DEVELOPMENT OF ELECTRICAL AND ELECTRONIC EQUIPMENT WASTE COLLECTION MODEL FOR MALAYSIAN INDUSTRY

RAHMAH ABDULSALAM ATTALLAH

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2017

DEVELOPMENT OF ELECTRICAL AND ELECTRONIC EQUIPMENT WASTE COLLECTION MODEL FOR MALAYSIAN INDUSTRY

RAHMAH ABDULSALAM ATTALLAH

DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2017

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: (I.C/Passport No:)

Matric No:

Name of Degree:

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

Field of Study:

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date:

Subscribed and solemnly declared before,

Witness's Signature Date:

Name:

Designation:

ABSTRACT

Due to the growing awareness towards the environment, resources shortage and insufficient landfill capacities in many countries, more attention has been given by the government to take action for proper waste disposal, in order to protect the ecosystem. One of the serious waste types to be handled is the electrical and electronic waste (e-waste), which is estimated to be 20–50 million tons, generated per year worldwide, which certainly cause a negative effect towards the environment. The collection process of the e-waste is the most important stage to achieve successful e-waste management. In Malaysia, the current e-waste management model is not catering the huge increase of the e-waste, since only 5% of the accumulated waste is being recycled. On this ground, the aim of this study is to develop the model for electrical and electronic waste collection in Malaysia to overcome the problems threatening the environment. Content analysis approach is used to review the literature for evaluating the e-waste collection models in some of the developed counties. In order to develop the improved e-waste collection for Malaysia, benchmarking study was conducted, where the current e-waste collection model of Malaysia was benchmarked with the Switzerland e-waste collection model, as it is the best legal e-waste collection model in the world. The benchmarking parameters are: e-waste flow scenario, financial flow as well as rules and regulations of the e-waste collection implemented by the department of environment. An improved model has been developed based on the result of the benchmarking. A three case study was conducted to validate the improved collection model for the Malaysian industry, while questionnaires as well as a face to face interview was conducted to collect the data for the case studies.

The results show that the Malaysian e-waste collection scenario has several difficulties, as there are many parties responsible on the e-waste management which leads to the leaking of the e-waste in the environment, plus there are informal collection centers

which collect the waste and end up with the land filled without proper disposal. Furthermore, the amount of e-waste is increasing dramatically, which is very difficult to be handled with the current e-waste collection scenario, in addition, there are no strict rules and regulations for managing the e-waste and the financial flow of the e-waste. The simulation results show that the improved model is more efficient than the current collection model in terms of the amount of e-waste collected and the cost of the collection.

ABSTRAK

Disebabkan oleh peningkatan kesedaran terhadap alam sekitar, kekurangan sumber semulajadi dan kapasiti tapak pelupusan yang terhad di kebanyakan negara, perhatian yang lebih telah diberikan dalam usaha pengendalian sisa buangan yang teratur bagi tujuan melindungi ekosistem. Sisa elektrik dan elektronik (*e-waste*), dianggarkan 20-50 juta tan metrik dihasilkan setiap tahun di seluruh dunia, yang menyebabkan kesan negatif terhadap alam sekitar. Strategi logistik terbalik atau *reverse logistic* merupakan proses terpenting dalam memastikan kejayaan *reverse logistic.* Di Malaysia, model semasa pengurusan e-waste tidak dapat menampung peningkatan e-waste yang banyak,dimana, hanya 5% daripda jumlah sisa buangan dikitar semula. Disebabkan hal ini, matlamat kajian ini bertujuan menghasilkan model pengumpulan e waste di Malaysia untuk mengatasi masalah terhadap alam sekitar. Teknik analisis yang digunakan untuk mengkaji literatur dalam menilaian model-model pengumpulan e-waste terhadap beberapa negara maju. Dalam usaha membangunkan model pengumpulan *e-waste* yang lebih baik di Malaysia, kajian penanda aras telah dilaksanakan dimana model semasa penggumpulan *e-waste* Malaysia ditanda aras dengan model penggumpulan *e-waste* Switzerland, kerana negara tersebut mempunyai polisi model yang terbaik di dunia. Parameter-parameter penanda aras adalah: senario aliran *e-waste*, aliran kewangan, dan terma dan syarat untuk pengumpulan *e-waste* yang dilaksanakan oleh Jabatan Alam Sekitar. Model yang lebih baik telah dibangunkan berdasarkan penilaian tanda aras. Tiga kajian kes telah dijalankan untuk mengesahkan penambahbaikkan pengumpluan model untuk industri Malaysia, soal selidik, temu duga bersemuka juga dikendalikan untuk mengumpul data untuk kajian kes. Hasil kajian menunjukkan senario pengumpulan sisa buangan elektrik Malaysia menghadapi beberapa masalah kerana terdapat banyak pihak yang bertangunggjawab ke atas pengurusan sisa buangan elektrik yang menyebabkan pendedahan sisa buangan elektrik kepada alam sekitar tambahan pula, terdapat juga

pusat-pusat pengumpulan yang tidak sah yang mengumpul sisa buangan dan berakhir di tapak pelupusan tanpa melalui prosedur yang betul. Di samping itu, jumlah *e-waste* mengalami peningkatan yang drastik dan mengakibatkan kesukaran untuk mengurus dengan senario pengumpulan *e-waste* yang sedia ada, disamping itu, tiada terma dan syarat yang ketat untuk mengurus e-waste dan aliran kewangan e-waste. Hasil simulasi menunjukkan bahawa model yang ditambah baik ini adalah lebih efisien berbanding dengan model pengumpulan yang sedia ada.

ACKNOWLEDGEMENTS

First and above all, I praise God, the almighty for providing me this opportunity and granting me the capability to proceed successfully. This thesis appears in its current form due to the assistance and guidance of several people. I would therefore like to offer my sincere thanks to all of them. My great appreciation to Dr. Salwa Hanim Binti Abdul Rashid for her valuable and constructive suggestions during the development of this project which had contributed to this project. Her willingness to give his time so generously is very much appreciated. It gives me an honor also to acknowledge Dr. Olugu Ezutah Udoncy for his great contribution during the journey of this project which added a significant value to the outcomes of the study.

T would also like to acknowledge the University of Malaya Research Grant (RP018C-13AET) for the financial support.

I would also like to mention with great pleasure the role of my parents and all my family members for their patience and support at each and every stage of my life. I, therefore, aim and hope to make them feel proud of my work.

An extended thanks to all the Center of product design and development (CPDM) members for the huge supports provided during the research path.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

WEEE	:	Electrical and electronic equipment waste
E-waste	:	Electrical and electronic equipment waste
EOL	:	End of life
DoE	:	Department of Environment
EPR	:	Extended Producer Responsibility

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

The thesis mainly focuses on the improvement of the electrical and electronic waste (E-waste) collection model, through a comparison between Malaysian collection model and the world's best collection model, as well as a case study. This chapter offers a general idea, the purpose, and the significance of the study. The chapter presents the background, problem statement, the aim and the objectives of the research as well as the thesis structure.

1.1 Background

The growing awareness towards the environmental concern in many countries, has led to awareness on the protection of the ecosystem. Studies have shown that production and the manufacturing companies can decrease the stability of the ecosystem (Pfisterer and Schmid, 2002), as they are directly involved the conversion of raw materials to new products, and this will lead to a depleted raw material reserve. In addition, the manufacturing process itself harms the ecosystem in various ways, such as through emission. Furthermore, the method applied for the disposal of the end of life (EoL) products might leave a negative impact on the environment. Efficient collection of the end of life products will reduce the imbalance created in the ecosystem by reducing the overdependence on raw materials. In addition, pressure on the manufacturing process will be reduced by promoting the second-hand products, resulting from the recycling procedure (Cui and Forssberg, 2003). Apart from that, it has been resulted that the energy emission required for the new product is higher than for the recycled materials. The EoL product has gained a huge attention from the researchers which has led to the search for an efficient end of the life disposal process.

Owing to the rapid consumption of the globe, the electrical and electronics equipment industry (EEE) became one of the fastest-growing sectors in the world. Therefore, large amounts of waste of electrical and electronic equipments (e-waste) are generated worldwide, which certainly causes serious environmental issues (Ni and Zeng, 2009). E-waste is estimated to be tens of million tons generated per year (Robinson, 2009). E-waste contains not only toxic and hazardous contaminants, but also valuable and precious resources if not treated in a proper way (Cui and Forssberg, 2003; Ongondo et al., 2011). In recent years, the management of e-waste has drawn more and more attention from the public and research institutions because of the many environmental protection and economic benefits.

In order to minimize the hazardous effects of the e-waste on the ecosystem, reverse logistics have been implemented in many companies. Reverse logistics can be applied for proper end-of-life product management, thus the reverse logistics became more important in the overall industrial sector. More specifically, reverse logistics is the process of moving goods from their typical end of life destination for proper disposal.

Collection process is the first stage of reverse logistics; it is the most important stage to achieve successful reverse logistics. Klausner and Hendrickson (2000) explained that both successful product take back strategy and maximum profit can be achieved by proper collection strategies for EOL products. On this ground, this study aims to propose the collection model of the reverse logistics network, especially for the electrical and electronic equipment waste, in order to achieve the desired goals by the company as well as to overcome the weakness in the existing models.

1.2 Problem statement

Due to the rapid growth of the electrical and electronic industry, large amounts of electrical and electronic equipment waste, estimated to be 20–50 tons (Malaysian Department of Environment, 2009), is generated per year worldwide. Shortage of raw material, and limited landfill capacity in most of the countries effected, is owing to the lack of electrical and electronic equipment waste management. E-waste, especially computer, contains a variety of toxic and heavy metals, such as lead, mercury, cadmium, chromium and plastic that cause toxic pollution if inadequately disposed (Pinto, 2008). Hence, it is crucial to have a good e-waste management system in order to reduce the harmful effect on humans and the environment. Although there are different methods for e-waste disposing and management but almost all these methods leave a negative effect on the ecosystem. Therefore, a good system of e-waste management needs to be implemented in order to ensure a clean and safe environment.

1.3 Research Aim and Objectives

This project aims to develop a model for the collection of electrical and electronic equipment waste, e-waste for the Malaysian industry.

- **Objectives**

  1- To **benchmark** the current e-waste collection model of Malaysia with the world's best **e-waste collection model**.

  2- To **propose** an **improved collection model** for the e-waste model for the Malaysian industry.

  3- To **validate** the improved e-waste collection model.

1.4 Scope of research

The study focuses mainly on the collection process of electrical and electronic waste. The study is limited to the Malaysian e-waste industry. However, the study describes the environmental knowledge and information, as well as the appropriate e-waste collection processes in other countries, which may be useful in addressing the problem in the collection process in Malaysia. Furthermore, this research looks for some initial steps which could help in overcoming the challenges of improving the collection of e-waste.

1.5 Methodology overview

To improve the e-waste collection model for the Malaysian industry, a comparison study has been conducted, whereas the e-waste collection model for Malaysia was compared with the world's best collection model, the Switzerland model. Based on the comparison study, an improved model was proposed. A three case study for a licensed recovery center in Malaysia was conducted, the data for the case study was collected through a semi-structured interview, as well as a questionnaire. Flexsim software was used to simulate the proposed model.

1.6 Thesis structure

The thesis divided into five chapters as shown in the summary below:

Chapter 1: This chapter contains an overview of the background of the study, problem statement, aim and objectives, scope of the research and the thesis structure.

Chapter 2: This chapter offers review of the literature by presenting some terminologies, as well as the key concepts related to the study such as, supply chain, sustainability, sustainable supply chain, in addition to the key terms related to the electrical and electronic waste collection process. Moreover, the chapter presents the e-waste collection models in overseas as well as that in Malaysia, in order to highlight the research gaps.

Chapter 3: This chapter presents the research methodology and the techniques that have been followed to achieve the targeted objectives of the research. The chapter consists of three sections which are; method of data collection, the process of modeling and simulation.

Chapter 4: This chapter presents the result and the findings, as well as critical discussion of the results. The chapter is divided into three main categories; results of the literature review, model development and simulation, and the model validation.

Chapter 5: This chapter presents the validation of the proposed e-waste collection model, through case studies at three e-waste collection centers in Malaysia.

Chapter 6: This chapter provides the conclusion of the findings, and presents the review of the achievements of the research aims and objectives.

1.7 Chapter summary

This chapter serves as a gateway to the research by highlighting the problem statement and giving a background of the study, and also identified the aim and objectives of the research. Moreover, this chapter shades a light on the significance of the study.

CHAPTER 2: LITERATURE REVIEW

This chapter aims to presents the literature review of the related theoretical aspects and methodological techniques, in order to provide the basis for the study. The chapter divided into five sections, where section 2.1 presents the review of the key concepts and related theoretical terms associated with the study, section 2.2 and 2.3 offers critical review on the reverse logistics as well as e-waste models, section 2,4 provides the conceptual model concluded from the literature review, as for the last sections 2.5 and 2.6 will summarize the literature review by presenting the gaps in addition to the research question. Figure 2.1 below presents the framework mapping of the sections literature review chapter.

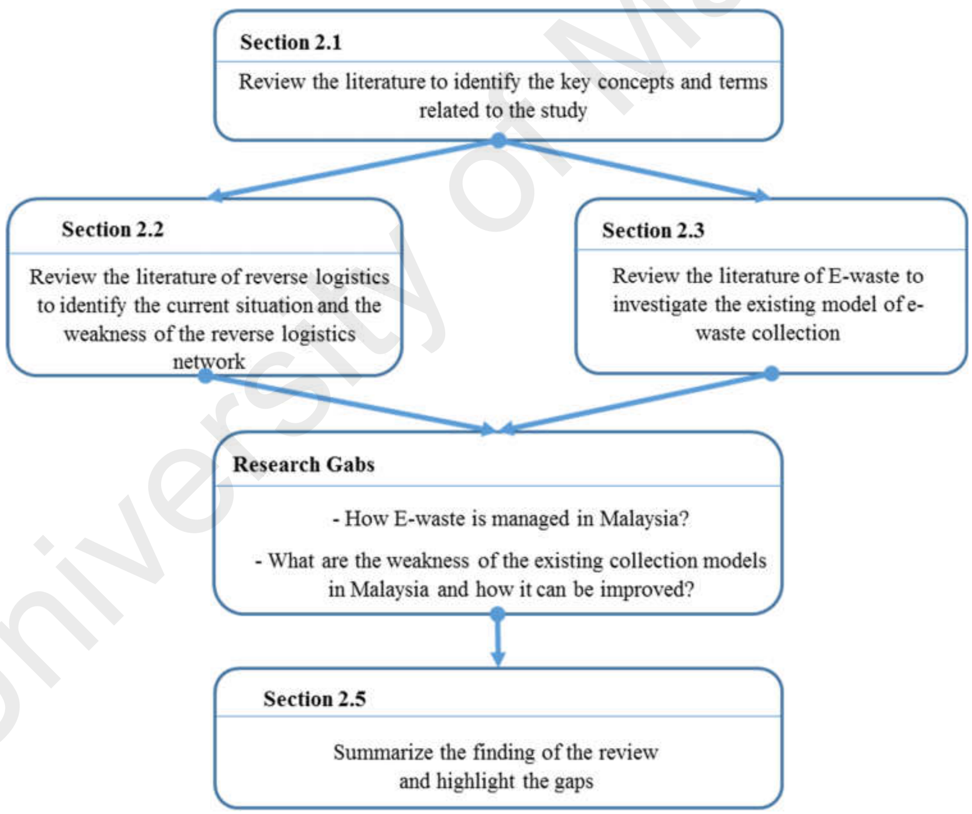

Figure 2.1: Flow of the literature review chapter sections

2.1 Key concepts and theoretical background

This section reviews the literature and related theoretical concepts, so that the clear understanding associated with the reverse logistics identified, as follows:

2.1.1 Supply Chain

Supply chain is defined as an integrated process where the crude materials manufactured into end products, then conveyed to clients whether by retail, distribution, or both (Beamon 1999). Supply chain is the network that been created amongst different companies that distributing, producing or handling a particular product (Baporikar 2015).

2.1.2 Supply Chain Management (SCM)

Seuringa and Müller (2008) reported that, the movements of material as well as information are handled through the facilities like shopkeepers, production factories and dissemination centers describe the meaning of Supply Chain Management (SCM). Every company will think about the SCM as a critical part in their management and they always see the optimization of the SCM as a new way to reduce costs (Keely, et al 2001).

2.1.3 Sustainability

The global society has undergone a paradigm shift from environmental protection towards sustainability (Brand 2002). The term of sustainability was first introduced in 1987 by the World Commission on Environment and Development under the leadership of the former Norwegian Prime Minister Brundtland (Bruntland 1987). It defines that the development which is capable to fulfill today's needs for an intact environment, social justice and economic prosperity, without reducing the ability of future generations to meet their needs. Sustainability does not only focus on the environmental impact, it rather consists of the three pillars namely "environment", "economy" and "social well-being" (Brand 2002, Bruntland 1987). So, it is necessary to bring the three pillars of sustainability—environment, economy, social well-being in harmony in all areas of life, both nationally and internationally.

2.1.4 Sustainable Supply Chain Management (SSCM)

SSCM defined as the strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key interorganizational business processes for improving the long-term economic performance of the individual company and its supply chains (Lambert et al.2006). Material, information and financial of firms in the supply chain are handled in sustainable supply chain management with the consideration of three elements of sustainable development namely, environmental, economic and social that are obtained from stakeholder and customer needs (Seuringa and Müller 2008).

2.2 Literature review on Reverse Logistics (RL) network

This section presents the literature of the reverse logistics network in terms of the history, structure and the barriers of the network in Malaysian industry.

2.2.1 History of Reverse logistics

The term of reverse logistics often used to refer to the role of logistics in recycling, waste disposal, and management of end of life products or hazardous materials; a broader perspective includes all the related to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal. Pohlen and Farris (1992) gave a definition of reverse logistics, based on the role of the logistics and lead by marketing principles, as being: "… the movement of goods from a consumer towards a producer in a channel of distribution". In the late nineties, reverse logistics was defined, by including the processes and goals that involve in the reverse logistics (Rogers and Tibben 1999). According to Rogers and Tibben (1999), reverse logistics can be "The process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal". Reverse logistics have been adopted by many manufacturing industries to recycle their end-of-life products, as a component of closed loop supply chain (CLSC). Reverse logistic is a process of returning end of life product for the purpose of remanufacturing (Klausner and Hendrickson, 2000). For better understanding of reverse logistics, comprehensive differences between forward and reverse logistic need to be identified first. Tibben and Rogers (2002) distinguished between forward and reverse logistics. They described the forward logistics when raw material moves in forward direction from manufacturer to customer. Meanwhile, the reverse logistics as an opposite flow of material or product to generate value for proper dumping. The illustration of this comparison is shown in figure 2.2.

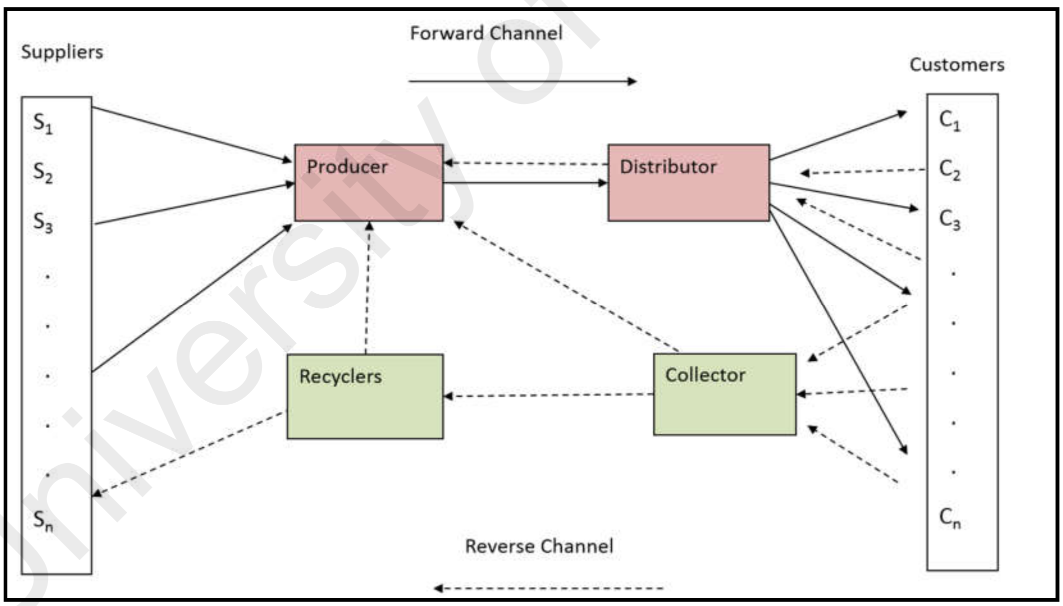

Figure 2.2: Difference between forward and revers logistics network (Source Fleischmann et al. 1997)

2.2.2 Reverse logistic network structure

One of the key objectives of reverse logistics is to collect the end-of-life product for remanufacturing or recycling or proper disposal. The exact stages in this conversion vary from one case to another (Fleischmann et al. 2000). Reverse supply chain has the following links which are considered the main arms in the network (Wenhui et al. 2011)

1. Collection and Take back

Collection means all of the actions that take place from the transportation of worn products obtainable and assembled them at any point where additional process is undertaken. One of the biggest challenges for reverse logistics is the selection of its path in returning of the end-of-life (EOL) products. Whatever the return inputs of reverse logistics are derived from new, used and recycled materials. Collecting approaches for EOL product mostly depends on accurate set up of collection points. Collection points basically deals with the collecting actions and optimum network design for returned goods (Cruz and Ertel 2009, Dehghanian and Mansour 2009, Harraz and Galal 2011). Product take back strategy and maximum profit that can be achieved by proper collection strategies for EOL products (Klausner and Hendrickson 2000). Krumwiede and Sheu (2002), addressed a model where engaging third party in reverse logistics responsible for collecting used products. Figueiredo and Mayerle 2008 also proposed a smart incentive plan to the users for collecting the product in to the desired place. Das and Chowdhury (2012) also established a lower cost improved recovery process through retail outlets shared with the regaining modules. Difficulties emerging in collecting or take back have been identified by many authors. Problems like location of the collecting point as well as in combining of retail deeds with outsourcing activities of reverse logistics have also been highlighted (Wojanowski et al. ,2007).

2. Reverse logistics structure

Structure of reverse logistics refers to the networking system, allocation of collection point, the system developed for the supply chain, integration and control of process (Wang 2008). Most authors paid particular attention on developing the network system for the reverse logistics as well as designing the strategic plan. Some of the authors who have looked at general design of reverse logistics network include, Jayaraman et al. (2003), Srivastava (2008), Zhou and Wang (2008), and Vahdani, Tavakkoli et al. (2012).

Kara et al. (2007) looked at different approach in designing reverse logistics by building a reverse logistics model that can predictively calculate the collection cost. In addition, Fleischmann et al. (2000) also reviewed the structure related articles in the research and provided idea about characteristics of product recovery network with link to carbon footprints. Inspection and amalgamation is another important aspect of reverse logistics structure, which has also been researched upon. Inspection covers all those operations which denote whether the collected products are in fact usable or not, and in what way. Spicer and Johnson (2004) looked at third party outsourcing for collection of EOL products to the inspection location , in a way that it becomes more the manufacturers responsibility than the consumer. This is sequel to governmental legislation on EOL product in many countries. Nnorom et al. (2011) looked at the global aspect and regulations of collected, and management of EOL product.

Integrating manufacturing and remanufacturing process is always a point of interest to the study in order to look into the reverse logistics structure. Chouinard et al. (2005), Fuente et al. (2008) have looked at the rearrangement of manufacturing processes, to make the integration of manufacturing and remanufacturing operation as a feasible option of reverse logistics. Rearrangement is required in the manufacturing procedure, info system and management of EOL products to achieve the integration of manufacturing and remanufacturing operations. In addition, Wu (2012) discussed the cost associated to the integration of manufacturing and remanufacturing process. Other researchers paid attention to the mechanism of inventory e.g. (Kleber et al. 2002), product take back e.g. (Ye et al. 2011), product design and supply chain incentive e.g. (Figueiredo and Mayerle 2008) for integrated system.

3. Reverse Logistics process

Process of reverse logistics covers the area of remanufacturing, refurbishing, disassembly, inventory mechanism, reverse supply chain planning, after sales service and waste disposal (Fleischmann et al. 1997). The number of reprocessed products, cost, time, quality and demand made is uncontrollable compared to forward logistic. It is not always as symmetric as forward logistics (Qingli 2004). There are much difficulties in reverse logistics like unclear destination, many users to one collection center transportation, disposition not clear, more difficult forecasting, less transparent process visibility, complicated marketing and other product quality issue (Fleischmann et al. 1997).

4. Resell or output

Reverse logistics output refers to forwarding reusable goods and/or recyclables to a prospective marketplace and management of moving them to the imminent consumers. It not only helps to increase the product life cycle but also retains customer through improved service. Customer retention and relation can be achieved in reverse logistics through improvised return policies and it is beneficiary to the reverse logistics environment by greater customer relationship (Mollenkopf et al. 2007). Nevertheless, it directly helps to create sustainability in supply chain which has positive impact on social, environment and economic activity or triple bottom line of sustainability.

