixed	0	-
Repair and Refurbish	Normal	0.3	0.075
Recycle	Fixed	0	-

The SIMUL8 2010 (Exclusive education site edition) software package was used to generate the outputs. Shalliker and Ricketts (2008) suggested that the use of more replicates or runs of a simulation would provide a better and more reliable estimate for the range within the throughput which will lie on 95% of periods. Hence, before calculating the results, a required number of runs are estimated by using the "Calculate Required Number of Runs" menu of the software package in order to get better estimates for the mean and standard deviation.

The result based on the number of received mobile phones from both channels shows that the recommended number of runs is seven using a confidence interval of 95%. The study used one random number set and also five random number sets to deal with more uncertainty. The initial outputs of Simulation Model I and the results comparison between Simulation Model I and Pricing Model I are shown in Table 7.5.

From Table 7.5, the outputs show that the total profit based on one random number set and five random number sets are £305,153.99 and £305,050.98, respectively. Moreover, the initial results from Simulation Model I and Pricing Model I (£336,163.20) are relatively similar. Next, the sensitive analysis is conducted. This analysis includes six scenarios as follows: labour cost changes, recovering time changes, selling price changes, recovery efficiency changes, percentage changes of mobile phone types and new strategy implementation: higher offer price. The first, second, third, and fourth scenarios are affected by the model's parameters; on the other hand, the fifth and sixth scenarios are based on the results from the questionnaire survey presented in section 5.3 of this thesis.

Table 7.5: The Initial Outputs of Simulation Model I and Results Comparison between Simulation Model I and Pricing Model I

Simulation Object	Performance Measure	One random number set			Five random number sets			Pricing Model I
		-95%	Average	95%	-95%	Average	95%	
Off-line Delivery	No. Entered	61,495.85	64,125.43	66,755.01	61,574.25	63,572.43	65,570.61	
Online Delivery	No. Entered	20,471.42	20,944.86	21,418.29	20,067.78	20,956.00	21,844.22	
Inspect	No. Completed	81,675.16	83,640.86	85,606.55	81,659.51	83,557.29	85,455.06	
H Direct Resale Dispatch	No. Completed	5,495.80	5,631.43	5,767.06	5,530.41	5,655.43	5,780.45	
M Direct Resale Dispatch	No. Completed	12,887.62	13,212.86	13,538.10	12,801.98	13,148.57	13,495.16	
L Direct Resale Dispatch	No. Completed	18,383.56	18,841.14	19,298.73	18,416.07	18,858.86	19,301.64	
H Repair and Refurbish Dispatch	No. Completed	2,662.94	2,677.71	2,692.49	2,646.47	2,661.00	2,675.53	
M Repair and Refurbish Dispatch	No. Completed	6,661.24	6,674.57	6,687.90	6,653.18	6,668.00	6,682.82	
L Repair and Refurbish Dispatch	No. Completed	9,317.44	9,345.14	9,372.85	9,307.12	9,339.14	9,371.16	
Recycle Dispatch	No. Completed	12,251.86	12,510.57	12,769.28	12,237.91	12,535.71	12,833.52	
Simulation Total	Total Costs (£)	938,789.59	962,729.30	986,669.01	941,038.81	962,449.74	983,860.66	
Simulation Total	Total Revenue (£)	1,247,096.78	1,267,883.29	1,288,669.80	1,247,878.42	1,267,500.71	1,287,123.00	
Simulation Total	Total Profit (£)	301,173.65	305,153.99	309,134.32	301,261.60	305,050.98	308,840.36	336,163.20

Labour Cost Changes

It has been decided to alter the labour cost in order to forecast possible fluctuations and impacts on profit. Based on the results of the experiment, when decreasing the cost by £1 and when increasing the cost by £1 and £2, it is found the total profit has increased by 5.38% (one random number set) and 5.41% (five random number sets); decreased by 5.39% (one random number set) and 5.41% (five random number sets), decreased by 10.78% (one random number set) and 10.81% (five random number sets), respectively, compared with the outputs from Table 7.5. Figure 7.2 depicts the total profit impact of the labour cost changes.

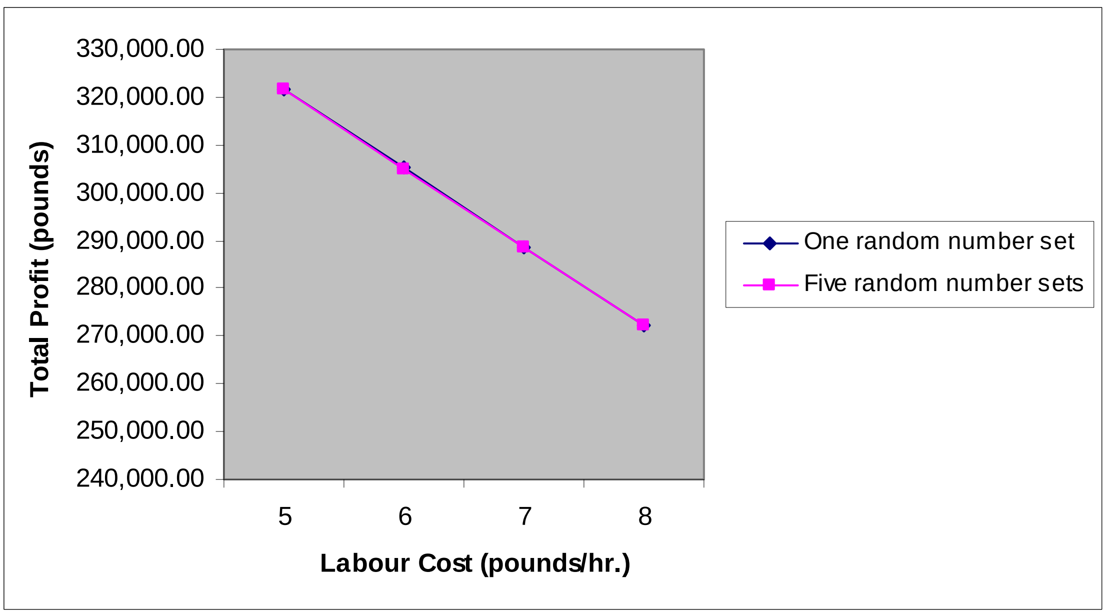

Figure 7.2: Total Profit Impact of the Labour Cost Changes

Recovering Time Changes

During analysis, changes were introduced to the inspecting time and the repairing and refurbishing time. In accordance with the outputs of the inspecting time changes, when decreasing the inspecting time by 10 %, normally distributed with mean 0.117 hour and standard deviation 0.029, it is indicated that the total profit has increased by 3.17 % (one random number set) and 2.18 % (five random number sets) compared with the results from Table 7.5.

When increasing the inspecting time by 10 %, normally distributed with mean 0.143 hour and standard deviation 0.036 and by 20 %, normally distributed with mean 0.156 hour and standard deviation 0.039, it is found that the total profit has decreased by 5.81 % (one random number set) and 5.83% (five random number sets) and decreased by 12.01% (one random number set) and 12.05% (five random number sets), respectively, compared with the outputs from Table 7.5. Figure 7.3 demonstrates the total profit impact of the inspecting time changes.

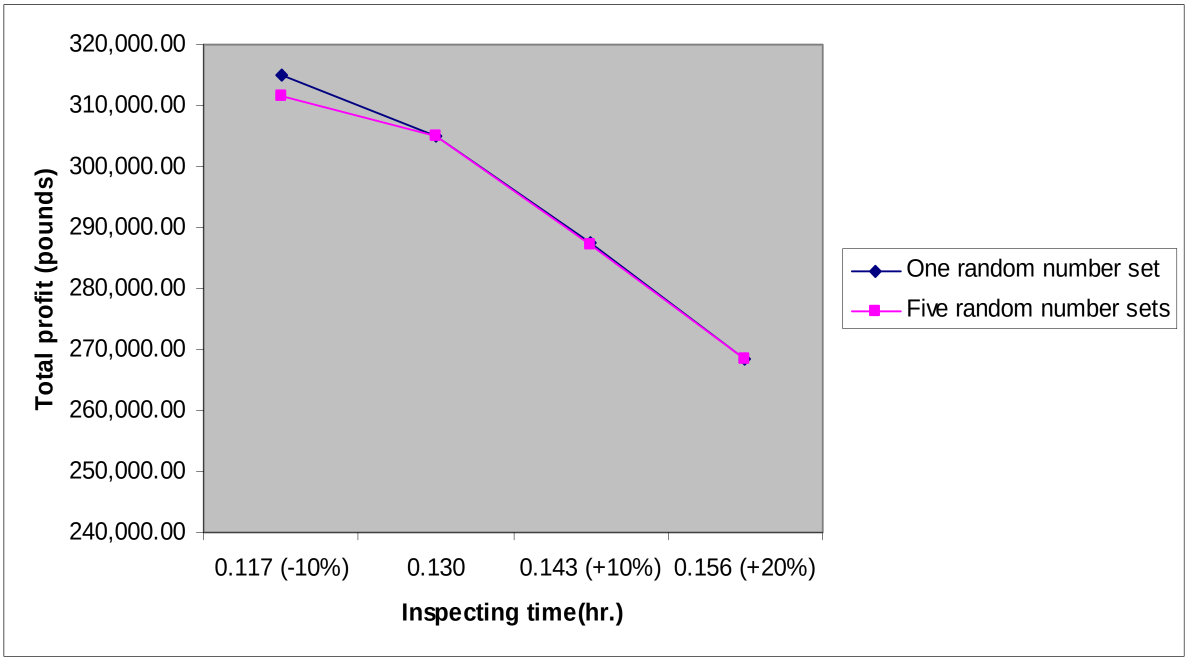

Figure 7.3: Total Profit Impact of the Inspecting Time Changes

With respect to the outputs of the repairing and refurbishing time changes, when decreasing the time by 10 %, normally distributed with mean 0.27 hour and standard deviation 0.068, it is found that the total profit has increased by 13.18 % (one random number set) and 13.12 % (five random number sets) compared with the results from Table 7.5.

When increasing the time by 10 %, normally distributed with mean 0.33 hour and standard deviation 0.083 and by 20 %, normally distributed with mean 0.36 hour and standard deviation 0.09, it is found that the total profit has decreased by 10.79 % (one random number set) and 10.67 % (five random number sets) and decreased by 19.76 % (one random number set) and 19.70 % (five random number sets), respectively, compared with the outputs from Table 7.5. Figure 7.4 demonstrates the total impact on profit of the repairing and refurbishing time changes. Hence, it can be concluded that the repairing and refurbishing time changes have more impact on the total profit than the inspecting time changes have.

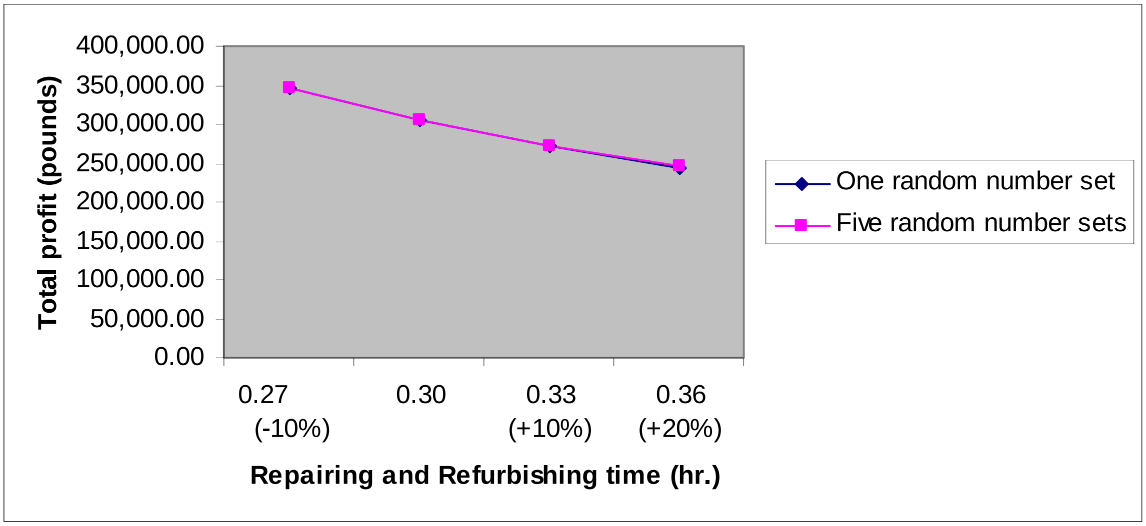

Figure 7.4: Total Profit Impact of the Repairing and Refurbishing Time Changes

Selling Price Changes

To allow the measurement of the impact on profit margins, was decided to alter the selling prices of high-end, mid-range, and low-end mobile phones by decreasing the prices by 10% and by increasing the prices by 10% and 20%. The results of the experiment are demonstrated in Figure 7.5: the total profit impact of the selling prices changes of high-end mobile phones, Figure 7.6: the total profit impact of the selling prices changes of mid-range mobile phones, Figure 7.7: the total profit impact of the selling prices changes of low-end mobile phones and Table 7.6: comparison of the total profit impact between the selling prices of high-end, mid-range and low-end mobile phones.

From Table 7.6, it can be concluded that the selling price changes of high-end handsets have the most significant influence on the total profit. This implies that the firm has to apply caution when making the decision to alter the selling prices of high-end handsets.

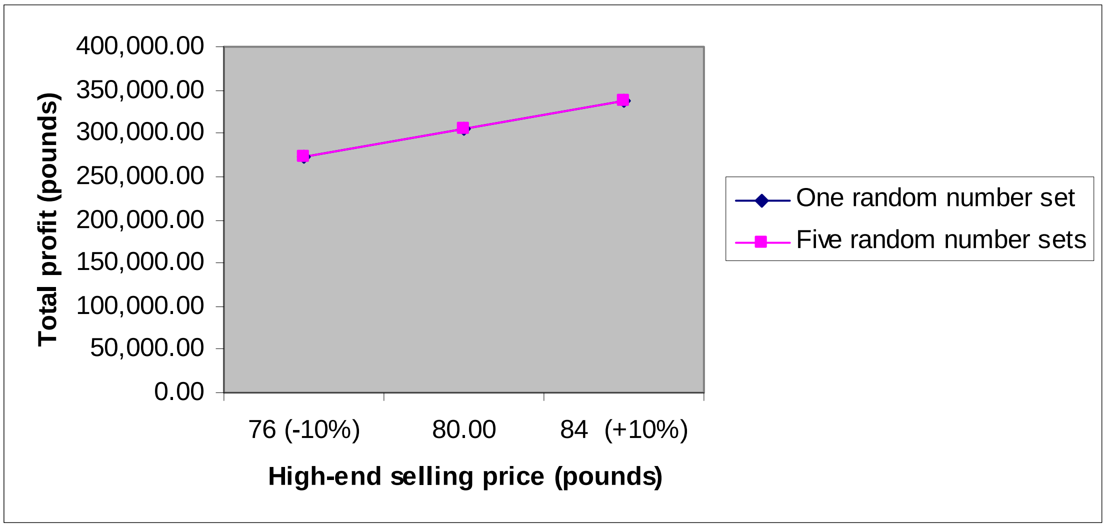

Figure 7.5: Total Profit Impact of the Selling Prices Changes of High-end Mobile Phones

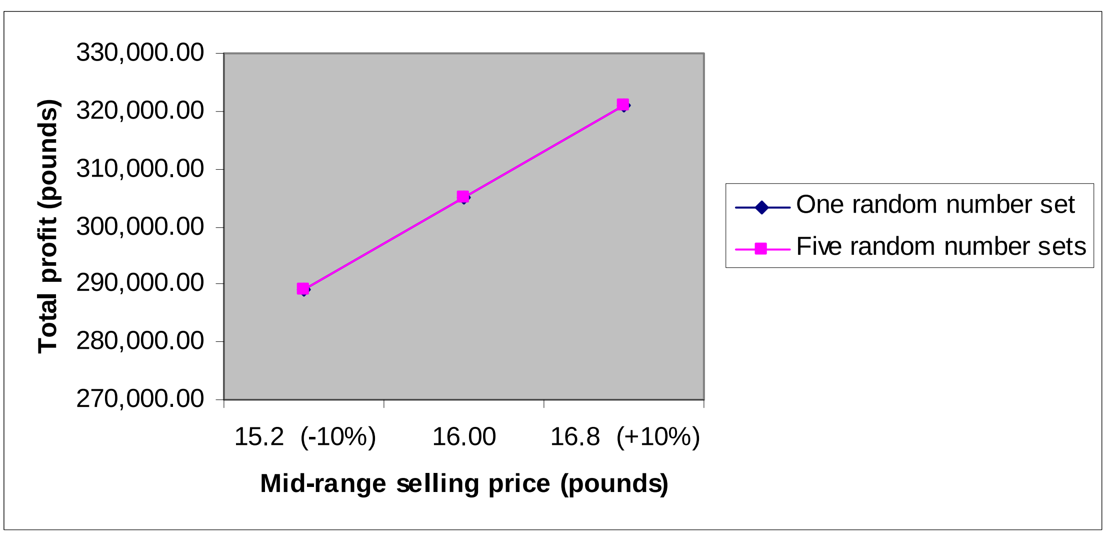

Figure 7.6: Total Profit Impact of the Selling Prices Changes of Mid-range Mobile Phones

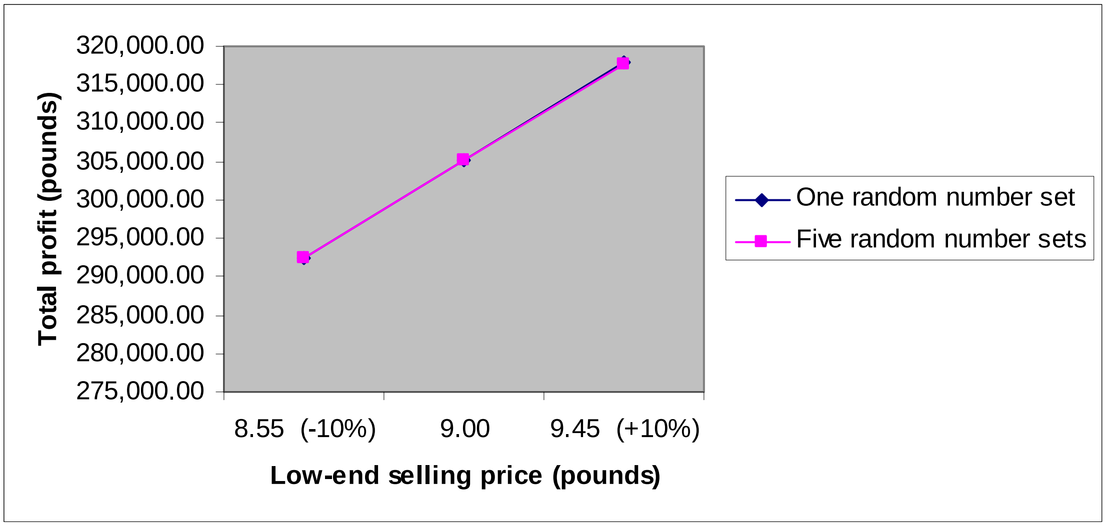

Figure 7.7: Total Profit Impact of the Selling Prices Changes of Low-end Mobile Phones

Table 7.6: Comparison of the Total Profit Impact between Selling Prices of High-end, Mid-range and Low-end Mobile Phones

Selling price (£)	Total profit (£)		Total profit impact (%)	
High-end handsets	One random number set	Five random number sets	One random number set	Five random number sets
76 (-10%)	271,917.41	271,785.26	-10.89	-10.90
84 (+10%)	338,390.56	338,316.69	10.89	10.90
Mid-range handsets	One random number set	Five random number sets	One random number set	Five random number sets
15.2 (-10%)	289,244.04	289,197.72	-5.21	-5.20
16.8 (+10%)	321,063.93	320,904.24	5.21	5.20
Low-end handsets	One random number set	Five random number sets	One random number set	Five random number sets
8.55 (-10%)	292,470.16	292,361.88	-4.16	-4.16
9.45 (+10%)	317,837.81	317,740.08	4.16	4.16

Table 7.7: Comparison of the Total Profit Impact between Recovery Efficiency Changes of Inspecting, and Repairing and Refurbishing Workstations

Efficiency (%)	Total profit (£)		Total profit impact (%)	
Inspecting	One random number set	Five random number sets	One random number set	Five random number sets
95.00	297,283.31	296,986.69	-2.58	-2.68
90.00	285,832.66	286,165.12	-6.33	-6.22
Repairing and refurbishing	One random number set	Five random number sets	One random number set	Five random number sets
95.00	286,881.16	287,052.16	-5.99	-5.93
90.00	269,809.27	269,933.23	-11.58	-11.54

Recovery Efficiency Changes

Recovery efficiency is one of the most imperative parameters impacting on the system performance measurement. This experiment introduced changes to the recovery efficiency of the inspecting workstations and the repairing and refurbishing workstations. It is assumed that the recovery efficiency is 95% and 90% as shown in the results presented in Table 7.7. The outputs from Table 7.7 shows that the recovery efficiency changes of the repairing and refurbishing work centres have more influence on the total profit than the recovery efficiency changes of the inspecting work centres have. This means that the recycling firm has to take the recovery efficiency of the repairing and refurbishing workstations into account when forecasting and calculating costs.

Percentage Changes of Mobile Phone Types

When analysing the results from the questionnaire survey presented in section 5.3 of this thesis, it is found that the current percentage of used high-end, mid-range and low-end mobile phone types are 27.68, 57.28 and 15.04 %, respectively. Hence, these figures are used as potential received handset types to carry out 'what-if' assessments in this study; the results are shown in Table 7.8. It can be seen that the number of repaired and refurbished handsets is comparable to the results presented Table 7.5 and that the total profit has increased by 11.61% (one random number set) and 11.42 % (five random number sets) compared with the outputs from Table 7.5.

