ELECTRONIC WASTE: CASE OF MICROWAVE OVENS IN THE UK

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By

Azadeh Dindarian
School of Electrical and Electronic Engineering

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Abstract

Despite the extensive research carried out on waste of electrical and electronic equipment (WEEE) over the past decades, little is known about the quality of electronic products discarded and the extent to which quality affects the decisions to dispose and reuse these products as well as the impact of the current design of products for reuse and remanufacture. This information is fundamental to understand the reasons for the recent unfettered growth in electronic waste, and to propose solutions to address this problem. In this thesis, using a multi-method approach, face to face semi-structured interviews and product fault find surveys, the author investigates and reports the reasons consumers dispose of microwave ovens and the quality of the products, in particular microwave ovens, that are discarded in the United Kingdom as well as recommended design changes to original equipment manufacturers in order to facilitate reuse and increase the lifespan of such products.

By collecting and testing 189 microwave ovens disposed of cosmetic imperfections, as well as electrical and mechanical defects, the results revealed that: (i) a fifth of all microwaves disposed are in perfect working condition and can be reused without any reuse process, (ii) a high percentage of the microwaves discarded have only very minor defects, (iii) almost all microwaves discarded with minor defects can be safely refurbished for re-use, (iv) very few components are responsible for most mechanical and electrical faults, (v) for most microwaves disposed of, the prices of the parts necessary for repair are a very small fraction of the average price of a new microwave.

Using face to face interviews with 82 persons disposing electronic microwaves it was also found that: (i) consumers are largely unaware of alternative routes to send their end-of-life/use functional products other than the public recycling facilities, and (ii) a large proportion of the consumers disposing of microwaves intend to buy a similar product, only partially supporting the widely-held belief that e-waste is driven by a desire for the latest technology.

Based on these results, the author argues that, for microwave ovens disposed in the United Kingdom via household waste recycling centres, the quality of the products discarded is not a serious impediment for reuse, neither are the prices of spare parts. Furthermore, the major factor preventing reuse is the current design of this product, which makes remanufacturing difficult and onerous, as well as the receptiveness of the market for second hand items. Using this information, the author also proposes small changes in design that can significantly improve reusability and, as a consequence, increases the life span of these products.

Declaration

No portion of the work referred to in this dissertation has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Azadeh Dindarian

Copyright Statement

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Glossary

A	Amps
AC	Alternating Currents
BSI	British Standards Institute
CLSC	Closed Loop Supply Chain
DC	Direct Current
DfM	Design for Manufacture
DfX	Design for X
DfE	Design for Enviroment
DfR	Design for Remanufacture/Recycle
DfD	Design for Disassembly
EA	Enviromental Agency
EEE	Electrical and Electronic Equipment
EU	European Union
E-waste	Electronic waste
EoL	End of Life
EPR	Extended Producer Responsibility
HWRC	Household Waste Recycling Center
IT	Information Technology
ISO	International Organisation for Standardisation
kg	Kilogram
OEM	Original Equipment Manufacturer
OECD	Organisation for Economic Co-operation and Development

Polypropylene	PP
Polyamide	PA
PCB	Printed Circuit Board
PVC	Polyvinyl chloride
PAS141	Publicly Available Standard 141
StEP	Initiative for Solving the E-Waste Problem
RoHS Directive	Restriction of Hazardous Substances Directive
V	Volt
VLGM	Viridor Laing Greater Manchester Limited
UK	United Kingdom
USA	United State of America
WAB	Waste Authority Body
WEEE	Waste of Electrical and Electronic Equipment
WEEE Directive	Waste of Electrical and Electronic Equipment Directive

List of Research Output

Published peer reviewed Journal

1. J. Quariguasi-Frota-Neto, Reade A., Dindarian A., A. Gibson."The newly created Publically Available Specification for reuse of used and waste electrical/electronic equipment: Goals, Intermediate Necessary Conditions (INCs) and research needs for successful uptake", *Journal of Manufacturing Technology Management* (under second review)
2. Dindarian, A., A. P. Gibson, and J. Quariguasi-Frota-Neto. "Electronic product returns and potential reuse opportunities: a microwave case study in the United Kingdom", *Journal of Cleaner Production*, Volume 32, Pages 22–31, 2012

Article in the conference proceeding

3. Dindarian A., Andrew Gibson, "Reuse of EEE/WEEE in UK: Review on functionality of EEE/WEEE at the point of disposal", *Sustainable Systems and Technology (ISSST), 2011 IEEE International Symposium on*. IEEE, 2011

Works in progress

4. Dindarian A., A. Reade, A. Gibson, J. Quariguasi-Frota-Neto, “The remanufacturing of washing machines in the UK”, Target Journal: *Journal of Cleaner Production*.

5. Dindarian A., Reade. A., A., A. Gibson, and J. Quariguasi-Frota-Neto, “Impact of warranty on remanufactured product and consumer behaviour towards remanufactured products”, Target Journal: *Journal of Cleaner Production*.

Peer reviewed conferences and workshop presentations

6. Dindarian, A., A.A.P. Gibson, and J. Quariguasi-Frota-Neto, Electronic Waste and Potential Re-use Opportunity in UK: The Case of Microwave Oven, SET for Britain 2012 poster competition, 12 March 2012, House of Common, London, UK
7. Dindarian A., Reuse of EEE/WEEE in the UK: Review on Functionality of EEE/WEEE at the Point of Disposal, StEP E-waste Summer school 2011, 11-22 September 2011, Eindhoven, Antwerp and Davos.
8. Gibson A.A.P., Dindarian A., S. Duffy, Electronic waste and consumer behaviour towards disposal methods, 10th International Electronics Recycling Congress IERC-2011, January 19 – 21, 2011, Salzburg, Austria
9. Dindarian A., S. Duffy, A. A. P Gibson, E-waste: an overview, PGR Poster Conference 2010, 24 November 2010, School of Electricaland Electronic Engineering, The University of Manchester, UK
10. Dindarian A., Electronic Waste - A proposed study to find out what happens to discarded Microwave Ovens, VIII Symposium of Mexican Students, 2nd July 2010, The University of Manchester, UK

To my little Princess

Chapter 1: Introduction

This chapter describes the background of the study that was undertaken in this thesis, and states the driving forces behind the research and the research objectives. The scope and limitations of the research are outlined. Furthermore, the contribution of the thesis is also summarised in this chapter. Moreover, the organisation of this thesis is outlined at the end of this chapter.

1.1 Introduction

Electronic waste or e-waste is one of the fastest growing types of waste in Europe [1], [2].[1] The e-waste is caused by short innovation periods and, consequently, short product life spans [3], [4]. The current volume of e-waste generated worldwide is estimated at between 20 and 50 million tonnes, and is estimated to grow at a rate of 4% per year [5], [6]. In the UK alone, almost one million tonne of e-waste is generated per year [5]. Such unfettered growth in e-waste poses serious threats for humans and the environment because e-waste contains a myriad of toxic substances as well as precious metals such as copper, iron, silver and gold [7]. It is estimated that the UK household produced around 940,000 tonnes of WEEE in 2006/2007 [5]. For example, in 2003, the UK households discarded 644,000 tonnes of large

[1]In this thesis, the terms e-waste, electronic waste and WEEE used synonymously.

household appliances which is equivalent to 14 million discarded units [5]. About 25% of discarded appliances are intended for reuse, being donated or sold as second hand products [8], [9]; the rest is either recycled or sent for incineration or to landfill. But on the other hand, experts have warned that, the UK will run out of landfill sites by 2018 [10].

In the case of microwave oven and its impact on the WEEE generation, for example, Huisman et al., [5] refer to a survey study conducted in the UK which shows that about 2.5 million households planned to purchase a microwave oven in the year 2006/2007 [11]. In addition, this study demonstrates that for microwave ovens alone, the weight of WEEE generated in a typical EU-15 household over 20 years is 39 Kilograms per household, with a typical lifetime of each product being 7 years.[2]

The alarming increase of e-waste and its potential risks to the environment and human health has resulted in the introduction of the European Union Waste Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC) [12]. The European Union's WEEE directive – now law in the UK and across the EU – has set firm targets for the collection, reuse and recycling of electronic goods (see, Section 1.2.3). Moreover, it has been widely emphasised that the sustainable end of life management, reuse and recycling, of the WEEE would reduce the environmental effects of the disposal as well as achieving greater resource efficiency and saving in the raw material [5], [3], [13]. One way to reduce e-waste in the UK and elsewhere is

[2] EU-15 is the number of member countries in the European Union prior 1 May 2004. The EU-15 comprised the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and United Kingdom.

to divert it to reuse, which is organised by reuse organisations [14]. In this thesis, reuse and remanufacture of the WEEE is considered to reduce the amount of generated waste and promote sustainable consumption and also it has social and economic benefits for the communities and charity groups involved; such as creating work space and training for unskilled workers in particular disadvantaged adults, and providing affordable equipments to the poorer families within the community [15], [16], [17].

Reuse of electrical and electronic equipment in particular ICT and large household goods can significantly save material and energy consumption, compared to the manufacturing of new products [18], [19] and it is likely that the interest for used equipment will increase in the future as demand for sustainable manufacturing and consumption increases [15].

This thesis motivated by points raised within the previous paragraphs and intended to provide an in-depth empirical study on the (i) functionality and cosmetic appearance of the discarded microwave ovens at the household waste recycling centres in the UK, as well as the impact of the quality of the disposed microwave ovens on the reuse and remanufacturing, (ii) the reason for disposal and consumer awareness of other disposal options, and based on this study (iii) the recommendation for possible design changes to facilitate reuse and remanufacturing and extend the life span of the product is given to the original equipment manufacturers.

The rest of this chapter is organised as follows. The relevant policies on the waste electrical and electronic equipment are given in Section 1.2. Section 1.3, provides the definition of the reuse and remanufacture of the products that are used throughout this thesis. In Section 1.4, the sustainable end of life management of the products in the context of this thesis is crystalised and the advantages of the remanufacturing to the other end of life management options are given. The motivations of the research are given in Section 1.5. The research objectives and questions are presented in Section 1.6. The scope and limitation of this study are given in Section 1.7. Furthermore, methodologies employed within this study are given in Section 1.8. Section 1.9, discusses the contribution of the research and Section 1.10 provides the structure of this thesis and summarises the six chapters' content.

1.2 Policies on the Waste of Electrical and Electronic Equipment

Waste policies, in particular within the European Union, have been adopted in order to tackle issues that are related to the e-waste, its recovery and disposal routes. The Waste Framework Directive (2008/98/EC), Extended Producer Responsibility (EPR-2001), waste electrical and electronic equipment (WEEE) Directive (2002/96/EC), recast of the WEEE directive (2012/19/EU), Restriction of Hazardous Substances RoHS Directive (2002/96/EC), The Basel Convention (BAN-1989)and Energy-related Products (ErP) Directive (2009/125/EC) are some of the examples of the relevant waste policies. Furthermore, the British Standards Institution Publicly available standard (BSI-PAS141: Re-use of used and waste electrical and electronic equipment (UEEE and WEEE), 2012), recently has been published to promote reuse of e-waste. The following sections give an overview of the regulations and standards that related to the reuse and remanufacturing of the electrical and electronic equipments products.

1.2.1 Waste Framework Directive (2008/98/EC)

The revised European Union Waste Framework Directive (2008/98/EC) came into force in December 2008 with following aim [20]:

> *"This Directive lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use."*

The Waste Framework Directive defines waste hierarchy, i.e., prevention, preparing for re-use; recycling; other recovery, e.g., energy recovery; and disposal, as a priority order within the waste prevention and management legislation as well as a policy alternative to landfill. Within the hierarchy the priority is given to waste prevention and reuse of waste in order to deliver best available environmental outcomes. Thus, reuse of WEEE is supported within this directive. The definitions of prevention and reuse within the directive are as follows [20]:

> *"Prevention: measures taken before a substance, material or product has become waste, that reduce:*
>
> *(a) the quantity of waste, including through the re-use of products or the extension of the life span of products;*
>
> *(b) the adverse impacts of the generated waste on the environment and human health; or*
>
> *(c) the content of harmful substances in materials and products;"*

And,

> *"Reuse: any operation by which products or components that are not waste are used again for the same purpose for which they were conceived."*

1.2.2 Extended Producer Responsibility (EPR)

The Extended Producer Responsibility principle (EPR) was implemented by the European Union Commission regarding the treatment of waste from electric and electronic equipment (WEEE) in 2001 by focusing on the extending producer responsibility beyond the use stage of the products and it is based on the Polluter-Pays Principles [1]. The Organisation for Economic Co-operation and Development (OECD) defines the Extended Producer Responsibility principle as [21]:

> *"...a policy approach under which producers accept significant responsibility - financial and/or physical - for the treatment or disposal of post-consumer products. Assigning such responsibility could provide incentives to prevent wastes at the source, promote product design for the environment and support the achievement of public recycling and materials management goals."*

The four principal goals of EPR, according to the OECD are [21]:

- Source reduction (natural resource conservation/materials conservation).
- Waste prevention.
- Design of more environmentally compatible products.
- Closure of material loops to promote sustainable development.

The EPR extends the producer responsibility from design step, production, through to end of life cycle of EEE product and makes producers responsible for managing the potential environmental effects of their products from the point of sale throughout the product's entire life cycle. Furthermore, EPR promotes eco-design of products such as easy to disassemble; lead free product, design for reuse and design for cost effective recycling [21].

Under EPR principle all producers and retailers must implement systems to allow any end users of the electrical and electronic equipment (EEE) to return the product for recycling at least free of charge and also producers and retailers must finance the cost of collection, treatment, recovery and environmentally sound disposal of all returned items [21], [22]. The OECD suggests following four measures to approach and implement EPR in national policies to allow end users to return the product: Product take back programs, Regulatory approaches, Voluntary industry practices and Economic instruments [21]. Moreover, the WEEE directive (2002/96/EC) and RoHS directive within the European Union are based on the EPR principles.

1.2.3 Waste Electrical and Electronic Equipment (WEEE) Directive

The Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC became European law on 13th February 2003 and came into the force from January 2007 in the UK [23].

Article 1, of the WEEE Directive (2002/96/EC) [24] outlines the objective of the directive as:

> *"... as a first priority, the prevention of waste electrical and electronic equipment (WEEE), and in addition, the reuse, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste. It also seeks to improve the environmental performance of all operators involved in the life cycle of electrical and electronic equipment, e.g. producers, distributors and consumers and in particular those operators directly involved in the treatment of waste electrical and electronic equipment."*

The aim of the WEEE directive is to prevent waste of electrical and electronic equipment and sets; defines targets for collection, treatment, recovery and recycling of waste electrical and electronic products. To achieve these targets, WEEE directive makes wide-range demands on producer responsibility such as financing the collection, treatment and recovery of waste electrical and electronic equipment by obligating distributors to allow consumers to return their waste equipment free of charge [24].

The definition of Electrical and Electronic Equipment (EEE) defined in Article 3 of WEEE directive as:

> *"electrical and electronic equipment' or 'EEE' means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields falling under the categories set out in Annex IA and designed for use with a voltage rating not exceeding 1,000 Volt for alternating current and 1500 Volt for direct current."*

The WEEE Directive (2002/96/EC) has ten categories of electrical and electronic equipment and they are categorised as:

1. Large household appliances (e.g., refrigerators and microwave ovens)
2. Small household appliances (e.g., irons and vacuum cleaners)
3. IT and telecommunications equipment (e.g., computers and printer units)
4. Consumer equipment (e.g., radio and television sets and Hi-fi recorders)
5. Lighting equipment (e.g., fluorescent lamps, low pressure sodium lamps)
6. Electrical and electronic tools with the exception of large-scale stationary industrial tools (e.g., drills and saws)
7. Toys, leisure and sports equipment (e.g., video games and electric trains)
8. Medical devices with the exception of all implanted and infected products (e.g., radiotherapy equipment and cardiology)

9. Monitoring and control instruments (e.g., smoke detectors and heating regulators)
10. Automatic dispensers (e.g., automatic dispensers for solid products and hot drinks).

Article 4. of the WEEE directive enforces the responsibility, including selection of materials and design, disassembly and recovery, on producers for the environmental impact of their products throughout the product life cycle.

> *"Member states shall encourage the design and production of electrical and electronic equipment which take into account and facilitate dismantling and recovery, in particular the re-use and recycling of WEEE, their components and materials."*

The WEEE directive is based on the principle of producer responsibility and it sets a minimum collection target of 4 kg per year per inhabitant for WEEE from private households. However, the target of collection rate have been achieved and regarded as underestimated for some countries such as Germany [5]. Under the WEEE directive, manufacturers will have to recycle some 65 percent of their products and components. Article 6, outlines the requirement for producers to develop systems to treat WEEE using best available treatment, recovery and recycling techniques in accordance with community legislation. Based on the Articles 8 and 9, of the directive the producers of the products are responsible for financing the collection, treatment and sound final disposal of WEEE from both households and non-households for new WEEE.

Articles 5 and 7, of the WEEE directive set two weight-based targets, one for reuse and recycling (without specific targets for reuse) and one for recovery. However, the WEEE directive prioritise reuse before recycling. The target rate varies from 50% to

80% per category of WEEE by average weight of collected appliances. For instance, the recovery rate is set to 80% of the weight of collected appliances and for category one of the WEEE Directive, the reuse/recycling rate is set to 75% of the collected weight of the appliances.

1.2.4 Recast of Waste Electrical and Electronic Equipment Directive

The WEEE Recast or WEEE2 (2012/19/EU) was published on 24 July 2012 and replaced the WEEE directive [25]. It will be effective in the UK early in 2014. The Article 4, refers to the product design and original equipment manufacturers in implementing the design to facilitate reuse and disassembly and recycling according to the framework of Directive 2009/125/EC (ecodesign requirements for energy-related products):

> *"Producers do not prevent, through specific design features or manufacturing processes, WEEE from being re-used"*

Furthermore, Article 6 of the WEEE recast, requires that member states facilitate access to the collected waste by the reuse organisation prior to another sort of recycling in order to increase the reuse rate.

> *"In order to maximise preparing for re-use, member states shall promote that, prior to any further transfer, collection schemes or facilities, as appropriate, provide for the separation at the collection points of WEEE that is to be prepared for re-use from other separately collected WEEE, in particular by granting access for personnel from re-use centers"*

Moreover, the collection target rate has been revised to reflect the realistic collection target of the member of states. However, it does not have a specific target for reuse. According to Article 7 of the recast, from 2016:

> *"... the minimum collection rate will be 45 % calculated on the basis of the total weight of WEEE collected in accordance with Articles 5 and 6 in a given year in the Member State concerned, expressed as a percentage of the average weight of EEE placed on the market in the three preceding years in that Member State. From 2019 the rate will increase to 65% of the average weight of EEE placed on the market in the three preceding years in the Member State concerned, or alternatively 85 % of WEEE generated on the territory of that Member State."*

1.2.5 Restriction of Hazardous Substances (RoHS) Directive

The directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment is commonly known as the RoHS Directive [26]. The RoHS directive is based on EPR principle and in conjunction of the WEEE directive aims at reducing the environmental impact of the electrical and electronic equipment, by restriction on certain quantities of specified hazardous material in certain products.

The UK RoHS regulations came into force on 1 July 2006. The National Weights and Measures Laboratory (NWML) are the enforcement body for RoHS directive in the UK. The RoHS directive focuses on the first step of electrical and electronic equipment (EEE) life cycle chain, the design and material, used in electronic and electrical equipment manufacturing. The objective of the RoHS directive outlined in Article 1 of the RoHS directive [26] as:

"The purpose of this Directive is to approximate the laws of the Member States on the restrictions of the use of hazardous substances in electrical and electronic equipment and to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment."

RoHS directive bans sales and placing the new electrical and electronic equipment containing more than agreed levels of lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB) and polybrominated diphenyl ether (PBDE) flame retardants. For example, agreed level of the mercury used in compact fluorescent lamps must not exceed 5 mg of mercury per lamp on the EU market [26].

Under the Article 3, of the RoHS directive, the directive applies primarily to the following stakeholders: manufacturers of electrical and electronic equipment (EEE), the importers of these goods into the EU; the exporters of these goods to other EU member states; and those who re-brand equipment produced by other manufacturers.

The RoHS directive draws its scope, Article 2, from the WEEE Directive and applies to categories 1-7 and 10 listed under Annex 1A of WEEE Directive plus electric light bulbs and household luminaries [26].

1.2.6 Publicly Available Standard-PAS 141

The British Standards Institution Publicly Available Standard, BSI-PAS141: Re-use of used and waste electrical and electronic equipment (UEEE and WEEE), published on 31st March 2011, for reuse of EEE in the UK [27] and in the long run it is anticipated to be developed into a global standard by the International Organisation for Standardisation (ISO).

The BSI-PAS141 was developed by a diverse steering group of the waste advisory body (WAB) in the United Kingdom, such as manufacturers, recyclers, repair and reuse organisations. It is anticipated that the implementation of a common reuse standard across all industry sectors would provide a minimum standard for reuse of equipments and also create an auditable trail for the environmental agency in the UK. The aims of the BSI-PAS141 are as follows [27]:

- To encourage reuse, to reduce the e-waste, provide a quality benchmark and specification for the reuse of used electrical and electronic equipment and waste electrical and electronic equipment by UK reuse organisations operating in the commercial and third sector,
- To reduce the problem of brand damage caused by the commercialisation of low quality reused products sold,
- To prevent illegal exporting of WEEE deliberately mislabeled as reuse,
- To allow consumers to differentiate products that have been prepared for reuse from those that had not and
- To encourage the creation of jobs in the reuse sector.