Sbihi and Eglese (2007) also admitted green logistics approach in reverse logistics by giving emphasis on the hazardous output or waste management by keeping the logistics management environment friendly. Mallidis et al. (2012) study a model designed for supply chain network to assess the impact of ecological issues in transportation approach. Figure 2.3 Illustrate and summarize the structure elements of reverse logistics.

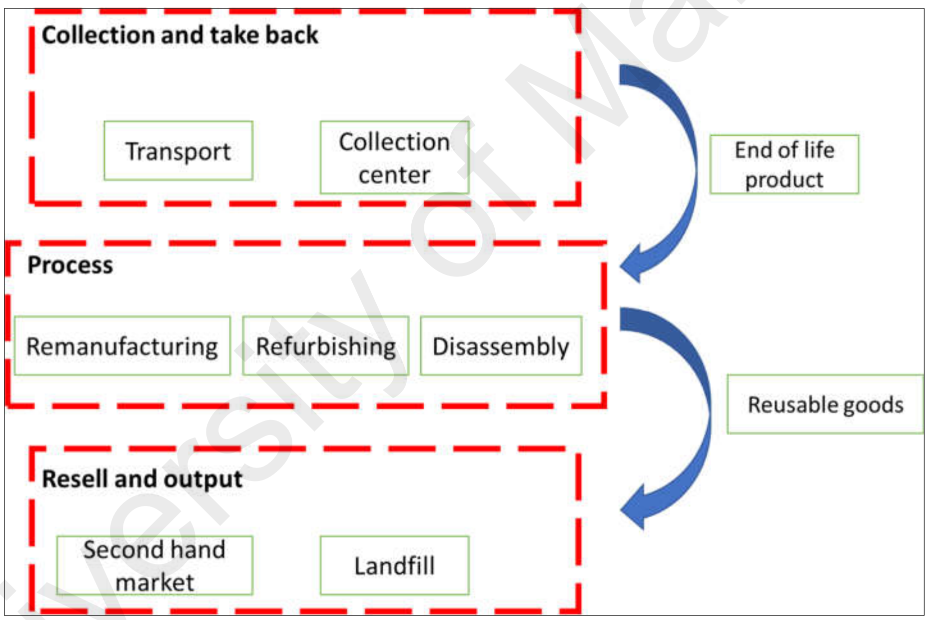

Figure 2.3 Reverse logistics structure

2.2.3 Key Issue of an Effective Reverse Logistic in Malaysia

Yacob et al (2012) stated, that when the product is defective or the product does not meet user requirement, customers and retailers will send back the product to manufacturers. In order to reduce its associated costs and to increase customer's relationship, manufacturers must manage the returned product effectively. Many manufacturing companies have failed to observe the significance of reverse logistics activities because they tend to focus on forward logistics. Reverse logistics is very important for the manufacturers to manage the enterprise activities such as production and distribution with the economic consideration. Most companies face some barriers while performing the reverse logistics, an effect to take into confederation the environmental issue in reverse logistics, these are some inherent barriers. The barriers categorized into two sections as follows:

a) External barriers which can be classified further into six factors which as follow:

(1) Financial Resources

According to Ravi and Shankar (2005), information systems and advanced technological entail a high cost for the businesses. So, the companies will not be able to afford to develop required programs and technologies due to limited financial resources, (Azzone and Noci 1998). After many years, when the product reaches to its end-of-life it will enter a collection system. The product from the collection system is delivered to a local recycler. The recycler then remanufactures the product, and send again to retailer stores. In every stage of the EoL products management requires financial support, for example transportation and collection fees. So, the lack of financial support, will negatively affect the process of the forward and reverse logistics.

(2) Lack of Awareness

There is a lack of environmental consciousness leads to limit the reverse logistics in activates as presented by Azzone, et al (1997) and Azzone and Noci (1998). Furthermore, Brio and Junquera (2003) stated that those practices are less known.

(3) Problems with Industrial Infrastructure

Post and Altman (1994) and Brio and Junquera (2003) demonstrated that, the infrastructure of companies has an effect on the reverse logistics process, some of the companies, have limited capacity to receive the returned products, where this will decrease the potential of implementing the reverse logistics this problem is also related to the financial resources, where increasing the capacity will requires more financial support.

(4) Environmental Legislations

Nowadays, companies must consider environmental friendly technologies in product establishment since the extended responsibility of the producer has been made clear by various legislations. However, Azzone, et al (1997) stated that the environmental legislations lead to inflexibilities in the technological considerations in order to implement environmental friendly technologies.

(5) Cooperation of the Supply Chain Partners

Trust and cooperation are key elements that must be stressed between the supply chain partners. It is not easy to carry out reverse logistics activities without the participation of supply chain partners within the company.

b) Internal barriers which can be classified further into three aspects which as follow

(1) Human Resource

Lack of training and human resources is another barrier to reverse logistics activities. Low level of skills and technical knowledge as well as specialist staff make it difficult for reverse logistics to be implemented efficiently (Hillary 2004).

(2) Organizational Structure

Environmental actions such as implementing reverse logistics in a company require criteria's of an organization to maximize the good effect. According to Post and Altman (1994), it is difficult to make changes in manufacturing processes due to insufficient organizational structure. According to Zilahy (2004) and Hillary (2004), internal barriers may come in term of inconsistent top management, low level of company culture and lack of commitment to environmental problems. In order to run environmentally-friendly standards operating procedures, every companies must come out with a well-defined strategic focus on environmental matters.

2.3 Electrical and electronic Equipment waste (e-waste)

This section presents a critical review on e-waste. In addition to the review of the existing e-waste collection models.

2.3.1 Background of Electrical and electronic Equipment waste (e-waste)

Owing to the rapid consumption of the electrical and electronics equipment industry (EEE), large amounts of the e-waste are generated worldwide, which certainly cause serious environmental issue (Ni and Zeng, 2009). It has been reported by the Department of the Environment (2009), that currently over 23,000 tons of waste is produced each day in Malaysia. Moreover, this amount is expected to rise to 30,000 tons by the year 2020 as shown in the Figure 2.4.

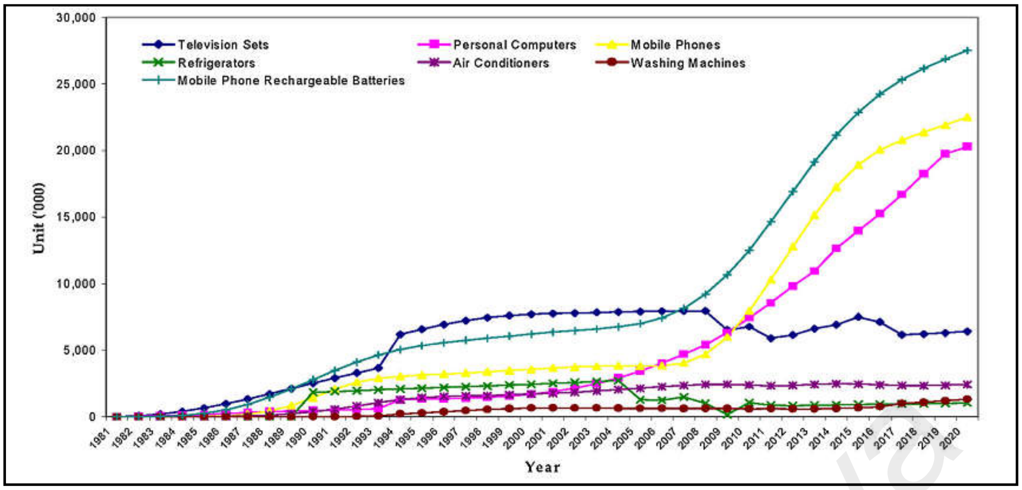

Figure 2.4: Projection of e-waste in Malaysia: adapted from (Malaysian Department of Environment 2009)

The amount of waste generated continues to increase due to the increasing population and development, and only less than 5% of the waste is being recycled (Desa et al, 2012). E-waste normally contains dangerous materials besides the reusable and valuable materials that can be recovered (Sodhi and Reimer 2001). However, e-waste contains also valuable and precious resources which could be recovered if treated in a proper way (Cui and Forssberg, 2003; Ongondo et al., 2011). E-waste can be divided into hazardous and non-hazardous categories because there are more than 1000 different substances in these wastes. Whereas, 50% of them are steel and iron, 21% of plastics, 13% of non-ferrous metals and other constituents. Non-hazardous materials such as non-ferrous metals contain metals such as aluminium, copper and valuable metals such as gold, silver, palladium, platinum, palladium and many more. For hazardous waste category, it consists of metals such as lead, mercury, cadmium, arsenic, hexavalent chromium and flame retardants (Suja et al 2014).

In recent years, recycling of e-waste has drawn more and more attention from the public and research institutions because of the environmental protection and economic benefits. In order to minimize the hazardous effect of the e-waste on the ecosystem, reverse logistics have been implemented in many companies. Collection process is the first stage of reverse logistics; it is the most important stage in order to achieve successful reverse logistics. Klausner and Hendrickson (2000) stated that product take back strategy and maximum profit that can be achieved by proper collection strategies for EOL products.

2.3.2 Solid waste collection

The waste collection is a process of taking back the used products from the consumers to place where further procedures like recycling, remanufacturing, and disposal are made. This section will introduce the e-waste types, as well as the collection system strategy implemented in different countries.

2.3.2.1 E-waste types

Brito and Dekker (2002) categorized the source of the e-waste into three types as following;

a) Manufacturing return: Components or products that have been recovered in the production phase are categorized under manufacturing return. For example, quality control returns are part of manufacturing returns. In addition to the quality defect, manufacturing return may have happened due to various reasons like left over raw material and left over final product during manufacturing.

b) Distribution return: Refers to all those returns that occur in supply chain process during distribution of the product.

c) Customer/User Returns: Refers to the kind of return, which is initiated by the customer. Customer can return both in use or end-of-life product. A warranty return is good example of such kind of return. In some cases, some manufacturers collect product after end of their life from the customer.

The scenario of the e-waste collection varies based on the source of the electronic waste, also there are some factors effecting the process of the e- waste collection. For example, the e-waste that come out of the manufacturing return is different from the customer return, as the manufacturing return does not required transportation if the recycling will be in the same manufacturing company. Customer return requires transportation as well as time, and by this cost of the collection will be higher. Same goes to the amount of the waste and other factors.

2.3.2.2 E-waste collection systems

There are different strategies of the collection system implemented in different countries that can reach the satisfactory level of recovery rate of the electrical and electronic equipment waste (Eglise and Pierre, 2000). It has been reported that, product take back strategy and maximum profit that can be achieved by proper collection strategies for the waste. (Klausner and Hendrickson 2000). However, the collection process is the costliest step of the recovery and the reused of the electronic waste (Lonn and Stuart, 2002; IAER, 2003). Many authors in the literatures have discussed the collection models types, (Lonn and Stuart, 2002, Eglise and Pierre, 2000 and Hainault and Smith, 2000), which listed as follows:

1. Curbside collection: involves the collection of e-waste either on a regular basis such as a general municipal waste collection or by request. The curbside waste collection program can basically reduce the operating costs. This type of collection model is the most convenient for residents. However, operating costs can be greater than for other collection options.

2. Special drop-off event: it held in a short period usually during a weekend to increase the number of the participants. There are two factors influencing the quantity of the waste collected by this type first the extent of participation by consumers, second is the weather during event of collection.
3. Permanent collection: This collection method held annually. Whereas the municipal solid waste collection site can be used for collection of e-waste, and that the devices be transported to a recycler when desirable quantities of electronic waste are collected. This type of program has been found a cost-effective method (IAER, 2003). This type of collection method is not applicable for every community size.
4. Point-of-purchase collection: where consumers bring their worn electronic equipment to a retailer when they purchase new electronic equipment so that the retailers of electronic products serve as the collection agency.
5. Extended Producer Responsibility EPR (Take-back) collection: This type of collection the manufacturers are obliged to take the responsibility in collection the worn electronic items from consumers. A lot of original equipment manufacturers (OEMs) have adopting the take-back collection systems for example IBM, Dell, HP, and other computer manufacturers collect unwanted computer and related products regardless of the original manufacturer (Environmental and Plastics Industry Council, 2003). EPR, one of the most promising policy options to address this issue is to extend the producers responsibility for their products beyond the point of sale, until end-of-product-life. EPR is defined as an environmental protection strategy that makes the manufacturer of the product responsible for the entire life cycle of the product and especially for the take back, recycling and final disposal of the product (Lindhqvist 2000). The original impetus for it was two-fold: to relieve municipalities of some of the financial burden of waste

management, and to provide incentives to producers to reduce resources, use more secondary materials, and undertake product design changes to reduce waste (OECD 2001). The manner in which the concept of EPR is incorporated and implemented can differ from one program to the other.

2.3.3 Importance of E-Waste Collection

Huge volume of electric and electronic equipment produced and worn in the globe and it is increasing over the time (Ongondo et al. 2011). This results a huge amount of the waste consequently, this great cumulative amount electric and electronic equipment waste (e-waste) became a common concern in many countries in the globe (Nnorom and Osibanjo 2008b). So, that almost all the countries are implementing strategies in order to properly disposed of the e-waste. The benefits of the e-waste management can be devided into two sections as following:

a) Inviromental impact

This includes the benefits that positively effect on the environment which also could be further divided into three sections which are

(1) Limit hazardous materials

E-waste contains several types of the hazardous material which cause a serious effect on the human health as well as give a negative effect on the environment. So, collecting the waste for recycling minimizes the effect of these materials. Safe collection of old electronic equipments will prevent the effect of toxic substances such as, Plastics, Mercury, Lead, Hexavalent Chromium, Cadmium,and Barium which cause a negative impact to the human health and the enviroment.

(2) Manage landfill capacity

Collecting and recycling the electronic waste solves the shortage of the landfill capacity in many countries. Moreover, collecting and recycling these wastes, landfill area is preserved from the generating waste stream which it can be filled with plant or and another commercial organization rather than WEEE (Pinto 2008).

(3) Sustain the natural resources

According to Pinto (2008), one of the benefits also is to preserve the natural resources. All the precious materials from the discarded electronics will be recovered to produce new products. By so doing that, the pollutions will be reduced as well as greenhouse gas emissions besides maintaining our natural resources due to low extraction of raw materials from the earth. Other than that, it keeps the surroundings environmentally protected.

b) Economic impact

In addition to the enviromantal impact of the well managment of the e-waste, implementing a strategy for the e-waste collection, will enhance the economy of the country as follows:

(1) Reduse natural resources intake

Reusing the collected metals of the e-waste is cost effective and money saving comparing than using raw metals, where utilizing the worn material in producing new product, this will lead to reduced the cost of the raw material.

(2) Career opprtunity

Another importance is in the area of job, e-waste collection can create job opportunities, The new and growing markets for dismantled valuable materials are created through recycling. They also create jobs for refurbishers and professional recyclers.

A summary of the importance of the e-waste collection is presented in Figure 2.5.

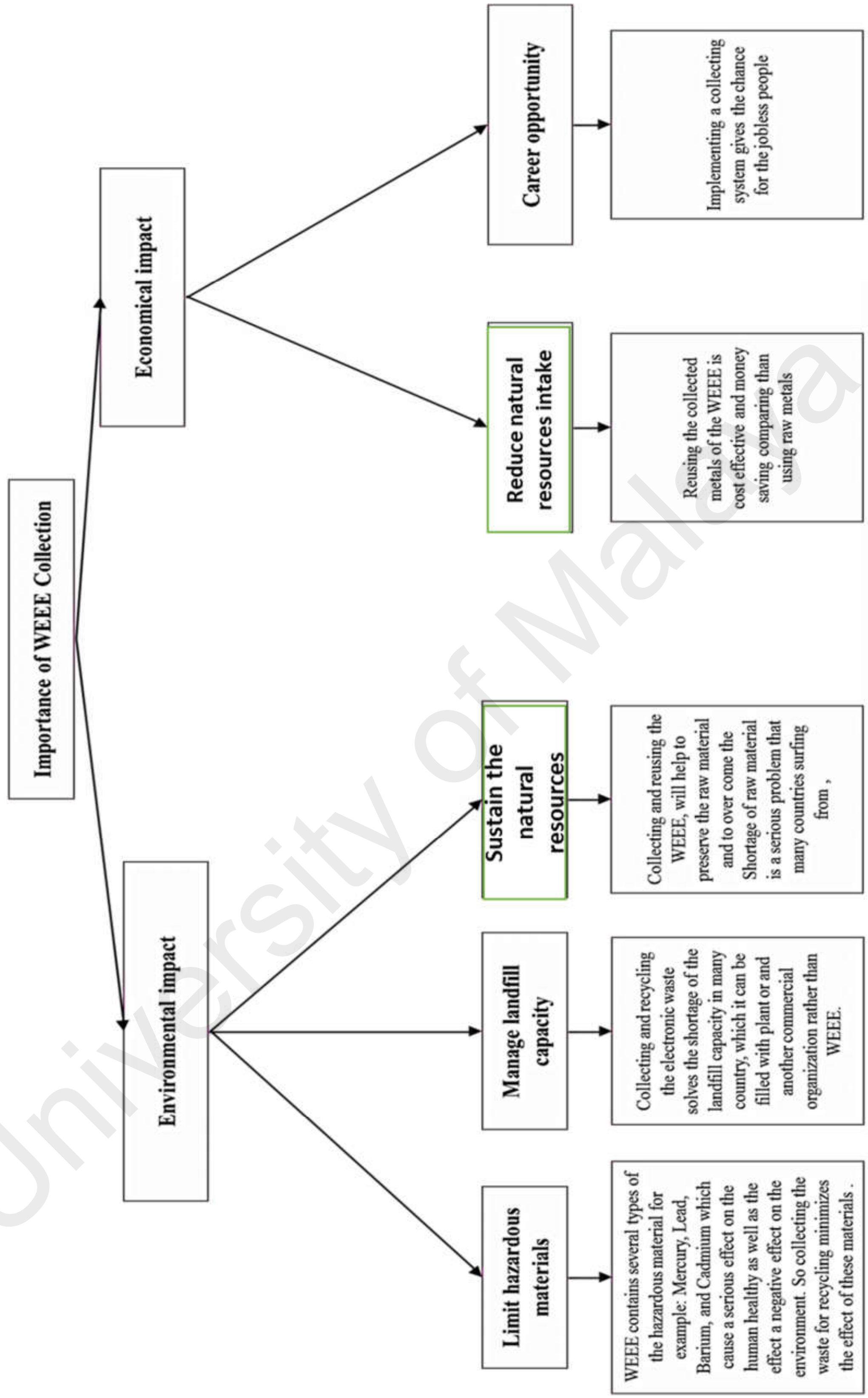

Figure 2.5: Summary of the importance of the e-waste collection (Compiled by the author)

2.3.4 Past Study of E-Waste Collection

Many researches in different countries have discussed and proposed models related to the e-waste collection. These model shades the light on different aspects, for instants, economical aspect, general scenario, model characteristic, e-waste generation, as well as in term of the e-waste collection (Hussain and Mumtaz 2014, Laha 2014, Needhidasan et al. 2014, and Niza et al. 2014). In addition to that, the models have been categorized into the type of e-waste that the model is handling. For example, some of the models limited their models to one or two types of e-waste such as the models proposed by (Andarani and Goto 2014, Estrada-Ayuba and Kahhat 2014) whereas the models only manage refrigerator and personal computer respectively. On the other hand, YläMella et al. (2014), Kiddee et al. (2013), Li et al. (2013), and Qu et al. (2013) have proposed general models which deals with all e-waste types. In addition to that, some of the models proposed to be suitable for one country only, such as the models proposed by Zeng et al. (2013), Dwivedy and Mittal (2012), Oliveira et al. (2012) while these models suite China, India and Brazil respectively. In contrast, models proposed by Ongondo et al. 2009 and Townsend (2011) are general, which suitable to many countries.

This section will be spotting the light, into some e-waste collection models in the world, the models were chosen based on the variety of the e-waste management procedure among the countries.

a) France E-waste collection model

There are two different approaches to collecting these wastes: the first has individuals deliver e-waste to collection points inside cities. Eco-Logic, Eco-Systems and EPR manage these points and deliver waste to recovery centers. The second approach involves producers or individuals using out-of-town recovery centers (Agence de and l'Énergie, 2014). The legal and operational frameworks of the system implemented by the companies are based on the collection of wastes, which are accompanied by sorting, selective treatment and recovery processes (Le portail 2015). Required finance for day-to-day functioning of the system (for collection, transport and recycling/disposal) is generated from different taxes, which have been applied since November 2006 (CNRS, 2015). Producers pay a fee for each product they supply onto the French market to their nominated E-waste. The fees vary according to the products and E-waste. The model below in Figure 2.6 presents the framework of e-waste collection model in France.

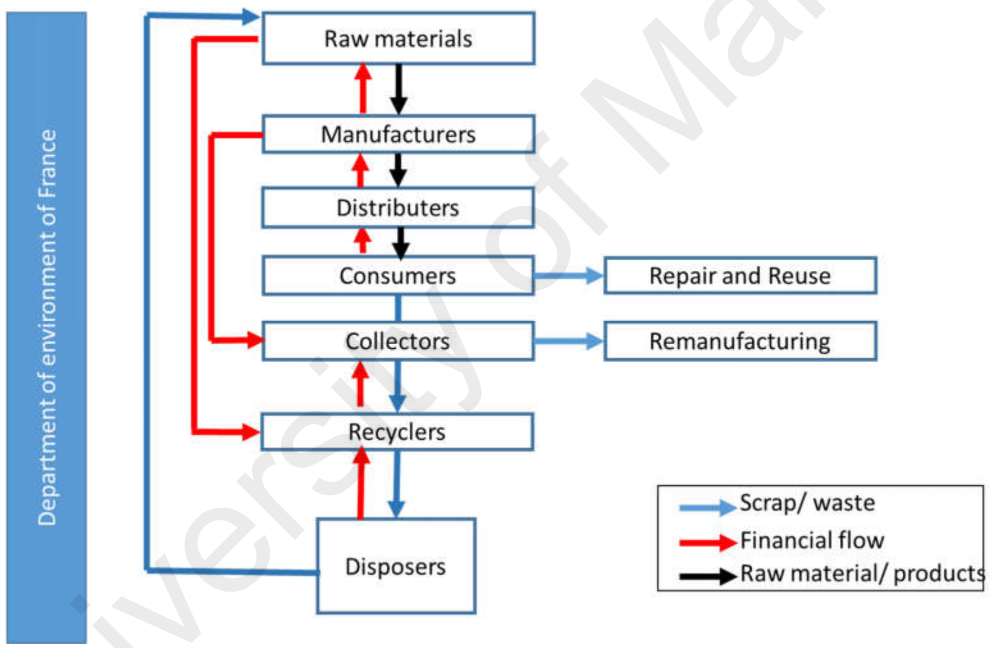

Figure 2.6: E-waste collection model for France. Source: adapted from European Parliament 2010)

b) Switzerland E-waste collection model

Switzerland has the first well-structured and legal e-waste management system in the world (Wager et al. 2011). This is due to the strong management of the two Producer Responsibility Organizations (PROs) which are The Swiss Association for Information, Communication and Organisational Technology (SWICO) and Stiftung Entsorgung

Schweiz (S.EN.S), both SWICO and S.EN.S have long period of experience in managing e-waste, having started their e-waste programs based on the principle of Extended Producer Responsibility (EPR), in which, manufacturers are responsible for taking back, handling, recycling and the disposal of e-waste, where the public waste management authority in responsible for the e-waste collection to the retails, the model in figure 2.7 presents the e-waste flow (Sinha et al. 2005), where the e-waste is divided into two section: retails stores, and collection points, where further procedures done.