Table 7.8: Total Profit Impact When Changing the Percentage of Received High-end, Mid-range and Low-end Mobile Phones

Simulation Object	Performance Measure	One random number set			Five random number sets		
		-95%	Average	95%	-95%	Average	95%
Off-line Delivery	No. Entered	61,495.85	64,125.43	66,755.01	61,574.25	63,572.43	65,570.61
Online Delivery	No. Entered	20,471.42	20,944.86	21,418.29	20,067.78	20,956.00	21,844.22
Inspect	No. Completed	81,675.16	83,640.86	85,606.55	81,659.51	83,557.29	85,455.06
H Direct Resale Dispatch	No. Completed	10,242.30	10,467.86	10,693.41	10,219.80	10,464.43	10,709.06
M Direct Resale Dispatch	No. Completed	20,978.90	21,553.29	22,127.67	20,946.72	21,481.57	22,016.42
L Direct Resale Dispatch	No. Completed	5,547.06	5,664.29	5,781.52	5,570.80	5,716.86	5,862.92
H Repair_Refurbish Dispatch	No. Completed	2,663.40	2,677.14	2,690.89	2,646.13	2,660.29	2,674.44
M Repair_Refurbish Dispatch	No. Completed	6,659.98	6,674.29	6,688.59	6,652.43	6,667.00	6,681.57
L Repair_Refurbish Dispatch	No. Completed	4,933.51	5,050.57	5,167.63	4,898.28	4,998.57	5,098.86
Recycle Dispatch	No. Completed	12,251.86	12,510.57	12,769.28	12,237.91	12,535.71	12,833.52
Simulation Total	Total Costs (£)	1,259,160.06	1,290,355.87	1,321,551.69	1,258,169.58	1,288,252.31	1,318,335.04
Simulation Total	Total Revenue (£)	1,601,187.65	1,630,951.29	1,660,714.92	1,597,902.84	1,628,132.43	1,658,362.02
Simulation Total	Total Profit (£)	338,211.85	340,595.41	342,978.98	336,423.54	339,880.12	343,336.70

Table 7.9: Total Profit Impact When Changing Percentage of Received High-end, Mid-range and Low-end Mobile Phones and Adjusting the Number of Workstations

Simulation Object	Performance Measure	One random number set			Five random number sets		
		-95%	Average	95%	-95%	Average	95%
Off-line Delivery	No. Entered	61,495.85	64,125.43	66,755.01	61,574.25	63,572.43	65,570.61
Online Delivery	No. Entered	20,471.42	20,944.86	21,418.29	20,067.78	20,956.00	21,844.22
Inspect	No. Completed	81,675.16	83,640.86	85,606.55	81,659.51	83,557.29	85,455.06
H Direct Resale Dispatch	No. Completed	10,242.30	10,467.86	10,693.41	10,219.80	10,464.43	10,709.06
M Direct Resale Dispatch	No. Completed	20,978.90	21,553.29	22,127.67	20,946.72	21,481.57	22,016.42
L Direct Resale Dispatch	No. Completed	5,547.06	5,664.29	5,781.52	5,570.80	5,716.86	5,862.92
H Repair_Refurbish Dispatch	No. Completed	5,329.55	5,346.00	5,362.45	5,309.07	5,327.14	5,345.21
M Repair_Refurbish Dispatch	No. Completed	10,663.99	10,687.14	10,710.29	10,653.27	10,677.14	10,701.01
L Repair_Refurbish Dispatch	No. Completed	2,663.80	2,671.86	2,679.91	2,650.47	2,662.29	2,674.10
Recycle Dispatch	No. Completed	12,251.86	12,510.57	12,769.28	12,237.91	12,535.71	12,833.52
Simulation Total	Total Costs (£)	1,276,776.92	1,307,811.05	1,338,845.18	1,276,140.22	1,305,793.20	1,335,446.18
Simulation Total	Total Revenue (£)	1,857,769.82	1,887,257.14	1,916,744.46	1,854,766.12	1,884,616.71	1,914,467.31
Simulation Total	Total Profit (£)	576,620.40	579,446.09	582,271.79	575,484.27	578,823.51	582,162.76

Therefore, it is suggested that the company needs to adjust the number of repairing and refurbishing work centres as required by the new proportion of handset classes. In order to forecast profit margin changes, it was decided to change the number of the recovering workstations for high-end, mid-range and low-end mobile phones from 10, 25, and 35 to 20, 40 and 10 workstations, respectively, due to the current percentage of used high-end, mid-range and low-end mobile phone types. After altering the number of workstations, the result from Table 7.9 indicates that the number of high-end/mid-range repaired and refurbished handsets has increased and the total profit has also increased by 89.89% (one random number set) and 89.75% (five random number sets) compared with the outputs from Table 7.5.

New Strategy Implementation: Higher Offer Price

The other results from the questionnaire survey presented in section 5.3 highlighted that the company should use Strategy 2: higher offer price as an order-winner to persuade customers to trade-in their used phone on its website. The 'what-if' assessments are carried out in order to investigate how this strategy would impact on the firm's total profit. It is decided to increase the offer prices of mid-range and high-end handsets (A and B grade handsets) which need to be repaired and refurbished because the offer prices of these mobile phone types are very low and the firm has high profit margin from these handset classes.

When increasing the offer prices, it is assumed that the number of received mobile phones will increase; as a result, there is a need to increase the number of repairing and refurbishing workstations. The results of this experiment are demonstrated in Table 7.10.

The outputs from scenario II, IV and V have a positively significant impact on the total profit.

7.3 Simulation Model II for the Computer Recycling Business

This simulation model is constructed in order to extend the study of Pricing Model II highlighted in section 6.3 by dealing with the element of uncertainty in terms of return quantity and reprocessing time. Namely, in Simulation Model II, return rate and reprocessing time are defined as exponential distribution and normal distribution, respectively. The primary objective of the simulation model is to investigate the revenue management impact of multiple recovery options systems affected by the model's parameters, and the results from the questionnaire survey presented in chapter 5 by carrying out "what-if" assessments. This model is based on Company B introduced in chapter 4 (the computer recycling business), which has applied a waste stream system.

This simulation model deals with three main academic contributions as follows: first, the proposed models considered only one recovery option (Guide Jr. et al., 2003; Vorasayan and Ryan, 2006; Qu and Williams, 2008; Liang et al., 2009; and Xiang et al., 2009) and two recovery options (Bakal and Akcali, 2006; and Mitra, 2007). On the other hand, Simulation Model II investigates multiple recovery options operation i.e. direct resale, repair, refurbishment and recycling, which are employed in Company B (the computer recycling industry).

Second, in the previous research, the element of uncertainty i.e. recovery yield uncertainty (Bakal and Akcali, 2006), selling price uncertainty (Liang et al., 2009), and recovery yield uncertainty and demand uncertainty (Xiang et al., 2009) were considered. On the other hand, this simulation model involves the element of uncertainty in terms of return quantity and reprocessing time. Third, most of the articles (Guide Jr. et al., 2003; Bakal and Akcali, 2006; Vorasayan and Ryan, 2006; Mitra, 2007; and Xiang et al., 2009) proposed models with a single time period while Simulation model II considers multiple time periods. The remainder of this subsection is as follows: model's assumptions, model formulation, and results and sensitive analysis.

Table 7.10: Total Profit Impact of New Strategy Implementation: Higher Offer Price

Scenario	Offer prices (£)	Return rate	Capacity	Total profit (£)		Total profit impact (%)	
				One random number set	Five random number sets	One random number set	Five random number sets
I	+ 20%	+10%	+10%	302,921.42	302,936.33	-0.73	-0.69
II	+ 20%	+10%	+ 20%	333,990.67	330,868.08	9.45	8.46
III	+ 30%	+10%	+ 20%	305,113.46	302,108.01	-0.01	-0.96
IV	+ 30%	+10%	+ 30%	334,659.14	331,640.04	9.67	8.72
V	+ 30%	+20%	+ 30%	331,839.46	329,359.71	8.74	7.97
VI	+ 40%	+20%	+ 30%	300,410.61	298,057.71	-1.55	-2.29
VII	+ 40%	+20%	+ 40%	324,109.21	321,205.07	6.21	5.30
VIII	+ 40%	+30%	+ 40%	321,399.19	319,104.96	5.32	4.61

7.3.1 Model's Assumptions

This section provides the assumptions for the model which are listed below:

- Grading, sorting, and testing are done by the firm and the duties are perfect (there is no misclassification that leads to defect).
- Yields of all reprocessed computers are perfect.
- All of the received computers are reprocessed, and all of the reprocessed computers can be resold.
- No fixed costs, no travel time and monopoly market.
- The computer demands of each recovery option are independent, due to the differentials in terms of price, quality, age and specification.
- There is a limit to recovery capacity due to recovery processing time.
- The model is for a multi-period time, and is not dependent on the product life cycle.
- The characteristics of workstations of each recovery type are identical.
- Return rates are exponentially distributed, and all reprocessing time is normally distributed.
- Due to the ease of traceability, this study assumes that the reprocessing layout is cellular manufacturing.

7.3.2 Model Formulation

This simulation model is also formulated by using the SIMUL8 simulation software package developed by the SIMUL8 Corporation. Model formulation is in reference to the recovery process of Company B presented in subsection 4.4.1 of this thesis. Simulation Model II is illustrated in Figure 7.8 and the number of workstations for each procedure and storage capacity are listed in Table 7.11. The performance measurement of the system is the total profit as shown in equation 7.2.

Total profit = Income –Grading, Sorting, and Testing Cost –Recovery Cost – Replaced Part(s) Cost (7.2)

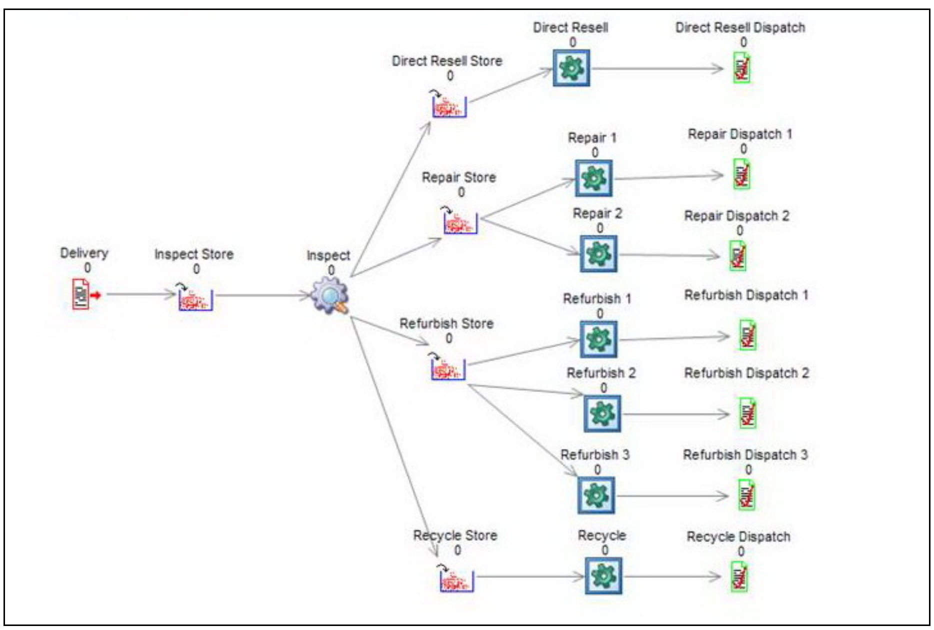

Figure 7.8: Simulation Model II

Table 7.11: Number of Work Stations for Each Procedure and Storage Capacity

Work Station	No. of work centres
Inspect	1
Direct resale	1
Repair I	1
Repair II	1
Refurbish I	1
Refurbish II	1
Refurbish III	1
Recycle	1
Capacity of all storage	infinite

7.3.3 Results and Sensitive Analysis

The return rate of received computers, all the reprocessing times and other parameters are estimated, based on the data collected during the structured interview and secondary data for the number of recovered computers sold in the year 2008. This model is on an annual basis. The parameters of the simulation model are listed in Tables 7.12, 7.13 and 7.14.

Table 7.12: Parameters of Simulation Model II

Total return	3718 unit/year
Working time	2080 hrs/year
Warm-up period	8 hrs.
Labour Cost	6 pounds/hr.

Table 7.13: Parameters of Simulation Model II

Types of computer	Percentage	Replaced part cost	Selling price/ unit
Direct Resale	1%	-	£39
Repair I			£75
Repair II	9%	£5	£99
Refurbish I		£60	£125
Refurbish II		£75	£150
Refurbish III	10%	£75	£175
Recycle	80%	-	£1.12[6]

Table 7.14: Return Rate and Operating Times of Simulation Model II

	Distribution	Mean (hr.)	S.D.
Return rate	Exponential	0.55	-
Operating time			
Inspect	Normal	0.5	0.125
Direct resale	Normal	0.5	0.125
Repair	Normal	1	0.25
Refurbish	Normal	0.5	0.125
Recycle	Normal	0.6	0.15

It is recommended that the use of more replicates or runs of a simulation would provide a better and more reliable estimate for the range within the throughput which will lie on 95% of periods (Shalliker and Ricketts, 2008). Hence, before calculating the results, a required number of runs are estimated by using the "Calculate Required Number of Runs" menu of the software package in order to get better estimates for the mean and standard deviation. The result based on the number of received computers confirms that the recommended number of runs is four using a confidence interval of 95%. Moreover, the study used one random number set and also three random number sets to deal with more uncertainty. The

[6] This figure is estimated from secondary data for the number of recovered computers sold in the year 2008 and the paper presented by Lee et al. (2004).

initial outputs of Simulation Model II and the results comparison between Pricing Model II and Simulation Model II are shown in Table 7.15.

From Table 7.15, the outputs show that the total profit based on one random number set and four random number sets are £37,697.55 and £37,075.80 respectively because the numbers of recovered computers are slightly different. Moreover, the initial results from Simulation Model II and Pricing Model II (£39,298.40) are relatively similar.

Next, the sensitive analysis is conducted. This analysis includes seven scenarios as follows: labour cost changes, recovering time changes, replaced part cost changes, selling price changes, recovery efficiency changes, new strategy implementation: offering cash back, and new strategy implementation: free collection service. The first, second, third, fourth and fifth scenarios are affected by the model's parameters; on the other hand, the sixth and seventh scenarios are based on the results from the questionnaire survey presented in section 5.4 of this thesis.

Table 7.15: The Initial Outputs of Simulation Model II and Results Comparison between Pricing Model II and Simulation Model II

Simulation Object	Performance Measure	One random number set			Three random number sets			Pricing Model II
		-0.95	Average	0.95	-0.95	Average	0.95	
Delivery	Number Entered	3,657.50	3,736.50	3,815.50	3,702.81	3,752.25	3,801.69	
Direct Resale Dispatch	Number Completed	29.97	41.25	52.53	32.89	37.00	41.11	
Repair Dispatch 1	Number Completed	148.39	173.00	197.61	148.57	171. 75	194.93	
Repair Dispatch 2	Number Completed	148.83	171.75	194.67	149.93	171.00	192.07	
Refurbish Dispatch 1	Number Completed	117.61	123.75	129.89	115.77	123.00	130.23	
Refurbish Dispatch 2	Number Completed	118.07	124.50	130.93	115.10	123.25	131.40	
Refurbish Dispatch 3	Number Completed	116.77	124.00	131.23	115.10	123.00	130.90	
Recycle Dispatch	Number Completed	2,893.53	2,976.75	3,059.97	2,981.34	3,003.25	3,025.16	
Simulation Total	Total Costs (£)	51,257.42	53,067.16	54,876.89	50,906.49	52,928.59	54,950.69	
Simulation Total	Total Revenue (£)	84,896.06	90,764.71	96,633.36	84,211.32	90,004.39	95,797.46	
Simulation Total	Total Profit (£)	33,270.12	37,697.55	42,124.99	33,057.22	37,075.80	41,094.38	39,298.40

Labour Cost Changes

It was decided to vary the labour cost to allow the analysis of fluctuations in profit. Based on the results of the experiment, when decreasing the cost by £1 and when increasing the cost by £1 and £2, the results show that the total profit has increased by 11.18% (one random number set) and 11.40% (three random number sets), decreased by 11.18% (one random number set) and 11.40% (three random number sets), decreased by 12.58% (one random number set) and 12.87% (three random number sets) respectively, compared with the results from Table 7.15. Figure 7.9 shows the total profit impact of the labour cost changes.

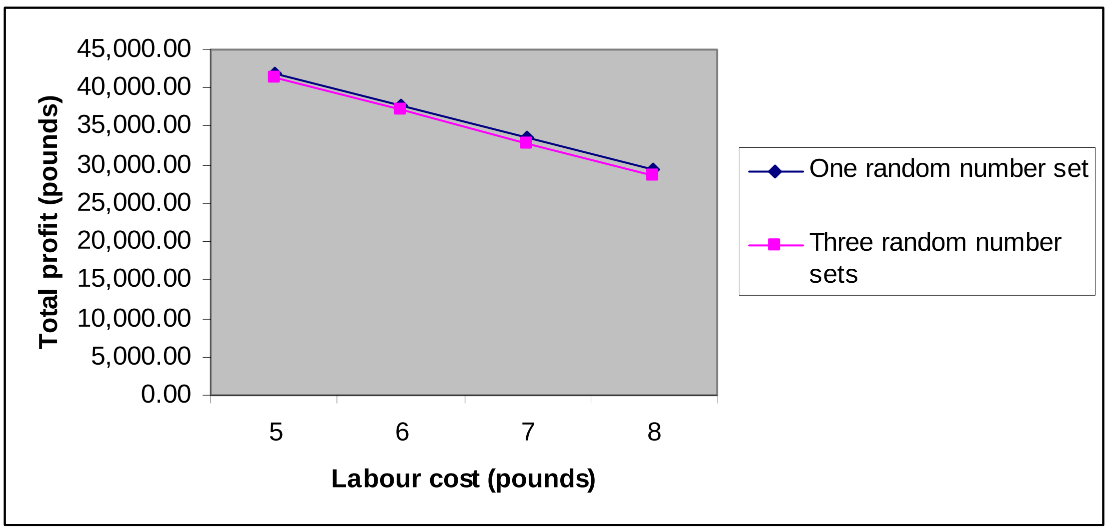

Figure 7.9: Total Profit Impact of the Labour Cost Changes

Recovering Time Changes

During analysis, changes were introduced to the recovering time i.e. inspecting time, direct resale processing time, repairing time, refurbishing time and recycling time. These changes include decreasing the time by 10% and increasing the time by 10% and 20%. The total profit impact of these time changes are demonstrated in Figures 7.10, 7.11, 7.12, 7.13, 7.14 and Table 7.16. The outputs from Table 7.16 indicate the changes in inspecting time have the most impact on the total profit of the system.