The guideline for preparing WEEE for reuse is broken into five separate sections: handling, preparation for reuse, reuse, recycling and operational management. Within each section a series of processes are given. For example, the BSI-PAS141 outlines the process for the preparation for re-use of equipment and components. The processes are as follows. *Visual inspection, Safety, Function, Data eradication and licensing, Disassembly, Original Equipment Manufacturer Warranty, Parts Replacement, Retesting, Cleaning, Classification.*

Under the BSI-PAS141, the organisation that carries out reuse process are obliged to provide a minimum warranty of 28 days for such reuse equipment. The reuse organisations are also required to obtain necessary operational regulations for health and safety, permits, licenses and other specific documents in order to operate under BSI-PAS141. Furthermore, those equipments that are not fit for reuse must be documented and assigned for recycling under the WEEE directive.

1.3 Scope and Definition of Reuse and its Processes

This section focuses on the scope and definition of reuse and the processes that involves in extending of the life span of the products. The remanufacture, refurbish or recondition, repair and upgrade are processes that involve in reuse preparation and consequently to prevent WEEE from extensive recycling [28]. Currently there are many well known definition for the reuse processes. In this thesis, the term reuse is refer to the best available end of life management strategy that has environmental, economical and social advantage over other end of life strategies i.e., recycling and incineretaion. And the term remanufacture is refer to the best available end of life management strategy process as the remanufacturing process that has environmental, economical and social advantage over other end of life process i.e., refurbish and repair furthermore the remanufacturing process is labour intensive and add value to the end product. In order to discuss and explain the research effectively following sections provide the definition of the reuse and remanufacture which are well known and are used within the closed loop supply chain and remanufacturing industry.

Furthermore, in this thesis the term reuse and remanufacture are used interchangeably in order to describe the life span extension of the products.

1.3.1 Reuse

The European Union Waste Framework Directive (2008/98/EC) defines the term reuse as follows [20]:

> *"...any operation by which products or components that are not waste are used again for the same purpose for which they were conceived."*

The term reuse is defined by StEP initiative, reuse task force as [28]:

> *"Reuse of electrical and electronic equipment or its components is to continue the use of it (for the same purpose for which it was conceived) beyond the point at which it specifications fail to meet the requirements of the current owner and the owner has ceased use of the product."*

1.3.2 Remanufacture

Thierry et al., [29] presented one of the early definition and process of remanufacturing, as follows:

> *"The purpose of remanufacturing is to bring used products up to quality standards that are as rigorous as those for new products. Used products are completely disassembled and all modules and parts are extensively inspected. Worn-out or outdated parts and modules are replaced with new ones. Repairable parts and modules are fixed and extensively tested. Approved parts are sub-assembled into modules and subsequently assembled into remanufactured products."*

The term remanufacturing defined by StEP initiative, reuse task force as [28]:

> *"Remanufacturing comprises any action necessary to build up as-new products using components taken from previously used electrical and electronic equipment as well as new components, if applicable. The output product meets the original OEM functionality and reliability specifications. To remanufacture a product requires the complete disassembly of the unit, thorough testing and replacement or reprocessing of all components not meeting these specifications. Depending on the applied components this process may significantly change the unit's composition and design."*

1.4 Sustainable Management of the End of Life of the Products

Remanufacturing is considered as part of the Closed Loop Supply Chains (CLSC) and the importance of remanufacturing within the CLSC is highlighted by the academic and scientific communities as a sustainable end of life option for products (see, e.g., [30], [31], [32], [33]). Guide et al., [34] described Closed Loop Supply Chain as a combination of the forward supply chain process and the reverse supply chain activities. They have identified five activities that constitute a reverse supply chain as: product acquisition, testing, sorting and disposition, refurbishing and remarketing. However, the focus of this thesis is on the product acquisition, testing, sorting and disposition, refurbishing or remanufacturing activities of the reverse supply chain as well as product design that classified within the forward supply chain. Figure 1.1 illustrates the closed loop supply chain including forward and reverse supply chain activities. Furthermore, the activities that this study seeks to explore are highlighted by a dashed black rectangle.

Sundin [35], outlines six remanufacturing process steps: *inspection, disassembly, part replacement/ refurbishment, cleaning, reassembly, and testing*. He suggested that the order of these steps depend on the remanufacturing volume or product type and can be carried out in any order, some steps even omitted to achieve identified remanufacturing goal. From the author's point of experience by visiting two remanufacturing organisations in the UK, a product can go through some steps of remanufacturing several times to achieve a desired remanufactured product.

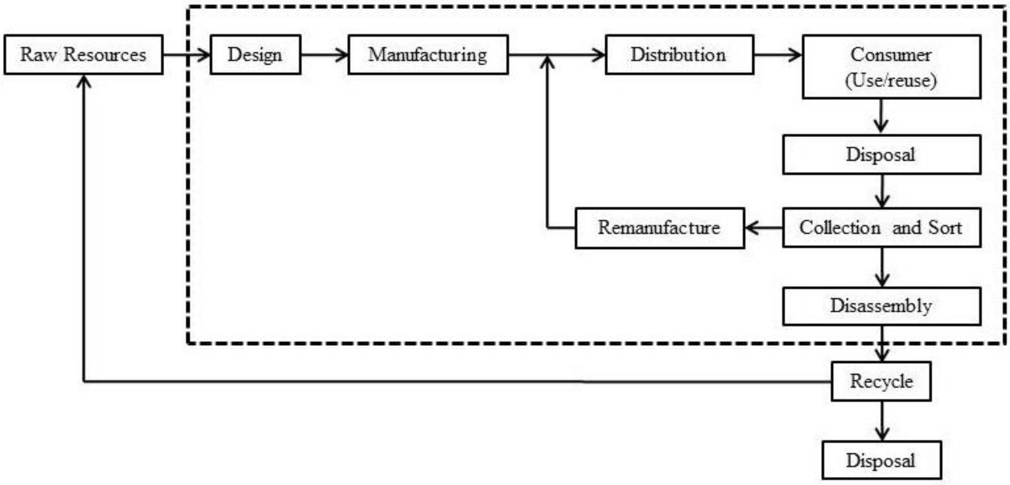

Figure 1.1: A closed loop supply chain diagram (adapted from [36])

Note: The dashed black rectangle represents the focus of this study, that is on the Supply side of the closed supply chain, design, manufacturing, distribution of remanufactured products, use/reuse, disposal, collection and test, disassembly and remanufacture.

1.4.1 Scale and Profitability of Remanufacturing Business

The remanufacturing business is recognised as a profitable business model, it is a US$53 billion industry with direct employment of 480,000 people in the US [37]. Unlike manufacturing a product the remanufacturing solely depends on the returned products which makes the product return management and remanufacturing complex [38]. Study by the Centre for Remanufacturing and Reuse (CRR), indicates that the UK's remanufacturing and reuse industry strong and worth £5 billion per year [39] and employing around 50,000 people in the UK [40]. Furthermore, charities in the UK claim that the market for a refurbished and remanufactured product is increasing [39].

Remanufacturing activities mostly carried out by OEMs (for instance, Xerox, Kodak, General Electric and Caterpillar [41]) or their approved sub-contractors, and small percentages by private and third sector organisations such as social enterprise organisations or charities.

It is noted that within an economically viable remanufacturing business, earning from selling remanufactured products must be higher than other product recovery options such as recycling and reuse [42], [43], [44]. Therefore, the remanufacturing business is in the current economic climate is beneficial to all stakeholders involved within the closed loop supply chain.

1.5 Research Motivation

Research on e-waste has flourished over the past two decades, in the fields of Industrial Ecology, Operational Management, Operational Research, and Waste Management. Most of the research carried out on the quality of the products, however, uses mathematical modelling as the methodological approach, and as a result, calls have been made for more empirically oriented work [45]. Furthermore, there is little information based on empirical data on the quality of the products that are discarded, and the extent to which quality affects the personal and second hand reuse of these products.[3] Moreover, the current design of the ovens that prevents reuse and remanufacturing needs to be investigated. Therefore, this thesis aims to contribute to the knowledge within the domain of waste management and closed loop supply chain by investigating the quality and functionality of the discarded ovens at the point of disposal and design factors that hinders their reuse.

There have been previous studies reported on the condition of a variety of electronic goods and its effect on the profitability and economic feasibility of recovery supply chains. Ravi [46] shows that the quality of computers returned for recycling varies substantially and proposes a system to classify them accordingly. Ferguson et al., [47], using analytical models, shows that quality grading can reduce the overall costs of remanufacturing. The potential of quality grading is also investigated in Guide and Van Wassenhove [48] and Guide et al., [34], also using an analytical approach. Kahhat and Williams [49] is one of the few studies that empirically investigated the quality of returned products for reuse. Unlike the study presented in this thesis, they investigated the quality of the exported personal computers from the United States to Peru. Geyer [50] also investigates reusability, and indirectly, the quality of returned mobile phones, and finds that a high percentage of the mobile phones returned be in good condition and consequently re-directed to the secondary market. However, the remanufacturability potential of the returned products in particular microwave ovens at the HWRCs are greatly missed by academics.

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[3]In this thesis a clear distinction between personal and second hand reuse is introduced to avoid confusion. This thesis refers to second hand reuse when a product changes hands from the user that purchased the new product to a second user that will use the product after it has been either simply purchased, or purchased after re-conditioning or remanufacturing. This thesis refers to personal re-use when the product is fixed at home and remains in the hand of the original owner.

Therefore, this thesis addresses the gap within the literature and empirically investigates the following three relevant questions that have not yet been empirically investigated:

- What are the consumers’ knowledge and behaviours with respect to the functionality and disposal of microwave ovens?
- What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?
- What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?

The overall aim of this research is to augment the understanding of the quality of the discarded products, their potential for reuse and consumer behaviour towards end of life electronic products in particular why consumer disposes their microwave ovens and their awareness of other disposal option for functional units. The focus of this thesis is on the e-waste, in particular microwave oven, disposed by consumers. Because understanding of the quality of the discarded products and the reasons leading to electronic products' end of life is vital to design and implement potential environmental friendly initiatives and furthermore, to increase reuse rate and awareness of their disposal route amongst the consumers and moreover to increase involvement of the OEMs in design for remanufacture.

1.6 Research Objectives and Questions

The primary objective of the research concentrated on the end of life of the electronic products. In particular, microwave ovens in order *to explore and analyse the functionality and quality of the microwave ovens at the point of disposal and its impact on the remanufacturing and reuse.*

The reason for focusing on microwaves was that the simple design and relative simple fault diagnosis techniques as well as ease of transportation of units allow the objective of the research to be achieved.

Using microwave oven case study, the primary objective of the study is translated into the following three research questions (RQ):

RQ1: "*What is the consumers' knowledge and behaviours with respect to the functionality and disposal of microwave ovens?*"

RQ2: "*What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?*"

RQ3: "*What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?*"

1.7 Scope and Limitation

The scope of this study is limited in many ways such as type and variety of products` make and models, type of return, the location of the household waste recycling centre

(HWRC) and the number of the tested ovens as well as the number of the semi-structured interviews.

In this study the makes and model of the ovens were not restricted to the certain available makes and model of ovens on the UK market. In other words, this study investigates the functional and cosmetic imperfection of the all returned ovens regardless of their makes and models at the given proposed research period with limited collected samples at the same time. Furthermore, regarding the tested ovens samples, 189 ovens where empirically tested and 82 face to face semi-structured interviews, due to limited time and resources, were conducted for the purpose of this study.

The focus of this thesis is on the end of life of the electronic products, in particular microwave ovens, which are returned by consumers to the HWRC based on the voluntary return. Therefore, the quality of the returned ovens via other types of return identified by Östlin et al., [51] such as ownership based, service contract, etc. are excluded from this study. The HWRCs in the UK are set up by the local authorities based on the environmental policies and legislation such as extended producer responsibility (EPR) and the WEEE directive. Moreover, the author speculates that the quality and functionality of the disposed microwave ovens collected from three HWRCs within the Greater Manchester area might be influenced by other factors such as socioeconomic factor of the consumers and the type of neighbourhood etc., that particular HWRC is located. The relationship between the usage phase (i.e., how often the unit has been used) and the functionality of the products at the point of disposal are also excluded from this research.

Furthermore, the focus of this research is on the supply side of the closed loop supply chain, more specifically returned products to the HWRCs. However, the author acknowledges that the demand side of the supply chain has a high degree of influence on the supply and incentives for reuse and remanufacture (see, Chapter 5 for more details) and it is excluded from the scope of this thesis. The interested readers of literature on demand and willingness-to-pay (WTP) for reused and refurbished products, are referred to the following literatures, e.g., Guide, Teunter, Van Wassenhove [34], Subramanian and Subramanyam [52] and Quariguasi-Frota-Neto et al., [53]. Moreover, the environmental benefits related to the remanufacturing of the microwave ovens have also been excluded from this thesis.

1.8 Methodology

Due to the nature of the research questions highlighted in Section 1.6, this research study uses an empirically multi-method methodology to answer the research questions. The research strategy employed was case study, which used the case of microwave ovens discarded at the household waste recycling centres in the UK.

Three distinct phases were established in this research study:

- Phase one: assesses consumers' intentions and behaviours with respect to the disposal of microwave ovens,
- Phase two: investigates the quality of, and the costs of remanufacturing, microwave ovens discarded in the United Kingdom, and

- Phase three: proposes design changes intended to increase opportunities for reuse and remanufacturing.

In phase one, 82 semi-structured face to face interviews with the public at the moment they were discarding their microwave ovens were conducted to find out the reasons behind discarding these products and their awareness of other disposal options.

In phase two, an extensive empirical research of 189 equipments being disposed was carried out. Ovens were tested for cosmetic imperfections, as well as mechanical and electrical faults. These products have been tested by technicians and academic researcher in the Microwave and Communications Research Group, School of Electrical and Electronic Engineering at the University of Manchester and at the Longley Lane household waste recycling centre (HWRC) in the Greater Manchester area. The microwave ovens were provided by two distinct sources. First, by Greater Manchester HWRCs operated by Viridor Laing, and second, via charity and social enterprise named CREATE UK (the units were sourced by CREATE UK from two HWRCs within the Greater Manchester).

In phase three, using dismantling survey of three disposed ovens, the potential of the small design changes that may significantly help reuse and remanufacturing and prolongs the life span of the products, in a labouratory environment investigated. The Chapter 4 of this thesis presents the methodologies employed to answer the three research questions.

1.9 Contribution of the Research

Driven by the trend towards sustainable consumption and reduce the generation of the electronic waste, it is now necessary to consider reuse and remanufacturing of e-waste and the impact of the product functionality at the point of disposal, the consumer behaviour and different designs of the individual product, in particular microwave oven, on the product remanufacturability in order to reduce the amount of waste. This area has rarely been studied. This thesis mainly contributes to the current empirical literature on closed loop supply chains that brings together the three related areas in the domain of sustainable consumption such as reuse and remanufacture as follows:

- The consumers' intentions and behaviours with respect to the disposal of microwave ovens.
- The quality of, and the costs of remanufacturing, microwave ovens discarded in the United Kingdom.
- Proposed design changes intended to increase opportunities for reuse and remanufacturing.

It is demonstrated that based on the results, many discarded items are either in perfect working order or have only minor faults, and a high percentage to be candidates for repair or remanufacture. However, the reuse of the discarded ovens can be increased if the current product design integrates the design changes to facilitate reuse and remanufacture. In addition, it is noted that the lack of the market for second hand items is the major pitfall of the reuse and remanufacture. The contributions of this thesis are as follow:

- *Assesses consumers' intentions and behaviours with respect to the disposal of microwave ovens,*

This thesis contributes to the understanding of the consumer intention and behaviour towards disposal of the products, especially functional ovens that are the important factor to achieve sustainable consumption and consequently reuse and remanufacture. The result can aid the stakeholders such as government, local authorities and waste prevention managers to design a network and campaign to increase the awareness of the other disposal option for unwanted functional products among the consumers. Furthermore, it can also assist decision makers to identify functional equipment at the earliest stage possible for instance, by allocating a separate storage area for an unwanted functional product that consumer return to the HWRCs.

- *Investigates the quality of, and the costs of remanufacturing, microwave ovens discarded in the United Kingdom,*

This thesis contributes to the understanding of the quality and factors that influence the remanufacturability of the discarded ovens at the HWRC in the UK. Furthermore, analysis of the empirical data can potentially help stakeholders such as local authorities, waste managers and reuse organisations focus on the ways to reclaim these products, which has great potential for reuse at the earliest possible and divert them to reuse channels and increase the reuse rate of the e-waste. Moreover, these results could help the decision makers at the reuse organisations to expand their reuse activities to include microwave ovens to their product portfolio as a potential remanufacturable product.

- *Proposes design changes intended to increase opportunities for reuse and remanufacturing.*

The design changes to facilitate life extension intended to increase opportunities for longer lifespan and reuse and remanufacturing are proposed to original equipment manufacturers. It is shown that by minor design changes the life extension of the ovens is possible. Furthermore, the empirical results could help and influence governments and decision makers to further support the design for remanufacture within the design stage of the products and to develop and introduce the stronger incentives for OEMs and other players within the field in order to promote reuse and life extension of electronic products from the early stages of the manufacturing.

1.10 Thesis Organisation

The thesis consists of six chapters. Introduction chapter gives the background of the study, the driving forces behind the research, the research objectives and questions. Furthermore, in this chapter the regulation and directives related to the e-waste, reuse and remanufacture which have been addressed in this thesis are reviewed. Moreover, the Chapter 1 highlights the scope and limitations of this study. The contributions of this thesis are also summarised.

The key literature within the domain of reuse and remanufacturing are reviewed and discussed in Chapter 2. The focus of this review is on the following literature streams, the importance of the quality core and barrier to obtain core for remanufacturing, consumer behaviour towards disposal and its impact on the level of the collection of the core and the importance of design for remanufacture in remanufacturing operation as an option for end-of-life of Waste of Electrical and

Electronic Equipment (WEEE). The gap within the literature identified and therefore lays the foundation for the research.

Chapter 3 gives an overview of the history of the microwave oven and provides a deeper knowledge and understanding of the components and technology used within manufacturing of a microwave oven. The overview of the raw materials in the microwave oven, the microwave oven heating technology and operation are described, the description of the various components and their use within an oven as well as the mechanical and the electrical parts are described in this chapter in order to familiarise reader with the technology and performance of the ovens.

Chapter 4 describes the research methodologies and the relation between research questions and the research methods in detail. Furthermore, the required arrangements for semi-structured interview are explained in further detail. The arrangements for testing of the microwave ovens at the household waste recycling centre (HWRC) and the University of Manchester are explained separately. The methodology chapter gives a comprehensive description for microwave oven test procedures, the method employed to answer research question three and the microwave oven disassembly procedures. Finally the data analysis methods which were used in this study are described in this chapter.

Chapter 5 gives the findings of the research questions outlined in Chapter 1. The findings of the research question 1, "*What are the consumers' knowledge and behaviours with respect to the functionality and disposal of microwave ovens?*" the research question 2, "*What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?*" and the findings of the research question 3 "*What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?*" are analysed and discussed in details. This chapter presents the original research findings of this thesis.

Finally, Chapter 6 gives a summary and conclusion of the study. Limitation and contribution of this study are summarised in this Chapter. Furthermore, it suggests the potential future study within the domain of e-waste management and sustainable development for reuse and design for remanufacturing in detail.

1.11 Summary

This chapter described the background of the study that was undertaken in this thesis, and stated the driving forces behind the research and the research objectives. The scope and limitations are crystallised as well as contribution of the thesis is also summarised in this chapter. Following chapter presents the literature review in detail.

Chapter 2: Literature Review

This chapter explains and develops an understanding of the importance of the quality core and barriers to obtain core for remanufacturing in more detail. It also develops an understanding of consumer behaviour towards disposal and its impact on the level of the collection of the core. Furthermore, it develops, based on the extensive and systematic literature review, an understanding of the importance of design for remanufacture in remanufacturing operation as an option for end of life of Waste of Electrical and Electronic Equipment (WEEE).

2.1 Introduction

The literature review on remanufacturing is based upon the relevant literature to the research aims and questions identified in Chapter 1 on extent available reports, journals and conference papers. The available literature covers the research on many issues related to the remanufacturing such as closed loop supply chain (CLSC) and product recovery management, product return type, the importance of remanufacturing, definition and processes of remanufacturing, the importance of the quality of returned items (core[4] [37]) and barriers to core acquisition, consumer intention and behaviour towards product disposal, the market for remanufactured

[4]The core is often used, worn out or broken products and does not have any value for its owner. The term ‘core’ will be used throughout this thesis.

products as well as scale and profitability of remanufacturing business and finally the design for remanufacture (DfRem). Furthermore, the literature covers different type of products for reuse and in particular remanufacturing processes involves for products, e.g., automobile industry part remanufacturing [54], domestic appliances [35], IT equipment [55], mobile phones [56], [57] and Xerox Photocopiers [58].