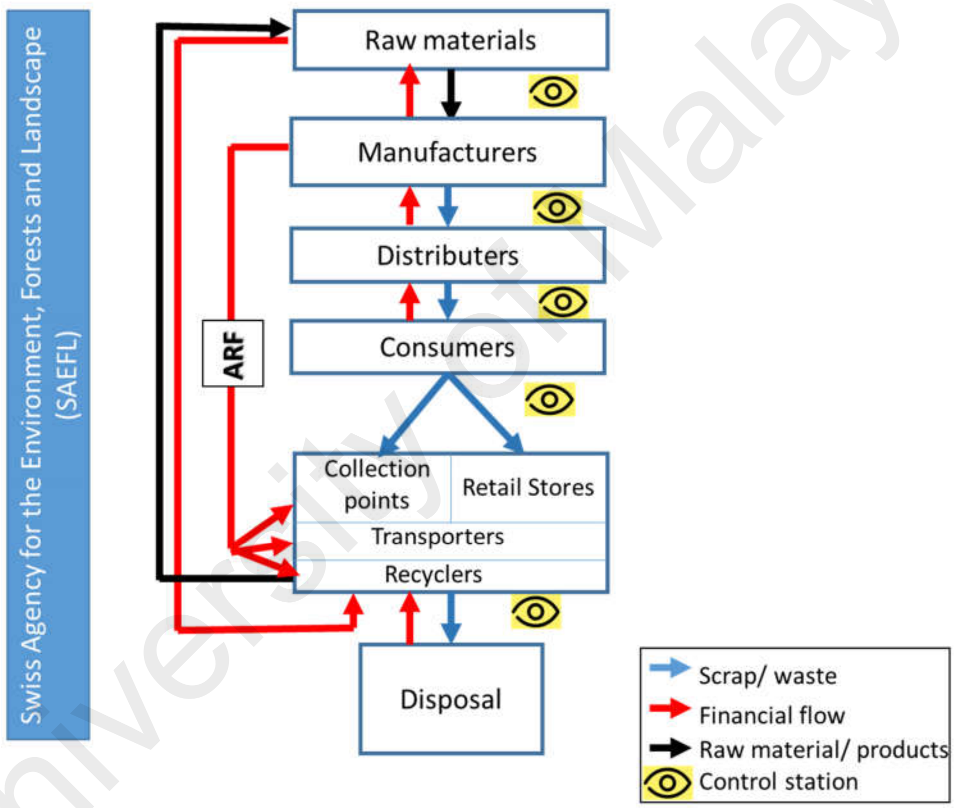

Figure 2.7: E-waste collection model for Switzerland. Source: adapted from (Widmer et al 2005)

c) India E-waste collection model

In contrast to Switzerland where the collection process made under the formal sectors, in India the e-waste collection process is considered an informal way, whereas a different branching of scrap industry receives the waste from many sources including old ships, end-of-life vehicles as well as electronic waste (Sinha et al. 2005) this illustration is presented schematically in the figure 2.8.

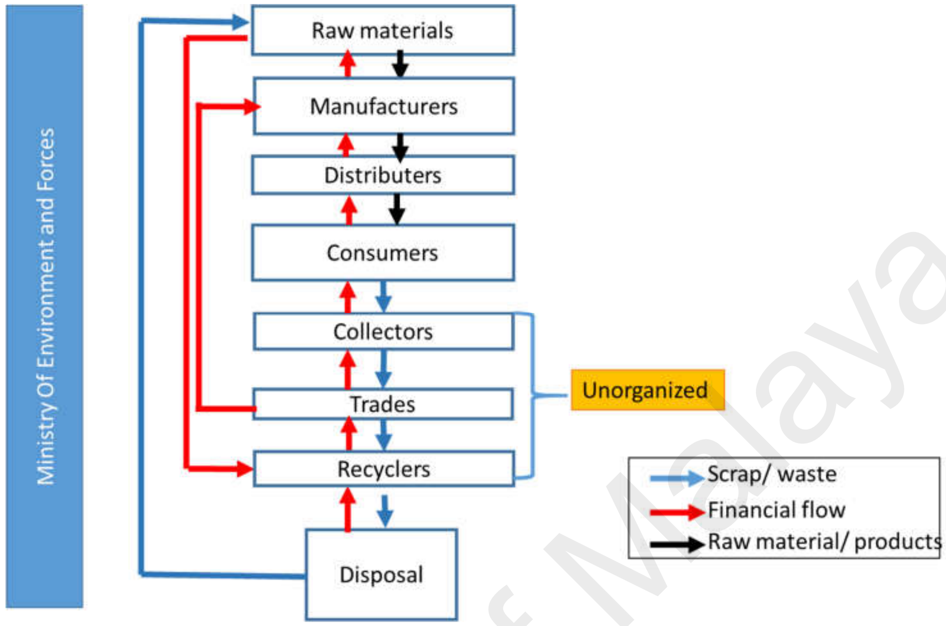

Figure 2.8: E-waste collection model for India. Source: adapted from (Widmer et al 2005)

d) China E-waste collection model

In china, recently, the collection rates from households increased, due to the new implementation of the legislation and developed infrastructure on e-waste and RoHS according to EU directives. However, consumers obliged to pay a fee for collection, which burden the citizen (He et al. 2006). As presented in the framework in figure 2.9.

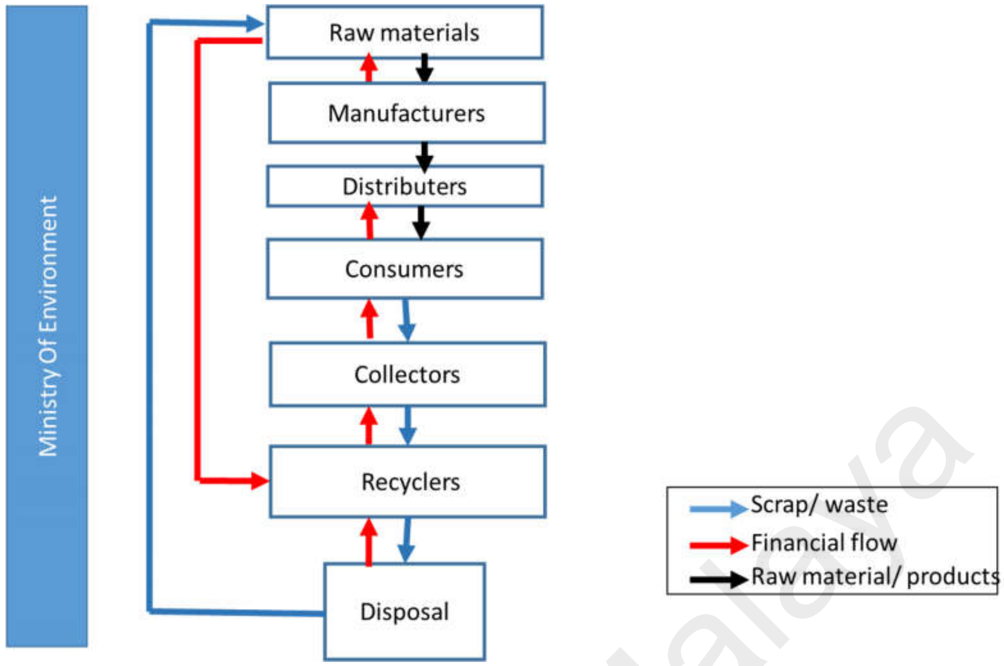

Figure 2.9: E-waste collection model for china Source: adapted from (Chung and Murakami, 2008)

e) United states of America E-waste collection model

In the USA the electrical and electronic equipment waste is considered to be one of the most rapid growing solid waste (Kahhat et al. 2008). As stated by US Environmental Protection Agency (2007), 80–85 % of e-waste end up in the landfills. Different collection systems of the e-waste have been adopted in the US according to state perspective, most of the states in US are adopting EPR policy (Silveira and Chang 2010). So far, the US lag behind other developed countries in terms of the e-waste management collection systems. On the other hand, some states, such as California, are quite advanced, with a number of companies working on collection, recovery and reuse of e-waste (Oliveira et al. 2012). Table 2.1, present a summary of the different e-waste collection models around the world.

Table 2.1: Summary of the different models (Compiled by the other)

Country	Amount of e-wate	Approach	Collection and treatment routes	Finical approach
France	1.8 m	EPR	Consumers send the waste to: 1. Repair and Reuse 2. Collection center which sent the waste to the remanufacturing center and recyclers.	Advance Recycling fee
Switzerland	68,000 (2003)	EPR	Consumers send the waste to the unit of, Collection centers, retail stores and recyclers	Advance Recycling fee
China	6.0 Mt (2014)	EPR	The waste collected by the formal and informal collection centers, then sent to the recyclers.	Consumers pay transportation & treatment
India	1.7 mt (2014)	EPR	Mostly informal collectors and recyclers collect the waste and sent to the disposal landfills	Pay & purchasing in every stage of collection

Table2.1, continued'

Country	Amount of e-wate	Approach	Collection and treatment routes	Finical approach
South Korea	2.2 mt (2014)	EPR, post-paid recycling fee	Formal collection system and municipal waste services collect the waste and send to the retailer stores and recyclers	Consumers pay transportation & treatment
USA	9.4 mt (2012)	EPR, ARF, voluntary	Municipal waste services and a number of voluntary schemes send the waste to the remanufacturing centers, retailers stores and disposal landfills.	Advance Recycling fee

2.3.5 E-Waste Management in Malaysia:

2.3.5.1 Introduction

As a result of the rapid growing of Malaysian population which estimated to be 30 million, the electrical and electronic waste rise up to 0.8–1.3 kg of waste per capita per day (Jalil 2010). It has been reported by the Department of Environment (2009), that between 2008 and 2020, a total of 761.507 million units of e-waste, e.g. TVs, mobile phones, PCs, washing machines, air conditioners, refrigerators and mobile phone rechargeable batteries, will be produced (Malaysian Department of Environment 2009). It also reported that the total of the cumulative of the electronic waste in Malaysia reaches 403.590 million units in 2008. The flow of E-waste in Malaysia produced from two main categories, industrial and non-industrial (household), which are collected as a whole unit of equipment or sub-unit of functional equipment. Whole units of e-waste considered as e-waste by the Department of Environment. However, this whole unites are not collected by e-waste contractors licensed by the DoE. In many cases of E&E manufacturing, e-waste generation is not quantified as whole units of e-waste, but rather taken as disassembled components (e.g., plastic fittings, chipboards, metal parts, cables, etc.), which are then collected by these contractors. Currently, a planned infrastructure is being promoted for whole units of e-waste to be collected from households, business entities and institutions (Malaysian Department of Environment 2009).

2.3.5.2 E-waste management scenario in Malaysia

Generally, the e-waste in Malaysia being managed by a general procedure set by DoE. According to the procedures, licensed collection center contractors are required to transport and deliver all e-wastes from the source of the e-waste (manufacturing return, and household return) to a licensed recycling plant as shown in the diagram below in figure 2.10.

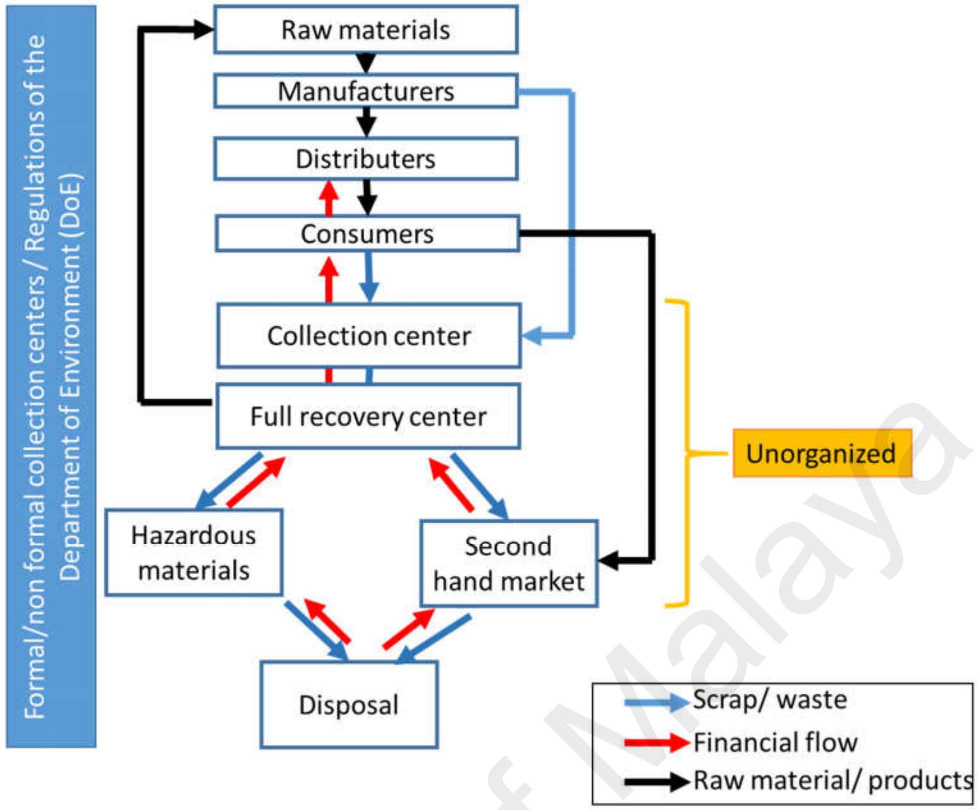

Figure 2.10: General e-waste scenario of e-waste collection. Source: adapted from (Department of Environment 2009)

There are several licensed collection centers in Malaysia which are distrusted in various part of the country, 122 partial recovery which take the responsibility of the collection of the e-waste only, on the other hand, there are 16 full recovery in Malaysia which includes all the service of treating the e-waste starting from the collection to the disposal going through the segregation, remanufacturing, as well as dealing with the hazardous materials. as illustrated in Table 2.2.

Table 2.2: Distribution of the E-waste collection centers in Malaysian state. Source: from (Department of Environment 2009)

State	Partial Recovery Facility	Full Recovery Facility
Wilayah Persekutuan	5	6
Selangor	25	2

Table 2.2, continued'

State	**Partial Recovery Facility**	**Full Recovery Facility**
Sarawak	5	0
Pulau Pinang	37	6
Perak	4	0
Negeri Sembilan	5	1
Melaka	12	3
Kedah	12	1
Johor	17	3
Total	122	16
Grand Total	**138**	

E-waste, a relatively recent addition to the waste stream in the form of discarded electronic and electric equipment, is getting increasing attention from policy makers as the quantity being generated is rising rapidly. One of the most promising policy options to address this issue is to extend the producers responsibility for their products beyond the point of sale, until end-of- product-life. Extended Producer Responsibility (EPR) is defined as an environmental protection strategy that makes the manufacturer of the product responsible for the entire life cycle of the product and especially for the take back, recycling and final disposal of the product (Lindhqvist 2000). The original impetus for it was two-fold: to relieve municipalities of some of the financial burden of waste management, and to provide incentives to producers to reduce resources, use more secondary materials, and undertake product design changes to reduce waste according to Organization for Economic Cooperation and Development OECD (2001).

2.3.5.3 Issues and barriers of e-waste collection in Malaysia

One of the main problems is the lack of knowledge of people, where many people do not understand the importance and benefits of recycling, which leads to the unwillingness to get rid of the discarding the e-waste products to the formal collection center. However, social organizations driving awareness activities. Hamzah et al. (2011) reported that the Malaysian systems for e-waste collection and the process of the collection are very loose, in addition to that, there is no market specified for finished products resulting from recycling.

The people, are aware of the value of the e-waste products, so they are willing to sell it, the informal e-waste collection, collect these items, and most are resold after a simple refurbishment or repair (Roslim 2012). The products are treated by unqualified workshops and small-scale factories using manual disassembly and the cycling of valuable materials (Babington et al. 2010). Also, this informal collection centers do not collect under any regulation, and most of the e-waste ends up in landfill. Without enforcing legislation, informal recycling workshops cannot be stopped completely (Hamzah et al. 2011).

Moreover, the limited number of personnel of the enforcement officers, and a lack of communication between staff especially from other government agencies, are one of the main problems is enforcing the law, which considered to be key weakness of the present e-waste management system.

According to Shumon et al (2013), one of the factors affecting e-waste collection is technological factor. Recovery technology availability for precious metal is limited and obsolete. Because of that, it leads to inappropriate value addition from recycling reuse and remanufacturing. Besides, eco-friendly disposal of e-waste is almost not available and there is no information technology adaptation in take back system. Another factor is logistics and transportation difficulties of e-waste, especially bulky home appliances such as refrigerators and washing machines. It is very difficult to move such that items without a proper transportation and equipment from customer's place to recovery center. The next factor is social and policy which is compulsory requirement of take back scheme through legislation is still to be implemented. Plus, social organizations initiative for voluntary take back of e-waste is not prevalent and lastly, consumers are in view to sell the e-waste for material value inside rather than to pay the recyclers for disposal. Collection cost is another factor that affecting the collection process in Malaysia (Hamzah et al. 2011). The expenses for treatment and collection are totally paid by the recycling companies in the formal stream, and this expense is usually higher than the income gained from the recovery of valuable materials. As such, these formal recycling plants are facing a challenge in paying the collection fees.

Not only Malaysia facing these problem; they are also some other countries such as, China, Taiwan, Thailand, the Philippines, Indonesia and other neighboring countries also have these barriers in e-waste collection (Kojima 2012).

Table 2.3: Barriers for sustainable e-waste management in Malaysia (source from: Shumon 2014)

Aspects	Barriers
Technological	• Recovery technology availability for precious metal is limited and obsolete. • Inappropriate value addition from recycling reuse and remanufacturing. • Eco-friendly disposal of e-waste is almost not available. • Information technology adaptation in take back system.
Engineering	• Efficient collection, dismantling, transportation system design and implementation. • E-waste collection center's to set up at places convenient to consumers before being sent to recovery plants. • Integrated reprocessing facilities are rarely seen. • Probable technically and economically feasible solutions development for every step of e-waste management like recycling remanufacturing, etc. • Logistics and transportation difficulties of e-waste, especially bulky home appliances such as refrigerators and washing machines
Social and policy	• Compulsory requirement of take back scheme through legislation is still to be implemented. • Social organizations initiative for voluntary take back of e-waste is not prevalent • Consumers are in view to sell the e-waste for material value inside rather than to pay the recyclers for disposal. • Revision on the law on import and export of e-waste

Table 2.3, continued'

Aspects	Barriers
Administrative	• Negotiating and settling the responsibility of the process with stakeholders. • Protection of confidentiality of intellectual properties of e-waste. • Negotiating and fixing the responsibility for the costs incurred. • Define and apply individual producer responsibilities

2.3.5.4 Collection Process of e-waste by E&E Industry in Malaysia

According to the study by Perunding (2009), e-waste should be managed in an environmentally sound management and thus, the E&E manufacturers must play an important role to achieve it. Manufacturers take back the unused E&E in some nations that run the TPB or Take Back Program in order to collect it in a proper way and recycle this waste. Normally, the programs operate in a regulated structure and formally in these nations. In order to decrease the volume of old or junked E&E from being thrown into landfills in Malaysia, some of the firms and manufacturers implement a Take Back Program (TBP) too (Shumon 2014). By doing that, it is also improving the awareness among the community and consumer regarding the current problem of e-waste. The following sections describe the management of e-waste in E&E industry.

(a) Motorola (M) Sdn Bhd

The first recycling efforts of Motorola Malaysia is recycling batteries for walkie-talkies back in 1998. The "ECOMOTO Take-back" campaign is the next step taken by Motorola Malaysia. In this campaign, the accessories such as cables, hands-free units and chargers are also included besides the cellular phones, broadband devices and batteries (Shumon 2014).

In order to increase the level of awareness among the public and to encourage recycling among its employees, there are the take-back bins placed at company's manufacturing firm in Penang, at selected Motorola outlets and in main town such as Kuala Lumpur, Petaling Jaya and Cyberjaya (Shumon 2014). The other initiative to attract more participation is "20-to-1" trade-in program. The concept is simple where every 20 units of unused rechargeable batteries returned will be given one free battery. There is no official date for this program to be launched to the public people because until now the initiative just implemented among Motorola's employees and dealers.

(b) Nokia Malaysia

Nokia Malaysia also has their own recycling bins which are about 30 bins around Peninsular Malaysia to receive any brand of discarded cell phones from their customers. The locations are Nokia centers, retail outlets and in some offices of mobile phone network operators such as Celcom and Maxis (Shumon 2014).

Like Motorola Malaysia, Nokia also receives any rechargeable batteries, chargers and other mobile phone accessories from their users. In 2007, Nokia has collected 900 kg of electronic wastes in their "Takeback" campaign that has been run since 2001. Every return of any old or discarded batteries and accessories will be offered 20% less for any of their products at dealer or Nokia centers to raise their awareness campaign (Shumon 2014).

(c) Dell Malaysia

Not only their product, Dell Malaysia has been ready to receive any IT products that manufactured by their main competitors. There are some kind of offer for the collection of the old computer when a consumer purchase and receive any new computer from Dell. There are about 6.5 tonnes of the discarded printers, notebook and desktop computers, monitors and accessories have been collected by Dell Malaysia since April 2007. From April to September 2007, Dell Computer Recycling Program in Penang has collected 3,827 kg of computer wastes. Second hand traders will buy any functioning computers collected and all the valuable metals from the non-functioning will be retrieved according to Dell (Shumon 2014).

2.4 Conceptual model

There are too many aspects to be considered to design a framework structure of reverse logistics. These aspects include the number and placement of the disassembly center, collection points, the number and the type of participants in the system, product characteristics and characteristics of the material flow. In order to attain cost effectiveness of the system, it is critical for the aspects in the chain work together.

Based on the literature review of the past e-waste model collection, a conceptual model for the e-waste collection in Malaysia, the conceptual model shows that, the source of the electrical and electronic waste divided into two categories; the industrial and non-industrial waste. The waste collected by the licensed collection centers. Lorries are the transportation to be used to collect the waste, the capacity of the lorry varies based on the amount of wasted to be collected. At the collection center, the waste is segregated by the workers into three categories; for second hand market, for hazardous materials processing center, and for remanufacturing companies.

2.5 Research gaps

According to the critical review presented in the field of study in this chapter, three main research gaps were found in this review:

Gap1: Lack of studies investigating the factors effecting the collection of the e-waste in Malaysia

Gap2: Limited studies identifying the collection process of the electrical and electronic equipment waste in Malaysia.

Gap3: limited attention given to improve the collection process in Malaysia.

This research is therefore carried out to contribute to literature through filling the presented gaps.

2.6 Chapter summary

This chapter provided a review of literature on the field of the study. The first section presented the terminology and the key concepts related to the project, in addition to that a critical review was given to the reverse logistics network and explain the its network structure as well as the problems and the barriers with the revere logistics implementation in Malaysia. In addition, detailed review of the electrical and electronic waste in terms of the importance, and the existing model, also the e-waste collection scenario was presented.

CHAPTER 3: METHODOLOGY

This chapter presents the research methodological steps that have been followed to achieve the targeted objectives of the research. The chapter is divided into three main sections, which are; extensive literature review which explains how the literature review has been established, followed by the benchmarking study section, which represents the steps followed to conduct the comparative study between the e-waste collection model of Malaysia and the world's best model, and the last section describing how the model validation was conducted. The framework below in figure 3.1 illustrates the linkages between the steps.

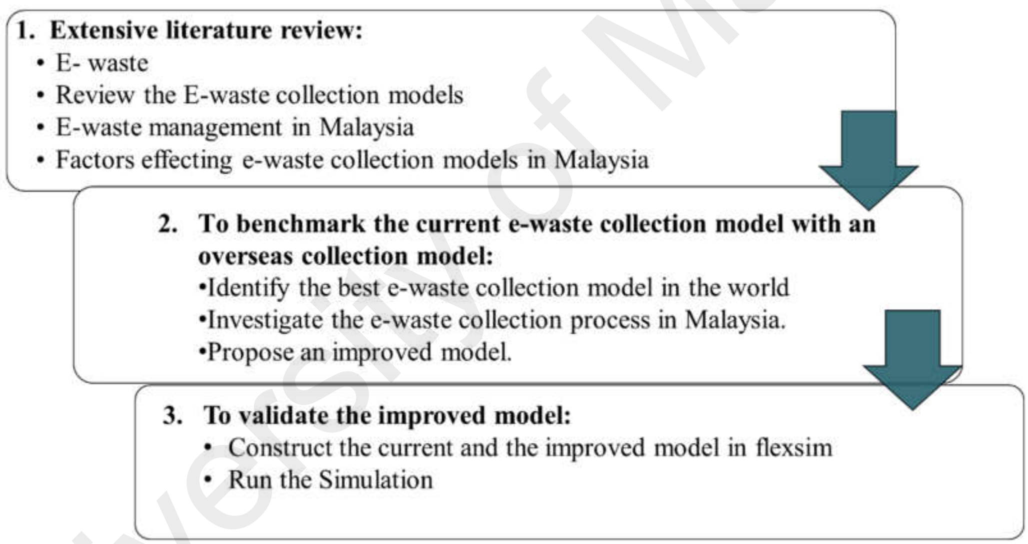

Figure 3.1: Methodology follow chart

3.1 Extensive literature review

In order to establish the extent of research that have been conducted in electrical and electronic equipment waste management as well as the reverse logistics, observation and content analysis approach was adopted to review the literature. All forms of recorded content were systematically assessed in the content analysis process. Content analysis is a research technique used to make replicable and valid inferences by interpreting and coding textual materials, by systematically evaluating texts (Duriau et al 2007), the content analysis has been identified as an efficient method in the review process and it has been widely used in literature. All forms of representative content of recorded communication have been scientifically evaluated in the content analysis method.

Literature was gathered from various e-sources. In addition, different published literature and books were covered in the acquisition of literature. For review of electronic sources, search engines were engaged to survey literature from Science Direct, Google Scholar, Springer Link, Ingenta Connect, INSEAD and Hindawi as well as a host of other electronic sources. More than 90 different aspects of research papers and books have been reviewed, to get a clear understanding on the e-waste management scenario of the globe. Aside from that, to review the e-waste collection models, various keywords were used to search literature. These keywords include reverse logistics, recycling, e-waste collection, collection models, and product returns.