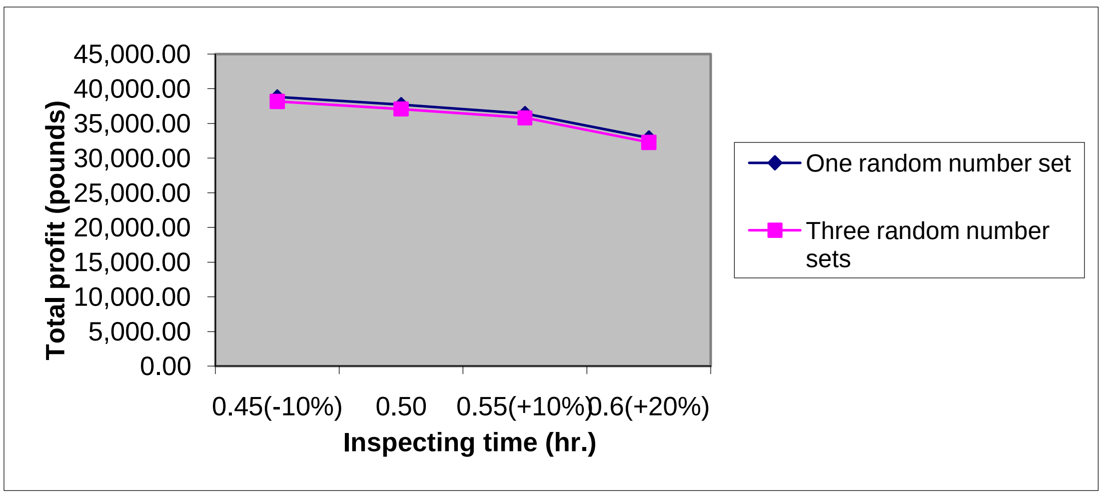

Figure 7.10: Total Profit Impact of the Inspecting Time Changes

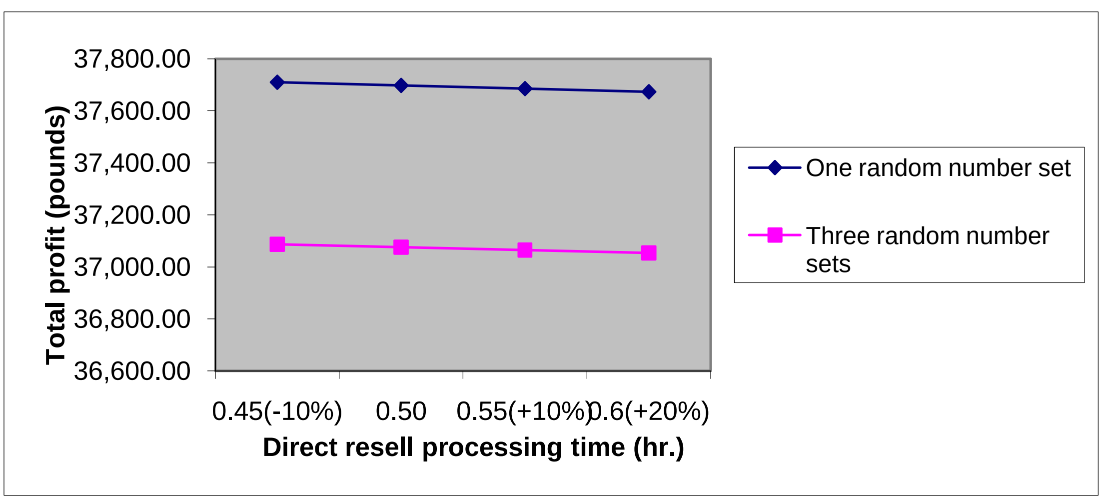

Figure 7.11: Total Profit Impact of the Direct Resale Processing Time Changes

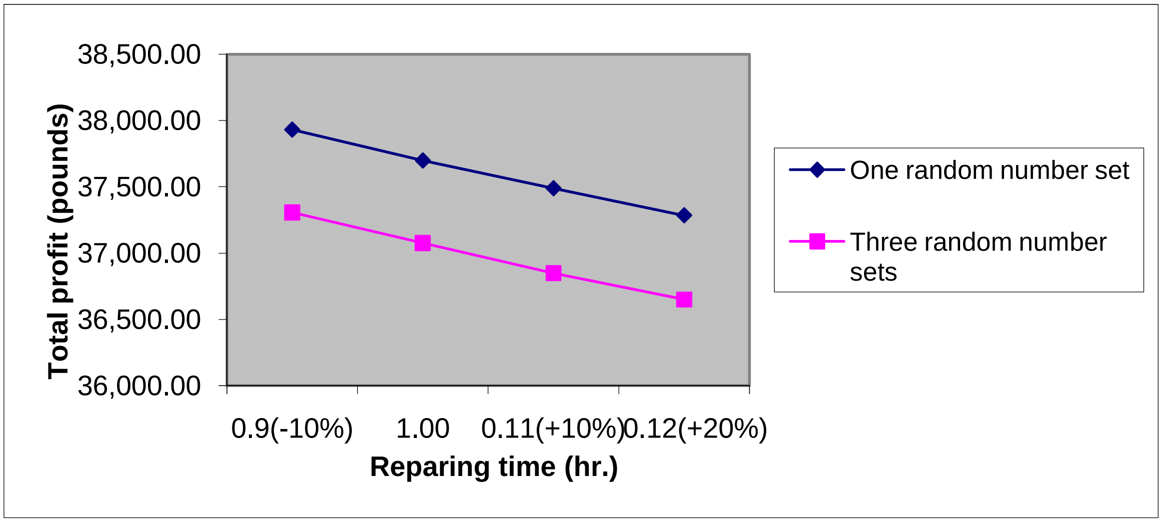

Figure 7.12: Total Profit Impact of the Repairing Time Changes

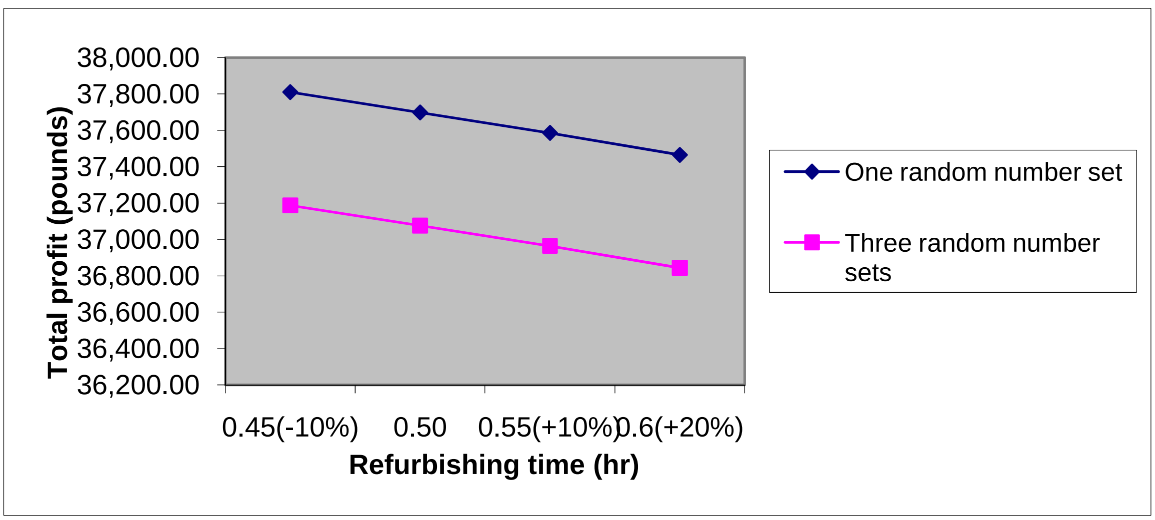

Figure 7.13: Total Profit Impact of the Inspecting Time Changes

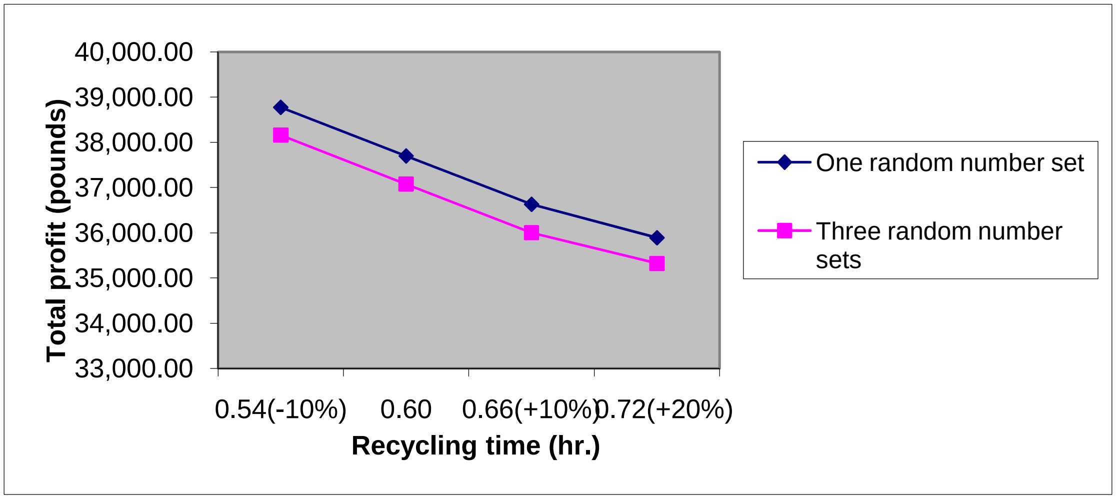

Figure 7.14: Total Profit Impact of the Recycling Time Changes

Table 7.16: Comparison of the Total Profit Impact between the Recovering Time Changes

Time (hr.)	Total Profit (£)		Total Profit Impact (%)	
	One random number set	Three random number sets	One random number set	Three random number sets
Inspecting				
0.45 (-10%)	38,822.38	38,174.53	2.98	2.96
0.55 (+10%)	36,422.36	35,792.99	-3.38	-3.46
0.6 (+20%)	32,895.05	32,276.47	-12.74	-12.94
Direct resale processing				
0.45 (-10%)	37,709.60	37,086.72	0.03	0.03
0.55 (+10%)	37,685.50	37,064.88	-0.03	-0.03
0.6 (+20%)	37,673.45	37,053.97	-0.06	-0.06
Repairing				
0.9 (-10%)	37,930.45	37,305.88	0.62	0.62
0.11 (+10%)	37,488.30	36,848.94	-0.56	-0.61
0.12 (+20%)	37,284.27	36,649.63	-1.10	-1.15
Refurbishing				
0.45 (-10%)	37,809.87	37,187.31	0.30	0.30
0.55 (+10%)	37,585.23	36,964.29	-0.30	-0.30
0.6 (+20%)	37,463.97	36,843.84	-0.62	-0.63
Recycling				
0.54 (-10%)	38,771.75	38,158.22	2.85	2.92
0.66 (+10%)	36,628.91	36,000.47	-2.83	-2.90
0.72 (+20%)	35,889.90	35,320.50	-4.80	-4.73

Replaced Part Cost Changes

To allow the evaluation of the impact on profit margins, a change to the replaced part cost was made by decreasing the cost by 10% and increasing the cost by 10% and 20%. Table 7.17 highlights the comparison of the total profit impact between replaced part cost changes. It can be seen that the replaced part cost for refurbishing has more influence on the total profit.

Table 7.17: Comparison of the Total Profit Impact between Replaced Part Cost Changes

Replaced part cost (£)	Total Profit (£)		Total Profit Impact (%)	
	One random number set	Three random number sets	One random number set	Three random number sets
Repairing				
4 (- 10%)	38,042.30	37,418.55	0.91	0.92
6 (+10%)	37,352.80	36,733.05	-0.91	-0.92
7 (+20)	37,008.05	36,390.30	-1.83	-1.85
Refurbishing				
54, 67.5 (-10%)	40,303.80	39,660.68	6.91	6.97
66, 82.5 (+10%)	35,091.30	34,490.93	-6.91	-6.97
72, 90 (+20%)	32,485.05	31,906.05	-13.83	-13.94

Selling Price Changes

Selling price changes were introduced in this experiment by decreasing the prices by 10% and increasing the prices by 10% and 20%; the outputs are shown in Table 7.18. The table shows that the selling price changes of refurbished computer III have the most significant influence on the total profit.

Table 7.18: Comparison of the Total Profit Impact between Selling Price Changes

	Total Profit (£)		Total Profit Impact (%)	
Selling price(£)	One random number set	Three random number sets	One random number set	Three random number sets
Direct resold computer				
35.10 (-10%)	37,536.68	36,931.50	-0.43	-0.39
42.90 (+10%)	37,858.43	37,220.10	0.43	0.39
46.80 (+20%)	38,019.30	37,364.40	0.85	0.78
Repaired computer I				
67.50 (-10%)	36,400.05	35,787.68	-3.44	-3.47
82.50 (+10%)	38,995.05	38,363.93	3.44	3.47
90.00 (+20%)	40,292.55	39,652.05	6.88	6.95
Repaired computer II				
89.10 (-10%)	35,997.23	35,382.90	-4.51	-4.57
108.90 (+10%)	39,397.88	38,768.70	4.51	4.57
118.8 (+20%)	41,098.20	40,461.60	9.02	9.13
Refurbished Computer I				
112.50 (-10%)	36,150.68	35,538.30	-4.10	-4.15
137.50 (+10%)	39,244.43	38,613.30	4.10	4.15
150.00 (+20%)	40,791.30	40,150.80	8.21	8.29
Refurbished computer II				
135.00 (-10%)	35,830.05	35,227.05	-4.95	-4.99
165.00 (+10%)	39,565.05	38,924.55	4.95	4.99
180.00 (+20%)	41,432.55	40,773.30	9.91	9.97
Refurbished computer III				
157.50 (-10%)	35,527.55	34,923.30	-5.76	-5.81
192.50 (+10%)	39,867.55	39,228.30	5.76	5.81
210.00 (+20%)	42,037.55	41,380.80	11.51	11.61
Recycled computer				
1.00 (-10%)	37,340.34	36,715.41	-0.95	-0.97
1.23 (+10%)	38,024.99	37,406.16	0.87	0.89
1.34 (+20%)	38,352.44	37,736.52	1.74	1.78

Recovery Efficiency Changes

It was decided to alter the recovery efficiency in this study. It is assumed that the recovery efficiency is 95% and 90% as the results show in Table 7.19: comparison of the total profit impact between recovery efficiency changes of each workstation. The outputs from Table 7.19 verify that the efficiency of inspecting workstation is the most important parameter impacting on the total profit because the number of recovered computers changes.

Table 7.19: Comparison of the Total Profit Impact between Recovery Efficiency Changes of Each Workstation

	Total Profit (£)		Total Profit Impact (%)	
Workstation efficiency (%)	**One random number set**	**Three random number sets**	**One random number set**	**Three random number sets**
Inspecting				
95.00	37,687.69	37,056.66	-0.03	-0.05
90.00	37,473.27	36,857.04	-0.59	-0.59
Direct reselling				
95.00	37,697.55	37,075.80	0.00	0.00
90.00	37,697.55	37,075.80	0.00	0.00
Repairing				
95.00	37,708.34	37,093.37	0.03	0.05
90.00	37,715.07	37,043.12	0.05	-0.09
Refurbishing				
95.00	37,679.74	37,053.10	-0.05	-0.06
90.00	37,704.73	37,045.51	0.02	-0.08
Recycling				
95.00	37,698.68	37,076.61	0.00	0.00
90.00	37,706.92	37,081.79	0.02	0.02

New Strategy Implementation: Offering Cash Back[7]

In accordance with the results from the questionnaire survey presented in section 5.4 of this thesis, it is suggested that the computer recycling business should implement a new strategy: offering cash back as an order-winner to persuade customers to send their old computer to the firm. Hence, this experiment assumes that the firm makes a decision to offer end users some cash back for repaired and refurbished computers, because these computer types have a higher profit margin. The new strategy will increase the proportion of received computers which can be repaired and refurbished. The results from this study are depicted in Table.7.20.

When offering five and ten-pound cash back for repaired computers with increasing return rate by 1% and 2%, respectively, it is found that the total profit has increased by 3.67 % (one random number set) and 3.00% (three random number sets), and 4.42% (one random number set) and 4.74 % (three random number sets) respectively. On the other hand, when offering five and ten- pound cash back for refurbished computers with increasing return rate by 1% and 2%, respectively, it is found that the total profit has increased by 3.18 % (one random number set) and 2.73% (three random number sets), and 3.93% (one random number set) and 4.26 % (three random number sets) respectively.

[7] Kelton et al. (2007) suggested that mathematical models are not capable of being used to model a pretty complicated system while a simulation can be used to mimic a complex system. Similarly, systems of the sixth scenario (new strategy implementation: offering cash back) and the seventh scenario (new strategy implementation: free collection service) are pretty complicated. Moreover, implementing these strategies causes an increase in the number of returns. Based on the assumption of Pricing Model II which is all of the reprocessed computers can be resold, this implies that the demand for reprocessed computers also increases. However, Pricing Model II does not include the number of sales as the model's parameter. Hence, a sensitive analysis of these scenarios cannot be conducted in Pricing Model II. Otherwise, a new formulation of demand rate and pricing model is required.

Table 7.20: Total Profit Impact of New Strategy Implementation: Offering Cash Back

Cash back (£)	Return Rate (%)	Total Profit (£) One random number set	Total Profit (£) Three random number sets	Total Profit Impact (%) One random number set	Total Profit Impact (%) Three random number sets
Repaired computer					
5	10 (+1%)	39,070.25	38,166.95	3.67	3.00
10	11 (+2%)	39,354.37	38,814.25	4.42	4.74
Refurbished computer					
5	11 (+1%)	38,885.25	38,067.98	3.18	2.73
10	12 (+2%)	39,170.45	38,636.29	3.93	4.26

New Strategy Implementation: Free Collection Service

Based on the results from the questionnaire survey presented in section 5.4 of this thesis, the new strategy: free collection service is also suggested as an order-winner for the computer recycling industry to persuade customers to send their old computer to the business. Hence, this experiment assumes that the firm classifies the return channels into two types: the drop-off channel and the collected channel as shown in Figure 7.15. Moreover, it is assumed that the collection cost is £7 per unit and when implementing this strategy, the return rate from the collected channel is 5 %, 10%, 15% and 20 % of the number of received computers from the drop-off channel.

The findings of this experiment are demonstrated in Table 7.21. The results indicate that when the rate is 5% and 10% the total profit is increased by 1.67% (one random number set) and 3.00% (three random number sets), and 2.59 % (one random number set) and 4.74 % (three random number sets) respectively. On the other hand, when the rate is 15%, the outputs show that the total profit has increased by 0.72% (one random number set) and decreased by 2.77 % (three random number sets). When the return rate is 20%, the outcome is the total profit decreases by 2.73 % (one random number set) and 7.74 % (three random number sets) respectively, because there is a limit to reprocessing capacity. Therefore, it is suggested that the company should increase capacity in order to deal with the larger number of received computers.

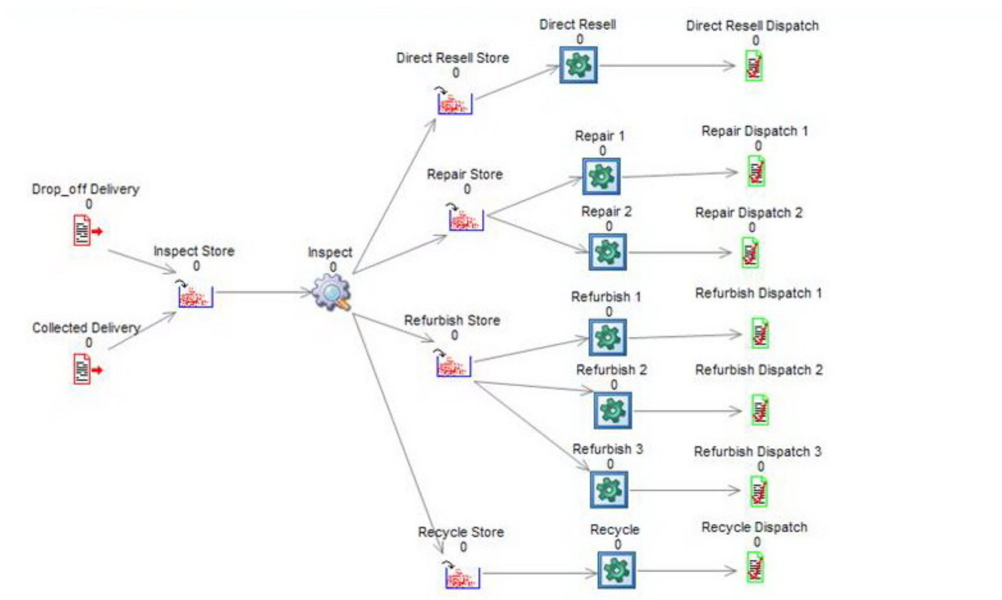

Figure 7.15 Simulation Model II Dealing with New Strategy Implementation: Free Collection Service

Table 7.21: Total Profit Impact of New Strategy Implementation: Free Collection Service

		Total Profit (£)		Total Profit Impact (%)	
Collection cost	Collected return rate (%)	One random number set	Three random number sets	One random number set	Three random number sets
£7/unit	5	38,318.93	38,166.95	1.67	3.00
	10	38,664.23	38,814.25	2.59	4.74
	15	37,960.48	36,030.95	0.72	-2.77
	20	36,658.94	34,187.68	-2.73	-7.74

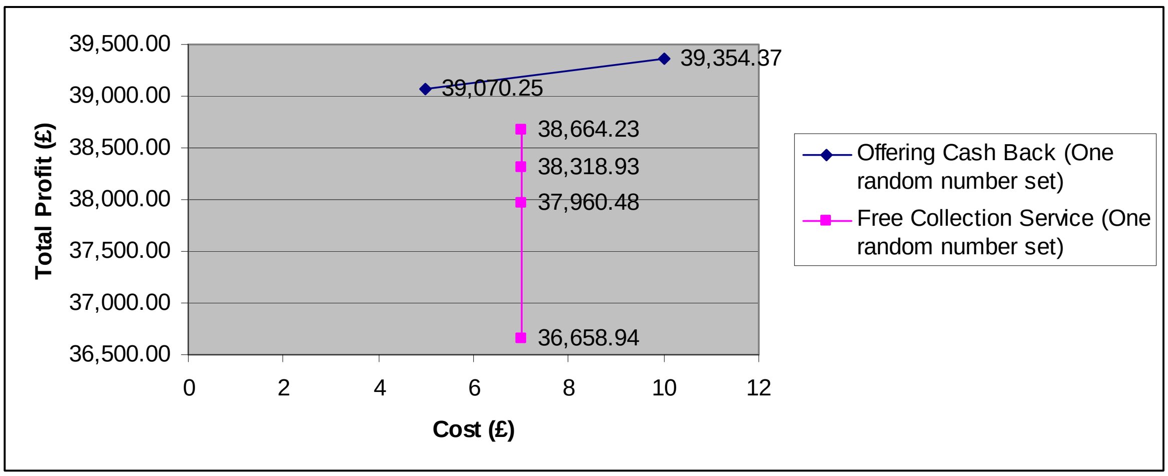

Figure 7.16: Comparison of Total Profit Impact between New Strategy Implementation: Offering Cash Back for Repaired Computers and New Strategy Implementation: Free Collection Service (One Random Number Set)

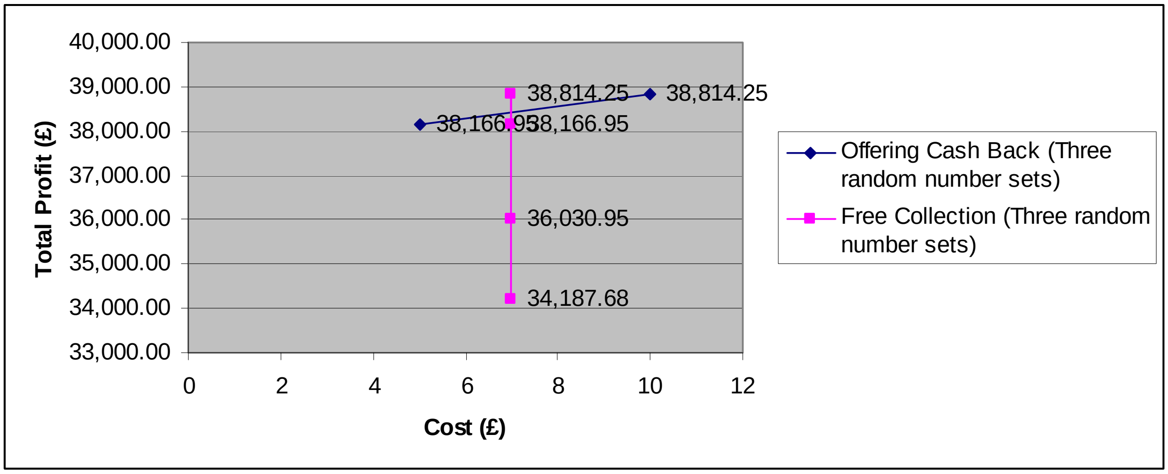

Figure 7.17: Comparison of Total Profit Impact between New Strategy Implementation: Offering Cash Back for Repaired Computers and New Strategy Implementation: Free Collection Service (Three Random Number Sets)