Based on the aims of this thesis (see, Chapter 1) the extensive and systematic literature review carried out to provide an in depth understanding of the background of the subject. The literature on the importance of the quality of core and barriers to acquisition are reviewed in detail and how it relates to successful remanufacturing business and remanufacturing process is discussed. Furthermore, the literature on the consumer intention and behaviour towards product disposal within the previous studies were evaluated in order to map consumer attitudes and behaviour towards disposal of WEEE. Finally, reviews the literature on the design for remanufacture (DfRem) were carried out in order to support the proposed design changes intended to increase opportunities for reuse and remanufacturing. Furthermore, Table 2.2 gives an aid to the highlighted issues and related literature as well as references that are listed in this chapter.

The organisation of the rest of this chapter is as follows. Section 2.2 presents literature on the importance of remanufacturing and the quality of returned items (core) and discusses the factors that determine successful remanufacturing in detail. Section 2.3 gives an overview and discusses the barriers to core acquisition within the industry.

The literature on the consumer intention and behaviour towards product disposal are covered in Section 2.4. Section 2.5 gives an in depth review of literature on the design for remanufacture (Dram) and available models and tools for Dram in order to uncover benefits of Dram for remanufacturing process. Finally, Section 2.6 summarises the chapter and the gaps that this thesis sets to address.

2.2 The Importance of Remanufacturing and Quality Core

Over the last decades, remanufacturing has become an important part of the reverse supply chain and in some cases profitable business, as the cost of the refurbishing and remanufacturing of core is only a fraction of the manufacturing of the new products. Following four advantages have been identified within the literature for Original Equipment Manufacturers (OEMs) that include remanufacturing processes within their business plan. Firstly, remanufacturing can increase both profit margins and sales of OEMs, reduce production cost and protect aftermarket [50], [59], [60], [61] by including remanufacturing strategy within the business strategies. Secondly, it can be beneficial for the environment [51] by reducing the use of raw materials and saving energy required to manufacture new products. Thirdly, in some cases it can help OEMs to comply with environmental legislation such as WEEE directive as well as preempting regulations [61] that imposed to OEMs by governments. Fourthly, the remanufacturing can be used as a strategy by OEMs to create a green image of their business and products [62] as well as a response to consumer demand for sustainable products [61] and consequently play a lead role in the market.

However, given the benefits and impacts of the remanufacturing business there are several factors influencing the success of the remanufacturing business. For example the quality of core is fundamental to successful remanufacturing process and it varies significantly, affecting the cost of remanufacturing [63]. Furthermore, the lack of available quality core and the difficulty to obtain such product are identified as one of the barrier for successful remanufacturing business [61], [64].

Previous studies have discussed the importance of quality core acquisition and stability of the flow of the core for the purpose of the remanufacturing within the closed loop supply chain (e.g., see, [17], [38], [48], [51], [65], [66]). The following sub-sections provide an in depth review of the literature surrounding the uncertainty of the quality, source, cost and classification of the core.

2.2.1 The Quality Core Uncertainty

One of the challenges that remanufacturers are facing is the uncertainty of the quality of the acquired cores for remanufacturing. Furthermore, the efficiency of the remanufacturing is undermined by uncertainty of quality core and it has influence on the profitability of remanufacturing [67], [68]. On the other hand, the uncertainty of the quality of the returned products has a huge impact on cores' end-of-life management [68]. Teunter and Flapper [63] presented a decision-making model on uncertainty of the quality of the core. In their model they address situations where core quality affects the acquisition and remanufacturing decisions and they analysed the situation where multiple (more than two) quality classes of cores are available for remanufacturing. Teunter and Flapper further [63], using numerical experiment and modelling techniques further show that the associated cost with remanufacturing is highly dependent on the quality of cores. Therefore, knowing the quality of the core in advance is important for remanufacturing.

2.2.2 The Source of Core

Östlin et al., [38] identified seven relationships for collecting core for the purpose of remanufacturing and discussed the difficulties as well as the costs of obtaining core across the seven types of the identified relationships between manufacturers/remanufacturers and users. The identified relationships are as follows: *ownership-based, service-contract, direct-order, deposit-based, credit-based, buy-back and voluntary-based relationships.* According to Guide and Van Wassenhove [48] quality and stability of the core depend on the source of acquisition of core. A study by O'Connell, Fitzpatrick and Hickey [69] on the potential for reuse of WEEE from various sources in Ireland found that the white goods sourced from retailers had a larger portion of appliances with potential for reuse compared to other sources, i.e., civic amenity sites (HWRCs) and kerbside collections.

In the literature, approaches to quality core acquisition are linked to the product recovery channels. For example, the functional sale or Product Service Systems (PSS) known as the best option to receive core with the advantage of knowing the time of return and the quality of core in advance and allowing better inventory control at the remanufacturing facility [62]. Thierry et al. [29] refer to PSS advantages to other recovery options as *"companies that lease their products are generally in a more favourable position than companies that only sell products.*

Lease companies usually have more information on the quality and return of used products".

The basis for the PSS is that the seller or OEM owns the product and the costumer only pays for the number of use of the product, i.e., the case of Xerox photocopier machine [58] and washing machine [62], and that the product is given back to the seller after the use period which is leased for and OEMs would benefit from information on the performance of the product throughout its life cycle, in particular during use phase, to improve the design of the product and increase the chance of remanufacturing of that product [62], [70]. Furthermore, Sundin and Bras [62] conclude that PSS practice is both environmentally and economically beneficial once combined with remanufacturing of products.

However, the focus of this thesis is only on the voluntary-based relationships, which is enforced by legislation such as the WEEE directive, and the quality of core [38] within this relationship, where cores are acquired from household waste recycling centres. In a situation where consumers return their unwanted cores to the designated collection centres voluntarily, these infrastructures are set up by local authorities in compliance with the WEEE directive and extended producer responsibility (EPR).

A recent study by WRAP [71], a UK based organisation for recycling, on the WEEE disposed at the HWRCs and via local authorities bulky waste collections in the UK suggest that the quality of the disposed items is relatively high via these routes that can be diverted to reuse market. However, the study is mainly focused on the white household goods except microwave ovens and does not empirically investigate the cause of the product disposal and furthermore does not suggest the design changes accordingly.

A survey of the literatures has shown that despite the importance of the voluntary-based return, there has been, limited number of previous academic studies that empirically investigated the quality of the voluntary returned products which are sourced from the household waste recycling centres in the UK and their potential for remanufacturing, in particular microwave ovens in details.

2.2.3 The Price of Core

The price of the acquired core is highly dependent on the quantity and quality of the acquired core [34], [72]. In addition, the price of the core is also dependent on the available information regarding the quality of the product from the seller [73]. Guide et al., [34] further developed a simple framework for determining the optimal prices and the corresponding profitability based on the quantity, quality and timing of the returned products within the buyback system.

Liang et al., [73] proposed a model to evaluate the acquisition price of cores based on the manufacturing costs and sale price of remanufactured products. Therefore, knowing the quality of available core from different sources is fundamental to core price and consequently successful remanufacturing business.

2.2.4 The Classification of Core

Once the core is acquired, it is important to decide which available core is suitable for reuse and remanufacturing [74], [75]. Furthermore, the classification of return products based on the quality of products pointed out in previous literature. For example, Ravi [46] proposed a system to classify the quality of return computers for recycling in order to increase eco-efficiency and quality of recycled end of life computers. The importance of the quality and suitable core for remanufacturing further emphasised by Kerr and Ryan [58] using a case study of Xerox photocopier machine.

White et al., [65] described the core quality as an important factor when it has to be decided whether the core is suitable for remanufacturing or part extraction. The quality of core and quality grading in remanufacturing are suggested by previous studies to be included within the remanufacturing business model design, e.g., potential of quality grading in remanufacturing and its advantages investigated by Guide et al., [34] and Guide and Van Wassenhove [48]. Furthermore, the value of quality grading in remanufacturing investigated using numerical study by Ferguson et al., [47] they concluded that a quality grading system in their case study resulted in increase of profit by 4% compared to the case where quality grading is not included within the remanufacturing business.

The literature review presented in the previous paragraphs, has identified following. First, the discussion so far within the literature has been about the importance and the uncertainty of the quality core for acquisition that remanufacturers are facing. Second the empirical data on the quality and functionality of the core is scarce which are fundamental to successful remanufacturing business. One of the aims of this study is to contribute to this field of study by investigating the quality and functionality of disposed microwave ovens at the household waste recycling centres in the UK and their impact on the remanufacturing, from remanufacturing point of view that in many cases in author's knowledge are still not known or understood.

2.3 Barriers to Core Acquisition

The main issue, which remanufacturers are currently facing, is the barrier in obtaining cores particularly to remanufacture electrical and electronic products which consequently have a huge impact on the remanufacturing and reuse rate. It has been noted that limited access to the core can create an inefficiency within remanufacturing business [66]. There are quite a few studies which have analysed the major barriers to core acquisition to remanufacture. Following four barriers have been identified within the previous literatures. First the competition between OEMs and third party remanufacturers to obtain core, second the current global, country and local specific environmental legislations, which prevent core acquisition, third lack of government incentives to core acquisition and finally the specific product design.

It has been pointed out that private and third party remanufacturers are often find themselves in competition with OEMs to obtain high quality core to remanufacture in order to fulfil their consumer demand [60], [76], [77].

Current WEEE directive implemented in the UK is described by an independent remanufacturer as a legislation, which resulted in increase of competition between recyclers and remanufacturers to obtain available cores to process [76]. In a recent study by Kissling et al. [64], they have also confirmed that "*re-use organisations often need to directly compete with recyclers for EEE, which has a potential for re-use*.". Furthermore, international regulation such as transboundary movements of used EEE described as an administrative cost to the reuse organisation, for example, in some cases, the cost of remanufacturing process, in particular labour, is high in developed countries and it is more economical to ship core to the developing countries to be remanufactured [64].

Subramoniam et al., [43] report current legislations such as WEEE Directive, RoHS and EPR; can act as drivers and barriers to remanufacture. Furthermore, country specific legislations can act as a barrier to core acquisition for example, the regulation in Brazil that prevents the import of used automotive parts. This regulation resulted in limited availability of parts for remanufacturing in Brazil [43].

The lack of government incentives for collection and disposal of products pointed out by Subramoniam et al., [43], as well as "Lack of legislation that sets incentives for re-use and enforces re-use" [64] as barrier for core acquisition to remanufacture. Furthermore, a weak government legislation on remanufacturing in India is identified as a barrier to growth in remanufacturing industry by Mondal and Mukherjee [78].

The product design is also known as a barrier to core acquisition [79], [80]. In this case only OEMs have the knowledge and the expertise of their own product design and sometimes the spare part for remanufacturing are not available for third party remanufacturers [15]. For example, Lexmark new printers and inks are operating with a fitted computer chip which communicate via a software that only Lexmark owns the copyright [81]. This prevents remanufacturers from collecting the products for the purpose of remanufacturing.

2.4 Consumer Intention and Behaviour towards Disposal

Consumer behaviour towards product disposal and their reason for disposal at the household waste recycling centres as recovery channel of WEEE is one of the important subjects yet to be investigated and literature covering this issue is scarce. Previous literature on consumer attitudes towards disposal or recycling in general covers the antecedents of disposal behaviour that is, factors that influence the decision of the owner whether to keep, donate, sell, dispose of, or recycle a product, for example, see, reference [82], [83], [84], [85]. The following sections provide an in depth review of the factors influencing disposal behaviour, consumers' reasons for product disposal, the incentives that influence on the consumers' disposal behaviour.

2.4.1 Factors Influencing Disposal Behaviour

The effect of demographic characteristics such as age and income on disposal behaviour and disposal channels in general are investigated by Bayrus [82], and Harell and McConocha [83] respectively.

The importance of socio-economic factors in recycling behaviour of consumers and its impact on quantities of general waste produced are investigated by Emery et al., [84]. However, recent study by Saphores et al., [86] indicates that *"socio-demographic characteristics play a minor role in e-waste recycling behaviour",* but on the other hand *"moral norms, toxicity knowledge, and recycling at work/school foster e-waste recycling; and moral norms, beliefs, and convenience increase willingness to recycle e-waste*."

Based on 67 empirical case studies, Hornik et al., [87] concluded that the strongest predictors of recycling behaviour by consumers are *"internal facilitators specifically, consumer knowledge and commitment to recycling as well as external incentives e.g. monetary rewards and social influence".* Furthermore, the findings of a study by Tonglet, Philips and Read [88] suggest that pro-recycling attitudes as well as previous recycling experience, and a concern for the community and the consequences of recycling are the major contributor to the recycling behaviour.

Disposal behaviour and disposal options of children's items by their mothers investigated by Sego [85], the author has identified five disposal options as follows *"thrown away, storage, give away, donate and sell"*. The study also found that mother's choice of identifying disposal channels is dependent to the personal meaning of such item which consumer attach to. Furthermore, Sego [85] concludes that *"disposal can be a challenging task for consumers as they manage the emotional issues associated with objects and the social dimensions of disposal channels."*

Mugee et al., [89] studied consumers' post-purchase behaviour by exploring, factors that influencing disposal decisions of products by consumers. The factors are as follows. The experience of attachment to a product, utility and appearance of the product over time.

Hibbert et al., [90] examined the consumer disposal behaviour in terms of the challenges that charities are facing to overcome stock flow in the UK. Their results from the household survey identified following reasons for disposal: *clearing up/clearing out, purchase of new/replacement goods, a request for goods, home decorating, moving home and bereavement*. Furthermore, they call for more research on consumer disposal behaviours and why they choose to use one channel of disposal against others. A study by Robinson and Read [91], using face to face interview of up to 11,000 residence within the London borough of Kensigton and Chelsea, found that the lack of awareness of other available recycling option among consumers impact their behaviour and attitude towards disposal and recycling. Their analyses show that the majority of respondents were unaware of recycling services such as kerbside collection and HWRC sites, offered by local authorities in the bourogh. They suggest an on-going process of awareness campaign and further academic research on this subject.

2.4.2 Consumer Behaviour on WEEE Disposal

To date, only a handful of scholars' articles have explored the consumer behaviour towards disposal of waste of electrical and electronic equipment. A study on the disposal behaviour of the Chinese households whom dispose of obsolete electrical and electronic equipment, have found that majority of the electrical and electronic equipments are sold to street collectors or as second hand appliances in the reuse market [92]. Furthermore, their analysis show that the price paid by street collectors for functional equipments are higher than those broken items.

Darby and Obara [93] assessed consumer behaviour towards disposal of small WEEE such as electric toothbrushes and electric toys in the UK. They found that a higher percentage of consumers whom they surveyed, disposed their small WEEE via household refuse collections (wheelie bins) and they did not have knowledge about other disposal options. Furthermore, the *"lack of information regarding consumer attitudes to WEEE and especially small WEEE"* identified by Darby and Obara [93]. They call for more research on this domain. Yet another study by Cooper and Mayer [9], investigated the consumer attitude towards purchase, use and disposal of household appliances in the UK (E-SCOPE study), they concluded that *"householders wanted better information on how to dispose of appliances safely."*

A study by Saphores et al., [86] about the consumer disposal behaviour and e-waste recycling at the drop-off centres (HWRCs) using survey, concluded that only one-third of respondents have recycled e-waste before, and three quarters of them are either "willing" or "very willing to do so". The willingness of Nigerian consumers to participate in a mobile phone recycling scheme is investigated by Nnorom et al., [94] they have found that nearly 65% of their respondents are either "willing" or "very willing" to drop-off electronic waste at a nearby recycling facility. The findings of the above studies indicate that consumer willingness to recycle would benefit from increased awareness of other disposal options such as reuse, remanufacturing and recycling.

2.4.3 Reason for Disposal of Products

To the author`s knowledge, only a limited published studies have highlighted indirectly the reasons for disposal of products, in particular electronic and electrical products. The reasons are as follows.

First, the rapid technological advances and increased market penetration of cheap electronics equipments, in particular IT and communication equipment [95], [6] and Television and related equipments [96].

Second, product functional obsolescence and shorter life span of the products [3], [97] that is also known as planned obsolescence (see Section 2.5.4). For instance, the life span of the CPUs is decreased from 4–6 years in 1997 to 2 years in 2005 [98] cited by [1].

And finally, *"the physically broken* "cited as the most common reason for mobile phone replacement among Chinese students [99].

2.4.4 Incentives that Influence the Consumer Disposal Behaviour

In general the financial incentives such as buy back and deposit-refund systems as well as correct amount offered to consumers are among the suggestions given by academia in order to influence consumer disposal behaviour and to increase the collection rate of the used products [86], [100], [101]. The convenience of use of the collection service such as distance and easy access to the collection sites are among the incentives to influence consumer disposal decision and willingness to participate in recycling [94], [102], [103], [104].

The importance of the incentives such as financial and convenience to return mobile phones by consumers are highlighted in a survey study by Ongondo and Williams [105]. Yet another study by Ongondo and Williams [102] on students' willingness to take part in mobile phone take back services found that *"monetary incentives such as cash payments and vouchers have the greatest influence over students' willingness to utilise take back services, followed by convenience and ease of use of the services".*

In summary, these issues highlight the importance of the consumer behaviour towards the disposal of electronic goods at the UK household waste recycling centres and reasons for disposing i.e., in the case of functional product. As well as, the level of awareness of other disposal options such as donating to charities for the purpose of reuse and remanufacturing for functional equipment. However, the available literature on above issues are in author`s knowledge are limited. This thesis addresses this gap in the literature by studying the consumer behaviour towards the disposal of functional electronic products at the HWRCs, more specifically, microwave ovens and its impact on the remanufacturing.

2.5 Design for Remanufacture (DfRem)

Design for remanufacture (DfRem) has been centre of the attention of many previous research studies, nevertheless the relationship between remanufacturing efficiency and product design has been recognised by academics [33]. However, as explained by Ijomah and Danis [15], the design changes to facilitate DfRem would be costly in terms of the product price, but it would lead to long term profitability for the OEMs once the cost of the waste disposal and other environmental legislation are considered.

Within the literature several definitions have been identified for DfRem, for example a well-known definition for DfRem by Charter and Grey [106] is:

> *"...a combination of design processes whereby an item is designed to facilitate remanufacture."*

And recently Design for Remanufacture (DfRem) is identified by Hatcher, Ijomah and Windmill [33], as:

> *"...a way to improve remanufacturing efficiency and may increase the profitability of remanufacture, making it more viable and lucrative product end-of-life strategy."*

The following subsection provides literature review on the DfRem from engineering and product design point of view, design to disassemble and development of design methods and tools for DfRem in order to understand the importance of DfRem and its impact on the reuse and remanufacture.

2.5.1 The Importance of Design for Remanufacture (DfRem)

The product or component remanufacturing steps such as inspection, disassembly, part replacement/refurbishment, cleaning, reassembly, and testing are highly dependent on the design of such product or component. Within the literature, the concept of design for "X" (DfX) is introduced. Where "X" can be i.e., remanufacturing (DfRem) [35], [33], environment (DfE) or recycle (DfR) [33]. Sundin [35], stated that DfRem could be seen as part of the design for environment (DfE). Furthermore, a series of design strategies that support reuse and remanufacturing are identified by Charter and Gray [106] such as design for disassembly, design for an upgrade, design for multiple lifestyle.

From perspective of the remanufacturing, it is important to tackle design issues early within the design stage of the products to maximise product remanufacturability and subsequently reduce the cost of remanufacturing and increase the profitability of the process [58], [60], [33], [107].

The environmental benefits of the DfRem are highlighted in [108], [109]. An earlier study [110] on remanufacturing concludes that environmental legislation has an impact on product design and end of life decisions. Furthermore, the manufacturers believe that adopting the environmental legislations within the product design is an opportunity to increase the sale of environmentally friendly products.

A study by Shu and Flowers [111] shows that sometimes manufacturing assembly design does not facilitate ease to remanufacture and disassemble, therefore, they are in direct conflict. On the other hand, more standardised and modularised use of components within manufacturing of a new product could increase the possibilities to cannibalise components for remanufacturing and reuse [51]. However, the OEMs can design products to reduce the interchangeability of components within the products thus consequently it increases the cost to remanufacture [79]. On the other hand the OEMs can benefit from design for remanufacture. For example, within the *'product-*

service system', which introduced by Sundin et al., [112]. They believe that product-service system will create incentives for OEMs to design a product, which is eco-efficient to remanufacture thus result in increase of profit margin.

The relationship between product design characteristics and the activities of the remanufacturing was investigated by Ijomah et al., [107] involving design and manufacturing engineers from academia and industry in the workshop settings. From the findings of the case studies and available literatures they highlighted the key design features that hinder remanufacturability such as material, assembly technique and product structure (dimension, internal arrangement, external features) against remanufacturing process activity.

Hatcher, Ijomah and Windmill [113], using case studies of three OEMs from the UK mechanical/electromechanical industry sector, investigated the internal and external operational factors, that influence the successful integration of 'design for remanufacture' into a company design process. They found that the operational factors such as design priorities, OEM-remanufacturer`s relationships, designer motivation and the design process were the most significant to influence the DfRem strategy within the design process of the manufacturers. The importance of the product design guidelines and engagement of products designer is highlighted by Subramoniam, Huisingh and Chinnam [114] in order to increase product remanufacturability.