3.2 Comparative analysis of the electronic waste collection models in Malaysia and Switzerland

Benchmarking is the strategy of measuring the quality of an organization's policies, products, programs, strategies, etc., by comparison with standard measurements, or similar measurements of its peers (Maire et al., 2005). In general, the benchmarking goals could be identified of higher customer satisfaction, for example process quality, on-time delivery, low cost, etc. It could also be identified in the form of better financial performance, such as more profitability achieved, return on savings, and return on assets (Vaziri, 1993).

In this study, a comparative study will be conducted to benchmark the e-waste collection model in Malaysia against the world's best e-waste collection model, which is the model of Switzerland, in order to propose an improved e-waste collection model in Malaysia.

3.2.1 Identifying the Benchmarking model

Assembling the benchmarking models will assist and help in evaluating the benchmarking models, in order to find the suitable model to conduct the comparative study to the e-waste collection models. An insight has been picked up into the strengths, weaknesses, similarities and differences that exist among the frameworks by reviewing them based on the number of phases/steps as well as the type of the benchmarking model, as follows:

- **Number of phases/steps**

The literature review shows that the benchmarking frameworks consists of a number of phases/steps which represent the stages of the benchmarking study that will be conducted using the model, the number of these phases/steps varies from one model to another, and it ranges from 5 up to 21 steps and from 2 to 7 phases. The number and arrangement of the phases and the steps has been claimed to be the key to success of the benchmarking study. As mentioned in the literature review, almost all the benchmarking models that have been reviewed are using the PDCA approach (Plane, Do, Check, Act) which is the major similarity among all the models. However, the major differences is the number of the phases and steps of these benchmarking frameworks, which in this manner, the Xerox benchmarking model has 10 steps in the benchmarking process (Camp, 1989), as for Filer et al. (1988) being a 7 steps process, Spendolini's (1992) a 5 steps process, IBM a 5 phases and 14 steps process (Eyrich, 1991), Alcoa's a 6 steps benchmarking, AT&T's a 12 steps benchmarking process (Bemowski, 1991) and many other academicians too have built up their own models. On the other hand, Kodali (2008) found in his research "benchmarking the benchmarking models" that 45 steps divided into 13 phases is the best practice benchmarking model, but it can be argued that the large number of phases and steps will lead to the complexity and difficulty of implementation.

- **Type of benchmarking model**:

Generic, process, functional, and many others, are all types of benchmarking models. In order to achieve the target goals by the company, the adoption of a benchmarking model for a company should be done by taking into account some important factors, for example, the extent of interdependence, number of benchmarking partners, degree of mutual trust, and strategic activities (Fong, 1998). The table below (Table 1) presents the definition of different benchmarking types. In fact, some studies believe that the benchmarking types could be divided into two major parts which are the internal and the external, and all the other types can be classified under these two major groups.

Table 3.1: Different types of benchmarking: Source from [Kodali (2008)]

Type	Meaning
Internal	Comparing within one organization about the performance of similar business units or processes
Competitor	Comparing with direct competitors, catch up or even surpass their overall performance
Industry	Comparing with company in the same industry, including non-competitors
Generic	Comparing with an organization which extends beyond industry boundaries
Global	Comparing with an organization where its geographical location extends beyond country boundaries
Process	Pertaining to discrete work processes and operating systems
Functional	Application of the process benchmarking that compares particular business functions at two or more organizations
Performance	Concerning outcome characteristics, quantifiable in terms of price, speed, reliability, etc.
Strategic	Involving assessment of strategic rather than operational matters
Competitive	Comparison for gaining superiority over others
Collaborative	Comparison for developing a learning atmosphere and sharing of knowledge

A previous review study shows that all benchmarking types have been widely used, however the generic type is the most used type followed by the functional and the process types as shown in Figure 3.2. This is due to the large area of application that could be covered by this type.

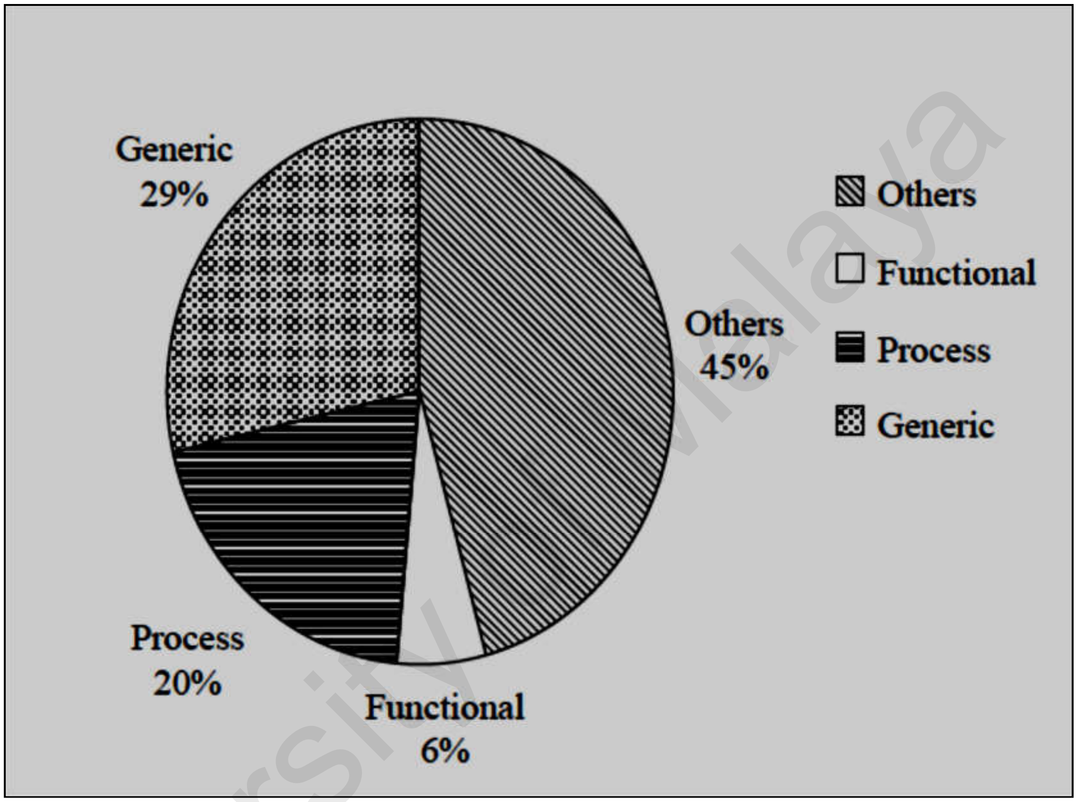

Figure 3.2 Number of models under each benchmarking type: Source from [Kodali (2008)]

In this project, the evaluation will take into account all the different aspects of the categorization mentioned in the previous section, except for the last type, as the proposed model will target the electrical and electronic equipment industry (EEE).

- **Weakness of the existing models:**

The literature review revealed that some of the existing frameworks suffer from common weaknesses, such as being complicated and rigid in nature. Moreover, almost all of the existing frameworks found in the literature were not specifically developed for the SME companies, and thus were not suitable for SMEs. Even if they appear to be suitable, they still suffer from certain problems such as the complexity and inflexibility, which need addressing. In addition, as has been shown in the review, the frameworks developed to date have been dominated by large company approaches. The problem highlighted indicates that current benchmarking implementation framework still suffers from many weaknesses that need improvements and are far from suitable for SMEs to apply.

The table 3.2 represents all the benchmarking models that have been reviewed, identifying its weakness, type, number of phases/steps and the size of company.

Table 3.2: Benchmarking models (Compiled by the author)

Author	Type	Number of phases/steps	Company size	Weaknesses
Spendolini (1992)	Generic	5 phases	Not indicated	1 - Only represent the steps to be taken in implementing benchmarking in specific business processes 2 - No general outline of the all benchmarking concepts
Zairi (1994)	Generic	2 phases 16 steps	large	The framework hypothetical stage as it has not been validated using actual field data
Voss et al. (1994)	Process	3 phases 6 steps	Small Medium large	The framework hypothetical stage as it has not been validated using actual field data

Table3.2, continued'

Author	Type	Number of phases/steps	Company size	Weaknesses
Malaysian Benchmarking service, NPC (1999)	Generic	3 phases 14 steps	large	1 - The framework did not provide the overall roadmap and guidelines for companies to follow in conducting the benchmarking study 2 - Requires many people to execute the various tasks of implementing benchmarking initiatives, such as supplier audits and collection of data on supplier capabilities
Crow (1999)	Generic	1phases 4 steps	Not indicated	1 - Too complicated framework as it has five major benchmarking dimensions which have been further subdivided into 28 best practices categories and comprise more than 270 best practices 2 - The framework hypothetical stage as it has not been validated using actual field data
Medori and Steeple (2000)	Generic	6 stages	Medium	1 - The checklist may be outdated with time and thus need to be constantly updated 2 - The framework hypothetical stage as it has not been validated using actual field data

Table 3.2, continued'

Author	Type	Number of phases/steps	Company size	Weaknesses
Davies and Kochhar (2000)	Generic	3 phases 6 steps	Large	1 - Too complex and complicated in nature for SMEs to apply 2 - Limited for application as it could only be used for selecting practices based on dependency relationships between practices and performance
Fong et al. (2001)	analytical	1 phases 4 steps	Large	1 - Limited for application as it could only be used for benchmarking value management process 2 - The framework hypothetical stage as it has not been validated using actual field data
Lee (2002)	Generic	4 phases	Large	The frameworks did not provide the overall roadmap and guidelines for companies to follow in conducting the benchmarking study 2 - Requires many people to execute the various tasks of implementing benchmarking initiatives such as, supplier audits and collection of data on supplier capabilities
Deros et al. (2006)	Generic	5 stages	Medium	1 - It is difficult to evaluate costs incurred against the improvement achieved especially the soft measures in benchmarking implementation

Table 3.2, continued'

Author	**Type**	**Number of phases/steps**	**Company size**	**Weaknesses**
Cocca & Alberti (2010)	Generic	-	Medium	The framework hypothetical stage as it has not been validated using actual field data

The benchmarking model has been chosen based on four general strategies suggested by Spendolini (1992) which are,

- Follow a simple, logical sequence of activity;
- Give heavy emphasis on planning and organization;
- Use customer-focused benchmarking; and
- Make it a standardized process for the whole organization.

The model by Spendolini (1992) prescribed a generic five stages benchmarking model, which is generic, simple, suitable for different sizes of company, and incorporates essential elements in the benchmarking process, and has been chosen because of the following,

1 - Simple and generic in terms of applications.

2 - Easily adapted by the organization.

3 - Flexible, where the benchmarking team can modify the process to suit their needs and requirement.

4 - Clear mapping between the phases and the steps.

5 - Identify the measurement and the target goals.

6 - Easily implemented with reasonable cost and time.

7 - Minimum number of manpower required for implementing the model.

The five stages benchmarking process begins with determining what to benchmark, forming a benchmarking team, identifying benchmarking partners, collecting and analyzing benchmarking information, and finally, taking the appropriate action as shown in Figure 3.3.

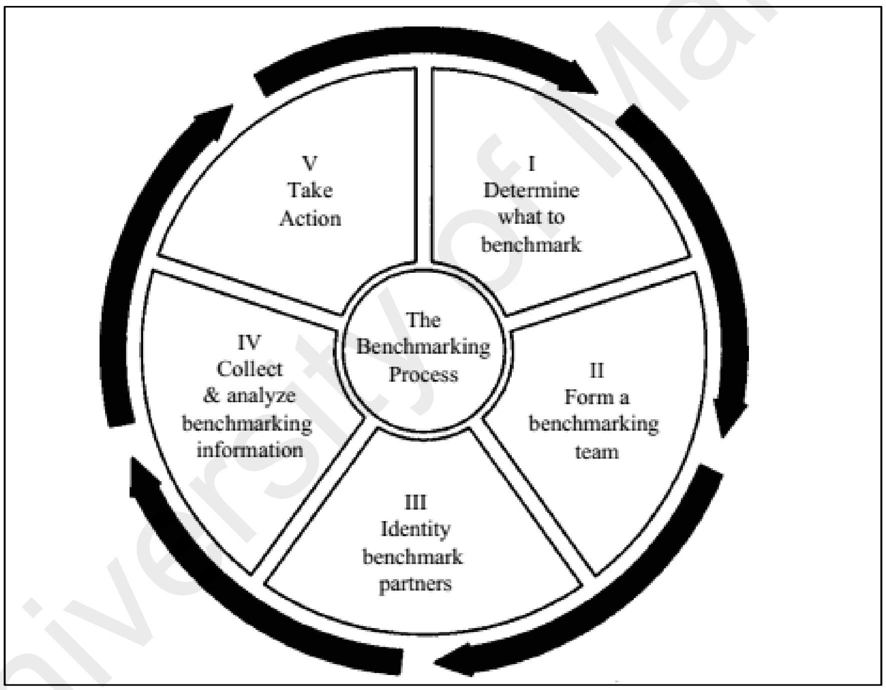

Figure 3.3: The five-stage benchmarking model. Source: Spendolini (1992)

3.2.2 Application of the benchmarking model

The benchmarking model has been applied by following the stages shown in the model of figure 3.4, as listed:

(a) Determine what to benchmark

Based on the literature review, the collection models will be benchmarked based on three main categories: structure of the e-waste collection model and the e-waste material flow, financial flow as well as the rules that are implemented in the country to manage the e-waste.

(b) Form benchmarking team

This step is not applicable in the study as it is suitable for the company use.

(c) Identify benchmarking partners

The benchmarking study will be targeting the Malaysian e-waste collection industry benchmarked with the Switzerland e-waste collection. The Switzerland e-waste collection industry is chosen to be benchmarked with the Malaysian industry as it is the first well-established and legal e-waste collection model in the world.

(d) Collect and analyze benchmarking information

The data for the Malaysian and Switzerland e-waste collection industries was collected mainly based on the literature review, in addition to direct data collection from the industry of the Malaysian e-waste collection.

(e) Take action

Based on the benchmarking study results, an improved model for the Malaysian e-waste collection industry is proposed.

3.3 Propose an improved e-waste collection model for the Malaysian industry

The improved e-waste collection model for the Malaysian industry is developed based on the benchmarking results. Whereas the advantages of the best collection model of the world will be proposed to the Malaysian collection model by taking into account the Malaysian rules and regulations of the e-waste managements.

3.4 Improved model validation

The proposed model has been validated through case study, which is defined as 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). The case study applied into the three licensed collection centers in Malaysia as only these three companies agreed to share the data with the author. Although Jennifer (2002) mentioned that if more cases can be marshalled to establish the case study, the more robust will the research outcomes be, Yin (2003) stated that, if the companies that are targeted for the case study include all the possible circumstances of the research, it shall be sufficient for the case study. The criteria of the amount of waste collection of the studied collection centers for the case study ranges from high, medium and small amount of waste, which includes all the possible circumstances that could be covered in the research. The case study has been achieved by following the listed steps below.

3.4.1 Data collection

The data collection is categorized into two types which are qualitative and quantitative data, as defined below (Joob and Hennei, 2005):

Qualitative data: data understandings of the complexity, details, and context of the research subject, often consisting of texts, such as interview transcripts and field notes, or audiovisual material.

Quantitative data: data that can be described numerically in terms of objects, variables, and their values.

The data collected, mainly through face to face interview as well as questionnaire for the selected licensed collection centers, also focused on the use of academic journals through literature analysis. The description about the data collection is demonstrated in more detail as follows:

(a) ***Interview***

Interview method is a direct method of collection of data, it is the most important method of data collection (Joob and Hennei, 2005). Through this method we can know the views and ideas of other people related to the field. Interviews can be conducted face to face or via telephone.

Saunders et al. (2007) stated that there are three different types of interview, namely structured interview, unstructured interview, and semi-structured interview. This classification is illustrated in the figure 3.4 below.

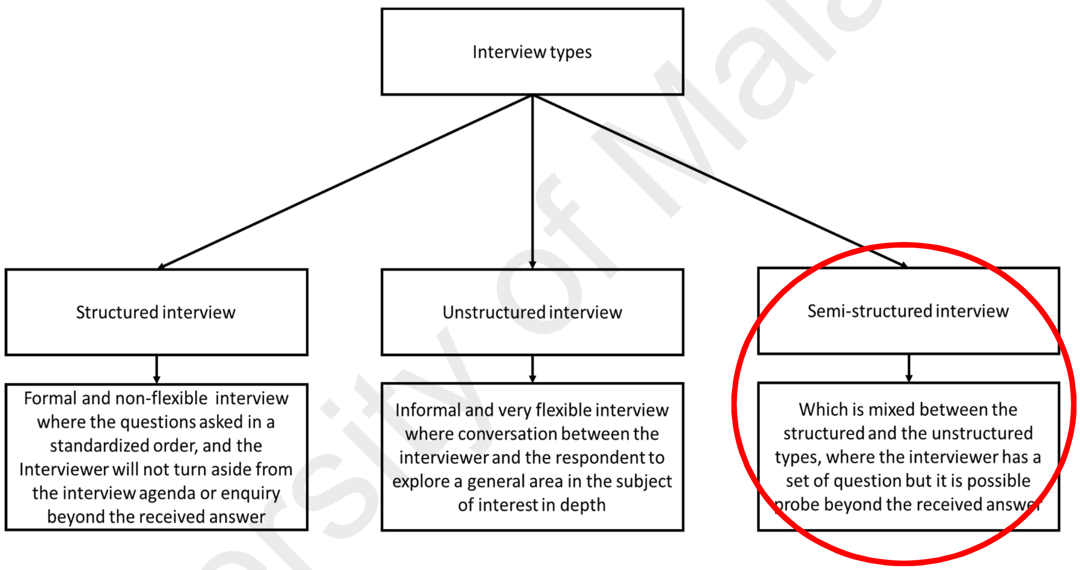

Figure 3.4 Three different types of interview (Saunders et al., 2007)

The semi-structured type of interview was adopted during the data collection. The questions in the interview remained similar throughout the interviews in order to ensure the validity of the questions. Both qualitative and quantitative date were collected throughout the interview. Some questions were occasionally added in order to deeply discuss the topic that would benefit the research. Moreover, probing questions were asked in order for the interviewee to freely explain about the topic investigated.

The interviews were conducted in Malaysia, especially in the state of Selangor. All the licensed electrical and electronic waste collection centers in Selangor, Malaysia were contacted for permission to conduct face to face interview and questionnaire, but only 4 collection centers agreed for the interview, and all underwent face to face interviews. Only three collection centers where chosen based on the seniority as well as having a recognized license and international certification.

English was used as the medium throughout the interview to ease the data analysis process. Important findings were written down during the interview, due to the will to emphasize the importance of the topic. Interview questions were asked based on the information needed to run the simulation for example, the amount of e-waste collected per month, number of workers needed to collect 1 metric ton of e-waste and the stages of e-waste collection followed by the collection center.

(b) ***Questionnaire***

This is an important and very popular method of data collection, which is widely adopted by individuals, organizations and governments. In this method, a series of questions designed to elicit information is filled in by all participants related to the field. The questionnaire is prepared and sent to respondents by mail or by hand (Saunders et al., 2007).

The questionnaire was conducted in Selangor, Malaysia, with only four respondents that filled the questionnaire, although all the licensed collection centers were contacted to participate in the questionnaire. Four respondents are enough for the case study according to Yin (2003), should the companies that are targeted for the case study include all the possible circumstances of the research. The questions were designed in a simple manner to ensure that the respondents understand and also would not find it to be time-consuming. The majority of the questions in the questionnaire are multiple choice questions as presented in the Appendix. The questions of the questionnaire were asked based on the data needed to run the simulation, as well as to emphasis and confirm the answers of the interview.

(c) ***Literature analysis***

The data in this type are those that have already been collected by others, for some purpose other than the problem at hand (Joob and Hennei, 2005). These are usually found in journals, periodicals, research publication, official records etc. (Hox, 2005). Secondary data may be available in the published or unpublished form. The secondary is used when it is not possible to collect the data by primary method. It has been collected in order to provide a good background, in addition to have general key concepts, theories and methods to count on the research, and to establish the extent of research that have been conducted in electrical and electronic equipment waste management, as well as the reverse logistics. In addition to the primary data, data like amount of e-waste and the number of collection centers, as well as the process of the e-waste collection were extracted and analysed. The observation and content analysis approach was adopted to review literature. The data was gathered from all forms of recorded e-sources such as Science Direct, Google Scholar, Springer Link, Ingenta Connect, INSEAD and Hindawi, as well as a host of other electronic sources that were systematically assessed in the content analysis process. The literature analysis has been identified as an efficient method in the review process and has been widely used in literature. More than 90 different aspects of research papers and books have been reviewed, to get a clear understanding on the e-waste management scenario of the globe, and to review the e-waste collection models, various keywords were used to search literature. These keywords include reverse logistics, recycling, e-waste collection, collection models, and product returns.

Simulating the proposed model using the flexsim

After the data collection of the three e-waste collection centers, a model of e-waste collection is to be designed using flexsim simulation package software and have the simulation results of the current practice compared with the proposed model. While constructing the model there are many factors to be considered. These factors include the amount of waste, location of the collection center, the allowed amount of waste to be collected, characteristics of the material flow and product characteristics. Figure 3.5 shows the steps followed to develop the e-waste current and the proposed collection model.

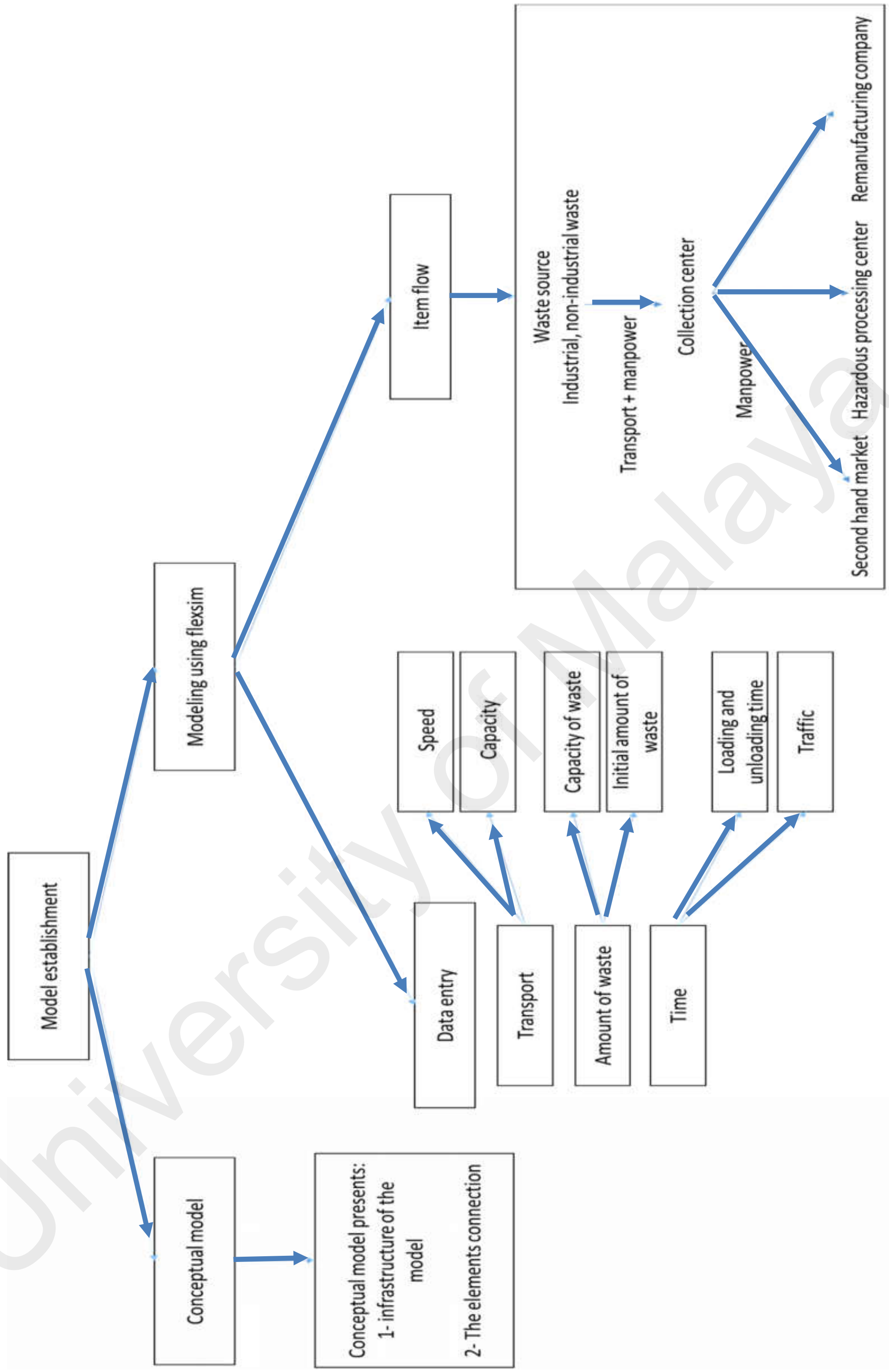

Figure 3.5 Steps in developing the e-waste current collection model for the Malaysian industry

3.4.2 Establishment of the simulation models

There are four steps for constructing a model in Flexsim. 1) Define the model objects and develop a layout, 2) Objects connection, 3) Data entry, 4) Run the model.