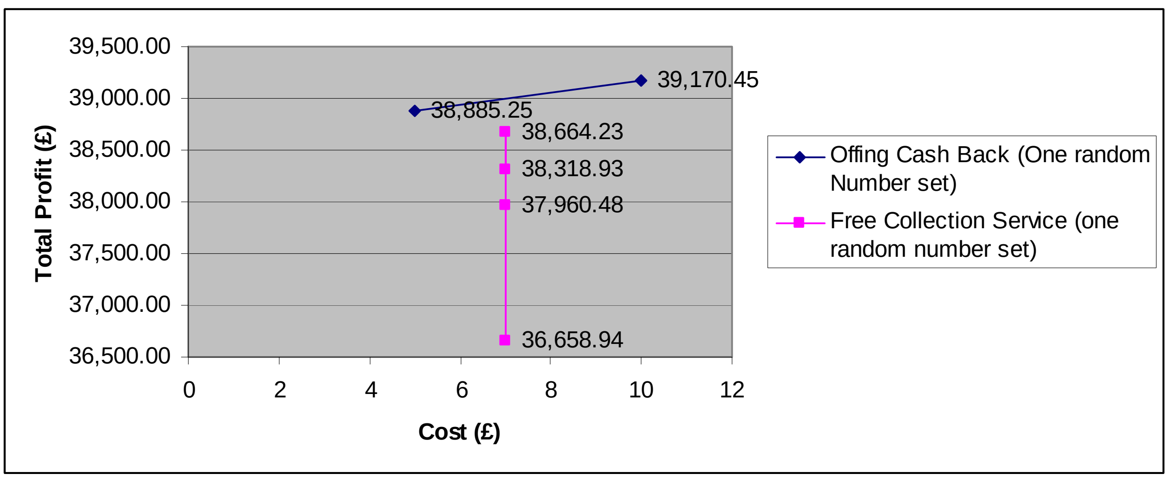

Figure 7.18: Comparison of Total Profit Impact between New Strategy Implementation: Offering Cash Back for Refurbished Computers and New Strategy Implementation: Free Collection Service (One Random Number Set)

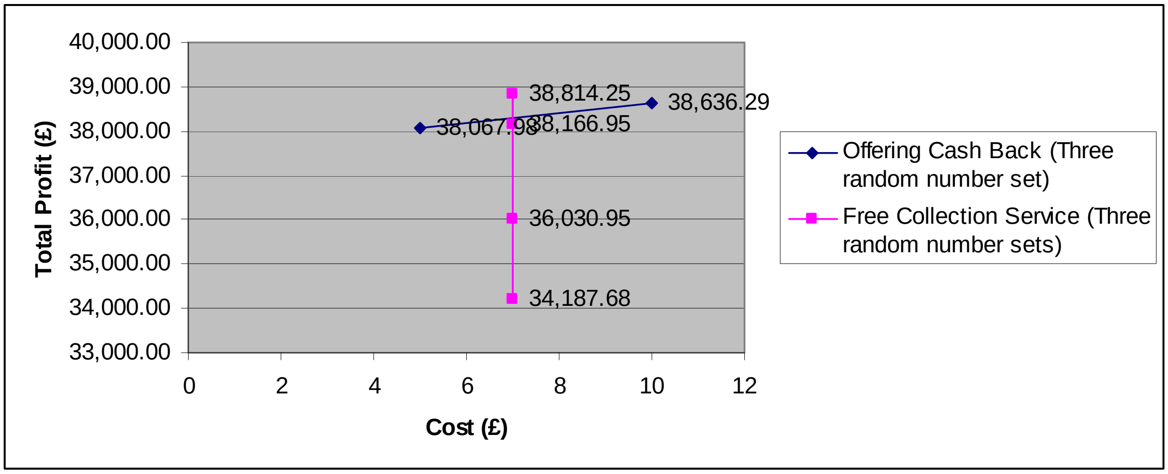

Figure 7.19: Comparison of Total Profit Impact between New Strategy Implementation: Offering Cash Back for Refurbished Computers and New Strategy Implementation: Free Collection Service (Three Random Number Sets)

In accordance with the comparison between offering cash back and free collection service strategies, the results from Figures 7.16, 7.17, 7.18, and 7.19 indicate that most of the experiments in the sixth scenario (new strategy implementation: offering cash back) have more influence on the total profit than most of the experiments in the seventh scenario (new strategy implementation: free collection service) have. Moreover, the company has to recruit more staff and consider a design of return collection and transport approaches to deal with the new strategy implementation: free collection service. Hence, it is suggested that the computer recycling company should implement “the new strategy: offering cash back” as an order-winner to achieve their business objective.

7.4 Conclusion

This chapter presents two simulation models to extend the study of the pricing models highlighted in chapter 6 of this thesis, in order to cope with the element of uncertainty in terms of return quantity and reprocessing time. These simulation models are formulated by using Company A presented in chapter 4 (the mobile phone recycling business) which has implemented a market-driven system, and using Company B introduced in chapter 4 (the computer recycling business) which has applied a waste stream system.

Altogether, this chapter addresses four main research gaps in academic literature discussed in chapter 2. These include multiple recovery options, multiple time periods, the element of uncertainty in terms of return quantity and reprocessing time and product substitution policy. Moreover, the mobile recycling business and the computer recycling business would be able to use the findings from these models to support decision making based on pricing and revenue management. In addition, the initial outputs (total profit) of Simulation Model I and Pricing Model I, and Simulation Model II and Pricing Model II are relatively similar.

Moreover, the sensitive analysis was conducted by carrying out "what-if" assessments in order to investigate the revenue management impact of the multiple recovery options system affected by the models' parameters and the results from the questionnaire survey demonstrated in chapter 5. The sensitive analysis of Simulation Model I includes six scenarios i.e. labour cost changes, recovering time changes, selling price changes, recovery efficiency changes, percentage changes of mobile phone types and new strategy implementation: higher offer price.

The sensitive analysis of Simulation Model II includes seven scenarios i.e. labour cost changes, recovering time changes, replaced part cost changes, selling price changes, recovery efficiency changes, new strategy implementation: offering cash back and new strategy implementation: free collection service. More importantly, with regard to the comparison between offering cash back and free collection service strategies, it is suggested that “the new strategy: offering cash back” should be implemented as an order-winner because the former has more impact on the total profit than the latter has. The next chapter provides conclusions of this thesis and future work.

Chapter 8: Conclusions and Future Work

8.1 Research Discussion

This thesis addresses the following research questions:

- What are optimal acquisition prices of received mobile phones and optimal selling prices of reprocessed handsets?
- What are optimal selling prices of reprocessed computers?
- Based on the total profit, what if the model's parameters changes?

The methodology used in this research is the triangulation approach, more specifically the multilevel model. In other words, this study uses the mixed research methods comprising of case studies, questionnaire survey, and empirical quantitative models. First, the case study subjects are two UK-based case companies i.e. Company A (the mobile phone recycling business) and Company B (the computer recycling business) as presented in Chapter 4. The questionnaire survey is then developed from the case companies. The results from two case companies and the questionnaire survey are used to formulate the pricing and simulation models.

RQ. 1: What are optimal acquisition prices of received mobile phones and optimal selling prices of reprocessed handsets?

To address this research question, Pricing Model I presented in section 6.2 is formulated by the use of a non-linear programming approach and using Company A data introduced in chapter 4 (the mobile phone recycling industry) which has implemented a market-driven system. This pricing model represents a deterministic process. As highlighted in section 6.2 of this thesis, the proposed models in the existing literature lack consideration of multiple recovery options operations, the return rates and the demand rates as exponential functions, as well as product substitution policy.

Hence, this pricing model provides three main academic contributions as follows: first, Pricing Model I took multiple recovery options operation (i.e. direct resale, repair and refurbishment, and recycling) into account. Second, in this pricing model a return rate and a demand rate were modelled as an exponential function. Third, a product substitution policy was included in the pricing model.

The results suggest that the proposed pricing model is able to calculate optimal profit-maximising acquisition prices of received mobile phones and selling prices of reprocessed handsets. Moreover, the sensitive analysis is carried out in order to investigate the impact of the pricing model's parameters on the optimal acquisition prices, optimal selling prices, and total profit. These parameters include the cost parameters (i.e. handling cost, repair and refurbishing operations cost and transportation cost), the minimal acquisition prices of A+ grade mobile phones and the maximum selling prices of reusable mobile phones. The results of these experiments for recycling of mobile phones are illustrated in section 6.2.3 of this thesis.

RQ.2: What are optimal selling prices of reprocessed computers?

Pricing Model II and Pricing Model III illustrated in section 6.3 and section 6.4, respectively, are formulated to determine optimal profit-maximising selling prices of recovered computers. The construction of these pricing models employs a non-linear programming approach and has used Company B data introduced in chapter 4 (the computer recycling business) which has applied a waste stream system. However, Pricing Model III is formulated by including the evidence from the questionnaire survey presented in chapter 5 to validate one of the main assumptions, the dependent demand assumption. This addresses the product substitution policy. These pricing models represent a deterministic process.

As discussed in sections 6.3 and 6.4 of this thesis, the literature review discovers that the research on pricing and revenue management in reverse logistics has not included the following aspects i.e. multiple recovery options operations, the demand rates as exponential functions, a limit of operations capacity and product substitution policy. Thus, these pricing models introduce four main academic contributions as follows: first, Pricing Model II and Pricing Model III were formulated to explore multiple recovery options i.e. direct resale, repair and refurbishment. Second, these pricing models include more investigation of recovery operations capacity. Third, in Pricing Model II and Pricing Model III, demand rate was defined as an exponential function. Fourth, Pricing Model III took product substitution policy into account.

It is proved that the proposed pricing models can calculate optimal profit-maximising selling prices of reprocessed computers. Furthermore, the sensitive analysis is carried out in order to investigate the impact of the pricing models' parameters on the optimal selling prices and total profit. These parameters include the cost parameters (i.e. grading, sorting and testing cost, recovery operations cost, and equipment cost), the limitation of operations capacity and the maximum selling prices of each recovered computer type. The results of these experiments for recycling of computers are illustrated in sections 6.3.3 and 6.4.3 of this thesis.

RQ.3: Based on the total profit, what if the model's parameters changes?

Two simulation models, Simulation Model I and Simulation Model II, are developed to further investigate the study of the pricing models presented in chapter 6. These models deal with the element of uncertainty in terms of return quantity and reprocessing time by assuming return rate is exponentially distributed, and reprocessing time is normally distributed. Hence, the proposed models are stochastic simulation. Simulation Model I and Simulation Model II are constructed based on Company A (the mobile phone recycling business) and Company B (the computer recycling business) as demonstrated in Chapter 4, respectively. To answer this research question, "what-if" assessments are carried out in order to investigate the revenue management impact of the multiple recovery options system affected by the models' parameters and the results from the questionnaire survey demonstrated in chapter 5.

The "what-if" assessments of Simulation Model I include six scenarios as follows: labour cost changes, recovering time changes, selling price changes, recovery efficiency changes, percentage changes of mobile phone types and new strategy implementation: higher offer price. The results of these scenarios for recycling of mobile phones are given in section 7.2.3 of this thesis. The “what-if” assessments of Simulation Model II include seven scenarios as follows: labour cost changes, recovering time changes, replaced part cost changes, selling price changes, recovery efficiency changes, new strategy implementation: offering cash back and new strategy implementation: free collection service. The results of these scenarios for recycling of computers are highlighted in section 7.3.3 of this thesis.

It is confirmed that the simulation models could complete the “what-if” assessments and the findings from these experiments have potential to support decision making based on pricing and revenue management for the recycled mobile phone and the recycled computer sectors. In addition, the initial outputs (total profit) of Simulation Model I and Pricing Model I, and Simulation Model II and Pricing Model II are relatively similar. As discussed in sections 7.2 and 7.3 of this thesis, the previous studies in this subject lack consideration of multiple recovery options, multiple time periods, the element of uncertainty in terms of return quantity and reprocessing time and product substitution policy.

Hence, the simulation models developed in this research offer four main contributions in the existing academic literature as follows: first, this study investigated multiple recovery options operation in these simulation models i.e. direct resale, repair, refurbishment and recycling. Second, simulation models with multiple time periods were proposed. Third, the simulation models took the element of uncertainty in terms of return quantity and reprocessing time into account. Fourth, a product substitution policy was addressed in Simulation Model I.

8.2 Academic Contributions

The contribution of this research work includes the generation of pricing and simulation models for the recycled mobile phone sector and the recycled computer sector. Moreover, this research work also contributes to the optimal pricing decisions based on the impact of the multiple recovery options; the impact of pricing models' parameters on the optimal acquisition prices, optimal selling prices, and total profit via the sensitive analysis; and the impact of the element of uncertainty in terms of return quantity and reprocessing time on the total profit. As mentioned in section 2.9, the literature review discovers that the previous studies on the subject have not paid attention to the following aspects i.e. multiple recovery options, return rate and demand rate as exponential functions, recovery capacity limitation, product substitution policy, the element of uncertainty in terms of return quantity and reprocessing time and multiple time periods.

Hence, altogether this research work has contributed six main considerations as follows: first, this research took multiple recovery options into account. Second, return and demand rate were assumed to be an exponential function. Third, this study included a limit to recovery capacity in the models. Fourth, this research proposed the models with levels of product substitution policy. Fifth, the element of uncertainty in terms of return quantity and reprocessing time was investigated in the simulation models. Finally, multiple time periods were addressed in simulation.

The research undertaken is related to pricing and revenue management. This research area is important because it has been noted as a niche research area and the fifth phase (prices and markets) of the evolution of closed loop supply chain research. Furthermore, the review of the academic literature presents that the previous studies have paid little attention to this research area since there are only a limited number of papers exploring a pricing and marketing decision of recovered products. Hence, the results of the research contribute to support current pricing and revenue management research. Future researchers will be able to expand these models.

8.3 Managerial Implications

Pricing and revenue management of recovered products has become a crucial issue concerning profitability in the mobile phone and computer recycling industries. The outputs from all the pricing models and the simulation models provide relevant decision-making support for the businesses. These outputs include optimal pricing decisions, the impact of the pricing model's parameters on optimal prices and total profit conducted by the sensitive analysis, the total profit impact affected by the simulation model's parameters and the results from the questionnaire survey demonstrated in chapter 5 and carried out by the "what-if" assessments. Hence, the results from these proposed models have potential to support decision making in the recovery operations and reverse logistics of many industries.

In particular, a decision maker would be able to use the models presented in sections 6.2 and 7.2 of this thesis to support pricing and revenue management decision making in the mobile phone recycling industry, which has implemented a market-driven system. The firm would specify both the acquisition prices for the received mobile phones and the selling prices of the reprocessed handsets.

From Figure 8.1, Pricing Model I demonstrated in section 6.2 can be applied in a deterministic system in which all the model's parameters are known. A manager is able to use this pricing model to calculate optimal profit-maximising acquisition prices of received mobile phones and selling prices of reprocessed handsets and also to investigate the impact of changes of the pricing model's parameters on the optimal prices and total profit. However, the pricing model lacks the ability to deal with the element of uncertainty.

Thus, Simulation Model I shown in section 7.2 was formulated to extend the study of the pricing model and to cope with the element of uncertainty of return quantity and reprocessing time in which return rate performs an exponential distribution and reprocessing time presents a normal distribution. This simulation is a stochastic model and it can be used when a manager does not know about return quantity and reprocessing time.

As highlighted in section 7.2.3, this simulation can be employed to investigate the total profit impact affected by the simulation model's parameters and can be applied for the risk evaluation of a new strategy implementation. More importantly, these proposed models would be able to applied in other WEEE recycling businesses, which have implemented a market-driven system to support their pricing decisions in reverse logistics operation. However, modification of models' assumptions is required to be suitable for a new company.

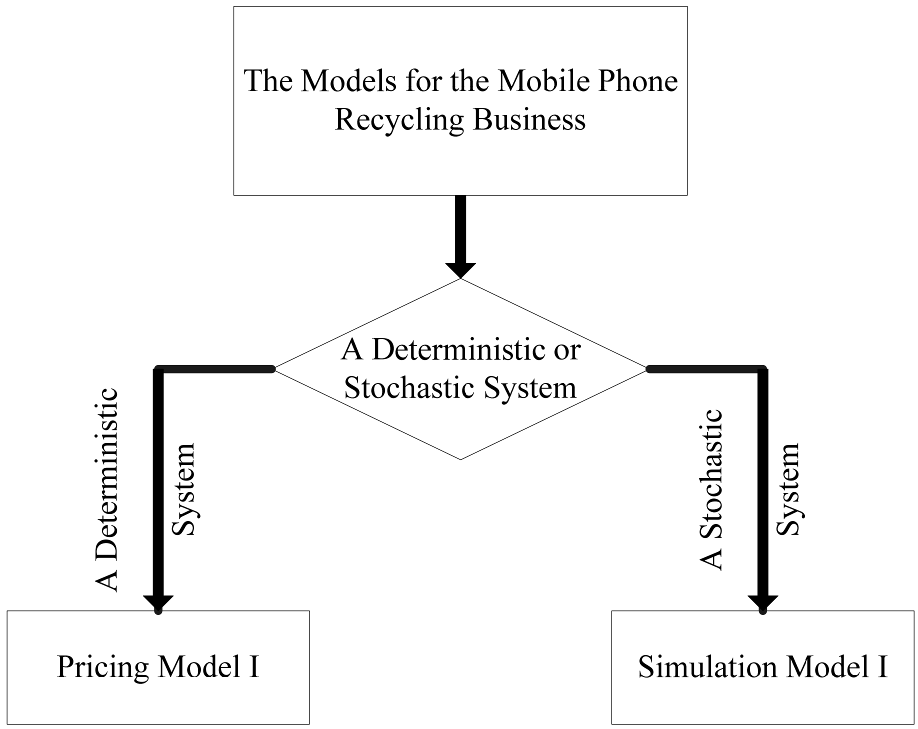

Figure 8.1: Implications of the Models for the Mobile Phone Recycling Industry

On the other hand, the proposed models presented in sections 6.3, 6.4, and 7.3 of this thesis can be implemented to investigate pricing and revenue management decisions in the recycled computer sector, which has implemented a waste stream system. The company specifies only the selling prices of the reprocessed computers. From Figure 8.2, a decision maker can use Pricing Model II and Pricing Model III illustrated in sections 6.3 and 6.4, respectively in a deterministic process in which all the model's parameters are known.

These pricing models can be used to calculate optimal profit-maximising selling prices of reprocessed computers and also to investigate the impact of changes of the pricing models' parameters on the optimal prices and total profit. Specifically, a manager would be able to use Pricing Model III when product substitution policy is considered. However, these pricing models cannot deal with the element of uncertainty.

Thus, Simulation Model II shown in section 7.3 was formulated to extend the study of the pricing models and to deal with the element of uncertainty of return quantity and reprocessing time which a return rate is exponentially distributed and reprocessing time is normally distributed. This simulation is a stochastic model and it can be used when return quantity and reprocessing time are not known. As presented in section 7.3.3, a manager can use this simulation to investigate the total profit impact affected by the simulation model's parameters and can apply for the risk assessment of a new strategy implementation. More importantly, these proposed models would be able to applied in other WEEE recycling industries which have implemented a waste stream system to support their pricing decisions in the recovery operations. However, adjustment of the models' assumptions is required to be suitable for a new business.