2.5.2 Design to Disassemble

One of the aspects of the DfRem is ease to disassemble of the products. The disassembly of the products is highly dependent on the choices of fastening and joining methods [115]. Shu and Flowers [111] developed a framework that evaluates the effectiveness and cost of joint design of product at the end of life option. Furthermore, they outlined a guideline based on the literature and collaborating with remanufacturers, for designers of the products based on the remanufacturing process to facilitate ease of remanufacturing. For instance, for disassembly process; they suggested using standard fastener in order to reduce disassembly time.

Using a case study, Amezquita et al., [116] investigated the remanufacturability and improvement of an automotive door assembly. Based on the disassembly and assembly of the product they proposed design change which increases the remanufacturability of the automobile door (e.g., choice of joints that are easy to disassemble).

2.5.3 Methods and Tools for DfRem

Many academics have developed methods and tools to support DfRem and argue that it will provide design indicators for product designers. The metrics for assessing the remanufacturability of a product based on the DfRemmetrics is introduced by Hammond and Bras [117]. From the product designer's point of view, the results of Design for Remanufacturing metrics are essential to provide a relatively efficient and effective means of feedback to design a product with integrated remanufacturability features [117].

Furthermore, the well-known study “RemPro-Matrix” is introduced by Sundin [35] (see, Table 2.1). This is a series of tasks in conjunction with remanufacturing steps i.e., inspection, cleaning, etc., for designing a product to achieve highest possible remanufacturability based on the product properties, i.e., ease of identification, ease of access, etc., and it can be used as a design tool by designers. The “RemPro-Matrix” can be used in, for example, disassembly phase. In this case, the product parts should be easy to be identified, to access, to handle, to separate and and easy to stock [35]. The “RemPro-Matrix” is used in this thesis as a tool to recommend design changes in order to facilitate reuse and remanufacturing of the microwave oven in Chapter 5 of this thesis.

Moreover, Hatcher et al., [33] concluded that all of the DfRem tools are developed based on remanufacturers experience in the process of product remanufacturing, and these might be in conflict with product design and manufacturing process. Furthermore, they call for close collaboration between designers and academic to implement these methods and tools within the real product design and manufacturing process. Hatcher et al., [33] urged the need for more case studies of different products for remanufacturing.

Table 2.1: The RemPro-matrix is showing the relationship between the preferable product properties and the generic remanufacturing process steps [35].

Product Property \ Remanufacturing Step	Inspection	Cleaning	Disassembly	Storage	Reprocess	Reassembly	Testing
Ease of Identification	x		x	x			x
Ease of Verification	x						
Ease of Access	x	x	x		x		x
Ease of Handling			x	x	x	x	
Ease of Separation			x		x		
Ease of Securing						x	
Ease of Alignment						x	
Ease of Stacking				x			
Wear Resistance		x	x		x	x	

2.5.4 Design of Durable product and its Impact on the Remanufacturing

Life extension or remanufacturing of the products is also depends on the durability of the products and the way they are designed. The durability of the products and life extension of the products has an impact on the sustainable consumption and increase efficiency of the available resources [118], [119] cited by [120]. However, despite the acknowledgment by the academia and environmentalist the research on the theme of the durability and life extension of the products is limited [120], [121]. In a study, Cooper [120] has proposed a preliminary model to demonstrate that sustainable consumption requires increased product life spans.

The reliability and durability of the products depend on the quality of the internal parts or components as well as shape and surface or external parts [121]. For example, the design of a product with less durable material such as plastic would result in decreasing their durability and remanufacturability of that product [107]. A study by WRAP [122] on a brand new microwave oven, identified the key opportunities to benefit microwave oven design in general form. For instance, it suggests "*modify the design to improve durability of components with the potential to fail".* It further gives an example of the complexity and weaknesses in the door release mechanism could lead to product returns and design change to the assembly of light bulb within the oven to provide more robust and easier access.

A study by Cooper and Mayers [9] on the opinion of the study participants regarding the durability of the products found that the product durability, in particular of small appliances, is low compared to the past. Furthermore the following common comments were stated by participants *"I think things have changed. I think they are made more disposable these days…Things used to last a lot longer*" [9]. This is called planned obsolescence of the products. Planned obsolescence is a term used to explain situation where *" a design plan that is intended to hasten existing products to become undesirable (not necessarily below that of competitive offerings) either functionally or psychologically and consequently to be replaced by new products"* [123].

Sundin [35] suggested that in order to avoid obsolescence, the products must be designed for easy upgrade with new technology in the remanufacturing process. Furthermore, increased life span of products by designing products to be durable and avoid planned obsolescence is essential to decrease the negative enviromantal imact of end of life of products [120]. On the other hand, Fishman, Gandal and Shy [124] show that *"planned obsolescence may be a necessary condition for the achievement* *of technological progress and that a pattern of rapidly deteriorating products and fast innovation may be preferred to long-lasting products and slow innovation".*

In summary, the survey of the literatures has shown that the focus of the previous literatures is on the DfRem of the other products except the microwave oven. In addition the previous literatures do not provide design change recommendation based on the failure mode or cosmetic imperfection of the disposed products in particular microwave oven. For example, Williams and Shu [125], carried out an empirical research on toner-cartridge remanufacturing industry, they quantified the amount of products (parts) discarded (as opposed to reused) and categorised design issues that were not in favour of the remanufacturing. Their study with empirical findings show the main design reasons for part discard and highlight areas in toner-cartridge design that are problematic for remanufacture. However, unlike this work they did not provide recommendations on design changes to facilitate remanufacturing and extend the end of life option. This is a gap that this study aims to close. Furthermore, Sundin, Lindahl and Ijomah [126] call for further research on the product data during use in order *to improve products' different life stages*.

2.6 Summary

The purpose of this chapter was to explain the importance of quality core and barriers to obtain core for remanufacturing in detail, and develops an understanding of the consumer behaviour towards disposal and the importance of design for remanufacture within the remanufacturing operation based on previous literature.

Several issues highlighted in the literature informed the subject of this study, Table 2.2 gives an aid to the highlighted issues and related literature as well as references that are listed in this chapter.

This chapter is divided into five sections according to the relevant available literature and research questions. Section 2.2 and Section 2.3 presented literature on the importance of the quality of returned items (core) and barriers to acquisition respectively. The literature on the consumer intention and behaviour towards product disposal are covered in Section 2.4. An in depth review of literature on the design for remanufacture (DfRem) and available models and tools for DfRem are given in Section 2.5.

The following gaps are identified within the literature that this study aims to close. The aim of this study is to contribute to the body of the literature by investigating and answering research questions that are given in Chapter 1 of this thesis. To the best of the author's knowledge, however, no empirical study has examined the potential and the opportunity to reuse and remanufacturing of recovered products based on the voluntary return, e.g., microwave ovens returned to the household waste recycling centres in the UK. Furthermore, there is no previous literature investigating the functional and cosmetic quality level of returned microwaves at the point of disposal and how it can affect the remanufacturing process.

The literature on consumer behaviour towards the disposal of electronic goods and reason for disposing, i.e., in the case of functional product, more specifically, microwave ovens and its impact on the remanufacturing is scarce. Furthermore, the level of awareness of other disposal option in the author‘s knowledge is limited.

Moreover, previous studies [90], [91], [93] call for further empirical study of consumer behaviour towards available disposal options.

Previous literature does not provide design change recommendation based on failure mode or cosmetic imperfection of disposed products in particular microwave ovens. This study aims to identify the design issues that hinder the remanufacturing of the microwave ovens and consequently to propose design changes intended to increase opportunities for reuse and remanufacturing. Moreover, the previous literature [33], urged the need for more case studies of different products from the design point of view to facilitate remanufacturing.

In contrast, based on the literature review presented in previous sections, gaps are identified and the aim of this study is to contribute to the following fields of study by focusing on a specific product, the microwave oven. Following Chapter, presents the microwave oven technology in details.

Table 2.2: The literature review of remanufacturing covered in this Chapter

Remanufacturing theme literature	References
2.1 Introduction	[35], [37], [54], [55], [56], [57], [58]
2.2 The Importance of Remanufacturing and Quality Core	[17], [38], [48], [50], [51], [59], [60], [61], [62], [63], [64], [65], [66]
2.2.1 The Quality Core Uncertainty	[63], [67], [68]
2.2.2 The Source of Core	[29], [38], [48],[58], [62], [69], [70]. [71]
2.2.3 The Price of Core	[34], [72], [73]
2.2.4 The Classification of Core	[34], [46], [47], [48], [58], [65], [74], [75]
2.3 Barriers to Core Acquisition	[15],[43],[60], [64], [66], [76], [77], [78], [79], [80], [81]
2.4 Consumer Intention and Behaviour towards Disposal	[82], [83], [84], [85]
2.4.1 Factors Influencing Disposal Behaviour	[82], [83], [84], [86], [87], [88], [89], [90], [91]
2.4.2 Consumer Behaviour on WEEE Disposal	[9], [86], [92], [93], [94]
2.4.3 Reason for Disposal of Products	[1], [3], [6], [95], [96], [97], [98], [99]
2.4.4 Incentives that Influence the Consumer Disposal Behaviour	[86], [94], [100], [101], [102], [103], [104], [105]
2.5 Design for Remanufacture (DfRem)	[15], [33], [106]
2.5.1 The Importance of Design for Remanufacture (DfRem)	[33], [35], [51], [58], [60], [79], [106], [107], [108], [109], [110], [111], [112], [113], [114]
2.5.2 Design to Disassemble	[115], [111], [116]
2.5.3 Methods and Tools for DfRem	[33], [35], [117]
2.5.4 Design of Durable product and its Impact on the Remanufacturing	[9], [35], [107], [118], [119], [120], [121], [122], [123], [124], [125], [126]

Chapter 3: Microwave Oven Technology

This chapter gives an overview of the history of the microwave oven and provides a deeper knowledge and understanding of the components and technology used within manufacturing of a microwave oven. Section 3.1 describes the history and development of the microwave ovens with a detailed explanation of their performance. Section 3.2 gives an overview of the raw materials in a microwave oven. The question of "How does a microwave oven operate?" is answered in Section 3.3. Furthermore, Section 3.4 gives the description of the various components and their use within an oven. Moreover, the mechanical and the electrical parts are explained briefly. Section 3.5 summarises the history and technologies of the microwave ovens.

3.1 History of the Microwave oven

The microwave heating effect was found out accidentally by Dr. Percy LeBaron Spencer during World War II radar research using a magnetron [127]. The first microwave oven was produced and patented by the Raytheon Corporation in 1946 [128]. Early microwave ovens were as big as a refrigerator and cost up to $5000, however, by 1975 due to technological advances and further developments the microwave ovens become smaller and less expensive which, resulted in increase of sale and acceptance within the household [128], [129]. The early version of a microwave oven developed in 1946 by Radarange which is shown in Figure 3.1 [128]. The first microwave oven, built in 1967, for use at home was called Amana Radarange. The Amana Radarange used 115 volt supply and had two buttons, *"start"* and *"light"*, and two cooking time knobs, one for cooking times up to five minutes, and one for longer cooking times up to 25 minutes [129].

Figure 3.1: An early version of a microwave oven, Radarange developed, 1946 [128].

Nowadays a countertop microwave oven cost between £40 to £200, depending to make and model, due to reduced cost of manufacturing as well as technological advances in manufacturing [127], and weighs between 10kg to 25kg. It can be seen with a variety of models and functions, i.e., manual or digital and can be found in every household in the UK and each household is likely to replace their microwave oven on average every 5-7 years due to functionality fault, improved lifestyle coupled with technology development and rapid changes in electronics [5].

3.2 Raw Materials in a Microwave oven

Limited information is available regarding the raw material of the components that a microwave oven consists, as well as its potential content such as hazardous substances and practice in recycling process. The most accurate information is mostly withheld by manufacturers of such products. However, by visual examination of three separate dismantled microwave ovens by the author (see, Section 5.3 of Chapter 5) it has been observed that the upper and lower case of a microwave oven is made of steel or stainless steel. The oven inside cavity is made of stainless steel, steel or aluminium. And sometimes with a top coat of light enamel paint, applied to achieve high visibility within the oven. The door is made of a combination of metal, glass and plastic. Glass is used in rotating cooking plate. The magnetron, transformer, screws are generally made of copper and steel. Some small parts such as fastener, interlocks, stirrer fan, etc. are made of various types of plastic such as Polypropylene (PP) and Polyamide (PA). Precious metals such as gold and zinc are used in printed circuit boards.

3.3 How does a Microwave oven Operate?

Microwave oven uses microwave frequency radiated energy in order to provide a heating effect [127]. Microwaves are a form of electromagnetic radio waves which both have electric and magnetic field properties [127], [130]. The frequency of the microwave used within the ovens is 2.45 GHz. The heating effect arises from the interaction of the electric field component with water, fat and sugar due to their dielectric properties. The microwave reacts with polar molecules which have negative and positive charges [130]. The microwave frequency radiated energy causes dipoles within the food's molecular structure to vibrate rapidly and consequently align themselves with the rapidly changing electromagnetic field to heat the food from the outer surface of the food to the centre [127], [131]. The advantages of microwave heating are as follows, faster heating rate and shorter processing time compare to the conventional heating as well as the size and energy efficiency of the microwave ovens [132].

3.4 Components within a Microwave oven

A typical microwave consists of following electrical and mechanical components that are used in sub assemblies of a microwave oven such as a magnetron, a high voltage transformer or an inverter, a high voltage fuse, a circuit doubler (capacitor and diode), a cooling fan and cooling fan motor, a control board and printed circuit board, a power cord and a plug, a thermostats, a bulb, one turntable motor, one filter printed circuit board, three to four micro switches, a turntable plate and turntable motor as well as a cooking chamber, a waveguide cover, door assembly and upper and lower case.

The following sections give an overview of the function of the most important components within the assembly of the oven in detail , e.g., magnetron, high voltage transformer, inverter, high voltage fuse, control unit, cooling fan.

3.4.1 Magnetron

The source of generating microwaves is a magnetron. The multicavity magnetron was first built by Randall and Boot and it produced a continuous 400 W of power at a wavelength of 9.8 cm in February 1940 [133]. The magnetron design has been changed since its invention to adapt the current need of the market for the compact and lightweight microwave ovens. It is becoming thinner and lighter compare to early versions of the magnetrons. Figure 3.2 illustrates a magnetron and its sub assemblies.

The domestic microwave oven uses continuous wave magnetron (CW) which has continued output power from a few watts to up to 10kW [134]. The magnetrons used in domestic ovens are operating at 2.45 GHz and air cooled by cooling fan assembled within the oven. The magnetron efficiency in a microwave oven is about 40-70% and subsequently 30-60% of the input power will be converted to heat at the node [127]. The magnetron converts the potential energy of electrons from the cathode into the microwave energy with the aid of a magnetic field and consequently it results of high oscillation efficiency.

As it is shown in Figure 3.2 magnetron's sub-assemblies are held within a metal strap. The resonant cavity of a magnetron made of highly conductive copper, which consists of a cylindrical anode and a cathode (filament) that emits electrons positioned on the central axis of the cylinder. The anode is made of copper that reduces the loss of microwaves and act as resonant cavity around the cathode (filament). The magnetron cathode (filament) is connected to the negative side of the power supply and anode is connected to the positive side of the power supply. In addition, a cooling unit which helps to dissipate the heat generated by resonant cavity is included in the magnetron assembly. A thermal protector is included in the magnetron assembly to prevent damage caused by overheating of the magnetron. The magnetic circuit within magnetron is formed by a pole piece and a yoke (magnetic path) which is made of iron. The magnetron consists of two permanent magnets to apply a magnetic field within a magnetic circuit. An antenna is connected to the magnetron and it transmits microwave energy stored in the resonant circuit to the cavity through a waveguide. A filter circuit which limits the leakage of unwanted radiation to the magnetic circuit is included in the input of the magnetron [127], [135], [134], [136].

The life expectancy of the ovens magnetron is typically 2000 hours of operation [137]. There are several reasons identified in reference [137], which may, reduce the life expectancy of a typical magnetron such as operating the oven with no-load, operating oven with too much metal in the cooking cavity, line voltage consistently too low or too high, improper installation or removal of the magnetron, obstruction in the waveguide, failure of stirrer mode operation, etc.

3.4.2 Waveguide

A waveguide is used to transfer the waves of energy generated by the magnetron to the microwave oven cavity. The waveguide is a metallic tube. The antenna of magnetron is positioned into the entrance of the waveguide. A waveguide cover is used to prevent food spillage into the waveguide; it's made of either a mica sheet or plastic. Figure 3.3 depicts the position of the waveguide and wave guide cover within a microwave oven assembly.

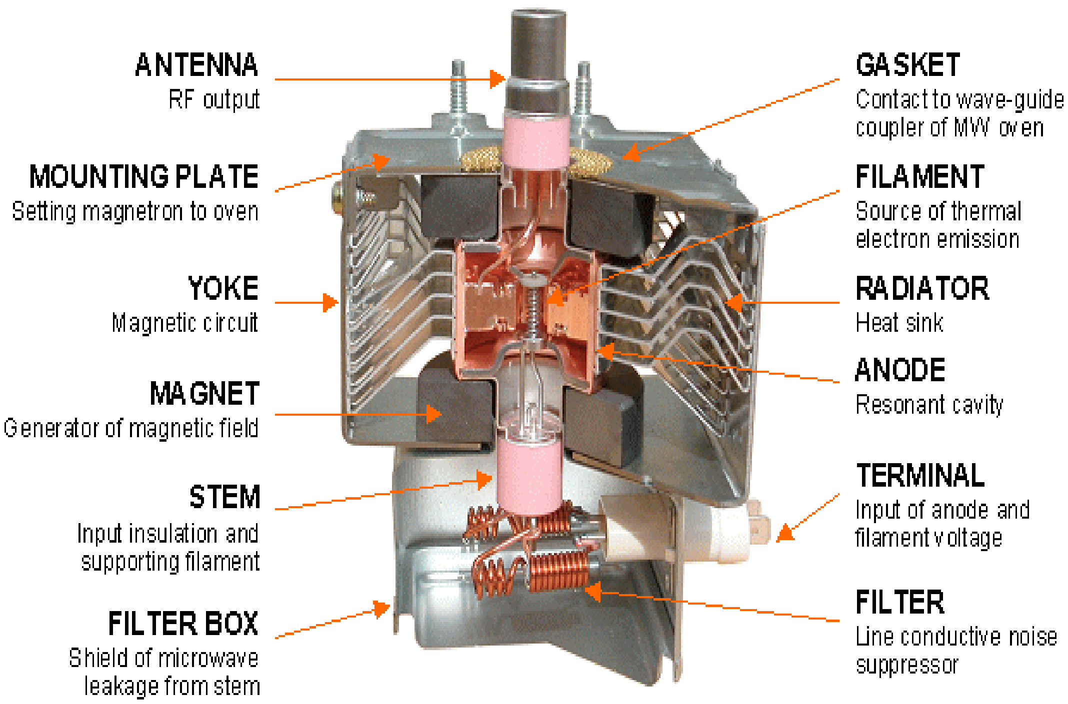

Figure 3.2: Structure of a magnetron and its sub assemblies [138].

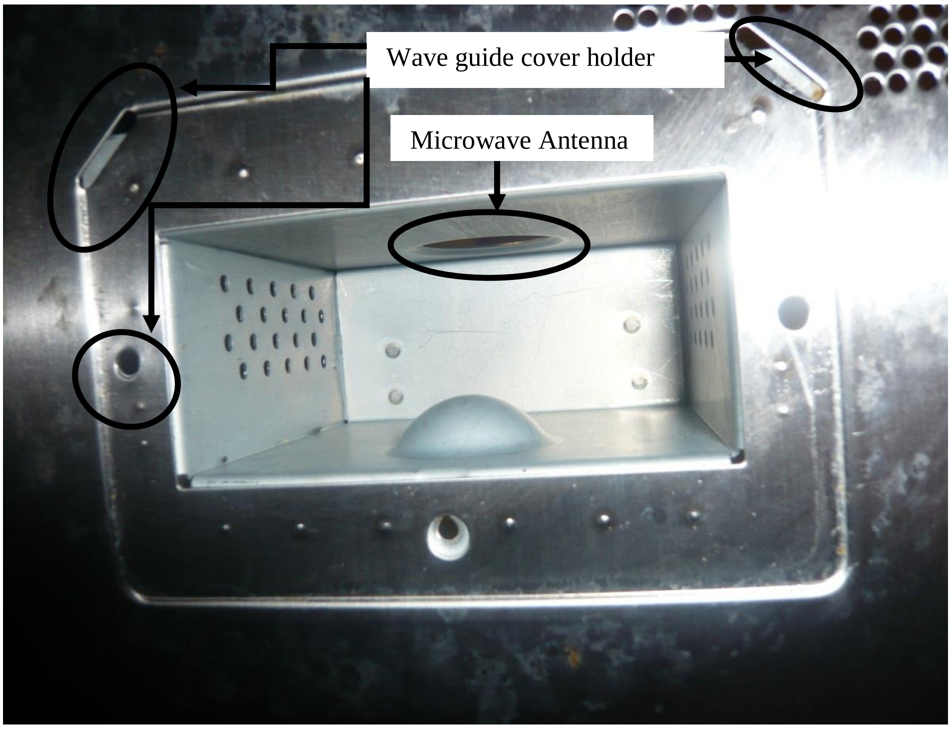

Figure 3.3: The position of the waveguide and waveguide cover within a microwave oven assembly

3.4.3 High Voltage Transformer

The high voltage (H.V.) transformer is responsible for providing power to the magnetron in order to enable a microwave oven to operate. The transformer is made of steel and copper. It comprises of two E-shaped cores (made of steel), and two separate insulated windings called coils made of copper, the first coil contains a primary winding connected to the low input voltage (feed from the power supply) and a secondary winding (coil) which produce a high-voltage output. The secondary windings are connected to the magnetron via a voltage doubler circuit which, supplies a high voltage power (DC) to the magnetron. Typically, input voltage is 230V-240V in AC at 60 Hz in primary and output voltage in the secondary is between 2000V to 2300V in AC, depended on the model and type of microwave ovens. Furthermore, the high voltage transformer also consists of a gap filled by insulation materials which are interposed between the primary and secondary winding [139]. Figure 3.5 depicts a high voltage transformer with primary and secondary terminals marked.