3.4.2.1 *Define the model objects and develop a layout*

The electrical and electronic equipment waste during the collection process passes through a number of steps. These steps are as follows:

1. Source of waste: as it has been mentioned in the literature review chapter, there are two sources of waste which are; industrial return and non-industrial return. The e-waste remains at the source, until the time of the collection.
2. Transport: the e-waste collected and transferred from one place to another using lorries, the size and the capacity of the lorry mainly depends on the amount of the e-waste that needs to be collected.
3. Collection center: the main object of the whole collection model, as it plays a role in managing every section of the model. The collection center is supposed to be trustworthy, as it is essential to be certified and licensed by the department of environment. Segregation of the e-waste by workers continued after the e-waste reached the collection center. The e-waste is segregated into three categories, as follows:
    - Secondhand market: the category includes the product that is still in good condition and can be used further, which is sent to the secondhand market to be sold at lower prices.
    - Hazardous materials: e-waste contains several types of hazardous materials, for example, lead and mercury. The dangerous metals are transferred to a specialized treatment center.

- Remanufacturing company: all the e-waste scrap parts are transferred to a remanufacturing company, where further recycling procedures follow.

The layout of the model is achieved by dragging the desired objects from the library and arranging the selected objects in the layout window. The object can be rotated in the x-, y-, z-axis and the height altered in the z-axis.

3.4.2.2 *Objects connection*

The Objects are connected to visualize all routing and mapping objects of the model.

The objects can be connected by dragging a line between them, and being connected is preferred by the objects. Generally, every object has to have an input and output, as well as central ports, there is no limit for the number of connections to present input, output and central ports.

In the case of the proposed model, the sources of the e-waste connected to the collection center. In addition to that, the collection center connected to three objects as output, which are the secondhand market, hazardous metal, and remanufacturing company. Moreover, the transports connected the e-waste sources and the collection center.

3.4.2.3 *Data entry*

After the creation of the layout and connecting the objects, the data will be added to each of the objects in the layout. This step could be made by double clicking on the created object and a window of information will pop up. Information such as capacities, transport speeds, loading times and so on, will be added on. With regards to the data of the model, it is explained as follows:

- Transportation:

  Lorry was used to transfer the waste from one place to another. The data entry for the transportation is divided into two sections, as follows:

  i. Capacity: the capacity of the transportation was set according to the amount of waste, whereby the capacity of the lorry used to transfer the amount of waste from the industrial source is 1 ton, while the number of lorries used to collect the waste from the non-industrial waste site is 3 lorries, due to the high amount of waste.

  ii. Speed: the speed of the lorry is set as 60 km/h, which is the average allowable speed of heavy vehicles, following the National Speed Limit Orders 1989 (Perintah Had Laju Kebangsaan 1989).

- Amount of waste: The amount of waste as stated in the literature is 57339 Metric tons/year. This amount is divided into industrial and non-industrial source of waste to be 285 and 1911.3 respectively. The unit of the amount of waste is converted into kilogram as flexsim does not accept the unit of metric ton. With regards to the capacity of the collection center, it varies from one collection center to another. As for the proposed model, the capacity of the collection center is set as 50 metric ton per month, which is the average capacity of the interviewed centers.

- Time: The unit of time in flexsim model is set to hours. The time is divided into two sections which are:

  i. Loading and unloading time: as found from the questionnaire and the interview, the loading and unloading time is the time taken to load the e-waste from the e-waste source to the lorry and from the lorry to the collection center, which is estimated to be 4 hours, with 3 hours spent for loading and 1 hour spent for unloading.

ii. Traffic: reflects the time taken from the e-waste source to the collection center and vice versa. The time mainly depends on the distance and the lag caused by traffic jams, as well as traffic lights.

3.4.2.4 Simulation

Once the electrical and electronic waste collection is created, a simulation could be performed by running conditional scenarios. Flexsim will generate a comparison of the data from each run. In addition to single runs, the results of each scenario can be compared or optimized.

3.5 Chapter summary

This chapter provided a detail of the methods that were used in order to achieve the objectives. Figure 3.6 below presents the summarized overview of the research method.

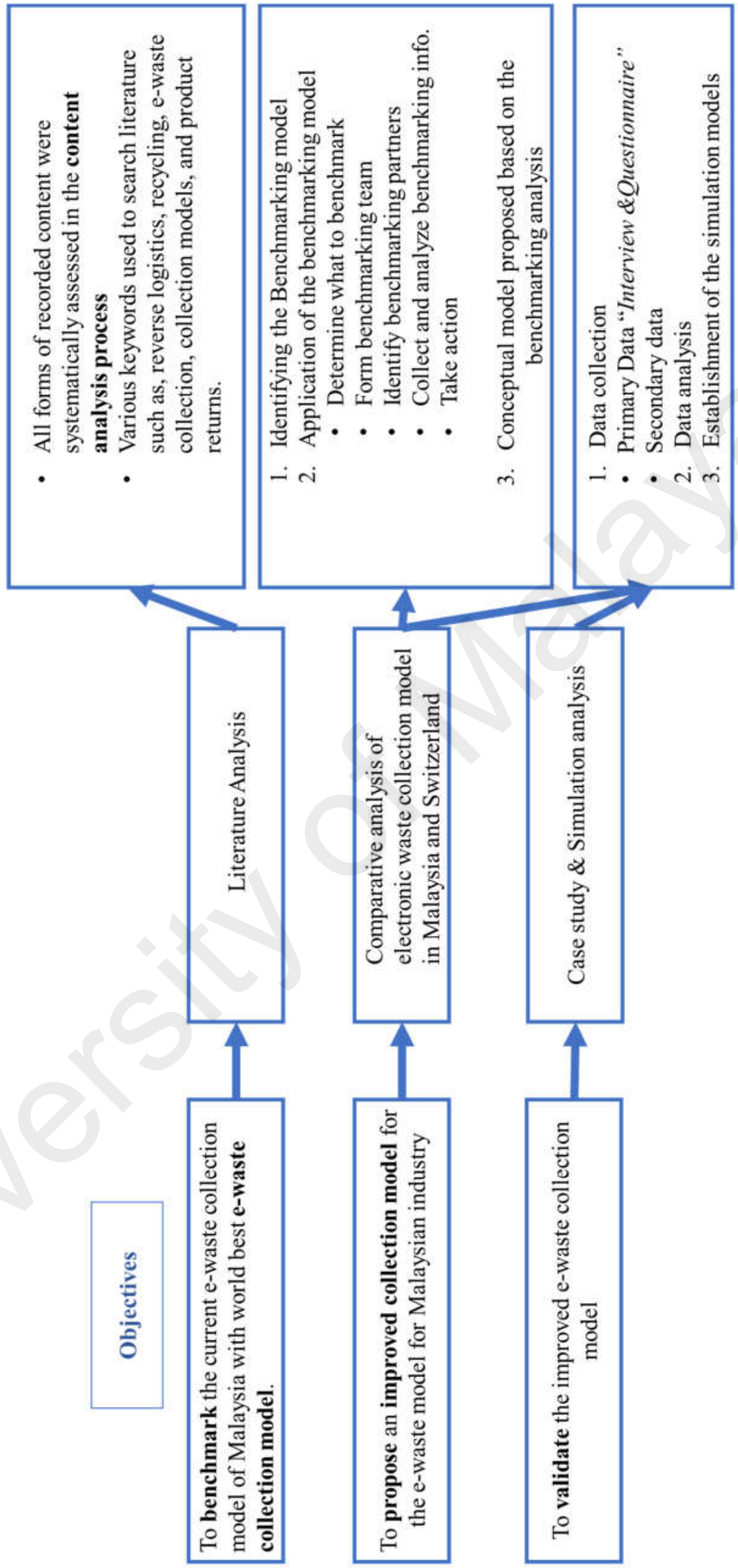

Figure 3.6 Summary of the research method

CHAPTER 4: RESULTS AND DISSCUSION

This chapter presents the results of the study and the related discussion. The data is presented in tabular and graphical form in order to ease the comparison and understanding process. The data is then divided into two sections, namely quantitative data and qualitative data. The data was collected through surveys and interviews to the licensed recovery centers in Malaysia, as well as literature review, where more than 90 different aspects of research papers were reviewed.

4.1 Results

The following sections presents the percentage of the returned questionnaire along with the qualitative data and the quantitative data results.

4.1.1 Returned questionnaire

A total of 12 sets of questionnaires were sent out to all target subjects through email and site visit interviews. All of them are licensed recovery centers with ISO 14001 certification. The target is to meet a total of 4 answered and completed questionnaires returned. The questionnaires were received either via email or directly by the interviewer during the personal interviews. Difficulties encountered in collecting data from the recovery centers are:

i. Most of them were not willing to participate in the survey.

ii. Most of the recovery centers were reluctant to divulge specific information regarding their e-waste collection.

4.1.2 Quantitative data

4.1.2.1 Amount of waste in Malaysia

The amount of e-waste in Malaysia over the period of 2004–2014 has been collected from the Malaysian department of environment, as presented in table 4.1.

Table 4.1: Amount of e-waste in Malaysia over the period of 2004–2014

Year	Amount
2004	469,584.07
2005	548,916.11
2006	1,103,4057.06
2007	1,138,839.52
2008	1,304,898.76
2009	1,705,308.14
2010	1,880,928.52
2011	1,662,031.54
2014	1,665,346.90

As shown in the table, the amount of waste is increasing over the years. The Malaysian department of environment stated that the amount of waste will be increasing if there is no action taken towards the management of the waste. This increase has been taken into account in proposing the new model.

4.1.3 Qualitative data

4.1.3.1 E-Waste Flow in Malaysia

Based on the interview and the questionnaire, the general current flow of the e-waste collection in Malaysia is presented in Figure 4.1.

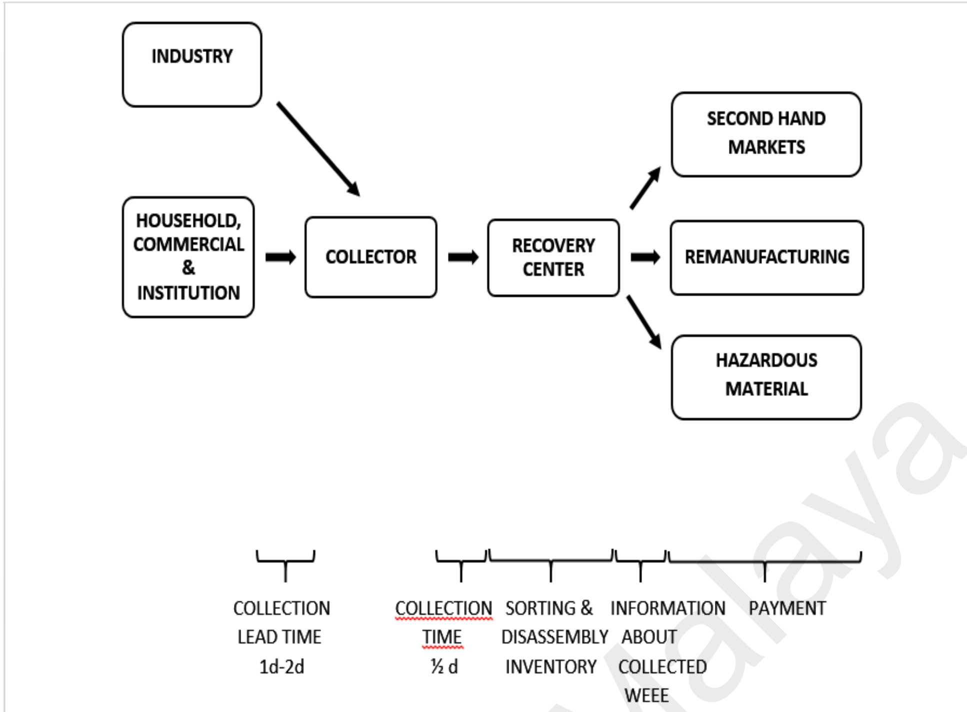

Figure 4.1: E-Waste Flow in Malaysia

From the collection points, the e-waste—which mostly come from industries, households, and commercial institutions—is transported by truck to the licensed collection center. The collection lead time is about one to two days where the waste is accumulated before the collector collects the waste. Normally, it takes about a half day to collect the waste and it actually depends on the distance and location. Then, further transfer is made to send the collected waste to the recovery center. In the recovery center, e-waste is segregated into different destinations either to secondhand markets, remanufacturing or hazardous material. However, the research only focuses on the collection of e-waste.

4.1.3.2 The Factors that affect the E-Waste Collection in Malaysia

Based on literature review, there are many factors that affect the e-waste collection in Malaysia. In order to support this statement, questionnaires were distributed among the recovery centers to determine the factors in the real environment.

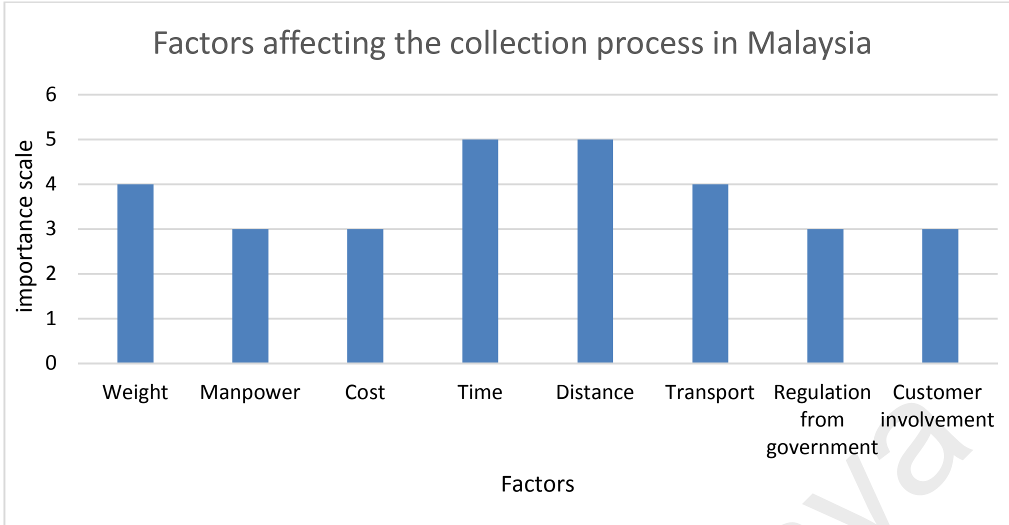

Figure 4.2: Factors that affect E-Waste Collection in Malaysia

Figure 4.2 represents all the factors that affect the e-waste collection in Malaysia. The factors include the weight of collection, manpower used to collect waste, collection cost, time taken to do the collection, travel distance and means of transportation. Most of the interview companies agree that all of the factors are important to the e-waste collection in Malaysia. Factor classified into five aspects based on the questionnaire and site visit interview. In the economic aspect, there are transportation costs, transporter costs, item costs, market fluctuations and global currency. Transportation costs such as fuel, toll and transporter costs are the most important in the economic aspect as they highly depend on a particular collection. For infrastructural aspect, the factors are facility access such as lift or manual, availability of labor, efficiency of workers where the most efficient and skilled will improve the collection and transportation used. Transportation time, load & unload time and delay time will affect the entire collection time. Another factor is distance that includes the traffic and lastly is quantity that represents the weight of waste and amount of precious material.

4.1.3.3 Malaysian and Switzerland e-waste collection model

The e-waste management in Malaysia is monitored mostly by the Malaysian department of environment. However, there are a number of informal parties giving a hand in the e-waste management. Therefore, an amount of waste will be miscounted in the cycle of three e-waste managements (Malaysian department of environment 2009). The general flow of the e-waste in Malaysia is presented in Figure 4.3, where the waste is collected by the licensed collection centers. At the collection centers, the waste is segregated by the workers into three main categories; secondhand market, hazardous materials processing center, and disposal (Malaysian department of environment {DoE}, 2009). As for the financial flow, there are no organized regulations (DoE, 2009), where in every stage of waste collection, informal paying and purchasing are performed randomly.

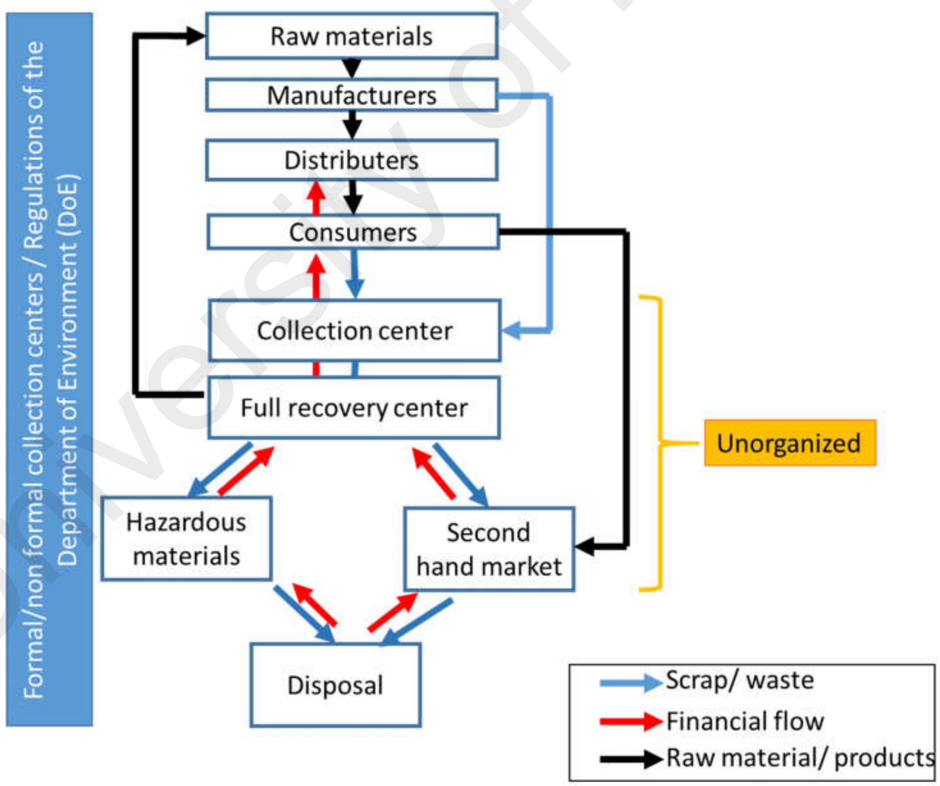

Figure 4.3 General e-waste scenario of e-waste collection in Malaysia. Source: adapted from (Department of Environment, 2009)

In Switzerland, the e-waste managed by the Swiss Agency for the Environment, Forests and Landscape (SAEFL), there is no informal collectors give a hand in the e-waste management. The e-waste is collected by the formal collectors and sent to a unit where recycling and retailer stores and remanufacturing process are performed. As for the financial flow, an advance recycling fee (ARF) is charged on all appliances based on the e-waste collection model in Switzerland. The ARF is used to pay for collecting, transporting, and recycling the disposed appliances as illustrated in figure 4.4.

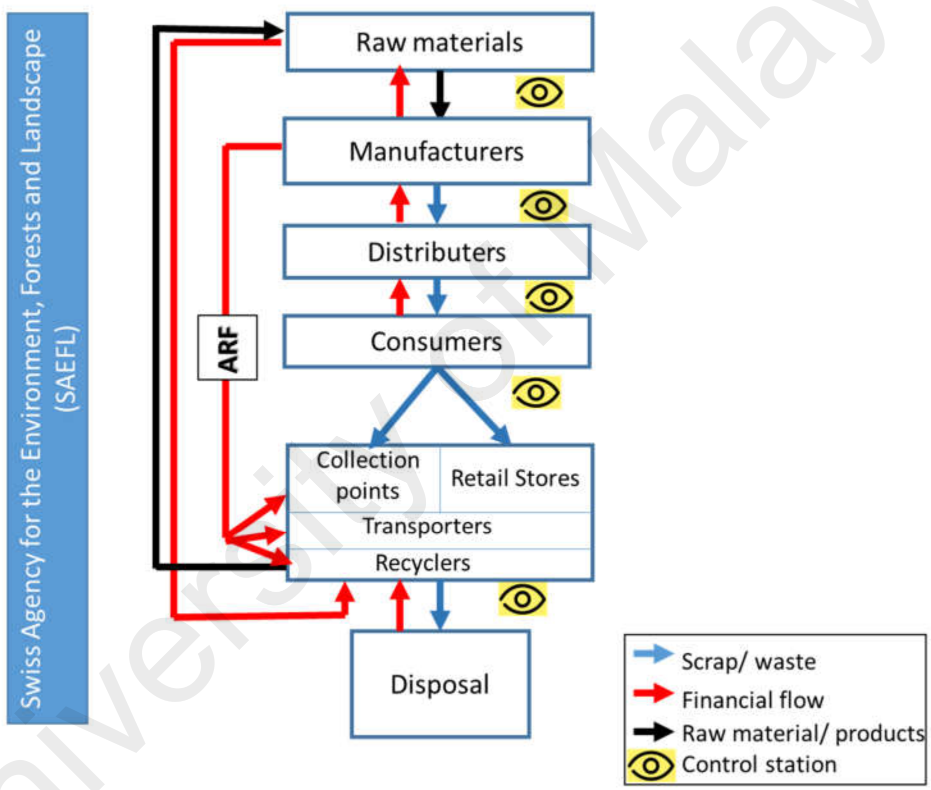

Figure 4.4 E-waste collection model for Switzerland. Source: adapted from (Widmer et al., 2005)

4.1.3.4 Benchmarking Study

A benchmarking study is conducted to aid the improvement of the current e-waste collection scenario in Malaysia. The Switzerland e-waste collection model was used to be benchmarked with the Malaysian industry e-waste collection model. The Switzerland model was used as it is the first legal and best e-waste collection model in the world. The benchmarking study is conducted using the benchmarking model which has been developed and validated in 1992 by Spendolini. (Please refer to figure 3.4 in section 4.1.3.4 Identifying the Benchmarking model)

4.1.4 Application of the benchmarking model:

4.1.4.1 Determine what to benchmark

The collection models will be benchmarked based on three main categories: structure of the e-waste collection model and the e-waste material flow, financial flow as well as the rules and regulations that are implemented in the country to manage the e-waste.

4.1.4.2 Form benchmarking team

This step is not applicable in the study as it is suitable for company use.

4.1.4.3 Identify benchmarking partners

The benchmarking study will be targeting the Malaysian e-waste collection industry benchmarked with the Switzerland e-waste collection. The Switzerland e-waste collection industry is chosen to be benchmarked with the Malaysian industry as it is the first well-established and legal e-waste collection model in the world.

4.1.4.4 Collect and analyze benchmarking information

The data for the Malaysian and Switzerland e-waste collection industries was collected mainly based on the literature review, in addition to direct data collection from the industry for the Malaysian e-waste collection. Switzerland has the first well-structured and legal e-waste management system in the world (Wager et al., 2011). This is due to the strong management of the two Producer Responsibility Organizations (PROs)—SWICO and S.EN.S. Both SWICO and S.EN.S have long periods of experience in managing e-waste, having started their e-waste programs based on the principle of Extended Producer Responsibility (EPR), in which, manufacturers are responsible for taking back, handling, recycling and the disposal of e-waste, where the public waste management authority is responsible for the e-waste collection to the retails. The model in figure 2.7 presents the e-waste flow, where the e-waste is sent to retails stores, and collection points, where further procedures are done. In contrast to the Malaysian e-waste collection strategy where the e-waste is collected via the collection center where further transfer to the recycler center is made, at the recycler center the e-waste undergoes a segregation into three sections which are the hazardous center, secondhand market, and disposal sections.

As for the financial flow of the Swiss e-waste collection model, an advanced recycling fee (ARF) is charged on all the appliances. The ARF is used to pay for the collection, the transport and the recycling of the disposed appliances. On the other hand, the financial flow for the Malaysian e-waste collection model, aside from the amount of money paid to the consumers in order to get the end of life electronic devices, another purchase is also made to send the collated e-waste to the recyclers and the disposal centers. Figure 4.5 presents the comparison of the collection model of the current Malaysian model verses the best e-waste collection model in the world, which is the Swiss model.