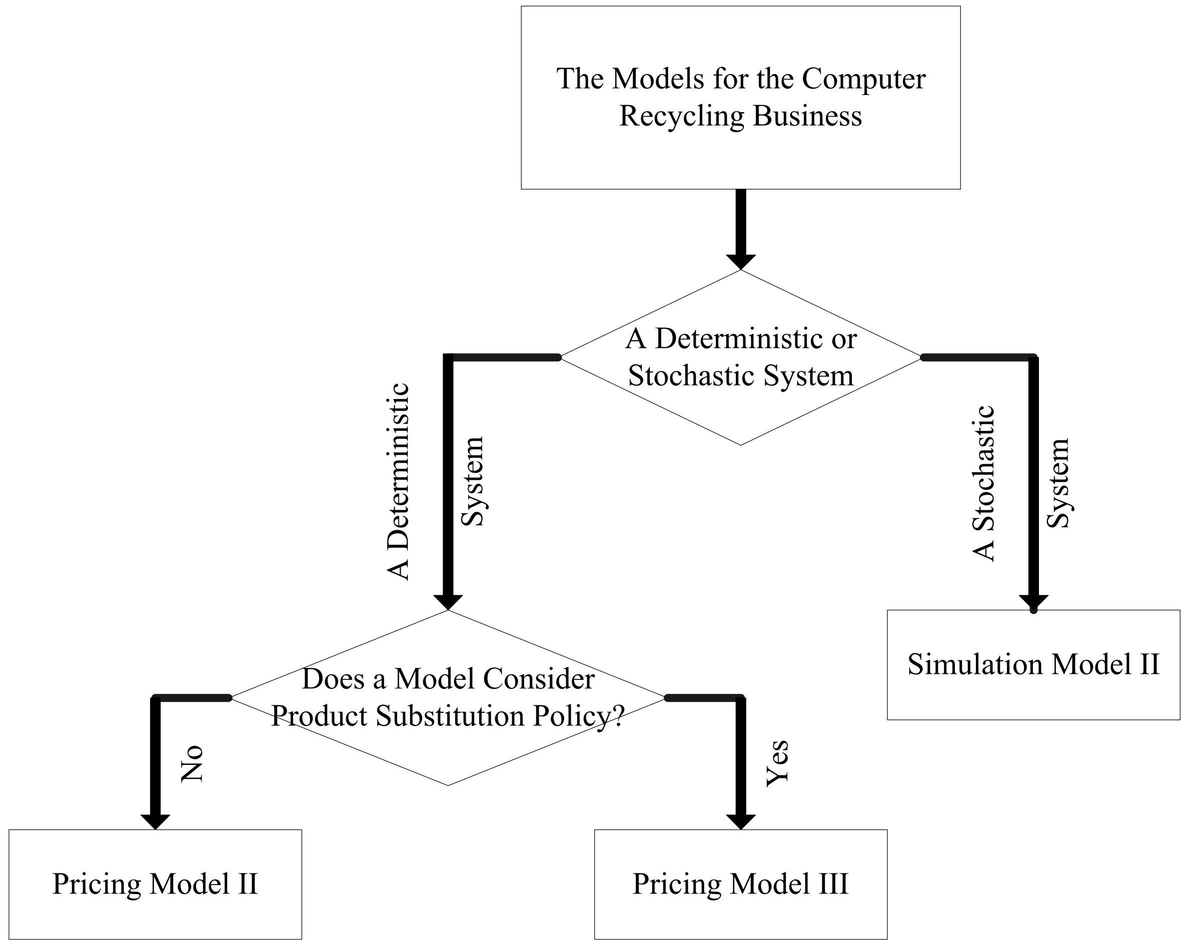

Figure 8.2: Implications of the Models for the Computer Recycling Industry

8.4 Limitations and Future Research

The research presented in this thesis has following limitations. The review of the literature on pricing and revenue management in reverse logistics discussed in section 2.8 is based on published peer-reviewed international journals. It excludes any other forms of publications including research working papers, conference papers and dissertations. Attempts have been made to collect required data from several mobile phone recycling companies and computer recycling companies. However, this has proved difficult and only a limited number of companies made it possible to collect the required data. Hence, further studies should be carried out on more case companies in order that a comparative study can be done to enhance the results' reliability, particularly the multiple recovery options operations for the reverse logistics programme in practice.

Because of the limitations related to data availability, the demand rates, return rates and parameters of all the pricing models presented in chapter 6, and the simulation models and the parameters demonstrated in chapter 7 are estimated from the structured interviews and limited secondary data. All the elements were not found to fully justify the use of an exponential function; however, the exponential function is robust and gives the best approximation possible given the conditions faced. Thus, it would be interesting to explore whether it is realistic for rates to behave as an exponential function, whilst trying to assume rates represent a logit function

In accordance with acquiring the required data by the use of the questionnaire survey, self-selection sampling, a well-established non-random sampling technique, has been used to select the sample representing the entire population; the sample size is not large enough to provide some required data because there were resource limitations in terms of time and availability of funds. Consequently, further research should use a random sampling technique to choose the sample representing the entire population with a larger sample size.

The proposed pricing models highlighted in chapter 6 have all considered single period, single objective, which is profit maximisation, and monopoly market. The demand rates and return rate are only assumed as an exponential function. Moreover, none of these models address the element of product life cycle. Therefore, pricing models with multiple periods and/or two or multiple objectives which explicitly analyse the tradeoffs between total profit and carbon footprint should be investigated. Furthermore, more investigation of oligopoly markets should be carried out.

All the proposed simulation models demonstrated in chapter 7 use only one performance measurement: that is total profit. Moreover, these models do not take the distance between facilities into account (there is no travel time) and consider only in-house, on-shore operations. Furthermore, these models only take the element of uncertainty in terms of return quantity and reprocessing time into account and the cell layout is assumed. Thus, future studies by the use of simulation model should consider travel time, the integration of profitability and sustainability (by using the performance measurement of total profit and carbon footprint), more investigation of the element of uncertainty in terms of return, demand, recovery yield, reprocessing time, and/or selling price, onshore versus offshore outsourcing decisions and other manufacturing layouts. Hence, future research should investigate the issues highlighted in this section.

References:

Ackoff, R. L. (1979). The Future of Operational Research is Past. *The Journal of the Operational Research Society,* 30(2), p. 93-104.

Anderson, D. R., Sweeney, D. J., & Williams, T. A. (2005). *An Introduction to Management Science: Quantitative Approaches to Decision Making* (11^{th} Ed.). Ohio: South-Western, a division of Thomson Learning.

Apisitpuvakul, W., Piumsomboon, P., Watts, D. J., & Koetsinchai, W. (2008). LCA of Spent Fluorescent Lamps in Thailand at Various Rates of Recycling. *Journal of Cleaner Production*, 16(10), p. 1046-1061.

Aras, N., Güllü, R., & Yürülmez, S. (2011). Optimal Inventory and Pricing Policies for Remanufacturable Leased Products. *International Journal of Production Economics,* 133(1), p. 262-271.

Bakal, I. S., & Akcali, E. (2006). Effects of Random Yield in Remanufacturing with Price-Sensitive Supply and Demand. *Production and Operations Management,* 15(3), p. 407-420.

Banomyong, R., Veerakachen, V., & Supatn, N. (2008). Implementing Leagility in Reverse Logistics Channels. *International Journal of Logistics Research and Applications,* 11(1), p. 31 – 47.

Bayindir, Z. P., Erkip, N., & Gullu, R. (2007). Assessing the Benefits of Remanufacturing Option under One-way Substitution and Capacity Constraint. *Computers & Operations Research,* 34(2), p. 487-514.

BBC News (2007, 24 January 2007). *Firms Helped to Make PCs Greener* [Online]. Available from: http://news.bbc.co.uk/1/hi/technology/6294799.stm [Accessed: 29 July 2011].

BBC News (2008, 21 July 2008). *Students Bring Kit Worth £6,000* [Online]. Available from: http://news.bbc.co.uk/1/hi/education/7517227.stm [Accessed: 30 March, 2011].

BBC News (2010, 26 May 2010). *Old Mobile Phones 'Could be Worth Cash'*[Online]. Available from: www.bbc.co.uk/news/10163924 [Accessed: 28 July 2011].

Bernon, M., & Cullen, J. (2007). An Integrated Approach to Managing Reverse Logistics. *International Journal of Logistics Research and Applications,* 10(1), p.41 – 56.

Bernon, M., Cullen, J., Rowat, C., & Rowley, J. (2004). *The Efficiency of Reverse Logistics* (No. 1-904564-07-0). Northants: The Chartered Institution of Logistics and Transport (UK).

Bertrand, J. W. M., & Fransoo, J. C. (2002). Modelling and simulation: Operations management research methodologies using quantitative modeling. *International Journal of Operations & Production Management,* 22(2), p. 241-264.

Beullens, P., Van Oudheusden, D., & Van Wassenhove, L. N. (2004). Collection and Vehicle Routing Issues in Reverse Logistics. In R. Dekker, M. Fleischmann, K. Inderfurth & L. N. Van Wassenhove (Eds.), *Reverse Logistics: Quantitative Models for Closed-Loop Supply Chains*. Berlin: Springer, p. 95-134.

Blaikie, N. (2000). *Designing Social Research: the Logic of Anticipation*. Cambridge: Polity Press.

Bloemhof-Ruwaard, J. M., Krikke, H. R., & Van Wassenhove, L. N. (2004). OR Models for Eco-eco Closed-loop Supply Chain Optimization. In R. Dekker, M. Fleischmann, K. Inderfurth & L. N. Van Wassenhove (Eds.), *Reverse Logistics: Quantitative Models for Closed-Loop Supply Chain*. Berlin: Springer, p. 357-379.

Blumberg, D. F. (1999). Strategic Examination of Reverse Logistics and Repair Service Requirements, Needs, Market Size, and Opportunities. *Journal of Business Logistics,* 20(2), p. 141-159.

Blumberg, D. F. (2005). *Introduction to Management of Reverse Logistics and Closed Loop Supply Chain Processes*. Boca Raton: CRC Press.

Bryman, A., & Bell, E. (2007). *Business Research Methods* (2nd Ed.). Oxford: Oxford University Press.

Bryman, A., & Cramer, D. (2005). *Quantitative Data Analysis with SPPS 12 & 13: A Guide for Social Scientists*. East Sussex: Routledge.

Burns, R. B., & Burns, R. A. (2008). *Business Research Methods and Statistics Using SPSS*. London: SAGE.

Carter, C. R., & Ellram, L. M. (1998). Reverse Logistics: A Review of the Literature and Framework for Future Investigation. *Journal of Business Logistics,* 19(1), p. 85-102.

Central Intelligence Agency (CIA). (2010, 5 March 2010). *The World Factbook* [Online]. Available from: www.cia.gov/library/publications/the-world-factbook/geos/th.html [Accessed: 18 March, 2010].

Chaisurayakarn, S., Griffiths, J., & Banomyong, R. (2008). 'Environmental Logistics in the Thai Battery Sector'. *the 13th International Symposium on Logistics*. Bangkok, Thailand, July 2008.

Charuvichaipong, C., & Sajor, E. (2006). Promoting Waste Separation for Recycling and Local Governance in Thailand. *Habitat International,* 30(3), p. 579-594.

Chavalparit, O., Rulkens, W. H., Mol, A. P. J., & Khaodhair, S. (2006). Options for Environmental Sustainability of the Crude Palm Oil Industry in Thailand through Enhancement of Industrial Ecosystems. *Environment, Development and Sustainability,* 8(2), p. 271-287.

Chiemchaisri, C., Juanga, J. P., & Visvanathan, C. (2007). Municipal Solid Waste Management in Thailand and Disposal Emission Inventory. *Environmental Monitoring and Assessment,* 135(1-3), p. 13-20.

Collis, J., & Hussey, R. (2009). *Business Research: a Practical Guide for Undergraduate and Postgraduate Students* (3rd Ed.). Basingstoke: Palgrave Macmillan.

Corporate Mobile Recycling Ltd. (2007). *Selling Mobile Phones: Sell Mobile Phone for Cash Here* [Online]. Available from: www.fonebank.com/recycle_mobile_phone.aspx?campaign=searchgoogle&kw=Mobile%20Phone%20Recycling&utm_source=google&utm_medium=cpc&utm_term=Mobile%20phone%20recycling&utm_campaign=recycletop&gclid=CLCw2Yu5v5wCFV8B4wod8j_LoA [Accessed: 18 September, 2009].

Craighead, C. W., Hanna, J. B., Gibson, B. J., & Meredith, J. R. (2007). Research Approaches in Logistics. *International Journal of Logistics Management,* 18(1), p. 22-40.

Creswell, J. W. (2008). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (3rd Ed.). Thousand Oaks, CA: Sage Publications Ltd.

Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and Conducting Mixed Methods Research.* Thousand Oaks, CA: Sage Publications Ltd.

Daugherty, P. J., Autry, C. W., & Ellinger, A. E. (2001). Reverse Logistics: The Relationship between Resource Commitment and Program Performance. *Journal of Business Logistics,* 22(1), p. 107-123.

Davey, S., Guide Jr., V. D. R., Neeraj, K., & Van Wassenhove, L. N. (2005). Commercial Returns of Printers: the HP Case. In S. D. P. Flapper, , J.A.E.E. Van Nunen& Van L.N. Wassenhove (Eds.), *Managing Closed-Loop Supply Chains*. Berlin: Springer, p. 87-96.

Dawes, J. (2008). Do Data Characteristics Change According to the Number of Scale Points Used? An Experiment Using 5-point, 7-point and 10-point Scales. *International Journal of Market Research,* 50(1), p. 61-77.

De Brito, M. P., & Dekker, R. (2004). A Framwork for Reverse Logistics. In R. Dekker, M. Fleischmann, K. Inderfurth & L. N. Van Wassenhove (Eds.), *Reverse Logistics: Quantitative Models for Closed-Loop Supply Chain*. Berlin: Springer, p. 1-27.

De Brito, M. P., Dekker, R., & Flapper, S. D. P. (2003). *Reverse Logistics - a Review of Case Studies* (No. ERS-2003-012-LIS). Rotterdam: Erasmus Research Institute of Management (ERIM), Erasmus University Rotterdam.

De Koster, R. M. B., & Zuidema, J. P. (2005). Commercial Returns in a Mail Order Company: the Wehkamp Case. In S. D. P. Flapper, J.A.E.E. Van Nunen, & L.N. Van Wassenhove (Eds.), *Managing Closed-Loop Supply Chains*. Berlin: Springer, p. 97-106.

Debo, L. G., Toktay, L. B., & Wassenhove, L. N. V. (2005). Market Segmentation and Product Technology Selection for Remanufacturable Products. *Management Science,* 51 (8), p. 1193-1205.

Debo, L. G., & Van Wassenhove, L. N. (2005). Tire Recovery: the RetreadCo Case. In S. D. P. Flapper, J.A.E.E. Van Nunen, & L.N. Van Wassenhove (Eds.), *Managing Closed-Loop Supply Chains*. Berlin: Springer, p. 119-137.

Dekker, R., Fleischmann, M., Inderfurth, K., & Van Wassenhove, L. N. (2004). Quantitative Models for Reverse Logistics Decision Making. In R. Dekker, M. Fleischmann, K. Inderfurth & L. N. Van Wassenhove (Eds.), *Reverse Logistics: Quantitative Models for Closed-Loop Supply Chain*. Berlin: Springer, p. 29-41.

Deneijer, M., & Flapper, S. D. P. (2005). The Closed-loop Supply Chain of Service Parts: the Whirlpool Case. In S. D. P. Flapper, J.A.E.E. Van Nunen, & L.N. Van Wassenhove (Eds.), *Managing Closed-Loop Supply Chains*. Berlin: Springer, p. 129-137.

Department for Business Innovation & Skills. (2009). *RoHS Regulations Government Guidance Notes*. London: Department for Business Innovation & Skills.

De Vaus, D. A. (1996). *Surveys in Social Research* (4th Ed.). London: Routledge.

Dowlatshahi, S. (2000). Developing a Theory of Reverse Logistics. *Interfaces,* 30(3), p. 143-155.

Driesch, H.-M., Oyen, H. E. v., & Flapper, S. D. P. (2005). Recovery of Car Engines: the Mercedes-Benz Case. In S. D. P. Flapper, Van Nunen, J.A.E.E. & Van Wassenhove L.N. (Ed.), *Managing Closed-Loop Supply Chains*. Berlin: Springer, p. 157-166.

Dyckhoff, H., Lackes, R., & Reese, J. (Eds.). (2004). *Supply Chain Management and Reverse Logistics*. Berlin: Springer.

Easterby-Smith, M., Thorpe, R., Jackson, P., & Lowe, A. (2008). *Management Research: Theory and Practice* (3rd Ed.). London: SAGE Publications Ltd.

Envirofone.com. (2008). *Envirofone.com: Get Cash for Your Old Mobile Phone* [Online]. Available from: www.envirofone.com [Accessed: 28 April, 2009].

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., & Strahan, E. J. (1999). Evaluating the Use of Exploratory Factor Analysis in Psychological Research. *Psychological Methods,* 4(3), p. 272-299.

Ferrer, G., & Swaminathan, J. M. (2006). Managing New and Remanufactured Products. *Management Science,* 52(1), p. 15-26.

Ferrer, G., & Swaminathan, J. M. (2010). Managing New and Differentiated Remanufactured Products. *European Journal of Operational Research,* 203(2), p. 370-379.

Field, A. (2009). *Discovering Statistics Using SPSS* (3rd Ed.). London: SAGE.

Flapper, S. D. P., Van Nunen, J.A.E.E. & Van Wassenhove L.N. (Eds.). (2005). *Managing Closed-Loop Supply Chains* Berlin: Springer.

Fleischmann, M. (2001). *Quantitative Models for Reverse Logistics*. Berlin: Springer.

Fleischmann, M. (2003). Reverse Logistics Network Structures and Design. In V. D. R. Guide Jr. & L. N. Van Wassenhove (Eds.), *Business Aspects of Closed-Loop Supply Chains: Exploring the Issues* (Vol. 2). Pittsburgh, PA: Carnegie Mellon University Press, p. 117-148.

Fleischmann, M., Bloemhof-Ruwaard, J. M., Beullens, P., & Dekker, R. (2004). Reverse Logistics Network Design. In R. Dekker, M. Fleischmann, K. Inderfurth & L. N. Van Wassenhove (Eds.), *Reverse Logistics: Quantitative Models for Closed-Loop Supply Chain*. Berlin: Springer, p. 65-94.

Fleischmann, M., Krikke, H. R., Dekker, R., & Flapper, S. D. P. (2000). A Characterisation of Logistics Networks for Product Recovery. *Omega,* 28(6), p. 653-666.

Frankel, R., Naslund, D., & Bolumole, Y. (2005). The "White Space" of Logistics Research: a Look at the Role of Methods Usage. *Journal of Business Logistics,* 26(2), p. 185-209.

Fuse, M., & Kashima, S. (2008). Evaluation Method of Automobile Recycling Systems for Asia Considering International Material Cycles: Application to Japan and Thailand. *The Journal of Material Cycles and Waste Management,* 10(2), p. 153-164.

GAMS Development Corporation. (2011). The GAMS System[Online]. Available from: www.gams.com/docs/intro.htm [Accessed: 27 August 2011].

Ghauri, P., & Grønhaug, K. (2002). *Research Methods in Business Studies: a Practical Guide* (2nd Ed.). Harlow: Financial Times Prentice Hall.

Gill, J., & Johnson, P. (2010). *Research Methods for Managers* (4th Ed.). London: SAGE.

Ginter, P. M., & Starling, J. M. (1978). Reverse Distribution Channels for Recycling. *California Management Review,* 20(3), p. 72-82.

Greasley, A. (2004). *Simulation Modelling for Business*. Aldershot: Ashgate Publishing Limited.

Guba, E. G., & Lincoln, Y. S. (2005). Paradigmatic Controversies, Contradictions, and Emerging Confluences In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE Handbook of Qualitative Research* (3rd Ed.). Thousand Oaks, CA: Sage Publications, Inc., p. 191-215.

Guide Jr., V. D. R., Jayaraman, V., Srivastava, R., & Benton, W. C. (2000). Supply Chain Management for Recoverable Manufacturing Systems. *Interfaces,* 30(3), p. 125-142.

Guide Jr., V. D. R., Neeraj, K., Newman, C., & Van Wassenhove, L. N. (2005). Cellular Telephone Reuse: the ReCellular Inc. Case. In S. D. P. Flapper, J.A.E.E. Van Nunen, & L.N. Van Wassenhove (Eds.), *Managing Closed-Loop Supply Chains*. Berlin: Springer, p. 151-156.

Guide Jr., V. D. R., Teunter, R. H., & Wassenhove, L. N. V. (2003). Matching Demand and Supply to Maximize Profits from Remanufacturing. *Manufacturing & Service Operations Management,* 5(4), p. 303-317.

Guide Jr., V. D. R., & Van Wassenhove, L. N. (2001). Managing Product Returns for Remanufacturing. *Production and Operations Management,* 10(2), p. 142-156.

Guide Jr., V. D. R., & Van Wassenhove, L. N. (Eds.) (2003). *Business Aspects of Closed-Loop Supply Chains: Exploring the Issues* (Vol. 2). Pittsburgh, PA: Carnegie Mellon University Press.

Guide Jr., V. D. R., & Van Wassenhove, L. N. (2005). The Evolution of Closed Loop Supply Chain Research, CLSC 2005 Presentation.

Guide Jr., V. D. R., & Van Wassenhove, L. N. (2009). The Evolution of Closed-Loop Supply Chain Research. *Operations Research,* 57(1), p. 10-18.

Guiltinan, J. P., & Nwokoye, N. (1975). Developing Distribution Channels and Systems in the Emerging Recycling Industries. *International Journal of Physical Distribution & Logistics Management,* 6(1), p. 28-38.

Hair, J. F., Black, B., Babin, B., Anderson, R. E., & Tatham, R. L. (2006). *Multivariate Data Analysis* (6th Ed.). New Jersey: Pearson Education.

Handfield, R. B., & Melnyk, S. A. (1998). The Scientific Theory-Building Process: a Primer Using the Case of TQM. *Journal of Operations Management,* 16(4), p. 321-339.

Heese, H. S., Cattani, K., Ferrer, G., Gilland, W., & Roth, A. V. (2005). Competitive Advantage through Take-back of Used Products. *European Journal of Operational Research,* 164(1), p. 143-157.

Hillier, F. S., & Lieberman, G. J. (2005). *Introduction to Operations Research* (8th Ed.). Singapore: McGraw-Hill Higher Education.

IBM Corporation (2011). *IBM ILOG CPLEX Optimization Studio - Features and Benefits* [Online]. Available from: www-01.ibm.com/software/integration/optimization/cplex-optimization-studio/about/ [Accessed: 27 August 2011].

Inderfurth, K. (2004). Optimal Policies in Hybrid Manufacturing/Remanufacturing Systems with Product Substitution. *International Journal of Production Economics,* 90(3), p. 325-343.

Jack, E. P., Powers, T. L., & Skinner, L. (2010). Reverse Logistics Capabilities: Antecedents and Cost Savings. *International Journal of Physical Distribution & Logistics Management,* 40(3), p. 228 - 246.