3.4.4 Inverter Technology

Recently microwave ovens fitted with inverter technology have been introduced. The power transformer is replaced by a circuit board, which converts the 60 Hz incoming line frequency to a variable rate of 20 to 45 kHz. A relatively small and light transformer is required to increase the voltage to the level required by the magnetron.

By varying the pulse widthof the frequency, the power can be linearly controlled for more precise cooking and defrosting levels. Less heat is dissipated so power efficiency is increased. The advantage of the inverter technology is the power efficiency of the oven and continuous use of the power [133]. Figure 3.4 depicts an continuous inverter technology used within the assembly of an oven.

3.4.5 High Voltage Fuse

A high voltage fuse is connected to the high voltage transformer secondary winding output (see, Figure 3.5) and to the capacitor. The purpose of the high voltage fuse is to protect microwave oven and user against short-circuits within the high voltage components of the microwave oven. Furthermore, once the high voltage fuse is blown, the oven may operate without magnetron heating the food within the cavity.

3.4.6 Voltage-Doublers Circuit

Within the circuit diagram (Figure 3.8 and Figure 3.9) of a microwave oven a capacitor and a diode (also known as Rectifier) are used to double the high voltage within the electronic circuit of the microwave oven i.e., from 2000 V in AC on the secondary output of the transformer to 4000V in DC in order to supply DC voltage to the magnetron tube. This circuit is called a voltage-doubler circuit. A schematic diagram of a voltage-doubler circuit is given in Figure 3.6. This circuit is connected to the output of secondary winding of high voltage transformer [140]. The output of the circuit is connected to the magnetron. Figure 3.7 shows a high voltage capacitor and a diode used in a microwave oven assembly.

Figure 3.4: The inverter used within a microwave oven

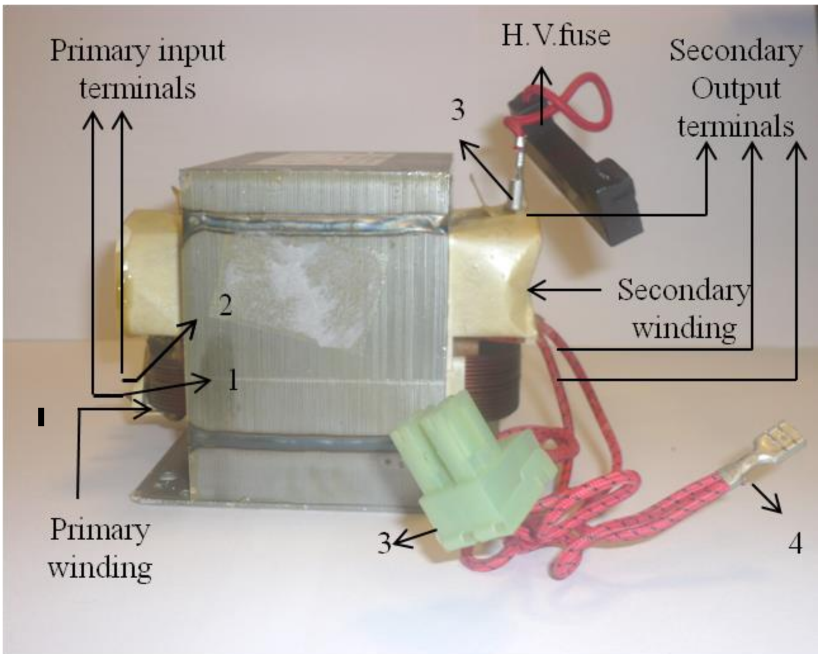

Figure 3.5: A high voltage transformer and high voltage fuse

Note: Figure 3.5 shows a high voltage transformer with primary input terminals (1 and 2) and secondary output terminals (3 and 4). The output terminals marked as 3 are connected to the high voltage fuse and to magnetron filament; the terminal marked as 4 is connected to the high voltage doubler circuit terminal (capacitor).

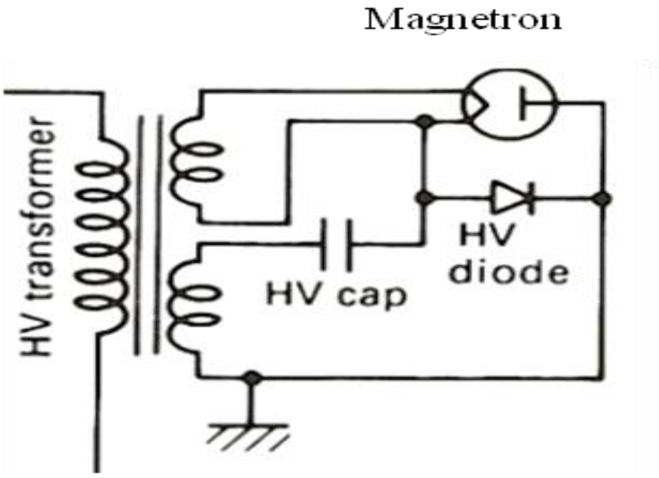

Figure 3.6: A schematic diagram of a voltage-doubler circuit [127].

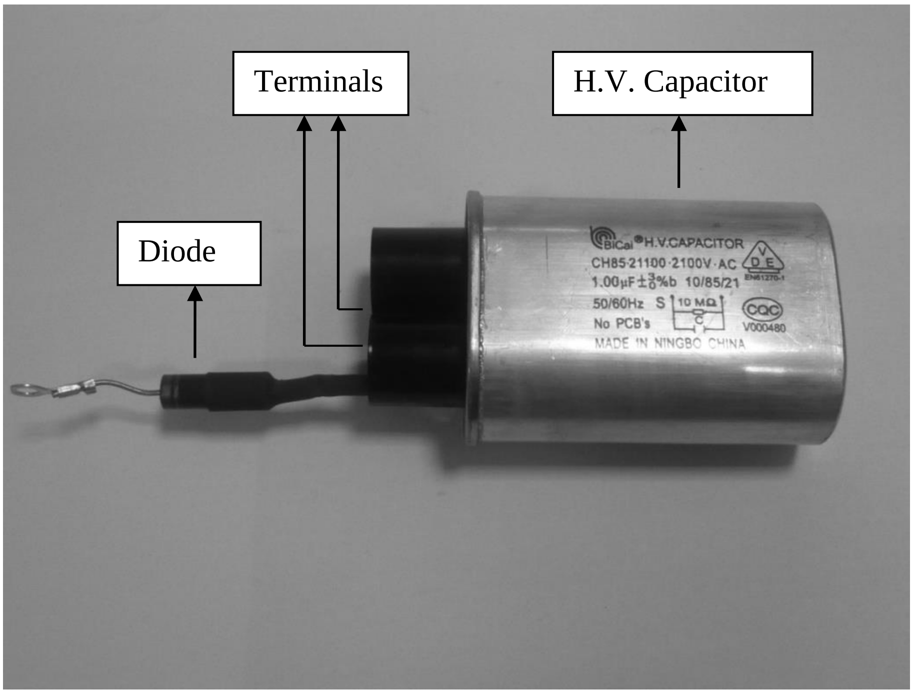

Figure 3.7: A high voltage capacitor and a diode used in a microwave oven assembly.

3.4.7 Control units

Control units are designed for safety and effective operation of the microwave ovens. The control units are divided into three categories: safety controls, door switch mechanisms and functional controls [127]. Two types of functional controls are available in the current microwave ovens, electro-mechanical controls and electric controls. Figure 3.8 illustrates a circuit diagram of an electro-mechanical control and Figure 3.9 illustrates a circuit diagram of an electric control.

3.4.7.1 Safety Controls

The safety control within a microwave oven is designed to protect users and microwave from component failure within the appliance. Furthermore, they can disable microwave oven from operation [127]. Four types of safety controls are included within the microwave oven circuit diagram [127] as follow:

- A line fuse connected to external power supply, it has two functions, first it protects the appliance against short circuits, and second, it is part of the door switch mechanism.
- The 'vent cut-out' (Thermostat). The vent cut-out is "*a non-resettable eutectic link type which will go open circuit at a predefined temperature"* and it is fitted to prevent failure on accidentally leaving the oven 'ON' for exceeded time as well as protect the oven from overheating its cavity and its contents in this case oven will be switched off by the vent cut-out.
- A magnetron cut-out (Thermistor). It is also "*a non-resettable eutectic link type"*. The magnetron cut-out protects the appliance from overheating of

magnetron which usually is the case when the magnetron cooling fan or magnetron itself fails to operate.

- The safety control which is available in some microwave oven designs is a fuse that is fitted on the printed circuit board to protect appliance or user against failure of the electronic components.

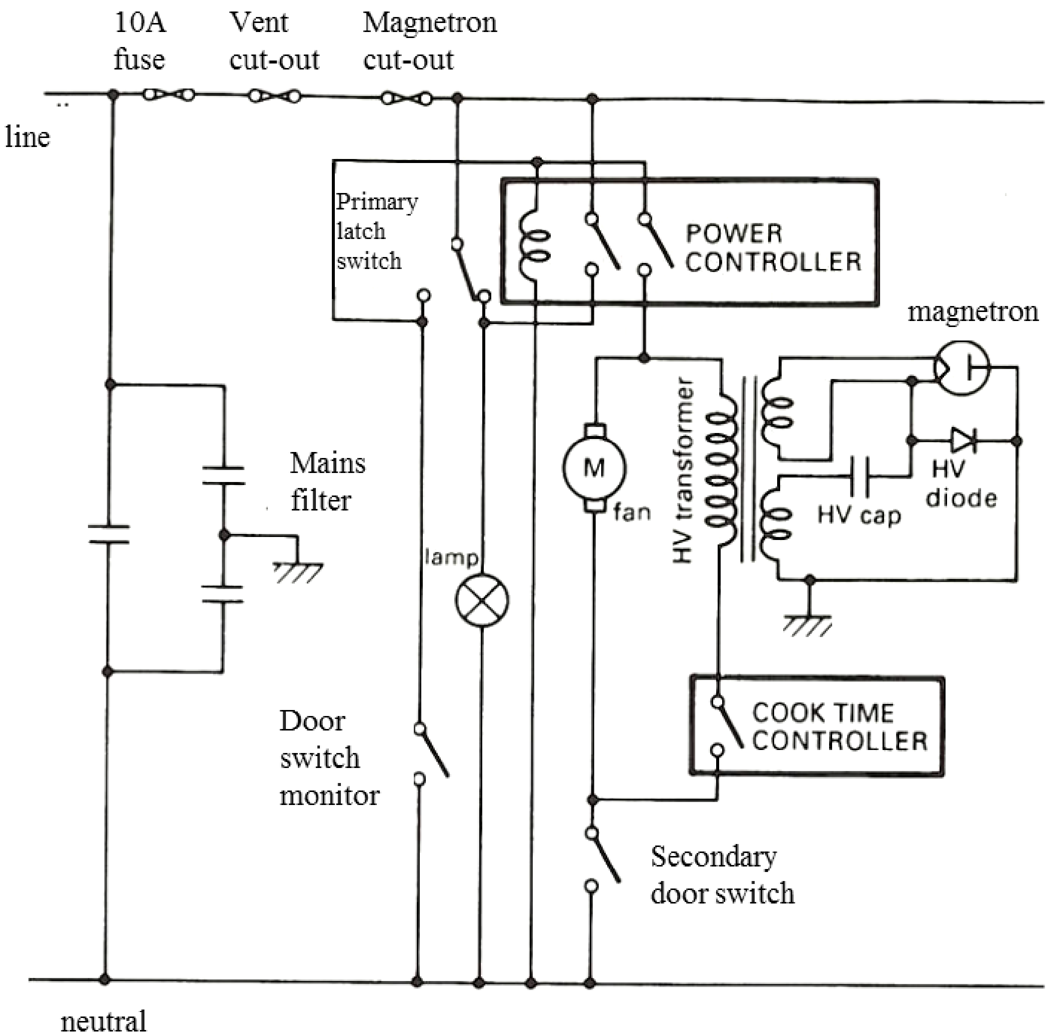

Figure 3.8: Microwave oven circuit diagram: The circuit diagram of an electro-mechanical control [127].

Note: all switches shown with the door open.

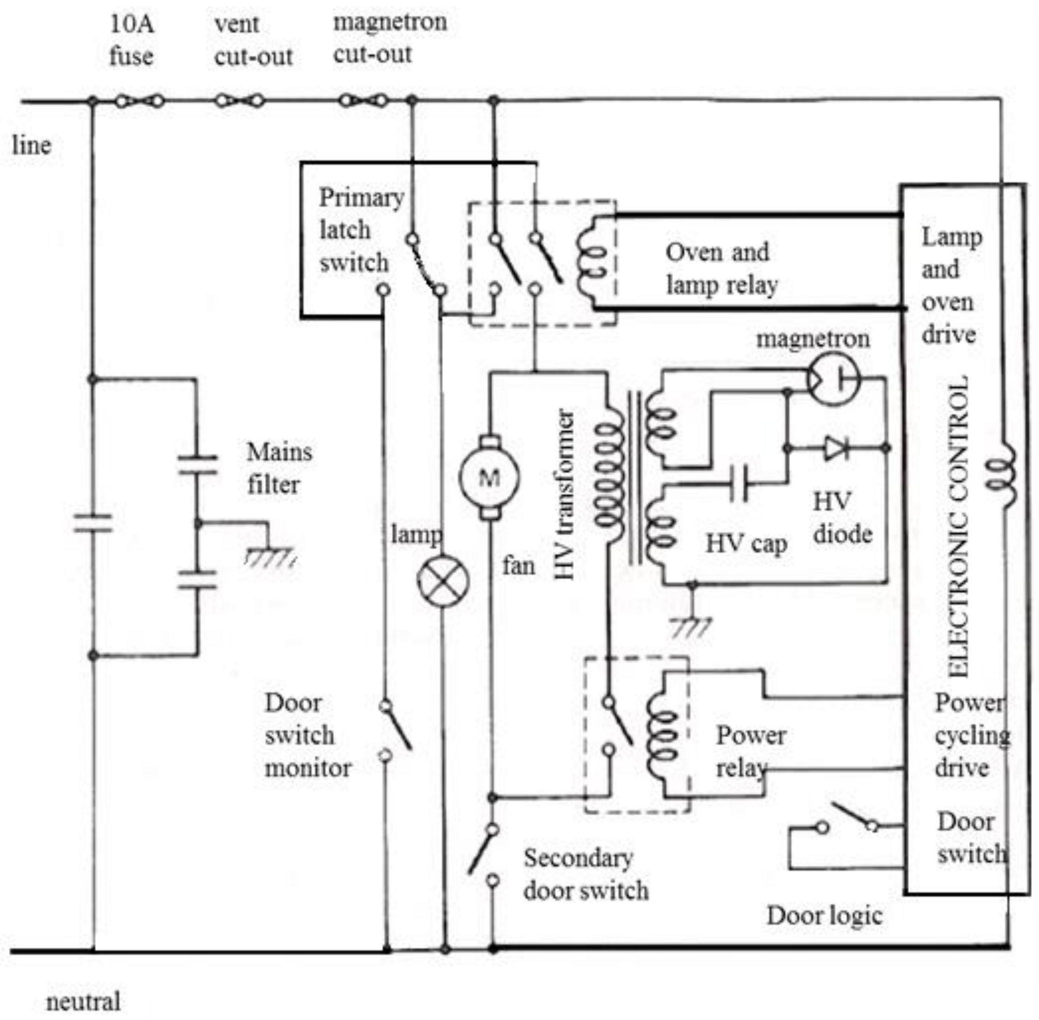

Figure 3.9: Microwave oven circuit diagram: The circuit diagram of an electric control [127].

Note: all switches shown with the door open.

3.4.7.2 Door Switch Mechanism

The door switch mechanisms act partly as safety control and as functional control. The door switch mechanism is included micro-switches either within a complete door assembly or separately operated by cams and plungers [127]. There are three safety or control switches i.e., a primary latch switch, door switch monitor and secondary switch monitor. Figure 3.10 shows one type of micro-switch, which is used in a microwave oven assembly.

Door switch functional controls

As a functional control of the electro-mechanical control (see, Figure 3.8) of a microwave oven the door switch will be used to [127]:

- Apply primary power to the magnetron when the oven door is latched closed and the Start button has been pressed.
- Switch ON the lamp when the door is opened.
- Signal to other functional controls that the door is closed (open), to enable the cooking cycle to proceed (or be terminated).

Door switch safety controls

Electro-mechanical door switch controls (see, Figure 3.8) for a microwave oven include a primary latch switch, door switch monitor and secondary switch monitor. These provide secondary removal of power supply from magnetron once oven door is opened. In the event of failure of a primary latch switch within the circuit, once the appliance door has opened, the door secondary switch safety control removes the power from the magnetron and once the door is opened wider the door switch monitor applies a short circuit across magnetron. In the case of failure of operation of primary latch switch and secondary switch monitor the short circuit will be applied by door switch monitor across the power supply. Consequently it will result in a blown fuse of the power cord [127]. For sequences of events on opening and closing the door of the ovens refer to reference [127].

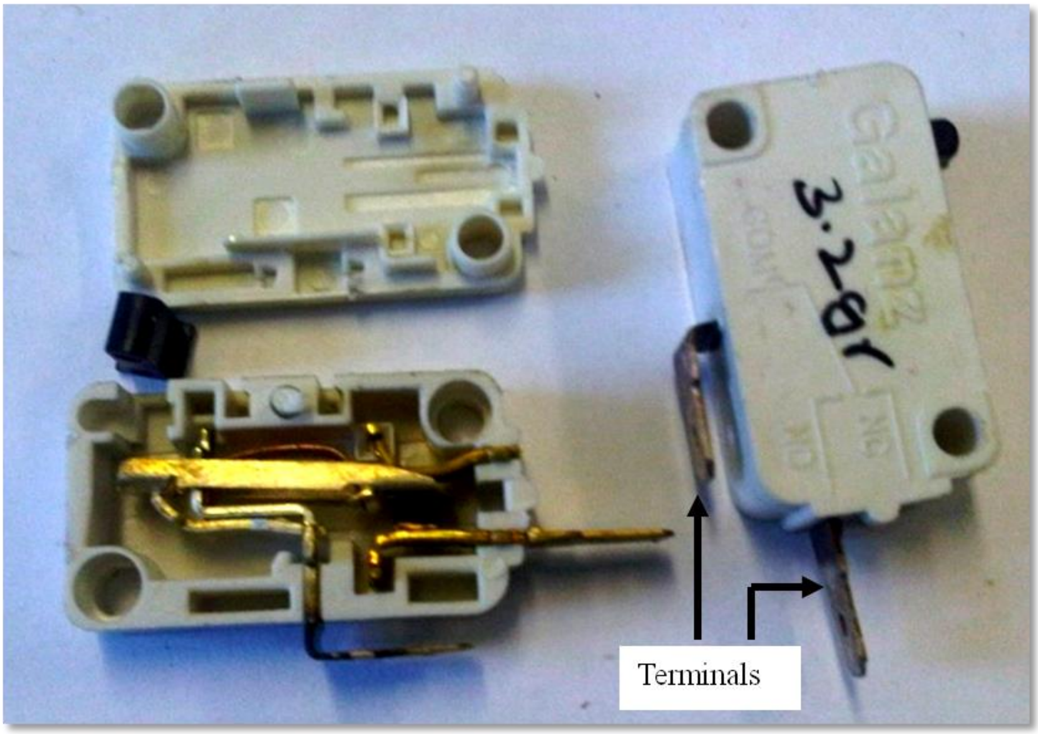

Figure 3.10: An example of two micro-switches, used in a microwave oven assembly

Note: In a typical microwave oven, four micro switches are used , e.g., door switch, primary interlock switch, monitor and light switch and secondary interlock switch.