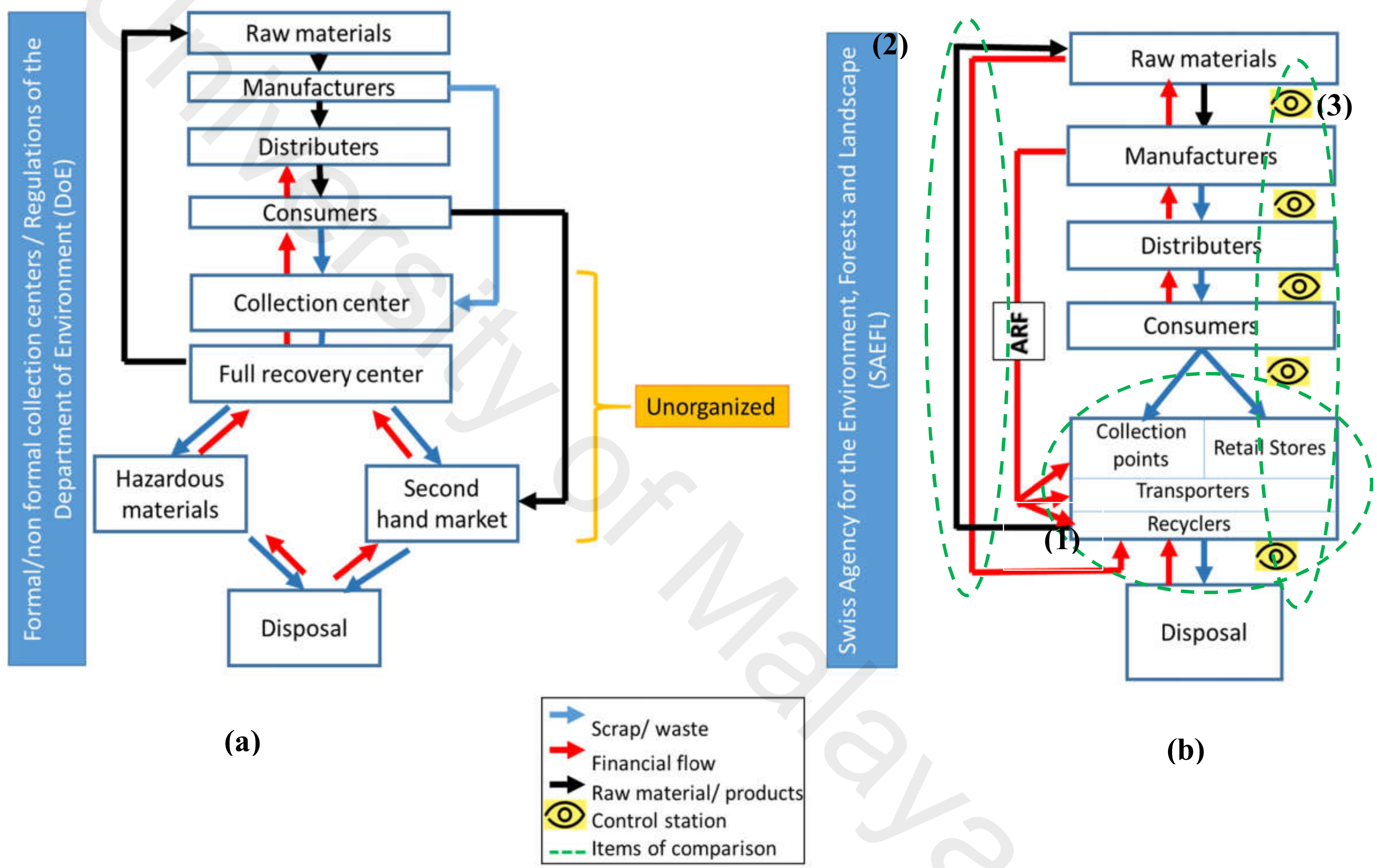

Figure 4.5: Comparison between Malaysian (a) and Swiss (b) collection models

Table 4.2: Summary of the benchmarking study between Swiss vs Malaysian e-waste collection model

Country / Parameters	Switzerland	Malaysia	Suggestions for improvement
System characterization	• The collection center, retail stores and the recyclers work as one unit and are monitored by a specialized e-waste management organization. • The Extended Producer Responsibility (EPR) strategy mainly used to manage the e-waste. This helps in the following: 1- Minimize the number of workers	• The e-waste in Malaysia is managed by isolated parties (Secondhand market, partial & full recovery centers and hazardous material management). • Only a few number of manufacturing companies are adopting the EPR strategy to manage the e-waste. • Informal collection centers, collects the e-waste.	All the parties of the e-waste collections have to work as one associated unit. • EPR is to be implemented to all the manufacturing companies.

	2- Minimize the time taken to manage a specified amount of waste 3- Increase the amount of e-waste managed	This will lead to the following: 1- More number of workers 2- Longer time taken to manage a specified amount of waste 3- Less amount of e-waste managed	
Financial flow	An advance recyclers fee collected from the consumers is then sent to the recyclers center as e-waste processing fee.	The collection centers buy the e-waste from consumers, and sell it to the recycler center where further process takes place.	An advance recycling fee is to be applied.
Regulation	The e-waste is monitored under the supervision of the Swiss Agency for the Environment, Forests and Landscape (SAEFL), moreover it is managed under two producer responsibility organizations (PROs) which are: SWICO and S.EN.S.	Under supervision of the regulation of the department of environment for the solid waste.	Strict rules and regulations to be implied against the informal collection center.

4.1.4.5 Take action

Based on the benchmarking study results, an improved model for the Malaysian e-waste collection industry will be proposed as shown in Figure 4.6.

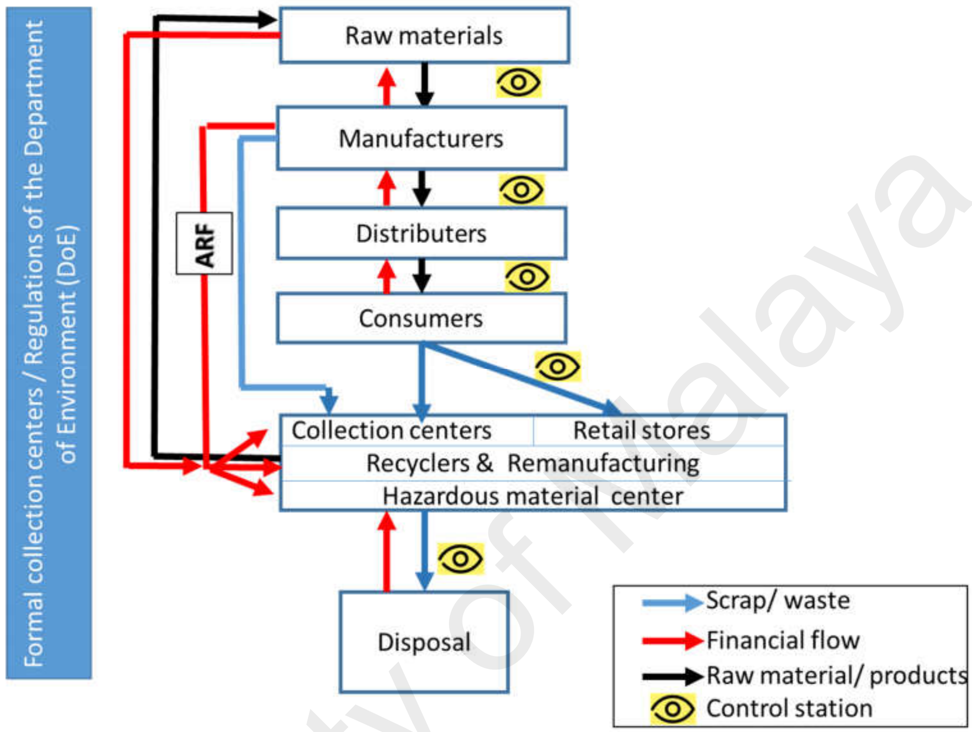

Figure 4.6: Improved e-waste collection model for the Malaysian industry

4.2 Discussion

4.2.1 Current e-waste collection models in Malaysia and Switzerland

The e-waste produced in Malaysia falls into two main categories: industrial and non-industrial (household) waste. These wastes are collected either as a whole unit of equipment or subunits of a functional equipment. However, whole units are not collected by e-waste contractors licensed by the Department of Environment (DoE). In electric and electronics manufacturing, e-waste generation is typically not quantified as whole units of e-waste — rather, the e-waste is quantified as disassembled components (e.g., plastic fittings, chipboards, metal parts, and cables), which are then collected by these contractors. At present, a planned infrastructure is being promoted for whole units of e-waste collected from households, business entities, and institutions (Department of Environment, 2009).

In general, the e-waste in Malaysia is currently managed following a general procedure set by the DoE. Based on this procedure, the contractors from a licensed collection center are required to transport and deliver all e-waste from the source (i.e., manufacturing returns and household returns) to the licensed collection center. The e-waste is then sent to the full recovery center where the waste is segregated into two categories: (1) hazardous materials, (2) secondhand market, and then to the disposal section. In terms of the financial flow, there is selling and purchasing in every stage of transportation.

On the other hand, Switzerland has the first well-structured and legal e-waste management system in the world (Wager et al., 2011) owing to the strong management of the two Producer Responsibility Organizations (PROs)—Swiss Economic Association for the Suppliers of Information, Communication and Organizational Technology (SWICO) and Swiss Foundation for Waste Management (SENS). Both SWICO and SENS have years of experience in managing e-waste, having initiated their e-waste programs based on the EPR principle, whereby manufacturers are responsible for take back, handling, recycling, and disposing e-waste, and the public waste management authority is responsible for e-waste collection and retailing. Figure 4 shows the e-waste collection model in Switzerland (Sinha-Khetriwal et al., 2005), where the e-waste is transported to the place where all processes such as collection, segregation, and recycling are made. There are no further transportation arrangements except for wastes that will be disposed into the landfill.

4.2.2 Comparative study of the Malaysia and Switzerland models

Benchmarking method was used to compare the e-waste collection model (Malaysian and Switzerland collection model). The purpose of the benchmarking study is to propose an improved model for the e-waste collection procedure in Malaysia, through improving the amount of the e-waste managed by the collection center at a reduced cost.

The comparison focuses on three main items, which are, the system characterization, financial flow and the rules and regulations. These three items were chosen for the benchmarking as it is directly related to the factors affecting the e-waste collection in Malaysia. That has been collected through survey and interview.

The comparison between the e-waste collection models in Malaysia and Switzerland. It can be seen that the e-waste in Switzerland is sent to a unit of collection points or a retailer store and then transported to the recyclers, where further procedures are implemented. These three parties (Collection points, retailer stores and recyclers) work in well interrelated manner and monitored strictly by governmental organizations, as shown in Figure 4.8 (b) label (1). This gives an impact on three main criteria which are as follows:

1- Employment potential: having an associated party of the e-waste taking back the e-waste, leads to fewer number of manpower. As stated by Sinha et al. (2005) the household appliances totaling over 34,000 tones (for all Switzerland), engages 470 workers including the collection, transportation, recycling and controlling. On the other hand, in the same research, the e-waste collection system in India, which has an isolated and not well-mechanized system, shows that 10,000 workers involved in the recycling and recovery operations in Delhi alone, where the figure would be much higher in the entire chain of collectors, transporters, and traders included.
2- Total collection time: having interrelated system of the e-waste collection, helps to get the procedures done in a faster time, as the queue time between every stage will be shortened, and this helps to shorten the lead time (Sinha et al., 2005).

3- Amount of e-waste managed: higher amount of e-waste could be managed in Switzerland due to the well-mashed parties of the e-waste management. It also helps to prevent any overlooked amount of e-waste (Widmer et al., 2005).

However, in Malaysia, the e-waste is collected by the collection center, which is then transported to the recycling center. At the recycling center, the e-waste is segregated and transported again to the centers of: (1) hazardous materials, (2) secondhand market, and then to the disposal. It can be seen that the Malaysian e-waste collection model has several stages of transportation, and this results in consuming time, money as well as manpower. Furthermore, a big amount of e-waste is overlooked, as all these parties are working isolated and not well-monitored and mashed with the rest of the e-waste management chain station. In contrast, in the Swiss e-waste collection model all the procedures on the e-waste management are performed at the same unit, therefore, further transportation is made.

As for the financial flow, an advance recycling fee (ARF) is charged on all appliances based on the e-waste collection model in Switzerland. The ARF is used to pay for collecting, transporting, and recycling the disposed appliances. Refer to Figure 4.8 (b) label (2). In contrast, in the e-waste collection model in Malaysia, the consumers are paid a certain amount of money in order to collect the EOL electronic devices. Payment is also made to send the collated e-waste to the recyclers as well as for disposal, as there are no clear rules proposed by the Malaysian department of environment.

The e-waste in Malaysia is managed and monitored by the Department of Environment (DoE), where a number of licensed collection centers collect and manage the e-waste under the rules and regulations of the DoE. At the same time, there are a number of informal collection centers that give a hand in the e-waste collection and management. The informal collectors cause a disorganization of the e-waste, where an amount of the waste flow out of the management cycle. On the other hand, the e-waste in Switzerland is managed by SAEFL (Swiss federal Agency Environment, Forest, Landscape) through the Swiss Association for Information, Communication and Organizational Technology (SWICO) and Stiftung Entsorgung Schweiz (S.E.N.S). Control stations is implanted to control and prevent any informal parties in managing the waste, as illustrated in Figure 4.8 (b) label (3). Very strict rules are imposed by the SAEFL, which is the reason the e-waste collection model in Switzerland is the best in the world.

4.2.3 Improved model of the e-waste collection model in Malaysia

Based on the benchmarking study conducted, general improved model of the e-waste collection has been proposed. The model has been improved to increase the amount of e-waste collected by collection centers at a reduced cost, and this has been achieved through improving the system characterization and the financial flow as well as the rules and regulations imposed by the DoE. In the improved model, the e-waste is transported from the consumers and the manufacturing plants to a unit of collection center, secondhand market, remanufacturing and recycling. An approach of ARF is proposed to be implemented in the improved Malaysian collection model in order to clearly manage the financial flow. Furthermore, a number of control stations is proposed to be implemented to the improved model to prevent any informal party from handling the e-waste.

4.3 Chapter summary

The results are divided into qualitative and quantitative data, which have been collected through survey and interview sessions as well as collected through literature review of the research papers related to the topic. Benchmarking study has been conducted between the Malaysian e-waste collection model and the world's first collection model (Switzerland model) in order to find an improved model to the e-waste collection model in Malaysia. A general conceptually improved model has been proposed and validated through case studies in the following chapter.

CHAPTER 5: VALIDATION OF THE PROPOSED MODEL

Case study of three licensed collection centers in Malaysia has been conducted, in order to validate the proposed model. The validation starts with identifying of the companies where the case study is implemented, by conducting interview sessions and surveys to four licensed collection centers in Malaysia. Flexsim software was used for model simulation and obtaining the results of the validation.

5.1 Identifying the companies for the case study validation

A case study is conducted to validate the proposed model for the e-waste collection in Malaysia. Four licensed collection centers in Malaysia were interviewed to select the best companies to conduct the case study, based on different parameters such as the amount of the collected e-waste, number of workers and cost of 1 metric ton of e-waste as shown below:

(a) Weight of collection

Once the EEE has been used until its end of life, the equipment will be collected by the collection center. The allowable weight per month for each recovery center varies from one another as prescribed in the license of the collection center. Based on the questionnaires and interview sessions, an analysis was performed of the amount of EEE collected per month by a recovery center. Figure 5.1 showed that company 1 has the highest collection of 48 metric ton per month, followed by 40 MT/mth for Company 2 and 3, and 10MT/mth for Company 4.

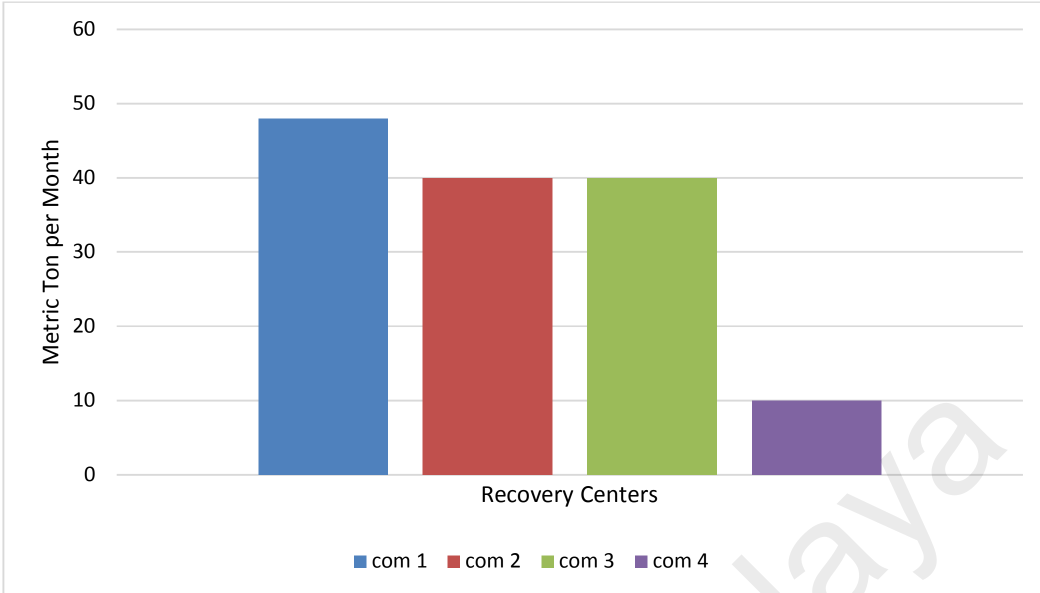

Figure 5.1 Weight of Collection per Month by Recovery Centers

(b) Average number of workers per collection

The number of workers depend on the amount of e-waste and the lower the number of workers, the lower the collection cost that is needed to collect e-waste from customers. Figure 5.2 shows that company 1 and 2 has the lowest average number of worker needed to collect e-waste which is 3 workers. Company 3 and Company 4 Full Recovery sent four and five workers respectively.

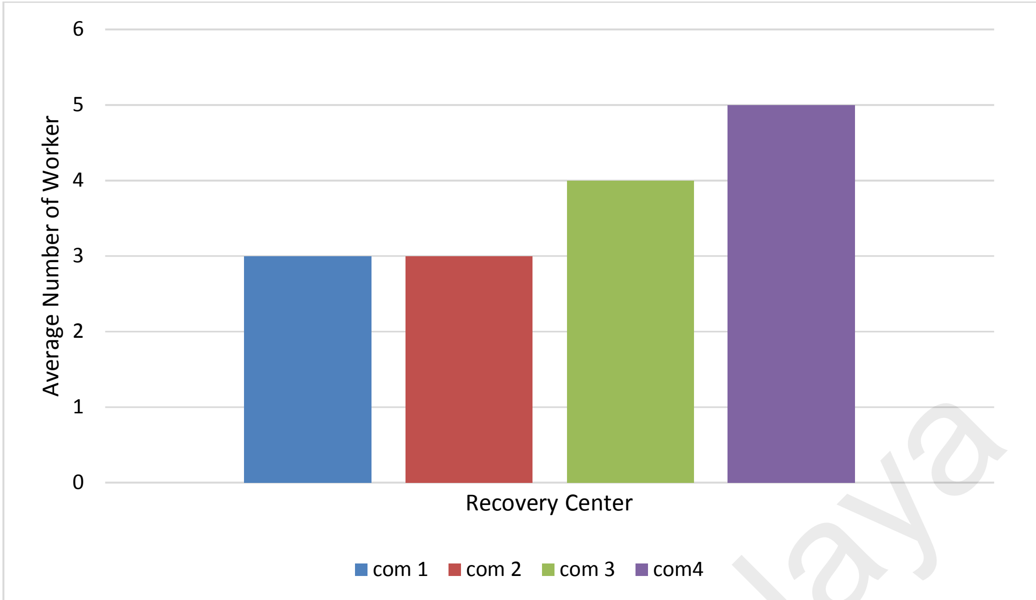

Figure 5.2: Average Number of Worker per Collection by Recovery Center

(c) Average collection cost per collection

The associated parameters are set constant for calculating the collection costs by using deterministic data. This includes average speed of transporter and its travel distance. The other factors that affect the collection cost include the fuel, toll, labor and items. Based on Figure 5.3, company 1 spends RM 800 to collect e-waste from customers, company 2 with the highest which is RM 1000, RM 900 for Company 3 and Company 4 with the lowest which is RM 300. The fact that Company 4 is the lowest due to the small amount of collection of e-waste from their customers.

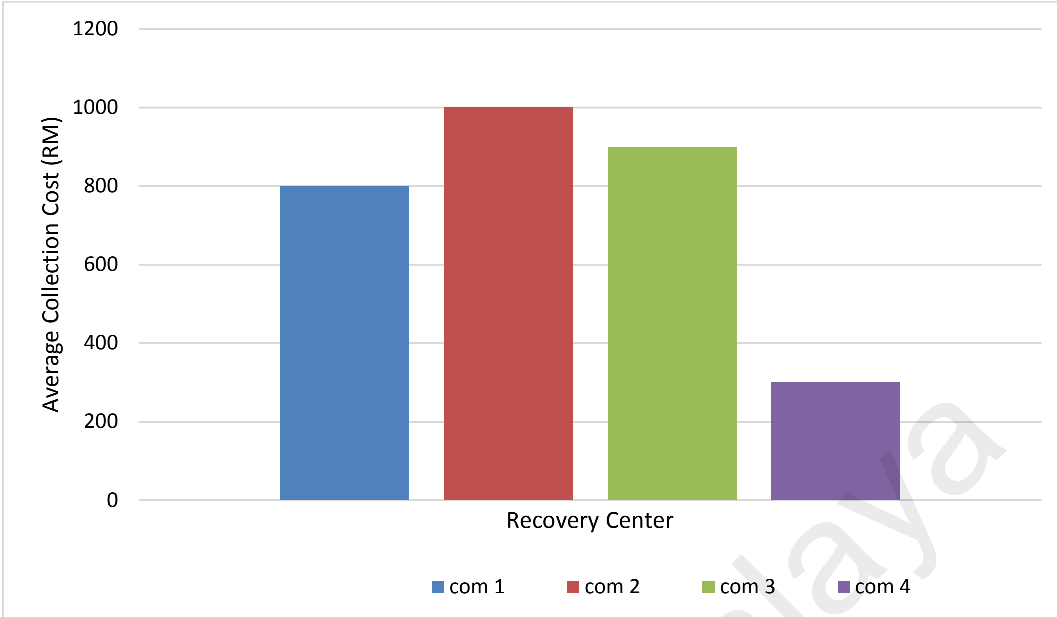

Figure 5.3: Average Collection Cost per Collection by Recovery Center

From the analysis, Company 1, Company 2, Company 4 will be selected to simulate a model for e-waste collection. Company 3 is excluded from the case study as it is relatively having the same results of Company 2.

5.1.1.1 Case study 1: Company 1

Company 1 Electrical & Electronics has the highest collection of e-waste with a total of 48 metric ton or 48,000 kilograms per month, Then, for the average number of workers per collection, Company 1 Electrical & Electronic required 3 workers per 1 metric ton, also 800 for collecting 1 metric ton. Based on the improvement aspects of the benchmarking study, the current model of Company 1 has been improved, as shown in Figure 5.4 which illustrates the current model and the improved model resulted after applying the improvement aspects.

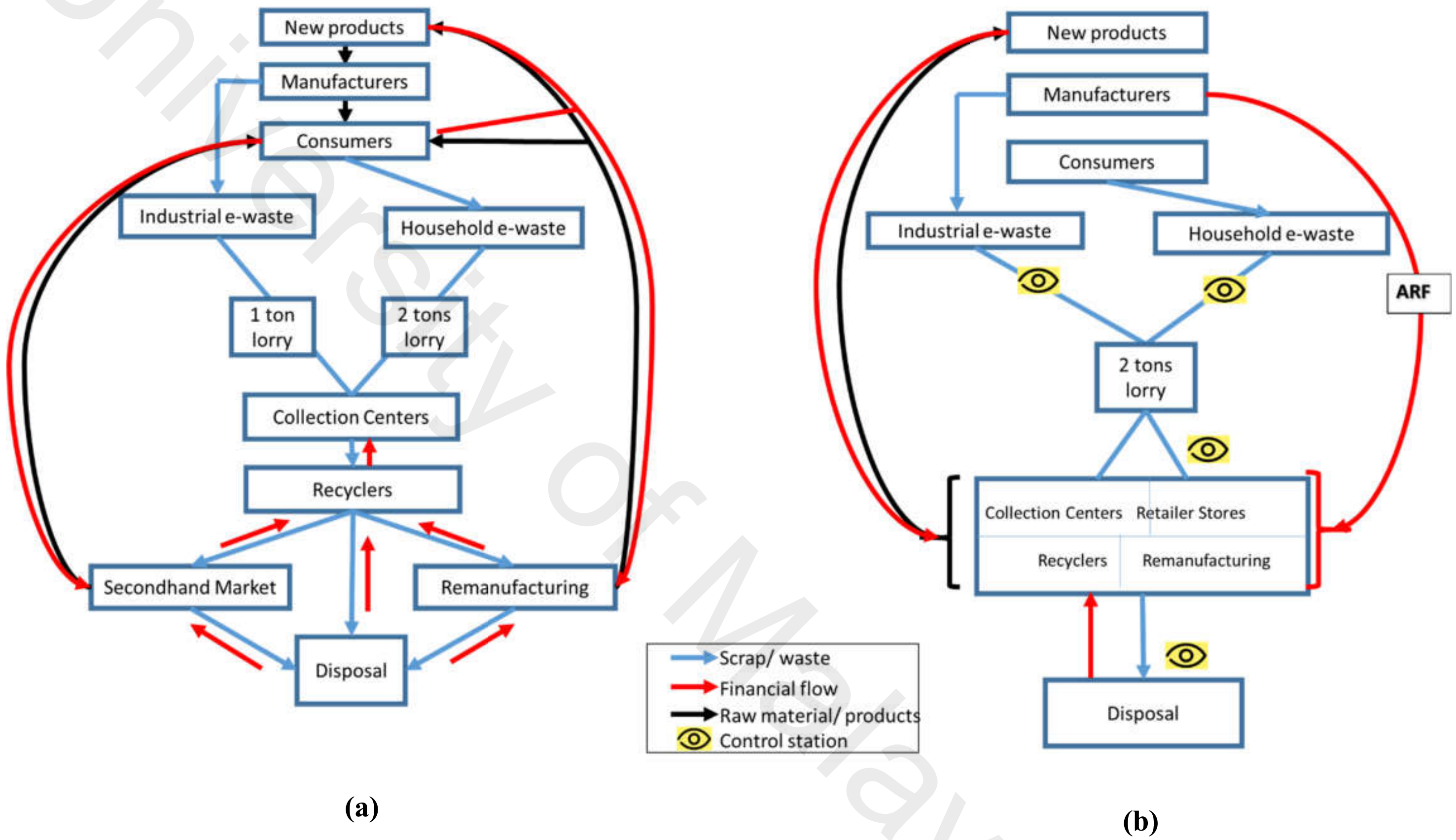

Figure 5.4: Case study 1, current model VS improved model

As it is clearly shown in the figure above, the 1 ton and the 2 tons lorries for transportation have been combined in the improved model, this is because it has been found that in each lorry there is unutilized capacity for the 1 ton and 2 ton lorries which is 60% and 40% respectively, as shown in Figure 5.5. As further improvement for the Company 1 collection center these two lorries have been replaced by one 2 ton lorry, and this will minimize the number of trips as presented in figure 5.6 and figure 5.7 which leads minimizing of cost and time.