Johnson, P., & Duberley, J. (2000). *Understanding Management Research: An Introduction to Epistemology*. London: SAGE.

Karakayali, I., Emir-Farinas, H., & Akcali, E. (2007). An Analysis of Decentralized Collection and Processing of End-of-life Products. *Journal of Operations Management,* 25(6), p. 1161-1183.

Kelkoo. (2009). *Mobile Phone Buyer's Guide* [Online]. Available from: www.kelkoo.co.uk/co_1625-mobile-phone-guide-mobile-phone-buyers-guide.html [Accessed: 15 September, 2009].

Kelton, W. D., Sadowski, R. P., & Sturrock, D. T. (2007). *Simulation with Arena* (4th Ed.). New York: McGraw-Hill Higher Education.

Kofoworola, O. F., & Gheewala, S. H. (2009). Estimation of Construction Waste Generation and Management in Thailand. *Waste Management,* 29(2), p. 731-738.

Kojima, M., Yoshida, A., & Sasaki, S. (2009). Difficulties in Applying Extended Producer Responsibility Policies in Developing Countries: Case Studies in E-waste Recycling in China and Thailand. *The Journal of Material Cycles and Waste Management,* 11(3), p. 263-269.

Kolbin, V. V. (1977). *Stochastic programming*. Dordrecht: D. Reidel Publishing.

Kopicki, R., Berg, M. J., Legg, L., Dasappa, V., & Maggioni, C. (1993). *Reuse and Recycling: Reverse Logistics Opportunities.* Oak Brook: Council of Logistics Management.

Krumwiede, D. W., & Sheu, C. (2002). A Model for Reverse Logistics Entry by Third-party Providers. *Omega,* 30(5), p. 325-333.

Kuik, R., Van Nunen, J. A. E. E., & Coenen, J. (2005). Commercial Returns of Sun-protection Products: the L'Oreal France Case. In S. D. P. Flapper, Van Nunen, J.A.E.E. & Van Wassenhove L.N. (Ed.), *Managing Closed-Loop Supply Chains*. Berlin: Springer, p. 79-86.

Kumar, S., & Putnam, V. (2008). Cradle to Cradle: Reverse Logistics Strategies and Opportunities across Three Industry Sectors. *International Journal of Production Economics,* 115(2), p. 305-315.

Kvanli, A. H., Pavur, R. J., & Keeling, K. B. (2003). *Introduction to Business Statistics* (6th Ed.). Mason, Ohio: South-Western, a Division of Thomson Learning.

Lee, C.-H., Chang, C.-T., Fan, K.-S., & Chang, T.-C. (2004). An Overview of Recycling and Treatment of Scrap Computers. *Journal of Hazardous Materials,* 114(1-3), p. 93-100.

Liang, Y., Pokharel, S., & Lim, G. H. (2009). Pricing Used Products for Remanufacturing. *European Journal of Operational Research,* 193(2), p. 390-395.

Lindo System Inc. (2008). *LINGO 11.0 - Optimization Modeling Software for Linear, Nonlinear, and Integer Programming.* Illinois: Lindo Systems Inc.

Lindo System Inc. (2011). *LINGO 13.0 - Optimization Modeling Software for Linear, Nonlinear, and Integer Programming* [Online]. Available from: www.lindo.com/index.php?option=com_content&view=article&id=2&Itemid=10 [Accessed: 27 August 2011].

Majumder, P., & Groenevelt, H. (2001). Competition in Remanufacturing. *Production and Operations Management,* 10(2), p. 125-141.

Mangan, J., Lalwani, C., & Gardner, B. (2004). Combining Quantitative and Qualitative Methodologies in Logistics Research. *International Journal of Physical Distribution & Logistics Management*, 34(7), p. 565 - 578.

Maximal Software Inc. (2008). *MPL Modeling System* [Online]. Available from: www.maximal-usa.com/mpl/[Accessed: 27 August 2011].

Meade, L., Sarkis, J., & Presley, A. (2007). The Theory and Pactice of Reverse Logistics *Journal International Journal of Logistics Systems and Management,* 3(1), p. 56-84.

Melnyk, S. A., & Handfield, R. B. (1998). May You Live in Interesting Times...the Emergence of Theory-driven Empirical Research. *Journal of Operations Management*, 16(4), p. 311-319.

Mentzer, J. T., & Kahn, K. B. (1995). A Framework of Logistics Research. *Journal of Business Logistics*, 16(1), p. 231-250.

Meredith, J. R., Raturi, A., Amoako-Gyampah, K., & Kaplan, B. (1989). Alternative Research Paradigms in Operations. *Journal of Operations Management*, 8(4), p. 297-326.

Mintel International Group Ltd. (2008). *PC Hardware - UK - December 2008*[Online]. Available from: http://academic.mintel.com/sinatra/oxygen_academic/search_results/show&/display/id=280357 [Accessed: 29 July 2011].

Mintel International Group Ltd. (2010). *Student Lifestyles - UK - June 2010* [Online]. Available from: http://academic.mintel.com/sinatra/oxygen_academic/search_results/show&/display/id=508478 [Accessed: 30 March, 2011].

Mitra, S. (2007). Revenue Management for Remanufactured Products. *Omega,* 35(5), p. 553-562.

Mitra, S., & Webster, S. (2008). Competition in Remanufacturing and the Effects of Government Subsidies. *International Journal of Production Economics,* 111(2), p. 287-298.

Mongkolnchaiarunya, J. (2005). Promoting a Community-based Solid-waste Management Initiative in Local Government: Yala Municipality, Thailand. *Habitat International,* 29(1), p. 27-40.

Morgan, G., & Smircich, L. (1980). The Case for Qualitative Research. *Academy of Management. The Academy of Management Review*, 5(4), p. 491-500.

Muttamara, S., Visvanathan, C., & Alwis, K. U. (1994). Solid Waste Recycling And Reuse In Bangkok. *Waste Management & Research,* 12(2), p. 151-163.

NetRegs. (2009a, 03 September 2009). *Waste Electrical and Electronic Equipment (WEEE)* [Online]. Available from: www.netregs.gov.uk/netregs/topics/WEEE/default.aspx [Accessed: 24 September, 2009].

NetRegs. (2009b, 03 September 2009). *Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS)* [Online]. Available from: www.netregs.gov.uk/netregs/63025.aspx [Accessed: 24 September, 2009].

Neuendorf, K. A. (2002). *The Content Analysis Guidebook*. Thousand Oaks, California: Sage Publications.

Oakshott, L. (1997). *Business Modelling and Simulation*. London: Pitman Publishing.

O'Leary-Kelly, S. W., & Vokurka, R. J. (1998). The Empirical Assessment of Construct Validity. *Journal of Operations Management,* 16(4), p.387-405.

Pallant, J. (2007). *SPSS Survival Manual: a Step by Step Guide to Data Analysis Using SPSS for Windows (Version 15)* (3rd Ed.). Maidenhead: Open University Press.

Pidd, M. (1998). *Computer Simulation in Management Science* (4th Ed.). New York: John Wiley.

Pohlen, T. L., & Farris, M. T., II. (1992). Reverse Logistics in Plastics Recycling. *International Journal of Physical Distribution & Logistics Management,* 22(7), p. 35-47.

Prahinski, C., & Kocabasoglu, C. (2006). Empirical Research Opportunities in Reverse Supply Chains. *Omega,* 34(6), p. 519-532.

Prechthai, T., Padmasri, M., & Visvanathan, C. (2008). Quality Assessment of Mined MSW from an Open Dumpsite for Recycling Potential. *Resources, Conservation and Recycling,* 53(1-2), p. 70-78.

Qiaolun, G., Jianhua, J., & Tiegang, G. (2008). Pricing Management for a Closed-loop Supply Chain. *Journal of Revenue and Pricing Management,* 7(1), p. 45-60.

Qu, X., & Williams, J. A. S. (2008). An Analytical Model for Reverse Automotive Production Planning and Pricing. *European Journal of Operational Research,* 190(3), p. 756-767.

Ray, S., Boyaci, T., & Aras, N. (2005). Optimal Prices and Trade-in Rebates for Durable, Remanufacturable Products. *Manufacturing & Service Operations Management,* 7(3), p. 208-228.

Reiner, G. (2005). Supply Chain Management Research Methodology Using Quantitative Models Based on Empirical Data. In H. Kotzab, S. Seuring, M. Müller & G. Reiner (Eds.), *Research Methodologies in Supply Chain Management*. Heidelberg: Physica-Verlag HD, p. 431-444.

Remenyi, D., Williams, B., Money, A., & Swartz, E. (1998). *Doing Research in Business and Management: an Introduction to Process and Method.* London: SAGE.

Revlog. (1998, 26 Feb 2002). *The European Working Group on Reverse Logistics* [Online]. Available from: www.fbk.eur.nl/OZ/REVLOG/welcome.html [Accessed: 14 Feb, 2008].

Robotis, A., Bhattacharya, S., & Van Wassenhove, L. N. (2005). The Effect of Remanufacturing on Procurement Decisions for Resellers in Secondary Markets. *European Journal of Operational Research,* 163(3), p. 688-705.

Rogers, D. S., Lambert, D. M., Croxton, K. L., & Garcia-Dastugue, S. J. (2002). The Returns Management Process. *International Journal of Logistics Management,* 13(2), p. 1-18.

Rogers, D. S., & Tibben-Lembke, R. S. (1999). *Going Backwards: Reverse Logistics Trends and Practices*. Reno: Reverse Logistics Executive Council.

Samart Corporation Plc. (2008). *Annual Report 2008*. Nonthaburi Province, Thailand.

Sasikumara, P., & Kannan, G. (2008). Issues in Reverse Supply Chains, Part I: End-of-life Product Recovery and Inventory Management - an Overview. *International Journal of Sustainable Engineering,* 1(2), p. 154 – 172.

Saunders, M., Lewis, P., & Thornhill, A. (2007). *Research Methods for Business Students* (4th Ed.). Harlow: Financial Times/Prentice Hall.

Savaskan, R. C., Shantanu, B., & Van Wassenhove, L. N. (2004). Closed-Loop Supply Chain Models with Product Remanufacturing. *Management Science,* 50(2), p. 239-252.

Savaskan, R. C., & Van Wassenhove, L. N. (2006). Reverse Channel Design: The Case of Competing Retailers. *Management Science,* 52(1), p. 1-14.

Sekaran, U., & Bougie, R. (2010). *Research Methods for Business: a Skill-building Approach.* (5th Ed.). Chichester: John Wiley.

Sengupta, J. k. (1982). *Decision Models in Stochastic Programming: Operational Methods of Decision Making Under Uncertainty*. New York: North-Holland.

Shalliker, J., & Ricketts, C. (2008). *An Introduction to Simulation in the Manufacturing Industry using SIMUL8 2008 (release 15), for SIMUL8 Corporation*.

Shi, J., Zhang, G., & Sha, J. (2011). Optimal Production and Pricing Policy for a Closed Loop System. *Resources, Conservation and Recycling,* 55(6), p. 639-647.

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2002). *Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies (2nd Ed.)*. Boston, MA: McGraw-Hill Education.

Simpson, B. (2009). *Recycle Old Mobile Phones for Cash* [Online]. Available from: www.recycle.co.uk/news/1216000.html#more-1216 [Accessed: 28 April, 2009].

SIMUL8 Corporation. (2001). *SIMUL8 User Manual*. Herndon, VA: SIMUL8 Corporation.

Souza, G. C. (2009). Remanufacturing in Closed-Loop Supply Chains. *Production and Inventory Management Journal,* 45(1), p. 56-65.

Spens, K. M., & Kovács, G. (2006). A Content Analysis of Research Approaches in Logistics Research. *International Journal of Physical Distribution & Logistics Management,* 36(5), p. 374-390.

Srivastava, S. K. (2008). Network Design for Reverse Logistics. *Omega,* 36(4), p. 535-548.

Stock, J. R. (1992). *Reverse Logistics*. Oak Brook: Council of Logistics Management.

Stock, J. R. (1998). *Development and Implementation of Reverse Logistics Programs.* Tampa: University of South Florida.

Suttibak, S., & Nitivattananon, V. (2008). Assessment of Factors Influencing the Performance of Solid Waste Recycling Programs. *Resources, Conservation and Recycling,* 53(1-2), p. 45-56.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using Multivariate Statistics* (5th Ed.). Boston, MA: Pearson Education.

Talluri, K. T., & Van Ryzin, G. J. (2005). *The Theory and Practice of Revenue Management*. New York: Springer-Science+Business Media, Inc.

Tayur, S. R., Ganeshan, R., & Magazine, M. J. (Eds.) (1998) .*Quantitative Models for Supply Chain Management*. Boston, MA: Kluwer Academic Publishers.

Technology Learning Center. (2010, 12 October 2009). *Computer Market Quarterly Year-end 2552 Against Violence* [Online]. Available from: www.tlcthai.com/webboard/view_topic.php?table_id=1&cate_id=31&post_id=75110&tltle=%B5%C5%D2%B4%A4%CD%C1%BE%D4%C7%E0%B5%CD%C3%EC-%E4%B5%C3%C1%D2%CA%B7%E9%D2%C2%BB%D5-2552-%E1%A2%E8%A7%C3%D8%B9%E1%C3%A7 [Accessed: 29 March, 2010].

Teddlie, C., & Tashakkori, A. (2009). *Foundations of Mixed Methods Research: Integrating Quantitative and Qualitative Approaches in the Social and Behavioral Sciences.* Thousand Oaks, CA: Sage Publications Ltd.

The Department of Trade and Industry (2000). *Unwanted Computer Equipment: a Guide to Re-use*. London: the Department of Trade and Industry.

The Environment Agency (2009, 14 September 2009). *Waste Electrical and Electronic Equipment (WEEE)* [Online]. Available from: www.environment-agency.gov.uk/business/topics/waste/32084.aspx [Accessed: 28 September, 2009].

The Mid Sussex District Council (2011, 21 April 2011). *All About Waste Reduction and Recycling* [Online]. Available from: www.midsussex.gov.uk/page.cfm?pageID=1686 [Accessed: 28 July 2011].

The University of Hull (2010). *Facts and Figures* [Online]. Available from: www2.hull.ac.uk/the_university/facts_and_figures.aspx [Accessed: 13 January 2010].

Thierry, M., Salomon, M., Van Nunen, J., & Van Wassenhove, L. (1995). Strategic Issues in Product Recovery Management. *California Management Review,* 37(2), p. 114-136.

Van Dalen, J., Van Nunen, J. A. E. E., & Wilens, C. M. (2005). The Chip in Crate: the Heineken Case. In S. D. P. Flapper, J.A.E.E., Van Nunen & L.N. Van Wassenhove (Ed.), *Managing Closed-Loop Supply Chains*. Berlin: Springer, p. 43-55.

Vorasayan, J., & Ryan, S. M. (2006). Optimal Price and Quantity of Refurbished Products. *Production and Operations Management,* 15(3), p. 369-383.

Webster, S., & Mitra, S. (2007). Competitive Strategy in Remanufacturing and the Impact of Take-back Laws. *Journal of Operations Management,* 25(6), p. 1123-1140.

Weems, G. H., & Onwuegbuzie, A. J. (2001). The Impact of Midpoint Responses and Reverse Coding on Survey Data. *Measurement and Evaluation in Counseling and Development,* 34(3), p. 166-176.

Xiang, L., Yong-jian, L., & Xiao-qiang, C. (2009). Collection Pricing Decision in a Remanufacturing System Considering Random Yield and Random Demand. *Systems Engineering - Theory & Practice*, 29(8), p. 19-27.

Yin, R. K. (2003). *Case Study Research: Design and Methods* (3rd Ed.). Thousand Oaks, CA: Sage Publications Ltd.

Appendix A: Interview Protocol

This structured interview is being undertaken to build knowledge and gain insights in to pricing and revenue management based on reverse logistics of electrical and electronic equipment recycling industry. This research is directed by Prof. Chandra Lalwani and Dr. Adrian E. Coronado Mondragon, and conducted by Mr. Piyawat Chanintrakul, Ph.D. student at Hull University Logistics Institute. All the data requested will be used for **academic research purposes only and used in strict confidentiality.**

Section A - Company's profile and General information of the Company

1. Could you please tell me about your company's background?

2. Could you please tell me about your company's primary product and product range?

3. Why did you make a decision to run a WEEE recycling business?

4. Could you please tell me about general information of a WEEE recycling business?

5. How do you feel about the WEEE Directive in the UK and EUROPE?

6. How many people do you currently employ?
[ ] 100 or fewer [ ] 100-200 [ ] 200-300 [ ] 300-400 [ ] over 400

7. What was the estimated turnover of business during the most recent year?
[ ] £ 10 million or less [ ] £ 10-20 million [ ] £ 20-30 million [ ] over £30 million [ ] other, please specific________________________________

Section B – Return Procedure and Recovery Procedure

1. Who are your suppliers? and please estimate the percentage of returns from each supplier

	Percentage
[ ] End users	______%
[ ] B2B	______%
[ ] Charity shops	______%
[ ] Other, please specific_______________	______%

2. Could you please tell me about you return and recovery procedure?

3. How many sorted quality classes of received goods?

[ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

4. How many old products in average you receive per year?

5. Does your company apply multiple recovery options operations depending on return quality such as direct resell, repair, refurbishment and recycling?

6. Which of the following Reverse Logistics activities does your company perform either in-house or by utilizing a third party?

Activities	In-House	Third Party
6.1 Collection of old mobile phone		
6.2 Sorting, Grading, and Testing		
6.3 Direct Resell		
6.4 Repair		
6.5 Refurbishment		
6.6 Remanufacturing		
6.7 Cannibalization		
6.8 Recycling		
6.9 Disposal		
6.10 Transportation of recovery items		

7. If we classify a number of received old goods in terms of quality and age, could you please give us the percentage of each class, a range of acquisition price per item that you pay to your suppliers and minimal acquisition price?

Quality	Percentage	Price Range	Minimal Acquisition Price (£)
1st Class (Direct Resell)			
2nd Class (Need to be repaired)			
3rd Class (Need to be refurbished)			
4th class (Need to be used other recovery methods)			

Age (Year)	Percentage	Price Range	Minimal Acquisition Price (£)
0-1			
1-2			
2-3			
3-4			
Over 4			

Section C- Logistics and Operations Costs and Labour and Machine time/Capacity

1. Could you please tell us about an average or a range of logistics and operations costs and Labour and Machine time/Capacity of the following activities?

	Cost Range (£)	Labour time (Hour)	Machine time (Hour)
1.1 Collection of old mobile phone			
1.2 Sorting, Grading, and Testing			
1.3 Direct Resell			
1.4 Repair			
1.5 Refurbishment			
1.6 Remanufacturing			
1.7 Cannibalization			
1.8 Recycling			
1.9 Disposal			
1.10 Transportation of recovery items			

Section D – Marketing Issues

1. Where is (are) your market of reprocessed goods?

1.1 [ ] a primary market, if possible, please specific_______________

1.2 [ ] a secondary market - [ ] A outlet shop or [ ] Undeveloped countries, if possible, please specific_________________

2. How many recovered products in average you sell per year?

3. How many market segments in terms of quality of recovered goods?

[ ] 1 [ ] 2 [ ] 3 [ ] 4

4. If we classify a number of sold recovered goods by means of recovery method and age, could you please give us the percentage of each class a range of selling price per item and maximum selling price?

Recovery Method	Percentage	Price Range	Maximum Selling Price (£)
Direct Resell			
Repair			
Refurbishment			
Others			

Age (Year)	Percentage	Price Range	Maximum Selling Price (£)
0-1			
1-2			
2-3			
3-4			
Over 4			

5. Who is (are) your main competitor(s) in the market?

Appendix B: A Questionnaire Survey

THE UNIVERSITY OF HULL

21 October 2009

Re: Research into Pricing and Revenue Management Based on Reverse Logistics

Dear Respondent,

The University of Hull Logistics Institute is conducting research on Reverse Logistics and seeks your opinion regarding mobile phone and computer services recycling.

We ask that you please participate in this survey, which will take approximately 10 minutes to complete. It is divided into 2 sections: section 1 deals with mobile phone recycling while section 2 deals with computer recycling. Your participation is very important to the completion of this research. Your responses will be kept strictly confidential and only aggregate data will be analysed. If you have any questions regarding any aspect of this research, please do not hesitate to contact me.

Thank you very much in advance for your assistance in this research.

Yours sincerely,

Mr. Piyawat Chanintrakul

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Section I: Mobile Phone Recycling Business

Q. 1 How often do you change your mobile phone?
[ ] Less than once a year [ ] Once every 1-2 year(s)
[ ] Once every 2 - 4 years [ ] Once more than 4 years

Q. 2 What type was the last mobile phone you used?
[ ] High end (ex. Sony Ericsson X1, Nokia N95, and Apple iPhone)
[ ] Medium end (ex. Sony Ericsson W980i, Nokia N78, and Samsung SGH U900 Soul)
[ ] Low end (ex. Sony Ericsson T250i, Samsung SGH J700, and Nokia 6300)

Type of Mobile Phone	Definition
High end	Smart phones include operating systems like Symbian to turn a phone into something closer to a laptop computer and full mobile internet access to reach your e-mail, video phone calls, and video services like TV and sporting clips
Medium end	Mobile phones include digital cameras, video recorder, full-colour screens, multimedia messaging, built-in radios and/or MP3 players
Low end	The simplest phone that you can use to make calls, access voicemail, send text messages and other simple functions

Please specify your handset model (optional)……………………………

Q. 3 What did you do with your old mobile phone?
[ ] Left it in a drawer (please go to Q. 5)
[ ] Donated it to a charity shop (please go to Q. 5)
[ ] Sold it via a mobile phone recycling company website
[ ] Sold it via a big retail supermarket or a mobile network provider
[ ] Sold it via a high street second hand shop
[ ] Other (please describe)………………………………………….