3.4.7.3 Functional Controls

The functional control of the microwave oven is responsible for pre-defined performance of the cooking functions specified by the manufacturer and has an impact on choice of consumers to buy the microwave ovens [127]. There are two types of functional controls available, electro-mechanical functional controls and electronic functional controls (see, Figure 3.8 and Figure 3.9 for a corresponding circuit diagram respectively).

Electro-mechanical functional controls

An electro-mechanical circuit includes a cook time controller (mechanical controller) as it is shown in Figure 3.8. The mechanical controller act as ‘motor driven timer’, the cooking time is defined by turning the controller to a specific time. Once the start button is pressed, the lamp, cooling fan and the magnetron will be powered [127].

Electronic functional controls

Figure 3.9 illustrates a microwave oven circuit diagram fitted with an electronic functional control. As it is shown in the circuit diagram, the oven relay, lamp relay and power relay interface between the electronic control and the oven circuit that result in the operation of a microwave oven fitted with electronic functional control [127].

3.4.8 Cooling Fan

A cooling fan and a motor are included within the assembly of the microwave oven. The purpose of the cooling fan and its motor is to provide cooling system while the magnetron is operating. Figure 3.11 depicts a cooling fan and cooling fan motor that are mounted to the microwave chassis.

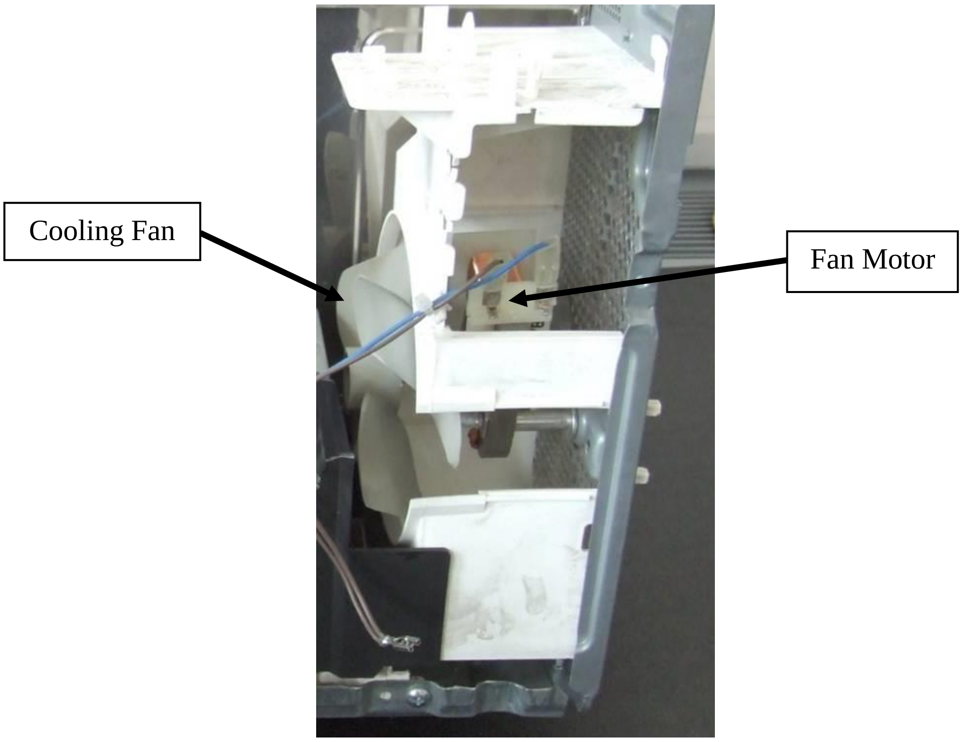

Figure 3.11: A cooling fan and a motor mounted to a microwave chassis.

3.4.9 Power cord and plug

The power to the oven is supplied by a power cord and a moulded electrical plug which is attached to the power cord and can be connected to the 230-240 volt mains supply socket. The power cord is made of PVC insulated fine gauge stranded copper wires for phase, neutral and earth, enclosed in an outer PVC sheath.

3.4.10 Thermostat

The thermostat (the vent cut out see, Section 3.4.7.1) in the oven controls the temperature of the magnetron as well as inside the cavity (in case of availability of the second thermostat). It is mainly made of the aluminum and plastic.

3.4.11 Bulb and Bulb Holder

A bulb and a bulb holder are used within the microwave oven assembly. The bulb and bulb holder are made of glass, metal and plastic. The bulb holder is screwed or pinned to the chassis of the oven and is connected to the circuit board as well as to a control circuit via two wires.

3.4.12 Turntable Motor and Turntable Plate

Turntable motor is located under the oven cavity and it is attached by one or two screws to the cavity. The terminals are connected to the control board via two wires. It is made of plastic and ferrous metal. A turntable coupler, made of plastic is attached to the motor from inside of the cavity. The turntable plate is made of glass. The purpose of the turntable plate is to provide more unified heating by passing the microwave standing wave pattern through the food.

3.5 Summary

This chapter covered the history and innovations (e.g., Magnetron and high voltage transformer) of the microwave oven. The complete description of the technologies used with in a microwave oven is given. The magnetron and its function within a microwave oven are discussed separately. The functions of high voltage transformer, high voltage capacitor and diode within an electric circuit of microwave ovens are described in this chapter. The function of the waveguide, power cord and plug, thermostat, bulb and bulb holder, turntable and turntable plate and cooling fan are explained. Furthermore, the reasons for employing the control units are discussed in detail. The importance of safety controls within a microwave oven design has been explained separately. The descriptions of the different type of functional controls are explained separately in this chapter.

The following chapter presents research methodologies undertaken in this thesis.

Chapter 4: Research Methodologies

This chapter describes the research methodologies employed in this study in detail. Furthermore, the relation between research questions and the research methods are described in Section 4.1. the data collection method is explained in Section 4.2. In Section 4.3 the required arrangements for semi-structured interview is explained in further detail. The arrangements for testing of the microwave ovens at the household waste recycling centre (HWRC) and the University of Manchester are explained separately in Section 4.4. A comprehensive description for microwave oven test procedures is presented in Section 4.4.2. The method employed to answer the research question three is given in Section 4.5. Furthermore, the microwave oven disassembly methods are given in Section 4.5.1.1. The data analysis methods which were used in this study are described in Section 4.6 of this chapter.

4.1 Research Design in a Nutshell

This thesis is based on the multi-method methodology to answer the three research questions given in Chapter 1 of this thesis. Furthermore, the research strategy employed was case study, which used the case of microwave ovens discarded at the household waste recycling centres in the UK. Multiple research methods were employed in order to collect empirical data thus fulfilling the three research questions. The type of the research questions in this study is the reason behind choosing the different data collection methods in order to answer research questions in this thesis [141]. Moreover, using the triangulation practice [142], in particular, the functionality of the 82 disposed ovens at the point of disposal were examined both from consumer view and technology perspectives using face to face semi-structured interview and fault diagnostic tests respectively.

Three distinct phases were established in this research study as:

- Phase one: assesses consumers' intentions and behaviours with respect to the disposal of microwave ovens,
- Phase two: investigates the quality of, and the costs of remanufacturing, microwave ovens discarded in the United Kingdom, and
- Phase three: proposes design changes intended to increase opportunities for reuse and remanufacturing.

In Summary, the empirical data were collected via a face to face semi-structured interview in phase one in order to answer research question 1 *"What are the consumers' knowledge and behaviours with respect to the functionality and disposal of microwave ovens?"*. This method is common (see , e.g., [93]) in waste management research in order to uncover consumers` waste behavioural research questions.

Product functionality analysis at the point of disposal, using fault diagnostic tests, and observation in phase two were used in order to collect empirical data and to answer research question 2 *"What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?"* Furthermore, the dismantling methods were used in phase three in order to answer research question

3: *"What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?"*. These methods are common (see , e.g., [143], [144], [145] for design for remanufacture or design for disassemble research examples) in order to gain an in depth knowledge and an empirical evidence to answer the research questions concern with functionality and design of the products.

This study focuses on the end of use/life of the microwave ovens disposed at the household recycling centres in the UK, more specifically within Greater Manchester. Following were the main reasons for selecting the microwave oven as the case study.

- The microwave ovens are found within most of the households in the UK.
- The consumers are often willing to dispose ovens at the recycling centres due to the weight of the unit compare to the other products (e.g., washing machine and cooling appliances) within the category one of the WEEE directive.
- The microwave ovens were one of the product which were prepared for reuse by reuse organisation, CREATE UK. However, the high cost of spare parts and relatively low availability of ovens to remanufacture despite of the demand for such products, resulted to withdraw the product from their business plan.
- The microwave ovens are designed with a relatively small number of components and the components are similar between most of the available brands.
- Despite of using multiple complex components within its assembly, given the knowledge of the fault diagnosis process within the school of Electrical and Electronic Engineering, it was relatively easy and less time consuming to carry

out fault diagnosis tests compare to other products within the category one of the WEEE directive.

- The relative easiness of access to the units by the researcher at the recycling centre to carry out the research compare to other products within the category one of the WEEE directive.
- The ease of transportation of the units at the University of Manchester to carry out fault diagnosis tests compare to other products within the category one of the WEEE directive.

The following sections explain the data collection methods used within this thesis based on the research questions in details.

4.2 Data Collection

The empirical data collection was conducted by multiple research methods depending on the research questions. The research began with an extensive and systematic literature review and continued throughout the research.

As outlined in Section 4.1, the three individual research questions employed three separate research methods in three phases. The investigation of the research question 1 was carried out through a qualitative method. The face to face semi-structured interview method was used in order to assess consumers' knowledge and behaviour with respect to the functionality and disposal of the microwave ovens. The investigation of the research question 2 was carried out through a quantitative method. The product functionality analysis using fault diagnostic techniques in the laboratory environment was conducted in order to answer research question 2 in details. This study was designed to investigate the quality of, and the costs of remanufacturing of the microwave ovens at the point of disposal. Furthermore, the investigation of the research question 3 was carried out through a quantitative method. The recommendations to optimise the design of the individual component or product in order to facilitate reuse or remanufacture were given using product and component analysis in a laboratory environment and observation techniques.

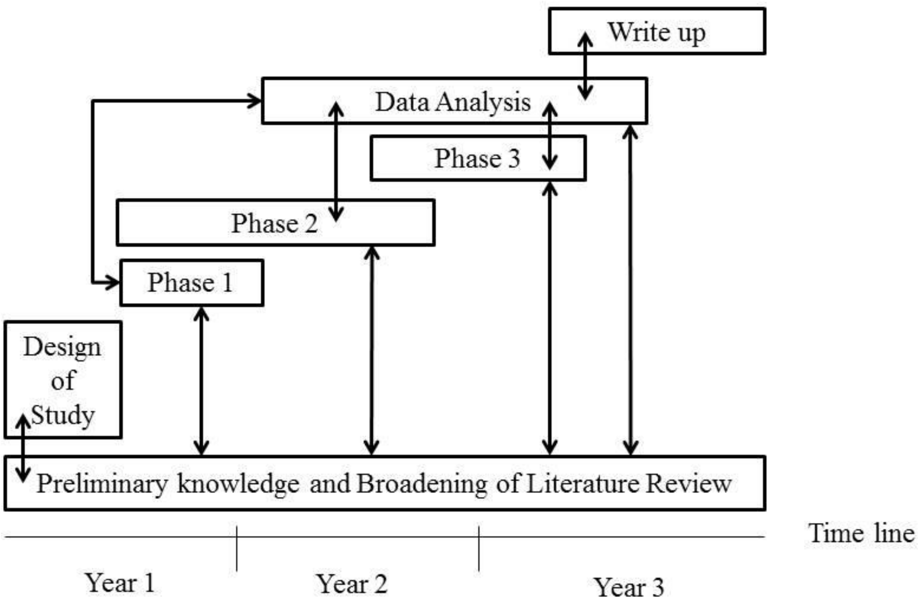

Figure 4.1: Research process

As Figure 4.1 shows, the research project took three years to complete the data collection phases, the data analysis and writing of this PhD thesis. The research methods and the questions, which were carried out in each study, are given in Table 4.1.

The following sections (Section 4.3, Section 4.4 and Section 4.5) discuss the methods to investigate the research questions and their respective justifications.

Table 4.1: The research questions, aims and methods presented in this thesis

	Research question	Aims	Research methods
Phase 1	RQ1: What are the consumers' knowledge and behaviours with respect to the functionality and disposal of microwave ovens?	To assess and analyse the consumers' knowledge and behaviours with respect to the functionality and disposal of microwave ovens	Face to face semi-structured interview
Phase 2	RQ2: What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?	To assess and analyse the quality, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom.	Product functionality analysis using fault diagnosis survey
Phase 3	RQ3: What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?	To recommend measures for optimising design and facilitating reuse and life span extension	Product and component analysis in a laboratory environment using dismantling survey

4.3 Method for the First Research Question

Research question 1: What are the consumers' knowledge and behaviour with respect to the functionality and disposal of microwave ovens?

Following subsections provide methods that were used to answer research question 1 in details.

4.3.1 Semi-Structured Interview

In order to answer research question one, a set of guiding questions were drafted (see, Appendix A1) to be administered by the researcher or an interviewer to the consumers discarding their unwanted microwave oven at the Longley Lane, Sharston Manchester HWRC (see, Appendix A3, for information and location of the Longley Lane HWRC). The questions were designed to be answered by 'Yes' and 'No' response. In addition, the respondent encouraged, circumstances including health and safety regulation permitted, to add his/her own comments to each answer i.e., the origin of the faults and reasons for disposal. The questionnaires were administered to the respondents using face to face semi-structured interview technique.

Face to face semi-structured interview has a number of advantages over other methods for primary data collection, e.g., mail questionnaires, including increased confidence that data collection instructions are properly followed, higher response rates, flexibility to answer new questions that may arise from the respondents' answers [146] and interviewee response freely to the questions [35]. Furthermore, in the particular case of this research, the researcher believes that face to face interviews provide more accurate answers. Moreover, since this study addressed a less focused audience to construct the study sample; some of the information regarding the reasons underlying the decision to dispose this product may have been forgotten. As disposing a microwave oven is hardly a memorable event and occurs, very infrequently, in this case, the researcher believes that asking the owner at the moment of disposal improves the accuracy of the answers. Moreover, it gives an opportunity to further uncover the respondents' view and comments in detail, e.g., knowledge on the type of fault in non-working microwave oven or the reason of disposal in the case of a working microwave oven.

Prior to the interview the theoretical background to proposed questions were carried out in order to find a gap within literature and available knowledge on the topic, and the questions drafted accordingly [141] with the aims of the study in mind. The interview guide questions were reviewed and evaluated by the research supervisor, the research technician, a member of the management team of the company Viridor Laing (Greater Manchester) Limited (VLGM) and furthermore by two research students for their internal validity and usefulness.[5]

The empirical data collected from semi-structured interviews was documented via a specially prepared questionnaire sheet. Each questionnaire had a unique number, which was associated with a particular discarded oven.[6] Each semi-structured interview lasted less than four minutes, depending on interviewees' willingness to answer questions and due to the nature of the location, which interview took place.

The interviewer who approached members of the public as they arrived at the recycling sites completed the questionnaires. In order to reduce the non-response bias and the answer bias by the respondents the educational purpose and importance of the study explained during the introduction to gain permission to interview as well as the

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[5]Viridor Laing (Greater Manchester) Limited (VLGM) is a partnership between Viridor and John Laing plc. VLGM provides facilities and services to manage household waste across nine districts of the Greater Manchester.

[6]This arrangement allowed comparing the consumers' responses with further fault finding data of the same unit, i.e., 'working' or 'not working' and reported fault details and triangulation of data.

anonymity of the respondents and the confidentiality of the respondents' answers was ensured throughout the interview as stressed by Sekaran [147]. Figure 4.2 shows the Longley Lane HWRC. Figure 4.3 depicts the agreed location of the semi-structured interview between the managers of the company VLGM and the University of Manchester research team.

4.3.1.1 Questions

The general topics of the interview were as follows:

- Characteristics of the product; i.e., make and model, approximate date of purchase
- Consumer knowledge on functionality of disposing oven
- Consumer knowledge of the failure mode of disposing oven
- Consumers attitudes towards latest innovation and technology upgrade
- Awareness of other disposal options

The first section of the questionnaire the ‘Characteristics of the product’ was used to find out the approximate age of the disposed products. Participants were asked to state the approximate date of the purchase of the oven. This question was to indicate the life span of the oven since purchase.

The second section of the questionnaire the ‘Reason for disposal’ was to find answers to the following questions. The respondents were asked to indicate their opinion on whether their oven is working or not working. This question was to try to know the reason behind the disposal of the oven from the respondent’s point of view.

The respondents who answered oven is ‘not working’ then asked whether could they identify the reason why the oven is not working. Furthermore, they were asked to give their reason why the oven is not working. This question was intended to ascertain whether or not the respondent has knowledge of the failure mode of the unit. To gauge respondent's attitude towards the latest innovation and technology upgrades the respondents were asked (in both working and not working case) whether they are replacing their unit with a more modern product.[7] This question was intended to ascertain whether the widely held belief that e-waste is always driven by a desire for the latest technology and innovation.

The respondents then were asked about their knowledge of other disposal options for their unwanted working item besides HWRCs. The question was designed to understand the level of the respondent knowledge of the other established disposal or reuse schemes within the Greater Manchester such as charities, as the participation in such schemes would increase the available items to reuse and remanufacture.

[7] The interviewer referred to the disposed oven while asking this particular question in order be clear with meaning of the modern oven.

Figure 4.2: The Longley Lane HWRC which semi-structured interview took place.

Figure 4.3: The agreed location for interaction with public.

4.3.1.2 Pilot study and further arrangements

Initially it was proposed that the researcher (author) from the University of Manchester should complete the questionnaire by approaching members of the public as they arrived at the recycling site. However, during the pilot study it was noted that the rate of the microwave ovens return for the disposal was low. The proposed arrangement to conduct the semi-structured interview was revised. Therefore, the following points were agreed. The semi-structured interviews were conducted by well-informed site greeting staffs, while collecting ovens from consumers whom discard such products.[8,9] These arrangements thought to be viable in order to collect more data via interviews and disposed products to answer proposed research questions within proposed research time scale.

The pilot study took place on the September 2010 in order to verify the validity and relevance of the questionnaire to the research questions and tested for appropriate wording.[10] However, 10 interviews were conducted by interviewers using the draft questionnaire as part of collecting the 10 ovens prior to the pilot study date.

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[8] The greeting site staffs are those standing next to the entrance of the site and greeting the consumers whom approach to the site and they ask facility users about type of the item to be disposed and advise consumers to dispose the item into the appropriate allocated container or cage. The term greeting site staff and site staff are used interchangeably in this thesis.

[9]Introduction to the semi-structured interview, questions and safety procedures were given by researcher, Viridor's site manager and waste prevention officer to the greeting site staffs prior to semi-structured interview that took place. Furthermore, during the presence of the researcher at the site, the site staffs were encouraged to conduct interviews in order to get familiar with questions and filling the appropriate part of the questionnaire. This practice ensured the consistency and reliability of the gathered data.

[10] During the pilot study, the researcher interviewed consumers discarding a wide range of electrical and electronic products such as CRT monitor, small fridge, hairdryer, deep fat fryer etc. as well as 6 consumers discarding ovens. The 27 semi-structured interviews were carried out in the presence of greeting site staffs (two at a time).

Furthermore, the researcher's observations during the pilot study and conversation between the site staffs and the researcher resulted in the following minor changes. It was decided that the wording 'working' and 'not working' ovens should be clearly recorded on each respondent/questionnaire sheet in order to aid interviewer to ask subsequent relevant questions.

4.3.1.3 Location and dates of the semi-structured interview

The semi-structured interview took place at the Longley Lane Household Waste Recycling Centre (HWRC), Sharston, within the Greater Manchester, from September 2010 to December 2010. The reasons behind the selection of the Longley Lane HWRC were two folded. First, the Longley Lane HWRC is the biggest and most up-to-date facility within Greater Manchester; second the managers of the Viridor Laing Greater Manchester Limited (VLGM) were able to provide a safe environment for the research team to carry out the research studies.

Due to lack of resources and limited time, 82 consumers (interviewees) whom typically, were members of the public approaching Longley Lane HWRC site to dispose their unwanted ovens were interviewed. However, in comparison and based on the previous studies, e.g., [93] therefore, the 82 semi-structured interviews viewed as adequate and appropriate for this study. The 82 respondents were chosen based on the systematic random sample technique [148]. Furthermore, as explained above, during the pilot study it was noted that the rate of the microwave oven returns for the disposal was limited thus it had an effect on the number of respondents within the time limit of the research. The followings were agreed, prior to the visit of the research team to conduct the fault finding analysis at the site on the allocated dates, the greeting staffs were to conduct the semi-structured interviews and to collect between 15-20 ovens directly from the consumers. Once they have successfully collected the required numbers, they would stop conducting more interviews and collecting more ovens.[11]

4.3.1.4 Interacting with the General Public

Prior to the first visit to the site to conduct the research, during the introduction meeting on Jun 2010 the researcher and managers of the facilities agreed to some rules that the researcher or interviewer required to follow. For example, pertaining to locations where members of the public could be approached.