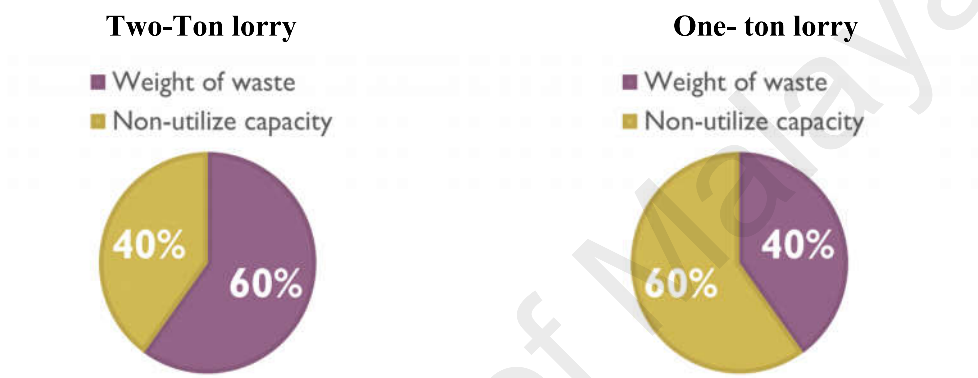

Figure 5.5: Percentage of Utilization for a One and Two Ton Lorry

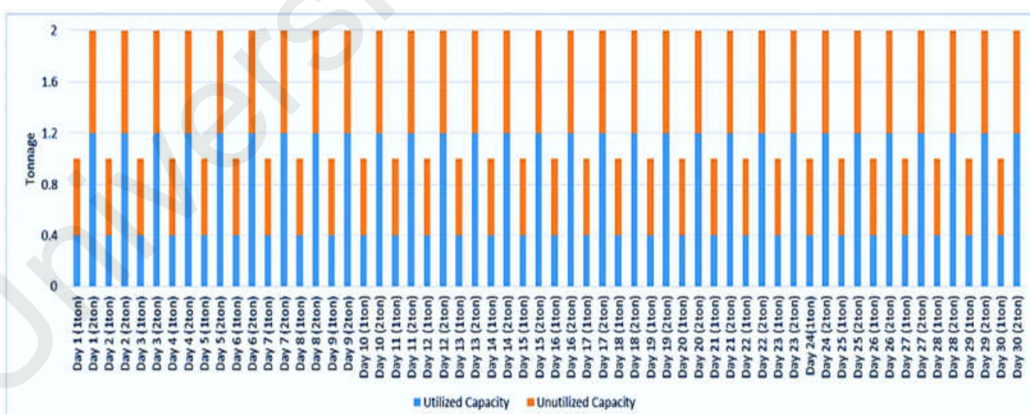

Figure 5.6: Tonnage of Lorry Capacity for the current model

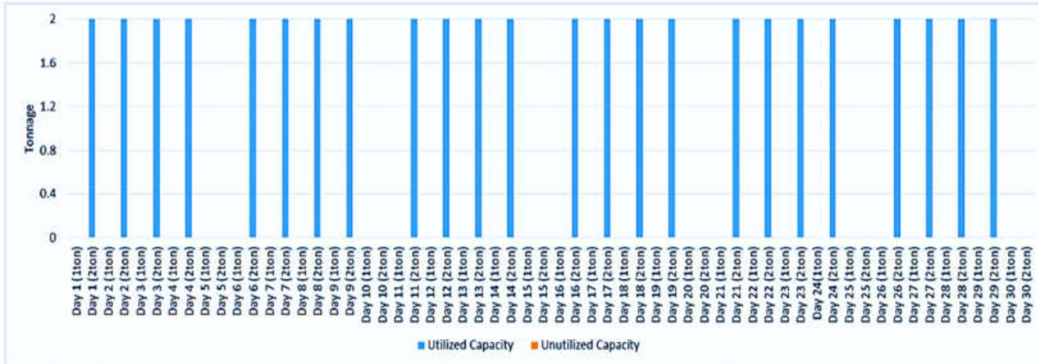

Figure 5.7: Tonnage of Lorry Capacity for the improved model

Flexsim simulation has been conducted for the current and the improved collection models of the respective company. The result shows that the amount of e-waste collected is higher in the improved model, whereas the current model is 48 metric ton per month and the improved model is 51 metric ton per month as shown in the chart presented in figure 5.8.

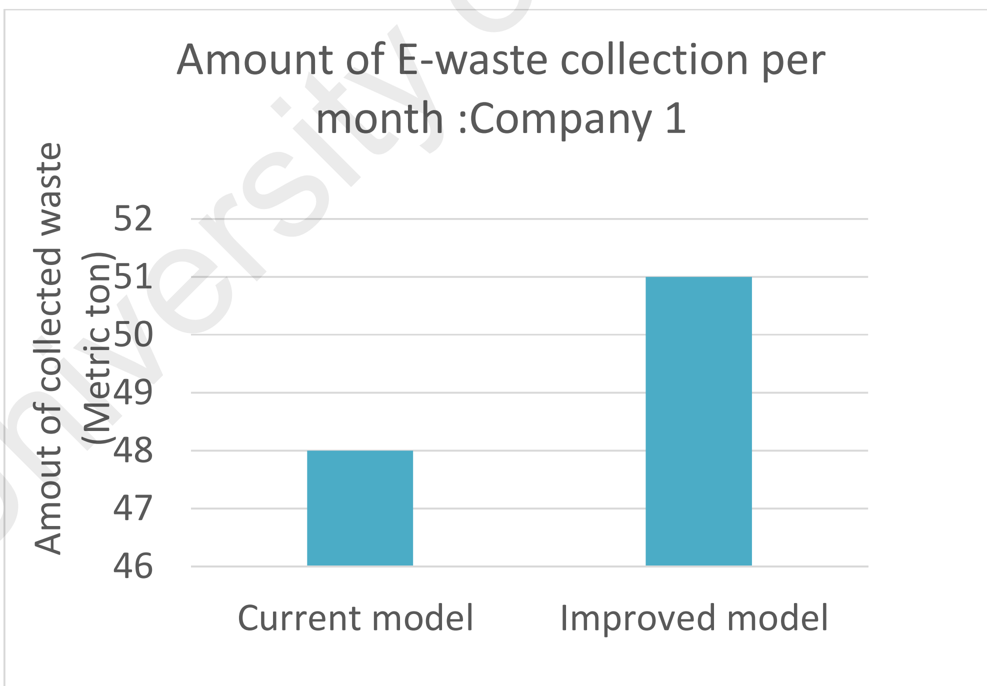

Figure 5.8: Amount of e-waste collection per month for Company 1: current vs improved model

As for the total cost (1 metric ton of e-waste in addition to the transportation cost, loading and unloading cost, worker) of the collection of 1 metric ton, it shows that the improved model gives lower cost compared to the current model as per Figure 5.9, due to elimination of a stage of transportation from the collection center to the recovery center.

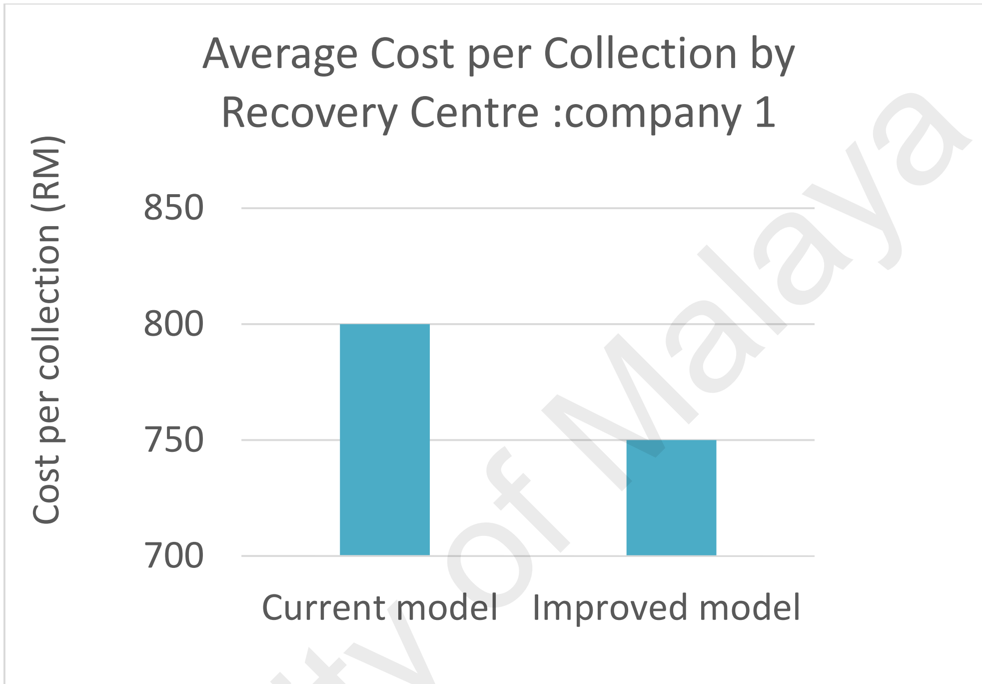

Figure 5.9: Average Cost per Collection Centre for company 1: Current vs improved model

5.1.1.2 Case study 2: Company 2

A second case study is conducted as Company 2 collection center, which collects 40 metric ton of the e-waste monthly and uses 3 workers to collect 1 metric ton to the e-waste by RM 850. The improvement aspects concluded from the benchmarking study were applied to the Company 2 as illustrated in Figure 5.10, where all the parties of managing the e-waste work is associated, also the control station implemented in every stage, to avoid any leaking of the e-waste out of the system. In addition, the ARF has been implemented to minimize the cost.

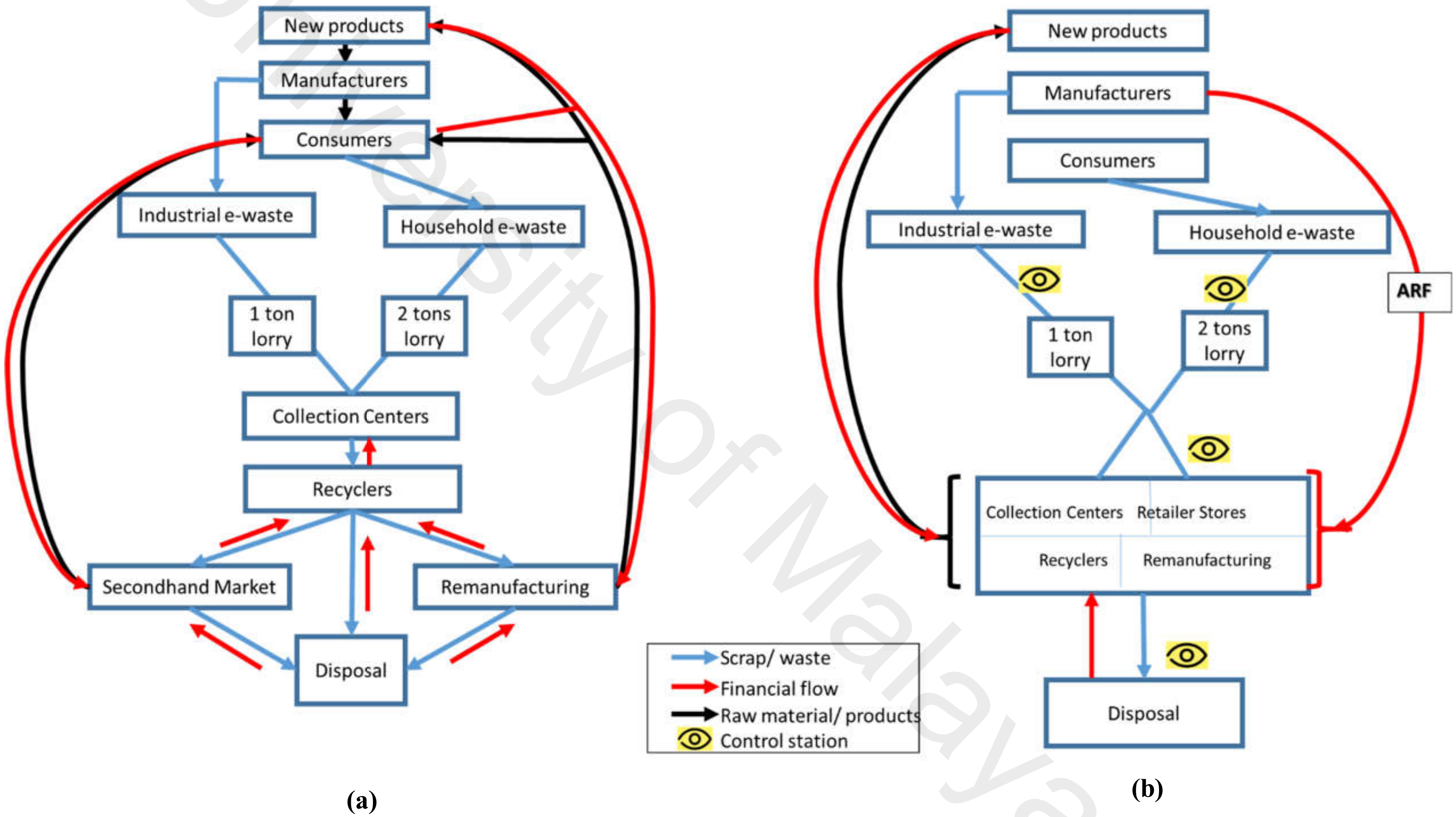

Figure 5.10: Case study 2, current model (a) VS improved model (b)

Flexsim simulation ran for the current and the improved model, the results show that the improved model can relatively collect more waste than the current model, where the current model collects 40 metric ton and the improved model collects 48 metric ton, as shown in Figure 5.11.

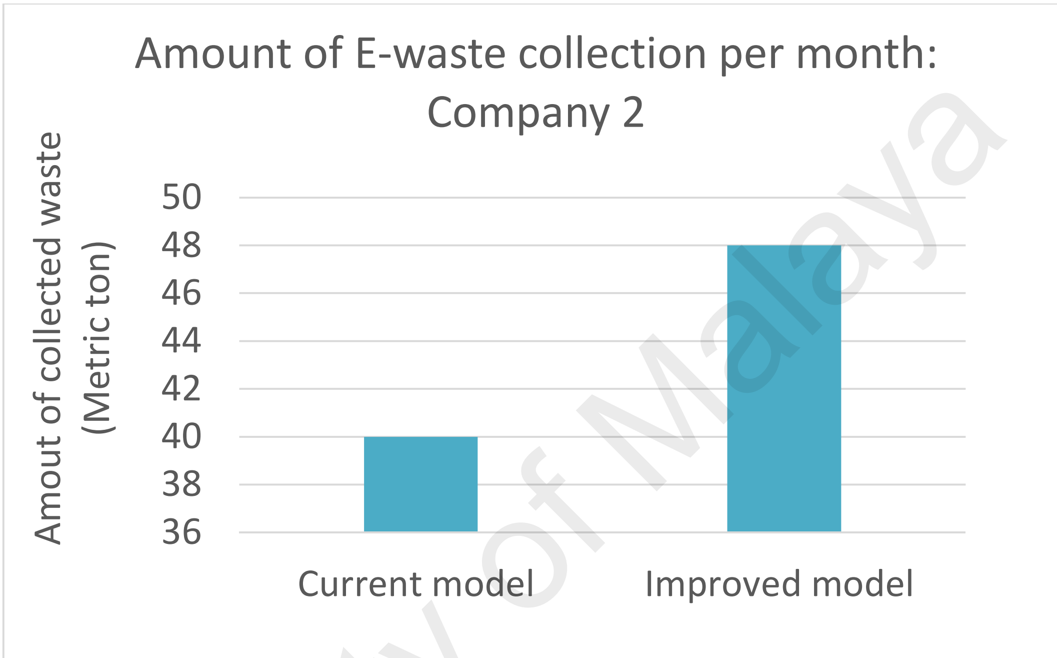

Figure 5.11: Amount of e-waste collection per month, Company 2: Current vs Improved model

As for the cost of the of the 1 metric ton for the current model is RM 850 whereas the improved model shows RM 750, which is due to the implication of the ARF strategy. As presented in figure 5.12.

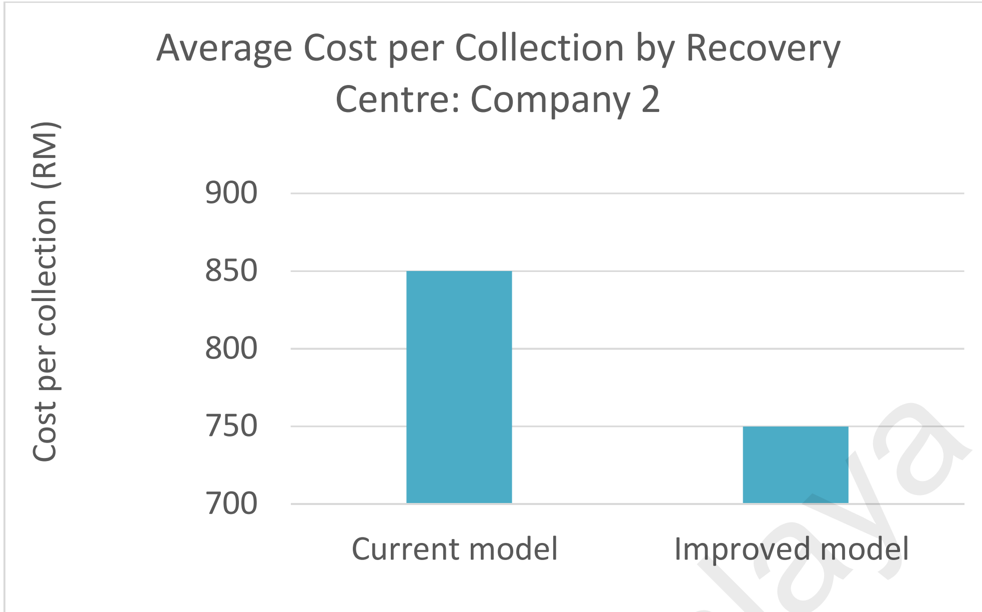

Figure 5.12: Average Cost per Collection Centre, Company 2: Current vs improved model

5.1.1.3 Case study 3: Company 4

The same goes for the last case study, Figure 5.13 shows the current and the improved model for the Company 3 collection center. This collection center collects 10 metric ton of e-waste per month, Company 4 collects from the non-industrial sources, the flexsim simulation shows the amount of waste for the improved model is higher than the current model as shown in figure 5.14. As for the collection cost of 1 metric ton the cost is lower than the cost of the current model as shown in Figure 5.15.

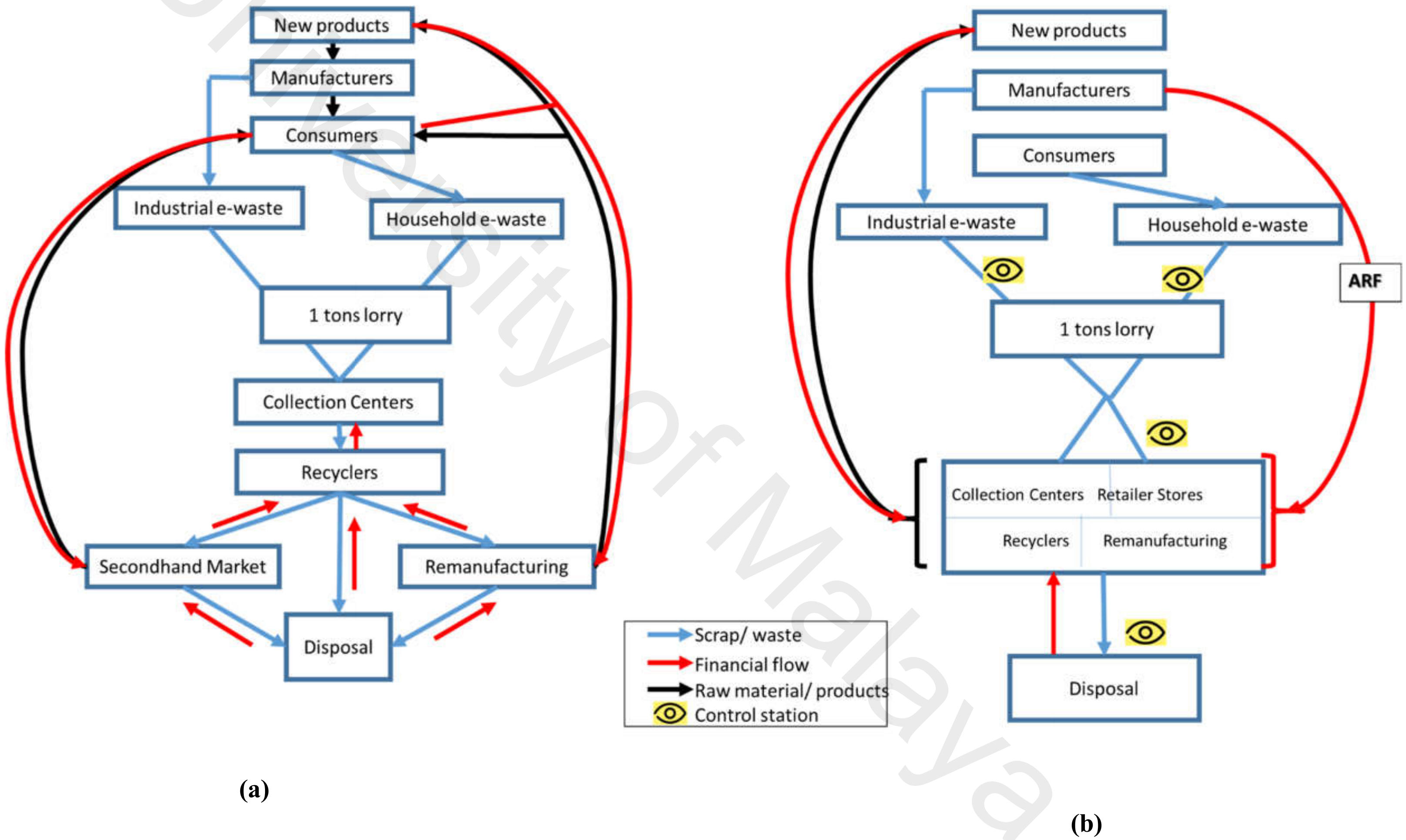

Figure 5.13: Case study 3, current model VS improved model

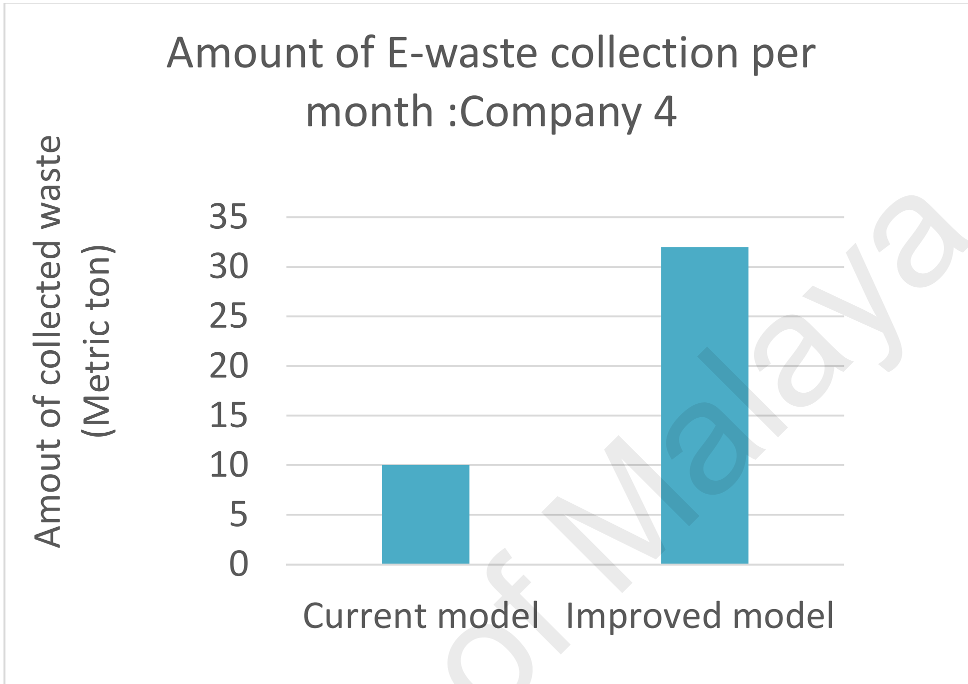

Figure 5.14: Amount of e-waste collection per month, Company 4: current vs improved model

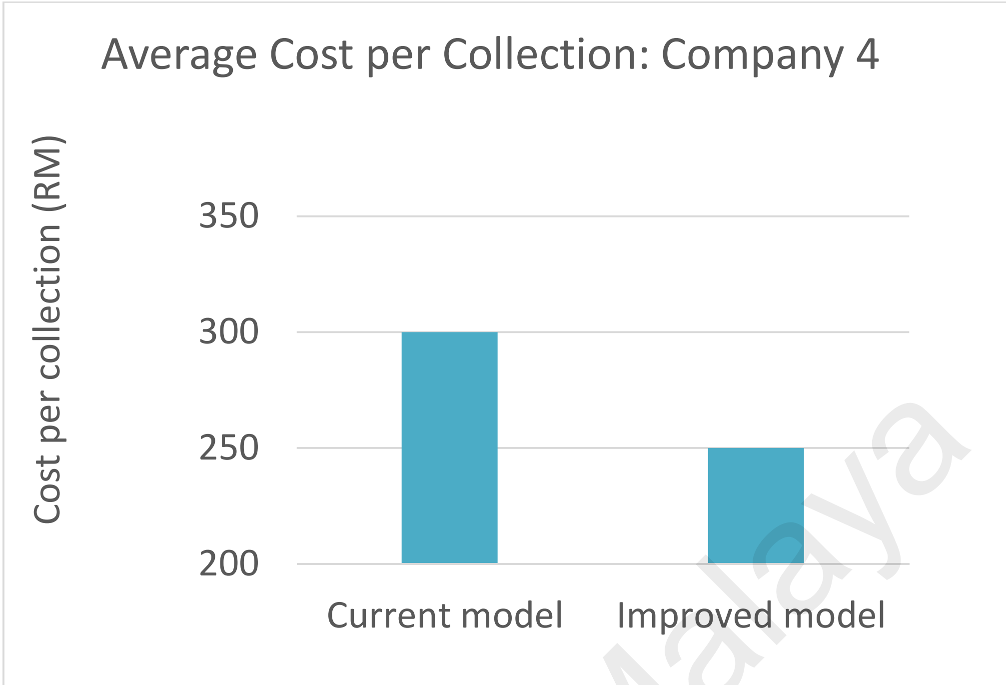

Figure 5.15: Average Cost per Collection Centre, Company 4: Current vs improved model

5.2 Chapter summary

Case study for three collection centres in Malaysia have been conducted. Flexsim was used to the simulation of the current and the improved model. The results showed the improved model is more efficient than the current model, based on the amount of waste collected as well as the total cost of 1 metric ton collection.