Q. 4 If you sold the handset via any of these channels, could you please tell us the selling price?
[ ] A phone in working condition £……………or ………… % of original price
[ ] A phone in non-working condition £……………or ………… % of original price

Q. 5 Let's imagine that you would like to sell your old mobile phone via a mobile phone recycling company website and the firm uses several strategies to persuade you to trade in the phone to its website. Please indicate how important you rate the following strategies.

Strategy	Very Unimportant	Unimportant	Neutral	Important	Very Important
1. More extensive mobile phone model list including your phone					
2. Higher offer price					
3. Faster payment process					
4. Alternative payment options such as a gift voucher, mobile phone airtime, and charity donation					
5. A wide range of collection methods such as a free post envelope, free courier collections, and a drop- off centre					
6. Friendly and professional customer service					
7. Corporate citizenship such as cash donation for a charity					
8. Green image such as helping the environment by recycling old mobile phones					
9. Other (please describe)………					

Section II: Computer Recycling

Q. 6 Do you own a computer?
[ ] Yes, please go to Q.7 [ ] No, please go to Q. 14

Q. 7 Please specify your computer type
[ ] A desk top [ ] A laptop

Q. 8 How often do you change your computer?
[ ] Less than once a year [ ] Once a year
[ ] Once every 2 years [ ] Once every 3 years
[ ] Once every 4 years [ ] Once every 5 years
[ ] Once every 6 years [ ] Once more than 6 years

Q. 9 What did you do with your old computer when you bought a new one?
[ ] Donated it to a charity shop, please go to Q. 11
[ ] Sold it via a high street second hand shop, please go to Q. 11
[ ] Gave it to a computer recycling service company, please go to Q. 10
[ ] Other (please describe)……………………………… , please go to Q. 11

Q. 10 If you gave it to a computer recycling service company, how was it collected?
[ ] By post [ ] By the company [ ] You sent it to the company

Q. 11 How many years did you use it?
[ ] Less than a year [ ] 1-2 years [ ] 2-3 years
[ ] 3-4 years [ ] 4-5 years [ ] More than 5 years

Q. 12 How much did you pay for it?
[ ] Less than £300 [ ] £300-£400 [ ] £400-£500
[ ] £500-£600 [ ] £600-£700 [ ] More than £700

Q. 13 Let's imagine that you would like to give your old computer to a computer recycling company. The recycling company also sells repaired and refurbished computers, new computer and computer accessories. The firm uses several strategies to persuade you to send your old computer to it. Please indicate how important you rate the following strategies?

Strategy	Very Unimportant	Unimportant	Neutral	Important	Very Important
1. Free collection service					
2. Offering you some cash back					
3. Special discount for buying a new computer or computers' accessories					
4. Corporate citizenship					
4.1 Free computer repair training for the long- term unemployed or high school students					
4.2 Donation of refurbished computer into the community					
4.3 Cash donation for a charity					
5. Green image such as helping the environment by recycling old computers					
6. Other (please describe)…………					

Q. 14 If a computer recycling company gives you some cash back, how much would you prefer the company pays for your old computer?

15.1 If a computer in working condition ………… % of purchase price
15.2 If a computer in non- working condition ………… % of purchase price

Q. 15 If a computer recycling company gives you a special discount for buying a new computer, how much cash/percentage would you want to receive?

£……………… or …………………. %

Q.16 Let's imagine that you would like to buy a repaired or refurbished computer and you have a computer specification in your mind. Unfortunately, that computer specification is not available. If there are other computers with different specifications and prices in a shop, would you consider product substitute?

[ ] Yes [ ] No

Appendix C: Reverse Logistics Programme: Illustrative Case Companies in Thailand

C.1 Introduction

Research in reverse logistics in developing countries like Thailand has been missing from academic and business practitioners' studies. It can be seen that only a handful of articles about reverse logistics programmes in the Thai context have been published in peer-reviewed international journals and conference proceedings. Hence, there are significant opportunities to do research in reverse logistics in this country, particularly with regard to an investigation of the implementation of multiple recovery options operations. This study focuses on reverse logistics in both the computer and mobile phone sector in Thailand, because both industries are currently considered as important economic factors in the country. To begin with the computer sector, in 2008, demand for computers including desktops and laptops was approximately 2.56 – 2.82 million units with an estimated value of Baht 47,452-51,295 million (Technology Learning Centre, 2010).

With regard to the mobile phone sector, in 2008, demand for mobile handsets in Thailand was approximately 8.8 million units with demand growth for handsets increasing every year (Samart Corporation Plc., 2008). Moreover, there were approximately 62 million registered mobile phone users in 2008, the 17^{th} largest total number of mobile phone subscribers in the world (Central Intelligence Agency, 2010). This appendix portrays how these industries in Thailand deal in practice with reverse logistics programmes based on the well- established framework proposed by De Brito and Dekker (2004), investigates whether the businesses have implemented multiple recovery options operations, identifies the possible obstacles and weaknesses in the industries, and advises practical recommendations.

With respect to the research approach, in this research work one case company in the computer industry in Thailand and four case companies in the mobile phone industry in Thailand are used to investigate how they have implemented reverse logistics programmes in practice. Participating companies include one computer manufacturer, one mobile phone network provider, and three mobile phone manufacturers. The methodology employed in this research includes the use of structured interviews, a variety of secondary data (e.g. an annual report, company websites, a company's product return manual, etc.), and the use of content analysis for data analysis. All the individuals interviewed are in senior and all interviews with the average duration of approximately 45 minutes were tape-recorded and carefully transcribed. Table C.1 shows the details of each interview.

The remainder sections of this appendix is built up as follows: section C.2 reviews reverse logistics research in Thailand; section C.3 demonstrates the background of the case companies; section C.4 illustrates the analysis of the current reverse logistics practices in the computer and mobile sectors in Thailand; and section C.5 provides the conclusions.

Table C.1: The Detail of Each Interview

Company	Interviewee	Nature of the Company
C	General Manager	A leading multinational computer and other computer-related product manufacturer
D	Assistant Vice President	A mobile phone network provider
E	Senior Customer Service Manager	A global mobile phone manufacturer
F	Strategic Business Management Officer	A global mobile phone manufacturer
G	Assistant Sales Manager	A Thai-based mobile phone manufacturer

C.2 Reverse Logistics Research in Thailand

Research into reverse logistics in Thailand has been missing from academic and business practitioners' studies. Altogether it found that only 13 articles about reverse logistics programmes in the Thai context have been published in peer-reviewed international journals (12 papers) and conference proceedings (one paper). These papers can be classified into two main groups i.e. waste recycling (11 papers) and other issues (two papers) as follows:

C.2.1 Waste Recycling

These papers on waste recycling include six papers related to municipal solid waste recycling, three papers related to electrical and electronic equipment waste recycling, and two papers related to other waste recycling.

In terms of municipal solid waste recycling, Muttamara et al. (1994) portrayed the reverse logistics programme of municipal solid waste recycling and reuse in Bangkok, and also provided the practical recommendations to improve the rate of recycling processes. Mongkolnchaiarunya (2005) has attempted to investigate whether participation of the people in an urban area can provide support in solving municipal solid-waste problems. The study aimed to introduce alternative solid-waste solutions into local government practices, in contrast with the traditional engineering methods, and also to estimate the potential impact and sustainability of these community-based solutions. Charuvichaipong and Sajor (2006) used a case study of failed public participation in the project of municipal solid waste recycling in Hatyai City in the southern part of Thailand in order to scrutinise the opportunity structures for participation and development of civic culture among local citizens.

Chiemchaisri et al. (2007) provided an overview of the latest trends of municipal solid waste generation, composition, and disposal in Thailand, and presented an inventory of the existing waste disposal facilities and their methane emission potential. Prechthai et al. (2008) determined the high potential of mined municipal solid waste from an open dumping facility for recycling. The recyclable waste is recovered as refuse derived fuel (RDF) and compost; by contrast, the remaining non-recyclable waste is disposed into landfill. Suttibak and Nitivattananon (2008) depicted the existing municipal solid waste recycling operations in a number of 120 urban areas in Thailand. Moreover, the study attempted to assess recycling performance and to determine the factors influencing the performance of the programme.

In accordance with electrical and electronic equipment waste recycling, Apisitpuvakul et al. (2008) used life cycle assessment (LCA) as an assessment tool in order to evaluate environmental impact potentials of recycling and landfill disposal of spent fluorescent lamps. Chaisurayakarn et al. (2008) presented a reverse logistics framework of the end-of-life mobile telephone battery sector in Thailand. Kojima et al. (2009) illustrated the concept of extended producer responsibility (EPR) in developing countries, compared the draft legislation on e-waste recycling in China and Thailand, and highlighted an overview of obstacles to the implementation of EPR in developing countries.

In terms of other waste recycling, Chavalparit et al. (2006) illustrated an application of clean technology and demonstrated the industrial ecology concept in the crude palm oil industry in Thailand, based on reuse, recycling, and utilization of solid and liquid waste and appropriate energy management. Kofoworola and Gheewala (2009) highlighted current construction and a demolition waste recycling programme in Thailand, and also estimated the quantities of construction waste generated in Thailand from 2002–2005 in order to develop an integrated waste management system and to implement policies for managing construction waste in Thailand.

C.2.2 Other Issues

Banomyong et al. (2008) presented an application of the ‘leagility’ concept in the reverse logistics process and investigated the impact of a leagile strategy in the reverse logistics (repair) process in terms of time and costs, in order to evaluate the worthiness of implementing such a strategy. Fuse and Kashima (2008) used an Asian international automobile recycling input-output (AI-ARIO) analysis as a tool in order to examine an appropriate recycling system for end-of-life vehicles (ELVs) from Japan in Thailand. It was identified that the ELV trade has a marked effect on the environment and the economy.

Based on the aforementioned literature review, it can be seen that reverse logistics research in Thailand is still at an early stage due to the fact that most current research focuses mainly on waste recycling (11 papers). Hence, it can be seen that there is plenty of scope for reverse logistics research in the context of Thailand. Table C.2 shows summary of reverse logistics research in the Thai context.

Table C.2: Summary of reverse logistics research in the Thai context

Topic	No. of papers	Authors
1. Waste Recycling	11	
1.1 Municipal solid waste	6	Muttamara et al. (1994), Mongkolnchaiarunya (2005), Charuvichaipong and Sajor (2006), Chiemchaisri et al. (2007), Prechthai et al. (2008), Suttibak and Nitivattananon (2008)
1.2 WEEE	3	Apisitpuvakul et al. (2008), Chaisurayakarnet al. (2008), Kojima et al. (2009)
1.3 Other Waste Recycling	2	Chavalparit et al. (2006), Kofoworola and Gheewala (2009)
2. Others	2	
2.1 Leagility implementation in the reverse logistics process	1	Banomyong et al. (2008)
2.2 End-of-life vehicles	1	Fuse and Kashima (2008)
Total	13	

C.3 A Background of the Case Companies

C.3.1 Company C: Computer OEM

Company C participating in this study is a branch of a leading multinational computer and other computer-related product manufacturer founded in Thailand in 1984, with the company headquarters located in Texas, USA. Since 1992, the firm has been included in Fortune magazine's list of the world's 500 largest companies. Currently, the corporation is the number one supplier of computer and other computer-related products in the United States, and the number two supplier worldwide. As a leading information technology corporation, the firm provides a wide range of product types including mobility products, desktop PCs, software and peripherals, servers and networking, storage and services.

The Thailand branch of Company C is in the Asia Pacific-Japan Commercial segment. The head office in Thailand is located in Bangkok, and the regional head office is located in

Singapore. Company C in Thailand classifies its customers into three main categories: Enterprises consisting of more than 1,000 employees, small-to-medium businesses (SMB) consisting of between 1 and 999 employees, and individual customers. Currently, it has roughly 80 employees including sales staff, marketing staff, administrative staff and financial staff. During the most recent year, the estimated turnover was $200 million ($140 million, $40 million, and $20 million from Enterprises, SMB, and the individual customers segment respectively). Moreover, it is in first, third, and fourth position in the Thailand market of Enterprises, SMB, and Individual customers segment, dominating 30%, 10%, and 10% respectively.

The major reason that Company C has implemented a reverse logistics programme is to improve customer satisfaction, and the products have been returned to the firm because of two primary reasons i.e. defect warranty returns and service returns (one-year warranty returns). The company has employed a closed loop network to cope with defect warranty returns and an open loop structure to deal with service returns (one-year warranty returns).

C.3.2 Company D: Mobile Phone Network Provider

Company D is one of mobile phone network providers in Thailand and it is a subsidiary company of a leading international corporation located in Hong Kong. Company D was found in 2000 in order to provide high speed voice and data wireless mobile service to customers and the head office is located in Bangkok. In 2003, the firm created a new segment in Thailand's telecom industry by launching new mobile services of Code Division Multiple Access (CDMA) network. CDMA is second-generation (2G) multi-media mobile telephone. Currently, the firm network service area covers only 25 provinces located in the Bangkok metropolitan area and in central, east coast and west coast regions of Thailand.

Furthermore, the firm provides a wide range of products and services including CDMA handsets, airtime tariff, prepaid and postpaid SIM card, mobile broadband internet, wireless broadband devices, and mobile phone accessories. Particularly, the firm offers a variety of mobile phone technology categories i.e. low-end, mid-range, and high-end handsets. A current number of sales are 120,000 handsets per year comprising 40%, 30% and 30% for low-end, mid-range, and high-end handsets respectively and the market share is approximately 1-2% in Thailand mobile phone market. The firm recently employs 1,000 employees and the estimated turnover is Baht 5,000 million in 2008. Company D implemented its reverse logistics programme to improve customer satisfaction. Handsets are returned for two main reasons i.e. service returns and warranty returns. The company has employed a closed loop network to cope with these returns.

C.3.3 Company E: Mobile Phone OEM

Company E is a branch in Thailand of a global mobile phone provider, the fourth-largest mobile phone manufacturer in the world with 4.9% of market share after Nokia, Samsung and LG in 2009. The firm is a joint venture established in 2001 by a Japanese consumer electronics company and a Swedish telecommunications company to make mobile phones. Its vision is to become the communication entertainment brand; so, the company provides handsets combing powerful technology with innovative applications for mobile imaging, music, communications and entertainment.

The Thailand branch of Company E is in the Asia Pacific Region. The head office in Thailand is located in Bangkok and the regional head office is located in Singapore. In terms of the company's products, the firm provides a wide range of mobile phones and mobile phone accessories. The estimated percentage of market share in Thailand is 5.00 % and mid-range and high-end handsets dominate 80 % of total sales number. The firm recently employs approximately 100 employees.

There are two main reasons why Company E has implemented a reverse logistics programme, which are corporate citizenship in terms of environmental issues, and to improve customer satisfaction. Handsets are returned to the company for two main reasons i.e. service returns and end-of-life returns. The company has set up an open loop structure to deal with these returns.

C.3.4 Company F: Mobile Phone OEM

Company F is a branch in Thailand of a global mobile phone manufacturer. It became the world's second largest mobile phone manufacturer in 2007, surpassing Motorola, and behind Nokia. For the mobile phone business in Thailand, the head office of company F is located in Bangkok and it organised sales of mobile phones itself in the middle of 2008. The estimated percentage of market share in Thailand was 20.00 % in 2008. Company F became the number one seller in Thailand handset market with 33.00 % of value market share in 2009 and low-end, mid-range, and high-end handsets account for 53%, 32% and 15%, respectively of total sales number.

Moreover, the company launches approximately 50 new handset models per year. Currently, the firm employs approximately 300 employees including marketing staffs and sale staff; and the estimated turnover was Baht 6,000 million in 2009. Company F implemented its reverse logistics programme to improve customer satisfaction and for the purpose of brand protection. With regard to the reasons for returns, the firm classifies these into three main types, i.e. B2B commercial returns, service returns, and warranty returns. The company has employed a closed loop structure to deal with B2B commercial returns and warranty returns

C.3.5 Company G: Mobile Phone OEM

Company G participating in this study is a leading Thai mobile phone manufacturer and it is a subsidiary of a Thai leading end-to-end solution and information technology service provider group. The firm is located in Nonthaburi Province, Thailand. The firm was set up in 2003 to import, distribute house brand mobile phones and other leading brands and also to market multimedia-related products and services. In addition, it was listed in the Stock Exchange of Thailand in 2008.

The firm sold a total of 4,038,191 handsets in 2008. The breakdown of this figure is that 2,780,061 handsets were sold in the domestic market and 1,258,130 handsets were sold in international markets such as Malaysia, Bangladesh, Indonesia, Vietnam, Laos, and India. Roughly speaking, a sales number of mid-range handsets account for 80-90 % of the total sales. In 2008, the company took second position in Thailand handset market, commanding 28% market share. The turnover was Baht 662 million in 2007 and Baht 730 million in 2008 and currently, the firm has approximately 1,000 employees.

Company G implemented its reverse logistics programme to improve customer satisfaction and to reduce costs. Handsets are returned for two main reasons, i.e. service returns and warranty returns. The company has employed a closed loop network to cope with these returns. Table C.3 highlights summary of the case companies' backgrounds.

Table C.3: Summary of the Case Companies' Background

Product	Computer	Mobile Phone			
Company	C	D	E	F	G
Market Share (%)	Enterprise-30% SMB- 10% Individual-10%	1-2%	5%	20 % (2008) 33 % (2009)	28% (2008)
Turnover (million)	$200	Baht 5,000 (2008)	N/A	Baht 6,000 (2009)	Baht 662 (2007) Baht 730 (2008)
No of employees	80	1,000	100	300	1,000

C.4 The Analysis of the Current Reverse Logistics Practices in the Computer Sector and the Mobile Sector in Thailand

C.4.1 Data Analysis Method

Easterby-Smith et al. (2008) mentioned that there are six different techniques for an analysis of natural language data. These include (quantitative) content analysis, grounded analysis, discourse analysis, narrative analysis, conversation analysis, and argument analysis. Neuendorf (2002) and Bryman and Bell (2007) pointed out that content analysis is the only technique of recorded human communications analysis that is suitable for quantitative research, whereas the others are qualitative analytic methods that may be applied to message content. Bryman and Bell (2007) argued that content analysis has several advantages.

These advantages include a very transparent research method, a method that can be used for longitudinal analysis with relative case, an unobtrusive method, a highly flexible method that can be applied to a wide variety of unstructured information types, and a method that can be used to provide complex information about the social group. Hence, (quantitative) content analysis is used in this research. Content analysis can be defined as "*the systematic, objective, quantitative analysis of message characteristics*" (Neuendorf, 2002, p.1). Bryman and Bell (2007, p.302) provided more comprehensive description of content analysis: "*an approach to the analysis of documents and texts (which may be printed or visual) that seeks to quantify content in terms of predetermined categories and in a systematic and replicable manner*".

C.4.2 Findings and Discussions

Based on the well-established reverse logistics framework presented by De Brito and Dekker (2004), key typologies were used as main themes in content analysis. These typologies include driving forces, the return reasons, the actors in reverse logistics, and the recovery process. From the interviews, the adopted typologies were identified and their frequencies are presented in Table C.4: summary of case companies' reverse logistics programme in practice and Table C.5: summary of case companies' recovery process in practice.

From table C.4, it was found that the driving forces behind the reverse logistics of the participating companies include cost reduction (cited by only one interviewee), market and brand protection (referred to by only one interviewee), improved customer relationship (mentioned by all the interviewees), and corporate citizenship (cited by only one interviewee). The interviewee from company G mentioned that cost reduction is one of the key reasons for the reverse logistics programme implementation. Company G sold approximately 2.78 million handsets in the Thai market in 2008, warranty returns accounting for approximately 4% of total sales. It can be seen that using spare parts for repair from the cannibalisation of handsets that are beyond economical repair can vastly reduce the cost of new spare parts.

Company F has attempted to distinguish its handsets from other competitors by setting the products in a premium position. The interviewee from company F pointed out that the collection of defective handsets would help the firm to protect its market and brand because other parties could not collect and resell their poor quality handsets on the market. Moreover, it can be seen that, in the competitive market, all the firms not only sell their products to customers, but also need to offer an extra repair service to them. Therefore, the reverse logistics programme is crucially considered as a tool to improve customer relationship and customer satisfaction.

In terms of corporate citizenship, Company E has established the return programme of end-of-life handsets in Thailand as a result of the sustainability policy from its headquarters. The policy aims to improve its impact on the environment and society based on three dimensions of sustainability: economic, environmental and social aspects of the company. The reasons for product returns are as follows: B2B commercial returns related to distribution returns (cited by only one interviewee), service returns (mentioned by all the interviewees), warranty returns (cited by four of five interviewees) and end-of-life returns (referred to by only one interviewee).