Following two options and procedures were used to conduct semi-structured interviews. However, in most occasions, the option 1, was used to conduct semi-structured interviews:

- Option 1: With the use of appropriate signage, by asking anyone who is disposing of electrical items to stop and while in the car or disposing product to answer the questions (Figure 4.4).
- Option 2: The researcher to approach any member of the public disposing of electrical items in the designated disposal area.

In both cases, the interviewers always seek the agreement of the public to conduct the interview before the introduction of the purpose of the research to the interviewees. The

[11] Due to health and safety procedures within the VLGM and limited storage space, it was not possible to store more than 20 units at a time thus systematic random sampling was employed.

questionnaires were completed with efficiency and with a pleasant manner. The interviewer followed the Viridor Safe Operating Procedures for HWRC operatives when interacting with the public and working on the site and the UoM health and safety procedure (see, Appendix A4). Figure 4.4 shows the researcher while conducting interviews (option 1). [12]

In addition each respondent was given a leaflet, at the end of each interview, containing contact details and information about reuse services provided by local reuse organisation and local authorities within the Greater Manchester. The leaflets were provided by the VLGM waste prevention unit (see, Appendix A3). It was intended to raise the awareness of reuse of unwanted products such as white household goods, furniture, books, CDs, DVDs and clothes as well as services offered within the area.

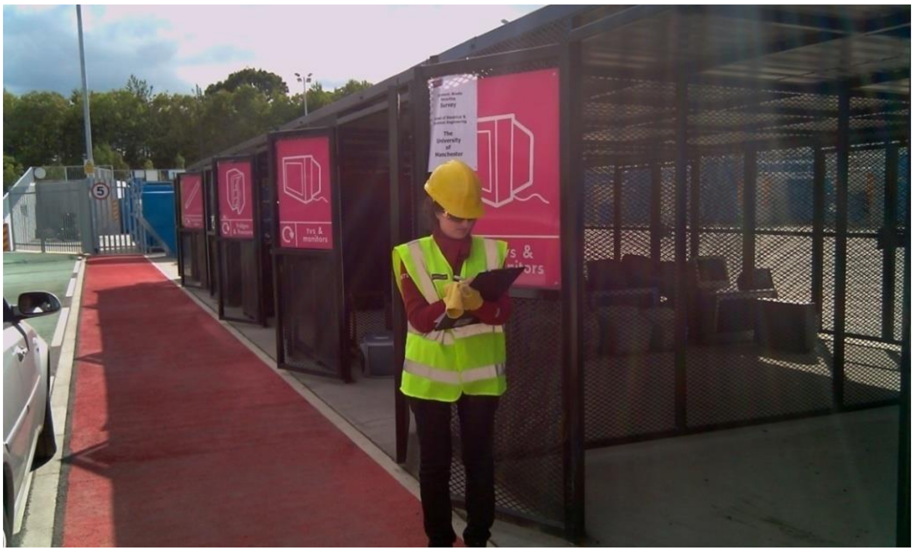

Figure 4.4: The researcher while conducting interviews and filling appropriate sections of the questionnaire.

[12] The Viridor Safe Operating Procedures for HWRC operatives were given to the researcher on each occasion to be read and signed at the HWRC site before entering to the site and conducting the research.

4.4 Method for the Second Research Question

Research question 2: What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?

Following sections provide methods that are used to answer research question 2, in details.

4.4.1 Functional and Cosmetic Appearance of the Products at the Point of Disposal

The empirical data of the product functionality analysis and failure types in the controlled environment were collected for this study via a questionnaire (see, Appendices A1 for ovens tested at the Longley Lane HWRC and A2 for ovens tested at the UoM). For this purpose, a questionnaire was designed that contained all the necessary test procedures, i.e., electrical and mechanical faults. The reason behind it is two folded, first to guide the researcher and technician, and second, to keep the procedure of the fault finding test constant throughout the testing of 189 ovens. Furthermore, this practice helped to increase the reliability of the collected data. The test procedures according to the questionnaire are presented in Section 4.4.2.

The functional tests of the ovens were conducted in two stages. 82 microwave ovens were collected directly from the consumers who discarded their unwanted ovens at the Longley Lane HWRC site. Furthermore, the fault diagnosis tests of 82 ovens were carried out at the Longley Lane HWRC site within the first stage.[13] The reason behind collecting ovens directly from the consumers at the point of disposal was to avoid potential damage caused by manual transfer into the recycling containers at the HWRC site and in order to establish the ovens potential to remanufacture at the point of disposal.[14]

During the second stage of the fault diagnostic tests a total of 107 microwave ovens which were collected and delivered by CREATE UK to the UoM from two HWRC sites within the Greater Manchester area, were tested and the results were recorded accordingly.[15] The reason behind the latter arrangement was as follow. Due to the limited resources and time in term of availability of experienced technician from the School of Electrical and Electronic Engineering in order to supervise the fault diagnostic tests at the Longley Lane HWRC site. The test procedures of the ovens at the HWRC site and at the UoM are given in Sections 4.4.1.1 and 4.4.1.2 respectively.

Role of the researcher

The researcher (author) was responsible for necessary arengments and overseeing project, setting up the test equipment's with help of the technician, conducting the visual inspection, power test and microwave leakage test, mechanical faults, in some occasion electrical faults (due to health and safety regulation of the UoM, see Appendix A11) and

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[13]Viridor Laing is the company responsible for managing the Greater Manchester HWRC sites. The disposal site is located on Longley Lane, which is part of the Greater Manchester area.

[14]Remanufacturers we interviewed indicated that damage is common in recycling centres owing to products being thrown into containers from up to two metres.

[15] Microwave ovens delivered by CREATE UK are sourced from two HWRC sites operated by Viridor Laing.

complete the relevant sections of the questionnaire for each fault accordingly in the presence of a competent technician.

Role of the technician

The technician was responsible for PAT test, supervising the researcher (author) during the test procedures and conducting most of the electrical faults. Furthermore, the technician(s) was responsible to validate the out come of the fault diagnostic tests.

4.4.1.1 Test at the Household Waste Recycling Centre (HWRC)

82 discarded ovens were examined and analysed using fault diagnostic tests within the designated area at the Longley Lane HWRC site by researcher (author) and a competent technician from the University of Manchester from September 2010 to December 2010.[16] All the tests carried out on the site were limited to fault diagnosis and further verification of the reported faults by consumers. The tests were not part of a repair service. At this stage, not a single microwave oven was removed from the Longley lane HWRC site by the researcher team.

Fault Diagnostic Study Time Table

The research team proposed an initial timetable of dates and times to carry out a fault diagnostic study at the Longley lane HWRC site. The initial trial of fault diagnostic questionnaire and fault diagnostic processes were carried out on September 2010. It was proposed that the period of six hours is primarily required to test the questionnaire and identify any deficiencies it may contain. In addition, this gave an opportunity to carry

[16]82 ovens are those collected directly from consumers at the HWRC part of face to face semi-structured interview.

out a time and motion study of the fault diagnostics on a sample of microwave ovens. To do so it was proposed that a sample of ten microwave ovens to be collected by VLGM greeting site staff prior to the pilot study date and have they placed them in the cage storage area.[17] Furthermore, due to slow rate of arriving ovens, the VLGM's managers were agreed that on the occasions prior to researchers' visits to the site, microwave ovens to be collected and semi-structured interview to be conducted by trained greeting site staffs (see, Section 4.3.1). Figure 4.5 depicts the container allocated by the VLGM to store collected ovens and conduct fault diagnostic study by a researcher and technician from the UoM.

Attendance on Site

The fault diagnostic tests were carried out by both researcher and a technician on site from September 2010 until December 2010. The research team was present at the Langley Lane HWRC site in six occasions in total, each visit lasted between 6 to 7 hours. This ensured both the researcher and technician were present during the site survey and fault diagnostic activities.

Safety Operation

The staff member who supervised and helps to conduct the fault diagnostic tests was a suitably qualified, trained and experienced electrical and electronic technician. The researcher was given necessary safety training by staff before undertaking any fault diagnostic tests. The researcher and staff have been involved in the development of

[17]Prior to this arrangement, an electronic copy of the questionnaire was e-mailed to the waste prevention officer of the VLGM. 76 semi-structured interviews were carried out by well-informed site greeting staffs of VLGM and 6 semi-structured interviews were carried out by the researcher.

suitable and sufficient risk assessments to control and identify the hazards. The researcher and staff referred to the University of Manchester risk assessments (Appendix A11) and Longley Lane HWRC Operation Risk Assessment & Control Document, and attended a site safety induction prior to starting any research work on the Longley Lane HWRC site.

Figure 4.5: The container allocated by VLGM to conduct a fault diagnostic study by researchers from the University of Manchester.

Mains Electrical Supply

During fault diagnostic tests the team used an appropriate petrol generator with a suitable residual-current circuit breaker (RCBO) protection device in order to protect the oven under the test and the technician and researcher from the hazard of electrocution.[18] The supply voltage and circuits from the generator were kept

[18]The residual-current circuit breaker (RCBO) is an electrical wiring device attached to power generator and protects the energised device and the user from electric shock.

electrically isolated from any of the electrical systems on the Longley Lane site. As a final precaution, the researcher and the technician stood on an insulating safety mat on the concrete floor and were always accompanied during the fault diagnosis tests.

4.4.1.2 Test at the University of Manchester

The stage 2 of this phase of the research was conducted from March 2011 to July 2011. One hundred and seven microwave ovens were collected by CREATE UK; directly from two HWRC sites based within the Greater Manchester:[19]

- Hurstwood Court Household Waste Recycling Centre in Bolton
- Sinderland Road Household Waste Recycling Centre in Trafford

For collecting purpose, a container was installed on both sites with clear reuse signage.[20] The units were collected without prior segregation (cherry picking). The CREATE UK collected the microwave ovens on a regular basis from HWRC sites, transferred them to their warehouse and once the collected units were sufficient for delivery the units were delivered to the UoM in two separate occasions. The collect staffs were followed CREATE UK collecting and handling procedures to minimise the damage to the units.

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[19] CREATE UK is a charity and social enterprise that has been operating successfully since 1995 in the North West of England, unfortunately due to financial difficulty and limited available core to remanufacture it is closed down in April 2012.

[20] The collection of microwave ovens by CREATE UK was part of reuse pilot project involving VLGM and CREATE UK to establish sustainable collection of white household goods for reuse purpose.

The ovens were stored in the designated storage area on the ground floor of the Sackville Street building of the UoM. Due to shortage of workshop space, only five ovens were transferred at a time for testing to the designated testing area of the workshop on the D floor of the Sackville Street Building.

Safety Procedure

The fault diagnostic tests of 107 ovens were carried out at the School of Electrical and Electronic Engineering of the University of Manchester, within the mechanical workshop (Room D8), Sackville Street building. Any tests carried out on the site were limited to the diagnosis of the faults and was not designed to be a ‘repair service’. Tests were carried out by the researcher in the presence of a technician.[21] During the fault diagnostic tests the research team complied with the University of Manchester, risk assessments and health and safety requirements (Appendix A11).

Mains Electrical Supply

The mains electrical supply was provided through a 240 V main socket.

4.4.2 Test Procedures

The test of the microwaves was limited to the only samples collected as part of the questionnaire process at the Longley lane HWRC site and those ovens that were delivered by CREATE UK. Prior to the test items were collected and stored in a secure caged area of the HWRC site (Figure 4.5) and at the University of Manchester. Prior to

[21]In total three technicians supervised the fault diagnosis tests at the University of Manchester.

the design of the test procedures, an extensive technical study was conducted by the researcher in order to gain an in depth knowledge of the functionality of the various components, electrical circuit of the oven and the relevant functionality test procedures. Furthermore, the researcher and an experienced technician were involved in designing the test procedures. The test processes were mostly adapted from the technician's expertise as well as available online databases such as [138], [149], [150]. Furthermore, the research supervisor and two technical staffs of the school confirmed the test procedures validity, based on the available test procedures as well as their knowledge and experiences. The units were visually inspected for any missing parts that hinder further scheduled tests. For example the missing power cords were replaced by a functional power cord to continue with the test or the units which had missing entire control unit or broken door and window redeemed as dangerous to test and were categorised as not tested units. The tests were conducted in five phases. Moreover, once the types of the faults were diagnosed the relevant sections of the questionnaire were completed for each fault accordingly. The test procedure work flow is given in Figure 4.20. The following sections describe each test procedure in detail.

4.4.2.1 Portable Appliance Test (PAT)

Phase one consisted of a Portable Appliance Test (PAT). The Portable Appliance Test (PAT) is an electrical safety standard test that assesses the electrical integrity of the earth and supply system in conjunction with the supply plug and cable. This test evaluates whether a particular electronic product is functionally safe for reuse. The products that failed this test were discarded and no further scheduled tests were carried out and ovens regarded as not tested.[22]

The combination of PAT testing and visual inspection were used within this phase.[23] Visual inspection was included, inspection of the plug and cord for any physical damage and loss of earth integrity, and deteriorating insulation integrity. The PAT testing was included, earth bond test (25A at 0.1Ω) and Insulation Resistance testing (500V at 2MΩ). The experimental setup for the Portable Appliance Test (PAT) is as follows. Power supply of the oven was plugged into the PAT testing 240 volt socket and the PAT test meter was plugged into the power supply (to the power generator at the HWRC and power supply socket at the UoM).[24]

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[22] The visual examination of the ovens (including physical, i.e., broken door) to determine the safety of the oven to be tested, as well as to find out the cause of failure of the PAT test were carries out, but the failure were not included within the findings and analysis as they were not suitable to consider to remanufacture. The ovens that found to be not safe to test regarded as not tested.

[23] The MEGGER Portable Appliance Tester (PAT1) was employed to carry out the PAT test.

[24] Some of the microwave ovens had damage or missing of cord, mains lead or plug. In this case, prior to PAT test, the damaged/missing component is replaced by functional spare parts in order to carry out relevant tests.

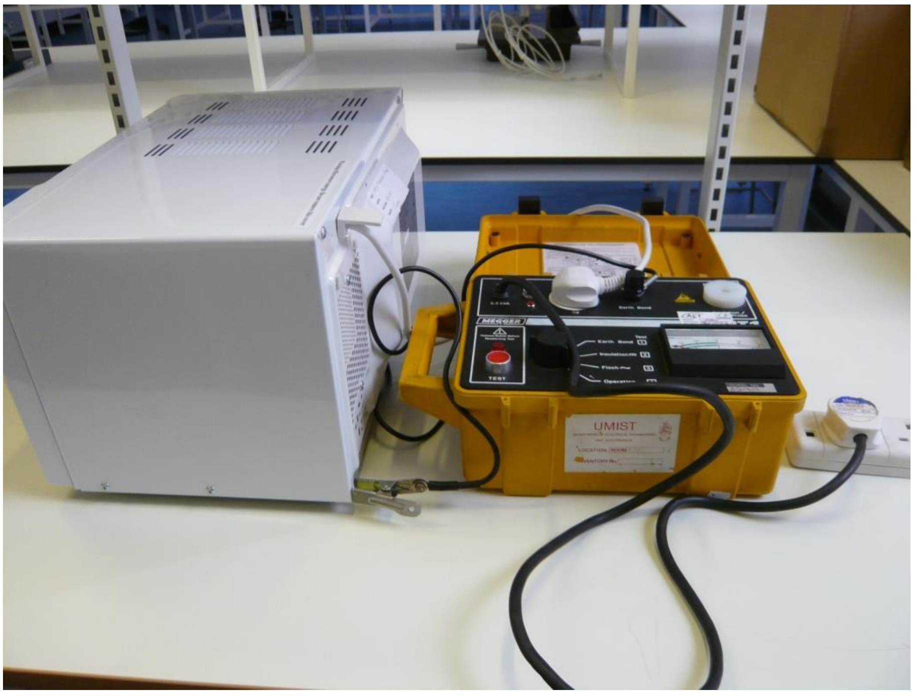


Figure 4.6: An illustration of the test arrangement for the PAT test at the University of Manchester

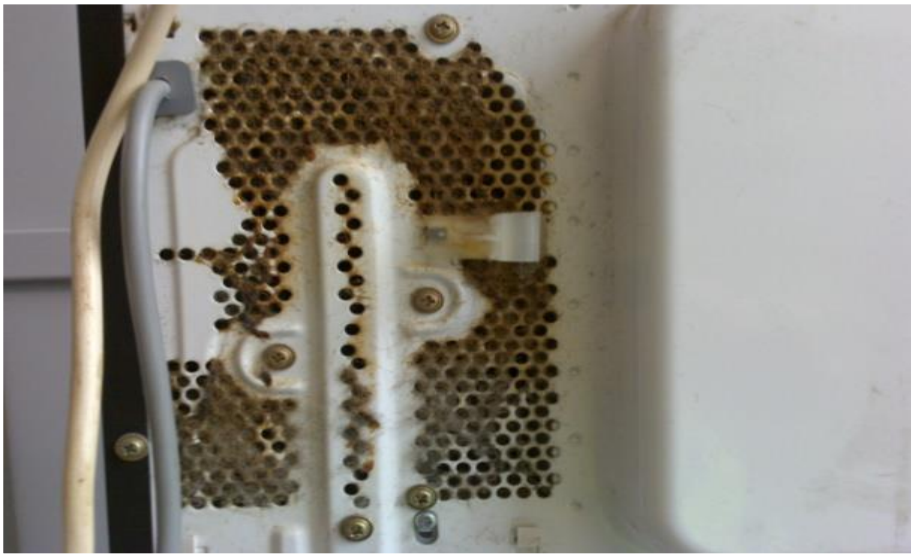
As it can be see in Figure 4.6 the earth continuity lead from PAT testing was connected onto the bare screw at the back of the microwave; and the start button on the PAT tester pressed to perform the earth continuity test. The earth continuity current test must be 1.5 times greater than plug fuse rating. In the microwave oven case, it must be greater than 20A, and the pass value of the test must be 0.1 Ohms or less. Insulation Resistance testing performed by applying a nominal voltage of 500V DC to the live conductors (active and neutral) of the unit, and placing 0 V reference on the earthed parts of the microwave oven in this case a bare screw at the back of the microwave oven.

4.4.2.2 Visual Inspection

Phase two involved visual inspection of all cosmetic imperfections. The cosmetic imperfections were included cracks in the paint; damage to top case, missing glass turntable plate, dirt, dust and any sign of sparks and burns within the cavity. All of the above cosmetic imperfections were categorised as M6 of the fault diagnostics test. The visual inspection carried out for all microwave ovens.[25] Figure 4.7 shows examples of cosmetic imperfection of an oven.

[25] Including those failed the PAT test and those ovens regarded as not tested (i.e., those with broken glass and unit with dismantled door) which were not safe to further test. However, the findings of the diagnostics tests of the ovens categorised as not tested, were not included within the further analysis within the next Chapter.

(a) Cracked paint



(b) Dirt and dust

Figure 4.7: Examples of cosmetic imperfection

4.4.2.3 Power Test and Microwave Leakage

In phase three, the microwaves were tested for output power and any adverse leakage of microwave radiation in order to establish the correct operation of the microwave oven.[26]

Output Power Test

In order to carry out the output power test of the oven a thermometer, 200 millilitres of water, a microwave oven heatproof container and a digital timer were used. Figure 4.8 depicts the equipment used to carry out power test of the ovens. The following test procedure was conducted for all of the operational ovens. A microwave oven heatproof container containing 200 millilitres of water at a starting temperature between 19 and 21 Celsius placed on the centre of the oven cavity to be heated. Then the maximum output power was selected and the start button was pressed in order to heat the water. The units able to elevate the starting temperature by 35 C in 60 seconds passed the test (adapted from [151]) and further scheduled tests were carried out to determine that the unit is working accordingly. Those units, which did not, performed accordingly recorded as not working and further electrical and mechanical tests were carried out to determine the cause of the defect.

[26] Some of the microwave ovens had damage or missing of cord, mains lead or plug. In this case the damaged/missing component is replaced by functional spare parts in order to carry out relevant tests.

Figure 4.8: The equipment used to carry out the power test of the oven

Microwave Leakage

A hand held microwave leakage detector was used to detect excess leakage level of the microwave ovens.[27] The maximum microwave leakage is set by available standards which it should not be more than 5mW/cm^2 emission level ([152] cited by [153]).[28] A visual check of the door seals and hinges were carried out in order to identify any damages before leakage test. For this purpose, a hand held leakage detector was used,

[27] The Robin TX 90 microwave leakage detector, with calibration traceable to National Physical Laboratory (NPL) of 10 points was employed. The device was used with x1 accuracy.

[28] Microwave leakage standard is adapted by the US Bureau of Radiological Health (BRH) in the US and Canada, this standard specified a microwave emission limit of 1 mW/cm^2 at 5 cm at manufacture and 5 mW/cm^2 at 5 cm after sale.

while microwave oven was operating.[29] The microwave leakage detector was held within the 5 cm distance away from the oven and moved around the door, door seals, hinges, edges and top case of the oven. Further test on ovens that showed leakage were not performed due to concenrned health and safety cautions. Figure 4.9 shows the microwave leakage test.

Figure 4.9: The microwave leakage test

[29] Before setting the oven to operate the followings were ensured. The highest power level was selected and a container filled with 200ml of water placed inside the cavity.