CHAPTER 6: CONCLUSION

6.1 General conclusion

This chapter presents the research conclusion, the significant findings, novelty, and the contribution to knowledge and industry. The research proposed an improvement for the e-waste collection model for the Malaysian industry.

6.2 Specific conclusion

An improved model of e-waste collection for the Malaysian industry has been achieved by setting objectives as follows:

1- Benchmarking study between the current Malaysian e-waste collection model and Swiss e-waste collection model, is achieved. Several highlights from this section as follows: Firstly, the financial flow for the collection process of Swiss model is clear and strict, where an advance recycling fee is taken from the customers while purchasing a new item. In contrast with the Malaysian financial flow where in every stage there is buying and selling, which leads to an unmanaged and unorganized process. Secondly, the e-waste in Malaysia is collected by the collection centers and then sent back to the recovery center where further process, for example, segregation, and re-manufacturing take place, where all the parties are working in an isolated manner. On the other hand, in Switzerland the e-waste management stages (collection, remanufacturing, segregation and disposal) are well-mashed and work as one unit. This will lead to a minimizing of the number of employments, time and cost. Thirdly, in Switzerland, strict and sealed rules and regulations are implied for the e-waste collection and this is the reason behind it being the best collection model in the world. However, for Malaysia, the e-waste is managed by both formal and informal collection centers, which leads to leaking of the e-waste out of the system and improper disposal of the e-waste.

2- An improved model for the e-waste collection is proposed, based on the benchmarking results. Following, are the improvements implemented and suggested to the current e-waste collection model of Malaysia. Firstly, the collection center and the recovery center work as one unit, which will minimize cost and time spent. Secondly, to implement a control station in every stage to prevent the informal parties to interfere in managing the e-waste. Lastly, Implement a strict rule for the financial flow, as advanced recycling fee from the customers.

3- Validation of the e-waste collection proposed model was achieved. Case study for three licensed collection centers in Malaysia undergo a case study simulation using flexsim. The results of the simulation show:

a) The amount of collected e-waste per month is higher compared to the current e-waste collection model.

b) The cost of collection for the 1 metric ton is relatively lower in the improved model.

c) According to the interview with the industry, the implementation of the control station in every stage of the collection process will help to improve the e-waste management. The same goes to the implantation of the fixed advance recycling fees.

6.3 Contribution to knowledge

The development of the electrical and electronic waste collection model for the Malaysian industry contributes to knowledge as follows:

Firstly, it contributes to new knowledge for understanding the current situation of the e-waste collection in Malaysia and identifies its weaknesses and barriers.

Secondly, the development of the new model of the e-waste collection in Malaysia offers valuable knowledge based on an insight to the factors affecting the e-waste collection in Malaysia.

6.4 Contribution to industry

As described in chapter 2, there are a number of collection centers in Malaysia that manage the waste, but their models are not catering the huge amount of the accumulating waste. So, this study gives an insight to improve the current collection models to increase the amount of collected waste at a lower price.

6.5 Recommendations for future research

The research provides an improvement for the collection stage of the e-waste management, and research should be conducted to propose an improvement for the other e-waste management stages, e.g. segregation, remanufacturing and disposal etc. Further research should be conducted to introduce the model in a mathematical model that attempts to ensure efficiency and user-friendliness.

6.6 Limitations of the research

limitations were experience in this research which are identified as follows. Firstly, time and financially problems were among the issues faced by the author during conducting the research. Secondly difficulties were experience to get the data from the collection centers through questionnaire and interview.

REFERENCES

Alberti, M., Caini, M., Calabrase, A. and Rossi, D. (2000). Evaluation of the costs and benefits of an environmental management system, International Journal of Production Research, Vol. 38 No. 17, pp. 4455-66.

Alshamrani, A., et al. (2007). "Reverse logistics: simultaneous design of delivery routes and returns strategies." Computers & Operations Research Volume 34(2): Pages 595–619.

Andarani, P., & Goto, N. (2014). Potential e-waste generated from households in Indonesia using material fl ow analysis. Journal of Material Cycles and Waste Management, 16 (2), 306–320.

Azzone, G., Bianchi, R., Mauri, R. and Noci, G. (1997): “Defining Operating Environmental Strategies: Programmes and Plans within Italian Industries”, Environmental Management and Health, Vol. 8, n.1, pp. 4-19.

BabaMd Deros Sha'ri Mohd Yusof AzhariMd Salleh. (2006), “A benchmarking implementation framework for automotive manufacturing SMEs”, Benchmarking: An International Journal, Vol. 13 No. 4 pp. 396 – 430

Barros, A. I., et al. (1998). "A two-level network for recycling sand: A case study." European Journal of Operational Research 110(2): 199-214.

Beamon, B.M. (1999), “Supply chain design and analysis: models and methods”, International Journal of Production Economics.

Brio, J.A., Junquera, B. (2003), “A review of the literature on environmental innovation management in SMEs: implications for public policies”. Technovation, 23, 939–948.

Brito, M. P. d. and R. Dekker (2002). "Reverse Logistics – a framework." Econometric Institute Report EI.

Carroll A. B., Buchholtz A. K., (2008), Business & Society, 9th Edition, CENGAGE Learning, United States of America

Chung, S., Murakami-Suzuki, R., 2008. A Comparative Study of E-waste Recycling Systems in Japan, South Korea and Taiwan from the EPR Perspective: Implications for Developing Countries.

Chouinard, M., et al. (2005). "Integration of reverse logistics activities within a supply chain information system." Computers in Industry 56(1): 105-124.

Crow, K. (1999), Benchmarking Best Practices to Improve Product Development, DRM Associates, 2613 Via Olivera, Palos Verde’s, CA 90274.

Cruz-Rivera, R. and J. Ertel (2009). "Reverse logistics network design for the collection of End-of-Life Vehicles in Mexico." European Journal of Operational Research 196(3): 930-939.

Cui, J., Forssberg, E., 2003. Mechanical recycling of waste electric and electronic equipment: a review. Journal of Hazardous Materials 99 (3), 243–263.

Davies, A.J. and Kochhar, A.K. (2000), “A framework for the selection of best practices”, International Journal of Operations & Production Management, Vol. 20 No. 10, pp. 1203-17.

Das, K. and A. H. Chowdhury (2012). "Designing a reverse logistics network for optimal collection, recovery and quality-based product-mix planning." International Journal of Production Economics 135(1): 209-221.

De Brito M.P. and R. Dekker (2002), “A framework for Reverse Logistics” Econometric Institute Report EI 2001-38, Erasmus University Rotterdam, the Netherlands.

Dehghanian, F. and S. Mansour (2009). "Designing sustainable recovery network of end-of-life products using genetic algorithm." Resources, Conservation and Recycling 53(10): 559-570.

De Figueiredo, J. N. and S. F. Mayerle (2008). "Designing minimum-cost recycling collection networks with required throughput." Transportation Research Part E: Logistics and Transportation Review 44(5): 731-752.

Eglise TL, Pierre DL. Recycling of electronic end-of-life devices. In: Proceedings of IEEE international symposium on electronics and the environment; 2000. p. 149–54.

Fleischmann, M., et al. (2000). "A characterisation of logistics networks for product recovery." Omega 28(6): 653-666.

Fleischmann, M., et al. (1997). "Quantitative models for reverse logistics: A review." European Journal of Operational Research 103(1): 1-17.

Frota Neto, J. Q., et al. (2008). "Designing and evaluating sustainable logistics networks." International Journal of Production Economics 111(2): 195-208.

Fong, P.S.W., Shen, Q. and Cheng, E.W.L. (2001), “A framework for benchmarking the value management process”, Benchmarking: An International Journal, Vol. 8 No. 4, pp. 306-16.

Harraz, N. A. and N. M. Galal (2011). "Design of Sustainable End-of-life Vehicle recovery network in Egypt." Ain Shams Engineering Journal 2(3–4): 211-219.

Håkan Aronsson and M. H. Brodin (2006). "The environmental impact of changing logistics structures." The International Journal of Logistics Management Vol. 17 , (3): pp.394 - 415.

Hampshire, UK: a case study. In: Cossu, R., Diaz, F.L., Steggmann, R. (Eds.), Sardinia 2009 Symposium. Proceedings of the Twelfth International Waste Management and Landfill Symposium. S. Margherita di Pula, Cagliari, Sardinia, Italy, October 5–9, Paper 370.

Hainault T, Smith DS. Minnesota's multi-stakeholder approach to managing electronic products at end-of-life. In: Proceedings of IEEE international symposium on electronics and the environment; 2000. p. 310–7. Hazen Research, Inc.; 1998.

He, W.Z., Li, G.M., Ma, X.F., Wang, H., Huang, J.W., Xu, M., Huang, C.J., 2006. WEEE recovery strategies and the WEEE treatment status in China. Journal of Hazardous Materials 136 (3), 502–512..

Hillary, R., (2004). 'Environmental management systems and the smaller enterprise', Journal of Cleaner Production, 12, pp. 561–569.

International Association of Electronics Recyclers (IAER). IAER electronics recycling industry report; 2003. Jung LB, Bartel T. An industry approach to consumer recycling: the San Jose project. In: Proceedings of IEEE international symposium on electronics and the environment; 1998. p. 36–41.

Jalil MA (2010) Sustainable development in Malaysia: a case study on household waste management. J Sustain Dev 3(3):91

Jayaram, J. and K.-C. Tan (2010). "Supply chain integration with third-party logistics providers." International Journal of Production Economics 125(2): 262-271.

Jayaraman, V., et al. (2003). "The design of reverse distribution networks: Models and solution procedures." European Journal of Operational Research 150(1): 128-149.

John Babington CCS, Ahmad Fariz M, Rawshan Ara B (2010) Bridging the gaps: a e-waste management and recycling assessment of material recycling facilities in Selangor and Penang. Int J Environ sci 1(3):383–391

Kahhat, R., Kima, J., Xua, M., Allenbya, B., Williams, E. & Zhanga, P. 2008. Exploring E-waste Management Systems in the United States. Resources, Conservation and Recycling 52, 955–964.

Kara, S., et al. (2007). "Simulation modelling of reverse logistics networks." International Journal of Production Economics 106(1): 61-69.

Karakayali, I., et al. (2007). "An analysis of decentralized collection and processing of end-of-life products." Journal of Operations Management Volume 25(6,): Pages 1161–1183.

Klausner, M. and C. T. Hendrickson (2000). "Reverse-Logistics Strategy for Product Take-Back." (pp. 156–165).

Kleber, R., et al. (2002). "A continuous time inventory model for a product recovery system with multiple options." International Journal of Production Economics 79(2): 121-141.

Koh, S.-G., et al. (2002). "An optimal ordering and recovery policy for reusable items." Computers & Industrial Engineering 43(1–2): 59-73.

Kojima M (2012) E-waste take-back system design. Paper presented at the Greater Mekong Sub-region (GMS) training workshop on building capacity to deal with the illegal shipments of e-waste and near-end-of-life electronics, Ha Noi, Viet Nam.

Kohn, C. and M. H. Brodin (2008). "Centralised distribution systems and the environment: how increased transport work can decrease the environmental impact of logistics." International Journal of Logistics Research and Applications Volume 11(3): pp 229-245.

Krikke, H. (2011). "Impact of closed-loop network configurations on carbon footprints: A case study in copiers." Resources, Conservation and Recycling 55(12): 1196-1205.

Krumwiede, D. W. and C. Sheu (2002). "A model for reverse logistics entry by third-party providers." Omega 30(5): 325-333.

Lee, P.M. (2002), “Sustaining business excellence through a framework of best practices in TQM”, the TQM Magazine, Vol. 14 No. 3, pp. 142-9.

Lonn SA, Stuart JA. How collection method and e-commerce impact product arrival rate to electronic return, reuse, and recycling center. In: Proceedings of IEEE international symposium on electronics and the environment; 2002. p. 228–33

Lindhqvist, Thomas. (2000). Extended Producer Responsibility in Cleaner Production. IIIEE Dissertations 2000:2. Lund: IIIEE, Lund University.

Lynn R. Kahle, Eda Gurel-Atay, Eds (2014). Communicating Sustainability for the Green Economy. New York: M.E. Sharpe. ISBN 978-0-7656-3680-5.

Mallidis, I., et al. (2012). "The impact of greening on supply chain design and cost: a case for a developing region." Journal of Transport Geography 22(0): 118-128.

Medori, D. and Steeple, D. (2000), “A framework for auditing and enhancing performance measurement systems”, International Journal of Operations & Production Management, Vol. 20 No. 5, pp. 520-33.

Min, H., et al. (2006). "A genetic algorithm approach to developing the multi-echelon reverse logistics network for product returns." Omega 34(1): 56-69.

Mollenkopf, D., et al. (2007). "Managing internet product returns: a focus on effective service operation." Decision Sciences 38(2):215-50.

Needhidasan, S., Samuel, M., & Chidambaram, R. (2014). Electronic waste-an emerging threat to the environment of Urban India. Journal of Environmental Health Science & Engineering,12, 36.

Ni, H.-G., Zeng, E.Y., 2009. Law enforcement and global collaboration are the keys to containing e-waste tsunami in China. Environ. Sci. Technol. 43, 3991–3994.

Nnorom IC, Osibanjo O (2008b) Overview of electronic waste (ewaste) management practices and legislations, and their poor applications in the developing countries. Resour Conserv Recycl 52(6):843–858. doi:10.1016/j.resconrec.2008.01.004

Nnorom, I. C., et al. (2011). "Global disposal strategies for waste cathode ray tubes." Resources, Conservation and Recycling 55(3): 275-290.

NPC (1999), Achieve business excellence through best practices, Malaysian Benchmarking Service, The Best Practices Division, National Productivity Corporation, available at: www.npc. org.my

OECD. (2001). Extended Producer Responsibility. A Guidance Manual for Governments. Paris: OECD. Peck, Philip. (2003). Interest in Material Cycle Closure? Exploring evolution of industry's responses to high-grade recycling from an Industrial Ecology perspective. IIIEE Dissertations 2003:2. Lund: IIIEE, Lund University.

Oliveira CR, Bernardes AM, Gerbase AE (2012) Collection and recycling of electronic scrap: a worldwide overview and comparison with the Brazilian situation. Waste Manag 32(8):1592–1610. doi:10.1016/j.wasman.2012.04.003

Ongondo, F., Williams, I.D., Keynes, S., 2011. Estimating the impact of the ‘‘digital switchover’’ on disposal of WEEE at household waste recycling centers.

Paola Cocca, Marco Alberti, (2010) "A framework to assess performance measurement systems in SMEs", International Journal of Productivity and Performance Management, Vol. 59 No. 2, pp.186 – 200

Pinto V. N., (2008), E-waste hazard: The impending challenge, 12(2), 65-70.

Pokharel, S. and A. Mutha (2009). "Perspectives in reverse logistics: A review." Resources, Conservation and Recycling 53(4): 175-182.

Post, J.E., Altman, B.W. (1994) Managing the environmental change process: Barriers and opportunities. Journal of Organizational Change Management, 7(4), 64. Retrieved July 5, 2008, from ABI/INFORM Global database. (Document ID: 704510).

Qin, Z. and X. Ji (2010). "Logistics network design for product recovery in fuzzy environment." European Journal of Operational Research 202(2): 479-490.

Ravi, V., Shanker, R. & Tiwari, M. K. (2005) Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach. Computer and Industrial Engineering, 48: 327–356.

Richey, R. G., et al. (2005). "Developing effective reverse logistics programs." Industrial Marketing Management 34(8): 830-840.

Robinson, B.H., 2009. E-waste: an assessment of global production and environmental impacts. Sci. Total Environ. 408, 183–191.

Rogers, D. and R. Tibben-Lembke (1999). "Going backwards: reverse logistics trends and practices." Reverse Logistics Executive Council Pittsburgh, PA.

Ronald S. Tibben-Lembke and Dale S. Rogers (2002). ""Differences between forward and reverse logistics in a retail environment"." Supply Chain Management: An International Journal Vol. 7(5): pp.271 - 282.

Roslim NF, Ishak MB (2012) Electrical and electronic waste condition and handling practices in Bangi industrial estate, Selangor. Int J Environ Sci 1(7):1655–1665.

Sarkis, J. (2003). "A strategic decision framework for green supply chain management." Journal of Cleaner Production 11(4): 397-409.

Sbihi, A. and R. Eglese (2007). "Combinatorial optimization and Green Logistics." 4OR 5(2): 99-116.

Scott, A. (2008). Taking it back: why reverse logistics will at last be taken seriously. Logistics & Transport Focus, 10(6), 34-35.

Seuringa S., Müller M., (2008), From a Literature Review to a Conceptual Framework for Sustainable Supply Chain Management, 16(15), 1699–1710

Shumon, M.R.H., Ahmed, S. & Islam, M.T. Environ Earth Sci (2014) 72: 2239. doi:10.1007/s12665-014-3129-5

Silveira G. and Chang S., (2010). 'Cell phone recycling experiences in the United States and potential recycling options in Brazil'. Waste Management. Vol.30: pp. 2278-2291

Sodhi, M.S. & Reimer, B. (2001) Model for recycling electronics end-of-life products. OR Spektrum 23, 97–115.

Stefan E. Genchev, R. Glenn Richey, Colin B. Gabler, (2011) "Evaluating reverse logistics programs: a suggested process formalization", The International Journal of Logistics Management, Vol. 22 No. 2, pp.242 - 263

Spendolini, M.J. (1992), "The Benchmarking Process", Compensation & Benefits Review, Vol. 24 No. 5, pp. 21-9.

Spicer, A. J. and M. R. Johnson (2004). "Third-party demanufacturing as a solution for extended producer responsibility." Journal of Cleaner Production 12(1): 37-45.

Sundarakani, B., et al. (2010). "Modeling carbon footprints across the supply chain." International Journal of Production Economics 128(1): 43-50.

Tengku-Hamzah T, Adeline, Adura (2011) Making sense of environmental governance: a study of e-waste in Malaysia. Dissertation, Durham University, UK

Terrance L. Pohlen, M. Theodore Farris, (1992) "Reverse Logistics in Plastics Recycling", International Journal of Physical Distribution & Logistics Management, Vol. 22 No. 7, pp.35 – 47

Tibben-Lembke, R. S. and D. S. Rogers (2002). "Differences between Forward and Reverse Logistics in a Retail Environment." Supply Chain Management: An International Journal 7(5): 271-282.

Voss, C.A., Chiesa, V. and Coughlan, P. (1994), "Developing and testing benchmarking and self-assessment frameworks in manufacturing", International Journal of Operations & Production Management, Vol. 14 No. 3, pp. 83-100.

Wa¨ger PA, Hischier R, Eugster M (2011) Environmental impacts of the Swiss collection and recovery systems for waste electrical and electronic equipment (WEEE): a follow-up. Science Total Environ 409(10):1746–1756. doi:10.1016/j.scitotenv.2011.01. 050

Wen-hui, X. I. A., et al. (2011). "The remanufacturing reverse logistics management based on Closed-loop supply chain management processes." Procedia Environmental Sciences 11, Part A(0): 351-354.

Widmer R, Oswald-Krapf H, Sinha-Khetriwal D, Schnellmann M, Bo¨ni H (2005) Global perspectives on e-waste. Environ Impact Assess Rev 25(5):436–458. doi:10.1016/j.eiar.2005.04.001

Wojanowski, R., et al. (2007). "Retail–collection network design under deposit–refund." Computers & Operations Research 34(2): 324-345.

Wu, C.-H. (2012). "Product-design and pricing strategies with remanufacturing." European Journal of Operational Research 222(2): 204-215.

Yacob P., Fared M., Wira A., Syaheeda N., (2012), Barriers to Reverse Logistics Practices in Malaysian SMEs, 1(5), 204-214

Yusof, S.M. and Aspinwall, E. (2000), “A conceptual framework for TQM implementation for SMEs”, The TQM Magazine, Vol. 12 No. 1, pp. 31-6.

Zairi, M. (1994), “Benchmarking: the best tool for measuring competitiveness”, Benchmarking for Quality Management & Technology, Vol. 1 No. 1, pp. 11-24.

Zhang B, Kimura F (2006) Network based evaluation framework for EEE to comply with environment regulations. In: Mechatronics and automation, proceedings of the 2006 IEEE international conference, pp 797–802

Zilahy, G., (2004), “Organizational factors determining the implementation of cleaner production measures in the corporate sector”, Journal of Cleaner Production, 12, pp. 311–319.

LIST OF PUBLICATIONS AND PAPERS PRESENTED

ISI Journal Paper

Rahmah Abdulsalam Attallah, Ezutah Udoncy Olugu, and Salwa Hanim Binti Abdul-Rashid, A Comparative Analysis of Electronic Waste Collection Models in Malaysia And Switzerland, journal of resources conservation and recycling **(Submitted)**

ISI proceeding paper.

Rahmah Abdulsalam Attallah, Ezutah Udoncy Olugu, and Salwa Hanim Binti Abdul-Rashid, Framework for the Development of Reverse Logistics Benchmarking Model, 26th IBIMA Conference on 11-12 November 2015 in Madrid, Spain conference proceedings (ISBN: 978-0-9860419-5-2, Published in the USA).

Conference paper

Rahmah Abdulsalam Attallah, Ezutah Udoncy Olugu, and Salwa Hanim Binti Abdul-Rashid, A Review on Reverse Logistics Processes with Respect to Carbon Footprint & Waste Management, 2nd International Conference on Waste Management and Environment (ICWME), 20th-22nd August 2015, University of Malaya, Kuala Lumpur.