Table C.4: Summary of Case Companies' Reverse Logistics Programme in Practice

	Company				
	C	**D**	**E**	**F**	**G**
Driving forces behind reverse logistics					
1. Economics					
1.1 Direct benefits					
Cost reduction	-	-	-	-	x
A potential profit source	-	-	-	-	-
1.2 Indirect benefits					
Market and brand protection	-	-	-	x	-
Entering new markets	-	-	-	-	-
Improved customer relationship	x	x	x	x	x
2. Environmental legislation	-	-	-	-	-
3. Corporate citizenship	-	-	x	-	-
Reasons for product returns					
1. Manufacturing returns					
Rework	-	-	-	-	-
Raw material surplus	-	-	-	-	-
Quality-control returns	-	-	-	-	-
Production leftovers/by-products	-	-	-	-	-
2. Distribution returns					
Product recalls	-	-	-	-	-
B2B commercial return	-	-	-	x	-
Stock adjustments	-	-	-	-	-
Functional returns	-	-	-	-	-
3. Customer returns					
B2C commercial returns	-	-	-	-	-
Service returns (repair, spare parts)	x	x	x	x	x
Warranty returns	x	x	-	x	x
End-of-use returns	-	-	-	-	-
End-of-life returns			x		
Actors in reverse logistics					
Forward supply chain actors	x	x	x	x	x
Specialised reverse chain players	-	x	x	x	x
Opportunistic players	-	-	-	-	-

Table C.5: Summary of Case Companies' Recovery Process in Practice

Product	Computer		Mobile Phone							
Company	C		D		E		F		G	
Activities	In-House	Third Party	In-House	Third Party	In-House	Third Party	In-House	Third Party	In-House	Third Party
1 Product Return Collection	-	x, √	-	x,√	-	x,√	-	x,√	x,√	x,√
2 Sorting, Grading, and Testing	-	√	√	-	-	√	√	√	√	-
3 Direct Resell	-	-	√	-	-	-	-	-	√	-
4 Repair	-	x	x,√	-	-	x	-	x,√	x	-
5 Refurbishment	-	-	-	-	-	-	-	-	-	-
6 Remanufacturing	√	-	-	-	-	-	-	-	-	-
7 Cannibalization	-	-	√	-	-	√	-	-	√	-
8 Recycling	-	-	-	-	-	√	-	-	-	-
9 Disposal	-	-	-	√	-	-	-	√	-	√
10 Transportation of recovery items	-	-	-	x,√	-	x,√	-	x,√	x,√	x,√

(x = service returns, √ = warranty returns or end-of-life returns)

Company F distributes handsets via three main distribution channels, i.e. dealers, organised retail groups and modern trade; as a result, the firm considers B2B commercial returns related to distribution returns as one of the major return reasons. On the other hand, the others have different forward logistics channels strategies, so they do not take this returns type into account. For example, Company C delivers products directly to customers, and the distributors of Company E take responsibility for all returns excluding service returns. Company D and Company G distribute handsets to customers mainly via their shops.

In terms of the actors in reverse logistics, forward supply chain actors (mentioned by all the interviewees) and specialised reverse chain players e.g. disposal and recycling specialists (cited by four of the five interviewees) are involved in the reverse logistics programme. Company C does not implement disposal or recycling as parts of its recovery process; therefore, only forward supply chain actors are responsible for the reverse chain. In accordance with the recovery process of warranty (defect) returns (cited by four of five interviewees), it was found that one recovery option, two recovery options, three recovery options and four recovery options (referred to by only one interviewee) have been used. For the recovery process of end-of-life returns (mentioned by only one interviewee), two recovery options have been implemented.

More importantly, from Table C.5, it is found that the demographics of the participating companies have an impact on outsourcing decisions of the process recovery operations. Company D and Company G have approximately 1,000 employees. As a result, the companies have sufficient resources to operate most of their process recovery operations in-house. By contrast, Company C, Company E, and Company F only have approximately 80, 100, and 300 employees, respectively. Therefore, these firms have made a decision that all process recovery operations are operated by a third-party service provider due to resource limitations. Figure C.1 depicts the relationship between the demographics of the participating companies and outsourcing decisions.

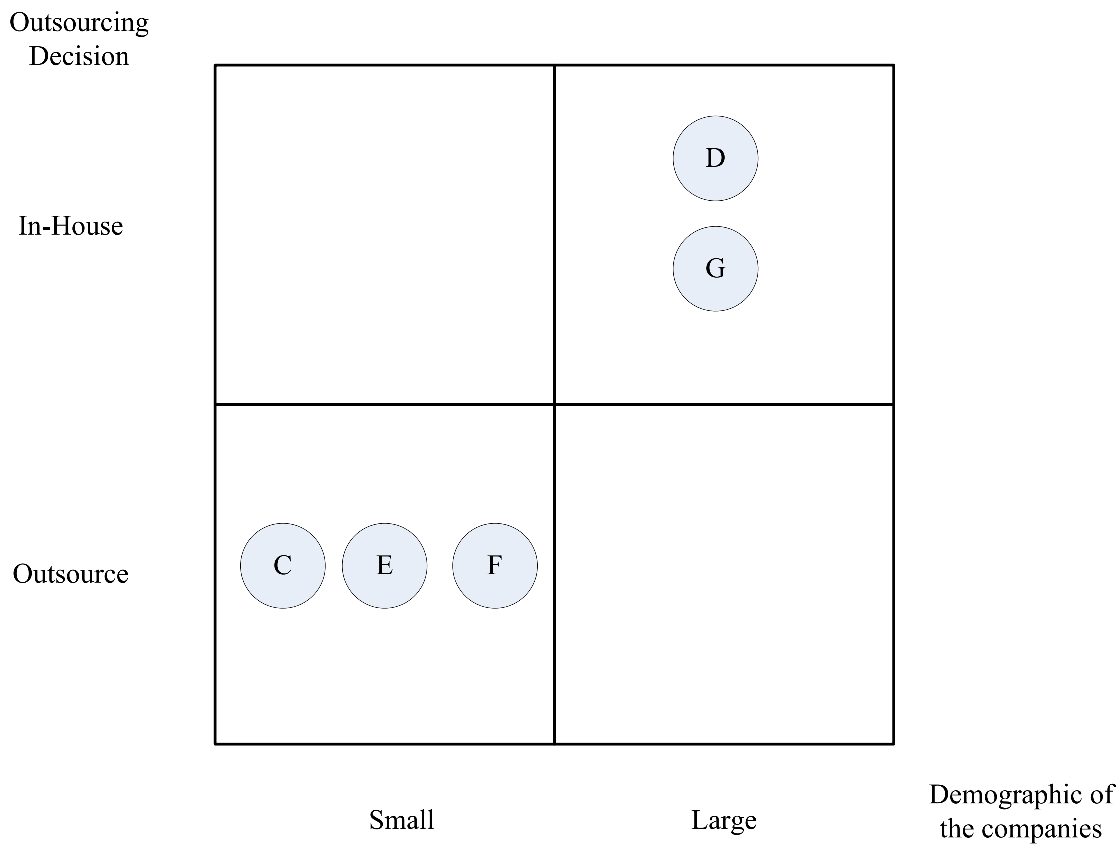

Figure C.1: Relationship between Demographic of the Participating Companies and Outsourcing Decision

C.4.3 Possible Obstacles and Weaknesses in the Industries, and Practical Recommendations

Based on information from the structured interviews, possible obstacles and weaknesses in the current reverse logistics practices of the Thai computer and mobile phone sector can be identified. In addition, practical recommendations based on best practices used in other countries can be proposed. The possible obstacles and weaknesses, and practical recommendations are as follows:

Obstacle and weakness 1: lack of proper reverse logistics network design, and return collection and transport approaches

None of the participating companies have yet set up the appropriate network design and return, collection and transport approaches for their reverse logistics programmes. For example, Company E, the mobile phone manufacturer, has implemented an end-of-life mobile phone returns programme. The interviewee from company E highlighted the fact that the operations costs of the programme are tremendously expensive.

"We use one of the biggest air third party service providers (DHL) to collect end-of-life handsets from the service centres and deliver them to the regional collection centre weekly. We pay a lot of money for these operations." ------ Company E

The company's service centres or authorised dealers are considered as the collection centres; however the number of collection centres is inadequate. End-of-life handsets are collected and delivered to the regional collection centre located in Singapore by a third party service provider each week, even though the number of handset returns is extremely low, and transportation cost per unit is high. After the recovery process, reusable parts are sent back to the original company in Thailand and non-reusable parts are recycled at factories located in Singapore or China. It can be seen that the reverse logistics network design, and return, collection and transport approaches are not well-designed.

Recommendation 1:

All participating companies may need to redesign their reverse logistics network design, and return, collection and transport approaches to reduce the cost of return operations, and to improve the efficiency and effectiveness of the reverse logistics operations. The recommendations for these issues are as follows:

In terms of reverse logistics network design, Fleischmann et al. (2004) mentioned that a reverse logistics network is much more complex than a traditional logistics network due to the three principle characteristics of a reverse logistics network that differ from a conventional logistics network, namely (1) the need for testing and grading of return products via a centralisation or decentralisation facility; (2) uncertainty in terms of quantity, quality and timing on the supply side of reverse flow; and (3) interaction, integration and coordination of different forward and reverse flows. In addition, the design of a suitable reverse logistics network that manages the arising return flows in an optimal way has an essential impact on the economic opportunities of recovering value from returns products of a closed-loop supply chain (Fleischmann et al., 2000).

To design a robust reverse logistics network, companies need to address the following issues: where to locate the various activities of the reverse logistics, how to design the corresponding transportation links, how to collect return products from the customer, where to grade and sort collected products, where to reprocess collected products, and how to redistribute recovered products to potential customer (Fleischmann et al., 2004). Figure C.2 demonstrates six aspects of reverse logistics network design.

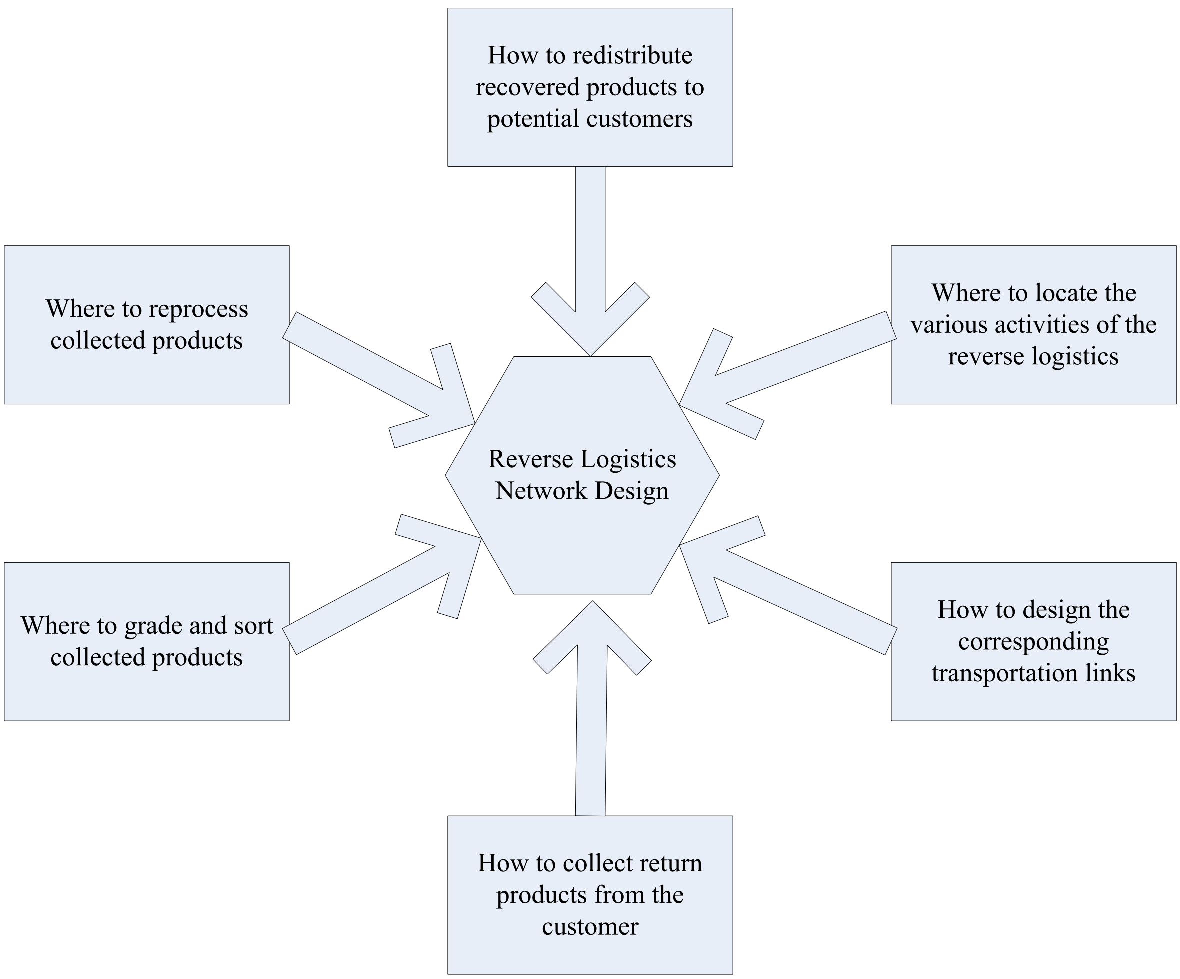

Figure C.2: Six Aspects of Reverse Logistics Network Design (Fleischmann et al., 2004)

With regard to the design of return, collection and transport approaches, Beullens et al. (2004) highlighted that the design of efficient and effective return, collection and transportation activities has an impact on the economic success of reprocessing products. The transport activities include the collection of used products from the disposer market, the delivery of recovered products to the reuse market, and the delivery of new products to the user market.

To design robust collection and transport approaches for reverse logistics, firms have to take four aspects into account. These aspects include the collection infrastructure (i.e. on-site collection, unmanned drop-off sites, and staffed and smart drop-off sites), the collection policy (i.e. periodic schedules, by monitoring demand, call service, and triggered by a distribution schedule), the combination level of the collection (i.e. separate routing of independent resources, separate routing of shared resources, co-collecting source-separated flow of goods, and integrating collection and delivery tasks), and the characteristics of the collection vehicles (i.e. traditional collection vehicles- a single compartment with a compaction mechanism, and collection vehicles for the integration of collections with deliveries). Figure C.3 illustrates four aspects of collection and transport approach design for reverse logistics.

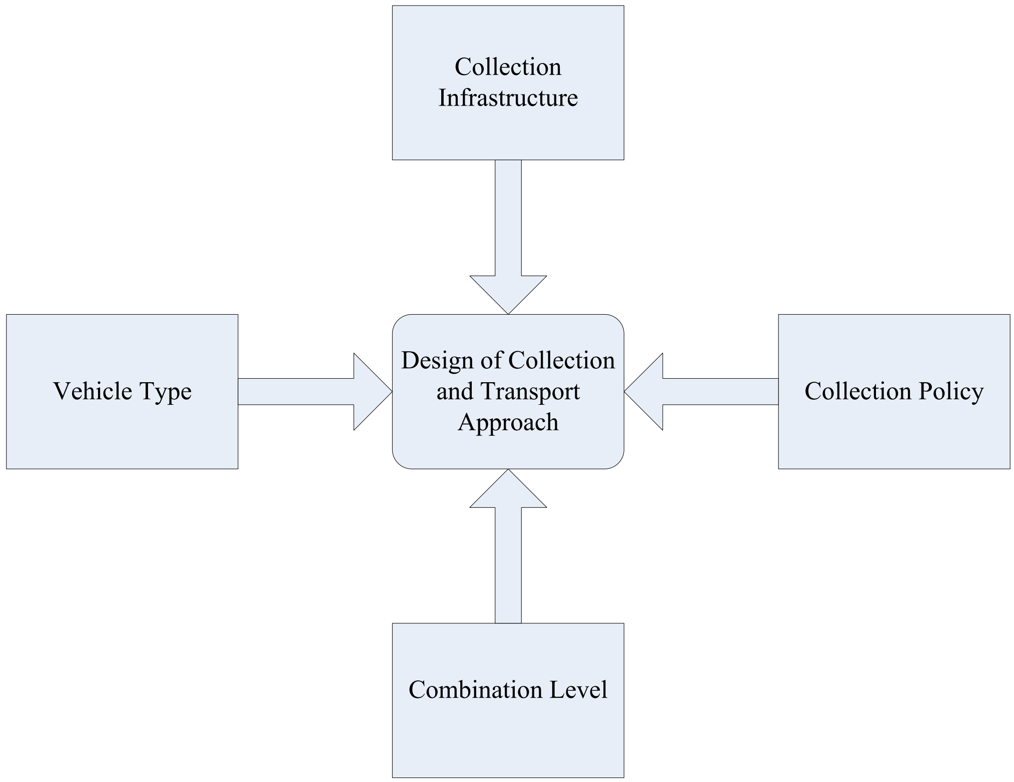

Figure C.3: Four Aspects of Collection and Transport Approach Design for Reverse Logistics (Beullens et al., 2004)

Obstacle and weakness 2: lack of environmental awareness

It seems that none of the actors involved in reverse logistics programmes pay attention to the environmentally-friendly recovery processes of non-reusable and end-of-life computers and mobile phones. In particular, Company D and Company E use roller trucks to destroy and dispose of non-reusable handsets, because the operational cost of disposal is much cheaper than those of environmentally-friendly methods such as recycling and proper disposal. This process will have a negative impact on the environment, because handsets contain several hazardous materials and improper procedures may cause emissions of these materials.

“ We use roller trucks to destroy warranty returns mobile phones which are in non-working condition and are beyond economical repair because the operations cost is cheaper than recycling operations cost. ” ------Company D

“A whole box of a poor quality handset will be sent to a third-party service provider in order to destroy because it is time-consuming and labour intensive to separate reusable parts or accessories in order to reuse or resell.” ------Company E

Furthermore, two interviewees from Company E and Company F also highlighted that the corporate social responsibility (CSR) programme, by implementing end-of-life returns, does not have any impact on increasing sales, due to the fact that Thai people show no concern for environmental issues. For example, customers may know about the harm end-of-life computers and handsets can cause to the environment, but they still bin them in municipal waste.

“Thais still do not have the environmental awareness; as a result, the implementation of end-of-life returns programme is not successful in Thailand. The programme may provide the firm some small benefits in terms of green image. However, it does not have any impact on increasing sales because customers mostly concern about a price of a mobile phone and its features as their major buying decision.” ------Company E

“The company organised sales of mobile phones itself in the middle of 2008. Currently, we use pricing strategy and high-technology handset features as order-winners in order to become the number one seller in the Thai market. Moreover, Thais show no concern for environmental issues as you can see that customers still bin end-of-life handsets in municipal waste. Hence, we believe that the implementation of end-of-life returns programme does not has any impact on increasing sales at the present." ------Company F

Recommendation 2:

The government must provide fundamental education to all reverse logistics players, that stress the harm which the inappropriate disposal of end-of-life computers and mobile phones can cause, and highlights the benefits of a sustainable recovery programme. In particular, the government may recommend that Company D and Company E implement more environmental multiple recovery options operations. Company D should include recycling and proper disposal operations in the reverse logistics process for seven-day warranty returns, and Company E should take cannibalisation, recycling and proper disposal into account.

Obstacle and weakness 3: lack of detailed legislation and guidance

There is a need for environmental legislation and standard guidance related to the recovery procedure of non-reusable or end-of-life computers and mobile phones. Current legislation does not force all reverse logistics actors to use environmentally-friendly recovery processes.

Recommendation 3:

The government should introduce specific environmental legislation to make it compulsory that all reverse logistics players have to reduce the number of non- reusable or end-of-life computers and mobile phones going to landfill, and improve recovery and recycling rates. For example, the UK government has launched the Waste Electrical and Electronic Equipment (WEEE) Regulations that came into force in January 2007 (NetRegs, 2009a).

C.5 Conclusions

This appendix presents a reverse logistics portrait of practices in the computer sector and the mobile phone sector in Thailand, based on the well-established framework by De Brito and Dekker (2004), and highlights the possible obstacles and weaknesses in the current practices of these industries. More importantly, this study also identifies practical recommendations to improve reverse logistics programmes that are suitable for the Thai computer sector and the Thai mobile phone sector. For the Thai mobile phone industry especially, this study can provide a clear picture of the industry due to the fact that the four participating companies represent 66% of the Thai market. Moreover, the results found that two mobile phone companies have implemented multiple recovery options operations for warranty returns. Hence, this work pioneers research on reverse logistics programmes in the Thai computer sector and the Thai mobile phone sector.

In terms of academic contribution, there has been a lack of research in reverse logistics in developing countries like Thailand from academic and business practitioners' studies. It was found that only a handful of articles about reverse logistics programmes in the Thai context have been published in peer-reviewed international journals and conference proceedings. Hence, the results of this study make a contribution to the current academic literature based on the empirical study of reverse logistics in developing countries. It is expected that other academics will be able to expand this research in further studies.

More importantly, this research found that having a reverse logistics programme is crucial, because it may provide several benefits, including direct and indirect profits for business, conformation to current and future environmental legislation, and corporate citizenship. Hence, the results of this study would provide different parties (from the Thai government to Thai computer and mobile phone businesses) some useful guidelines that can be used to improve reverse logistics programmes in the Thai context and as a reference to reverse logistics programmes in developing countries.

This research work is faced with several limitations. Firstly, due to access limitations, only one computer manufacturer, dominating 30%, 10%, and 10% of Thailand market of the Enterprises, SMB, and Individual customers segments respectively, participated in this research; as a result, this study may not present a whole reverse logistics portrait of practices in the Thai computer sector. Secondly, all the individuals interviewed provided nearly all the details of their reverse logistics programmes currently being practised, as did the two participating mobile phone companies, who have implemented multiple recovery options operations. However, these individuals interviewed could not give us the cost parameters of the reverse logistics operations since these data are confidential, and also difficult to estimate. Hence, a pricing model and a simulation for multiple recovery options operations based on the mobile phone sector could not be formulated.

Thirdly, because of limitations related to access and time availability, this study could not interview more individuals in each case company and all the reverse logistics players involved in the progammes to enhance results reliability. In terms of further studies, it would be fruitful if to interview more individuals in each case company and all the reverse logistics players involved in the progammes to enhance results reliability. Future research should conduct a comparative study between reverse logistics process of the industry in Thai and other developed countries. Moreover, further investigations should consider reverse logistics programme in other Thai electronic sectors such as a computer and home appliances.