4.4.2.4 Mechanical Faults

In phase four, the units were tested for mechanical faults (e.g., Faulty handle or door locking mechanism; Faulty or broken door).[30] The mechanical faults categorised as M1. Faulty handle or door locking mechanism; M2. Faulty or broken door; M3. Defective or damaged controls; M4. Out of order rotating base; M5. Damaged display and M6. Other faults including dirt, worn out inside coating, small cosmetic imperfections, and damaged case.[31] Detailed processes of testing of the each component within given categories are given in following subsections.

Faulty handle or door locking mechanism (M1)

The door handles and door locking mechanisms (i.e., door lever or push button) were visually checked to identify faulty, cracked or broken components. Figure 4.10 depicts an example of faulty door locking mechanism.

Faulty or broken door (M2)

The door hinges, door latches, door screen and seals were visually checked to identify any scratch, loose or faulty components.

[30] Each of 140 units was tested for M1, M2, M3, M4, M5 and M6 fault categories.

[31]Category 6 (M6) mechanical faults refer to cosmetic imperfections, see, Section 4.4.2.2.

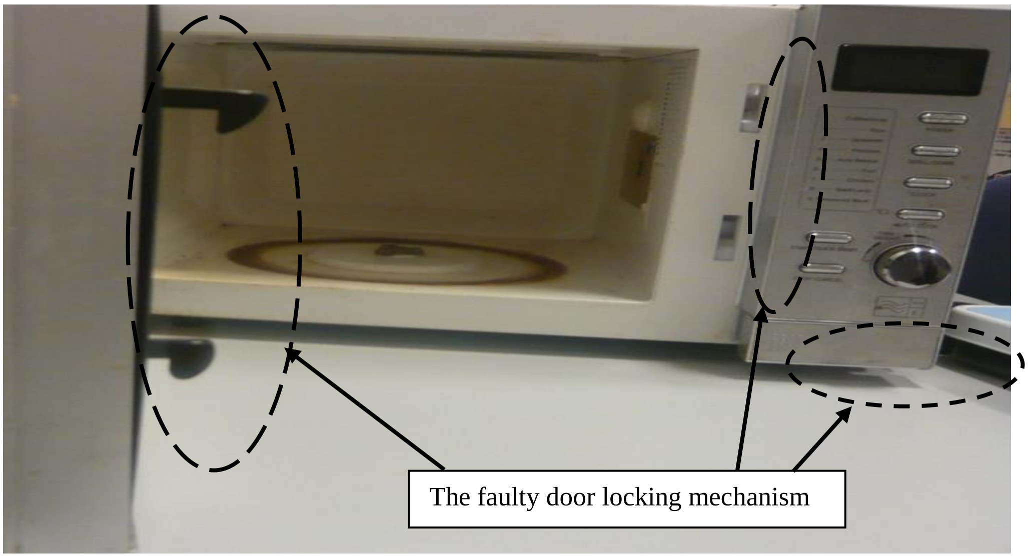


Figure 4.10: An example of the faulty door locking mechanism.

Figure 4.11: An example of damaged electro-mechanical control

Note: Figure 4.10 and Figure 4.11, depicts common identified faults within mechanical fault categories, namely as faulty handle or door locking mechanism (M1) and damaged electro-mechanical control (M3).

Defective or damaged controls (M3)

Two types of control units are available, electro-mechanical and electrical controls. The electro-mechanical controls are usually consisting of two knobs, one for power and one for the timer. A microwave oven could come with missing knobs or broken/damaged knobs. The electric control panel consists of a digital display unit, touch panel to indicate cooking time, choice of power level, etc. The control panels of the ovens were visually checked in order to identify faulty components. An example of the damaged electro-mechanical control is given in Figure 4.11.

Out of order rotating base (M4)

The rotating (turntable) base of the oven is made of plastic, and usually has 3-4 wheels, which provides support to the turntable glass. The rotating base was checked visually for any sign of damage. Furthermore, the rotating motor knob is made of plastic and usually detachable, in some cases the rotating motor knob was missing. A missing rotating (turntable) base and rotating motor knob were both common within the units, both cases were documented accordingly.

Damaged display (M5)

The ovens, which were equipped with an electric control panel usually, had a digital display unit. The display units were visually checked for any sign of mechanical damage, crack (scratch) and missing parts.

4.4.2.5 Electrical Faults

In phase five, the units were tested for electrical faults (e.g., damaged power cords, magnetron failure).[32] A multimeter was used to measure resistance and voltage across the terminals of the components. The specification of the multimeter is given in Appendix A8. During the fault diagnostic tests, the top cover and appropriate containment of the oven were removed in order to provide suitable access to the internal components. The Electrical faults were categorised as follow: E1. Damaged cord, mains lead, or plug or blown fuse (top or internal); E2. No voltage at the filter circuit input; E3. Voltage supply unavailable at the control circuit input; E4. Damaged high voltage (HV) transformer and fuse; E5. Damaged HV capacitor (Voltage-Doubler Circuit) and E6. Defective magnetron. The faults were documented accordingly. The detailed processes of the testing of each component within given category are given below.

Damaged cord, mains lead, plug or blown fuse (top or internal) (E1)

The microwave ovens were visually inspected for any visible sign of damage to the mains lead and plug. In case of damage or missing cord, mains lead or plug, prior energising microwave oven, the missing/damaged component was replaced with fully functional spare parts. The relevant section of the survey sheet was completed stating relevant fault diagnosis, e.g., 'damage or missing of cord, mains lead or plug'. Figure 4.12 depicts an example of the damaged cord of an oven.

Furthermore, the functionality of the top and internal fuse of the microwave oven was tested. To do so the oven connected to a 240 Volt socket and switched on by

[32] Each of 140 units was tested for E1, E2, E3, E4, E5 and E6 fault categories.

selecting/pressing start button, while it was set to the highest power level, with a container filled with 200 ml of water placed inside the cavity. Once it was established that the oven is fully operating, the unit was classified as 'Working' given that no other fault (mechanical or electrical) detected.

However, at this stage if the oven did not operate, the test on mains incoming internal fuse and internal fuse connected to the control circuit board were carried out. To do so the fuse resistance continuity checked across the fuse by using a multimeter that sets to read resistance in Ohm. The value of ohmmeter is set to maximum level, and if it indicated infinity, the fuse was open circuit and classified as defective. However, if the value is shown as zero, the fuse was functional. Once it was shown that the fuses were defective or blown, they were replaced by functional spare parts and above functional test repeated for the second time for a minimum of four minutes, moreover the test was repeated for three times with time interval of 10 minutes between tests in order to satisfy with the functionality of the unit and other components. If the oven operated at this stage, the relevant section of the survey sheet was filled with statement of defective top fuse or internal fuse and replaced with spare part. If at this stage microwave oven did not operate accordingly, further tests (E2, E3, E4, E5 and E6) were carried out to determine the cause of malfunctioning of the unit.

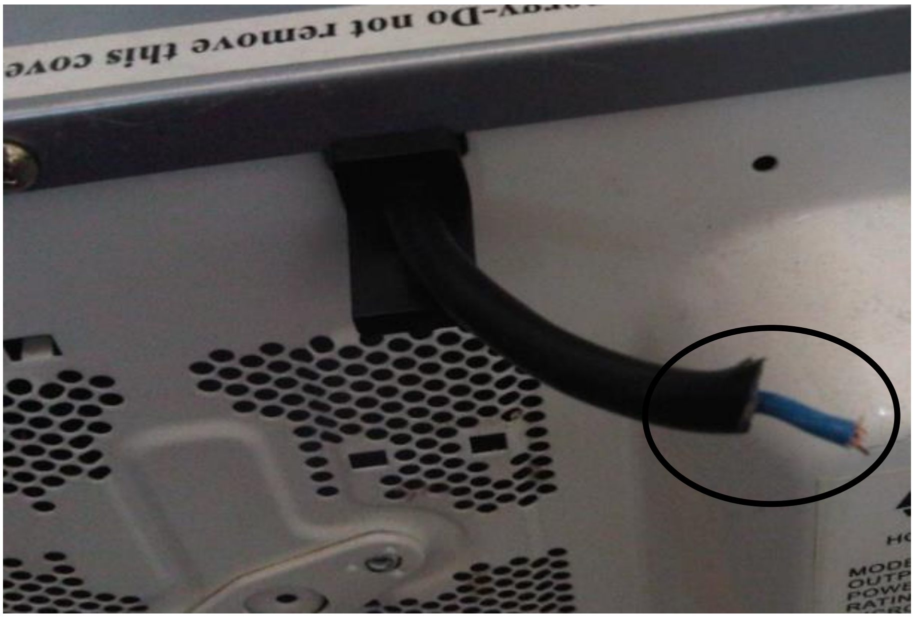


Figure 4.12: An example of damaged cord of a microwave oven

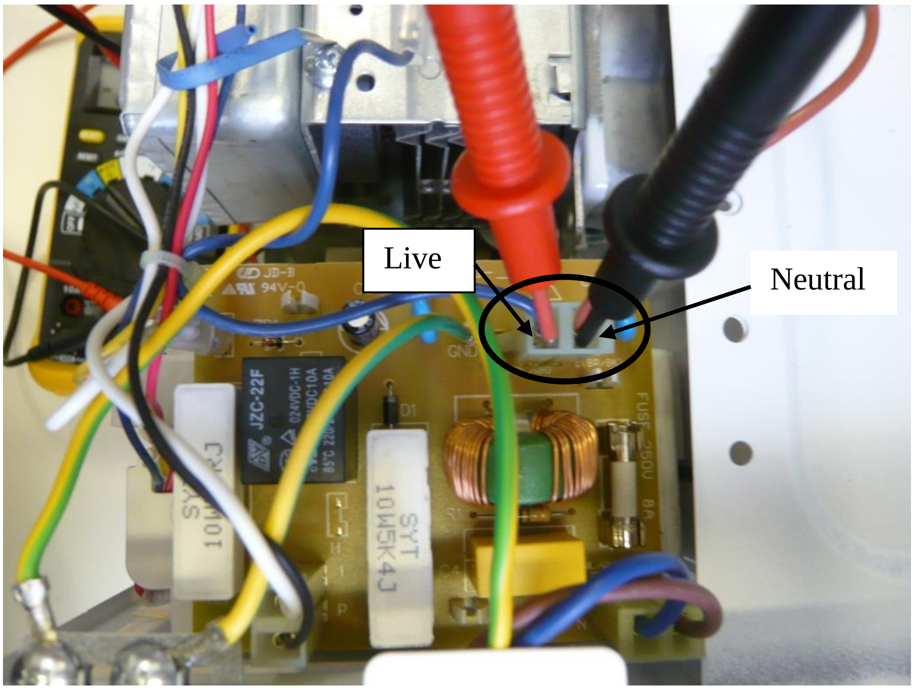


Figure 4.13: Voltage test across the output of the filter circuit board using a multimeter that set to read voltage value.

Note: Figure 4.12 and Figure 4.13, depicts test procedures that carried out to identify faulty components within the electrical categories of E1. Damaged cord, mains lead, or plug or blown fuse (top or internal); E2. No voltage at the filter circuit input.

No voltage at the filter circuit input (E2)

The voltage value across the input terminals of the circuit board was measured while the oven was plugged into the power supply using a multimeter that set to read voltage. The voltage across terminals should be ~ 230V, and consequently the component was deemed as functional. If it showed a value other than ~ 230V, the filter circuit deemed as faulty. Furthermore, as it is shown in Figure 4.13, while oven is plugged into the power supply, a multimeter set to read voltage is used to measure voltage value across the output terminals (live and neutral) of the filter circuit board. If the voltmeter shown ~ 230V, the filter circuit was deemed as functional. However, if it shows zero value it indicates that the voltage was not available at the output terminal of the circuit thus the circuit was faulty. This fault could be from the soldered components within circuit board or the connectors and the soldering joints of the components, e.g., resistors, capacitors and wires might be loose and thus result in malfunctioning of the filter circuit. Furthermore, usually a minimum of one fuse is used within the filter circuit design, in most of the cases, the fuse might be blown or fuse holder might be damaged.

Voltage supply unavailable at the control circuit input (E3)

Different types and sizes of the controllers are available, e.g., electro-mechanical or electrical. The majority of control circuit boards are mounted onto the back of the control panel. Once it was established that the controller is not responding, the power supply to the controller was checked. The power to the controller is supplied from the primary of the high voltage transformer. The measurement of the voltage across the primary of the H.V transformer as well as the input terminals of the controller using a voltmeter with the aid of two 4mm isolating test probes while the unit was plugged into the mains was carried out. The reading for a functional control circuit board would be ~ 230V. Figure 4.14, depicts the procedures. However, any reading below this value indicate that the voltage not available at the input of the control circuit board. Furthermore, if the voltage not available at the measured points, the wiring and connection points were checked for any defect. The resistance value for door interlock switches (primary, secondary and monitor interlock switches) were checked using a multimeter set to read resistance value, while the unit was unplugged, by closing and opening the door and the resistance value should be a few Ohms. Furthermore, the thermostat was checked for incoming voltage using a multimeter that sets to read voltage value, if the voltage was not available at the terminals, the fault was documented in the relevant section of the questionnaire. Moreover, the connections and the soldering joints of components, i.e., resistors, capacitors and wires might be loose and thus result in the non-response of the circuit. These were checked for the faults visually if needed. Figure 4.15 depicts the measurement of the voltage at the thermostat terminals using a voltmeter.

Damaged high voltage (HV) transformer and fuse (E4)

The purpose of the high voltage transformer is to provide high voltage power to the magnetron. A high voltage fuse is connected to the secondary winding of the H.V transformer. In the majority of the cases, the high voltage fuses were found to be defective. A multimeter was used to measure the resistance value of the H.V. fuse in ohm. The resistance value was measured between two terminals. For a functional unit the value should be zero ohms. If the resistance value shows infinity it indicates that the H.V. fuse is defective. Once it was established that the H. V. fuse is defective, the defective fuse was replaced by spare functional H. V. fuse. In order to make sure of the correct fault diagnosis, the power test was carried out, once the oven operated as normal, the fault diagnosis recorded as faulty H. V. fuse.[33] Furthermore, the terminals and wires of the H.V transformer visually inspected for any sign of damage. Figure 4.16 shows the arrangement for the high voltage fuse test using an ohmmeter.

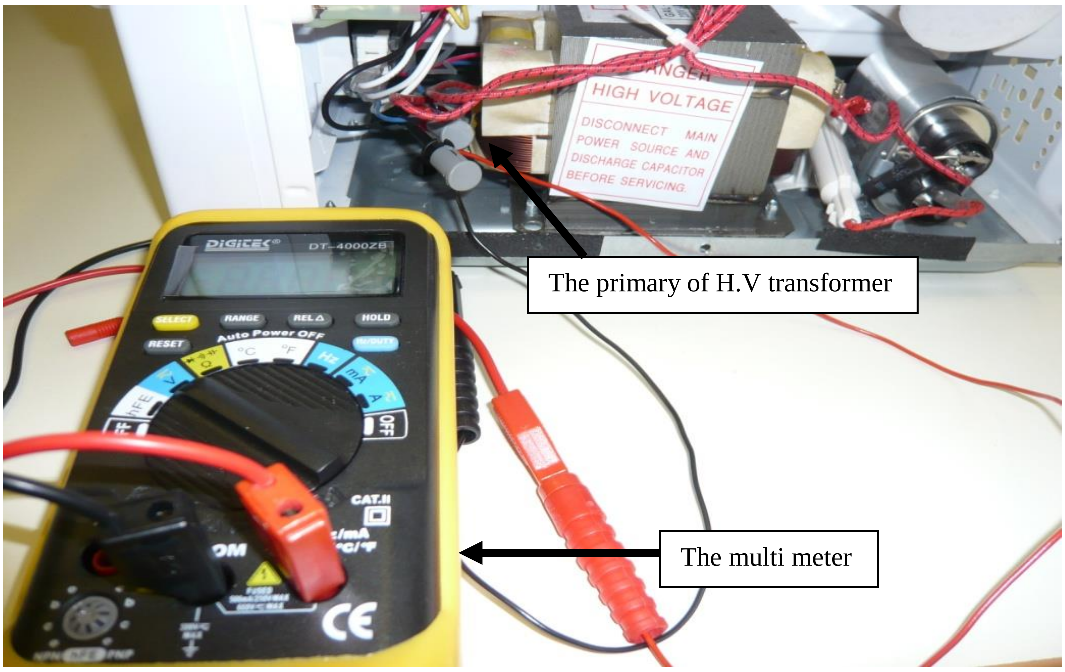


Figure 4.14: The measurement of voltage at the primary of H.V transformer using a multimeter that set to read voltage value.

Note: Figure 4.14 depicts the test procedure to identify faulty component within category 3 of electrical faults, Voltage supply unavailable at the control circuit board (E3).

[33]The top case of the microwave oven was assembled in order to operate oven safely and the power test in phase 3 was carried out.

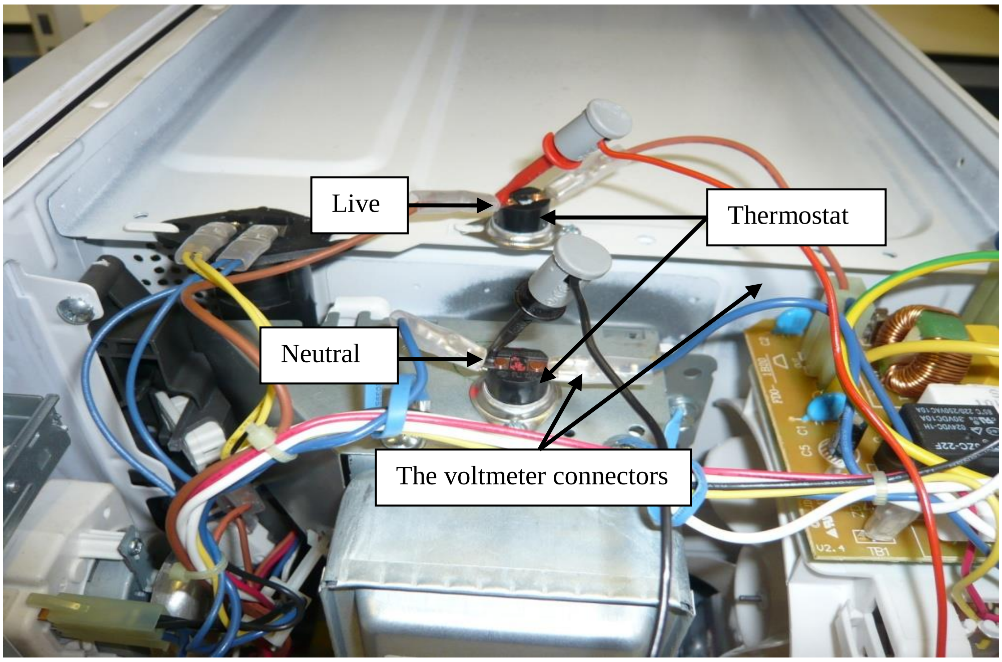


Figure 4.15: The measurement of voltage value at the terminal of thermostats using a multimeter that sets to read voltage value

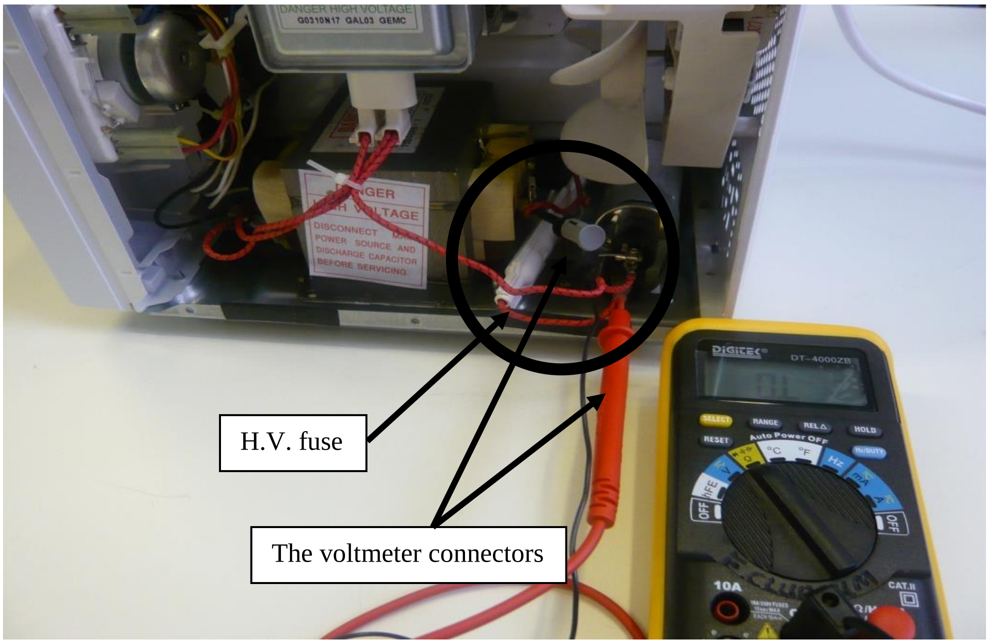


Figure 4.16: The test of high voltage fuse using a multimeter that sets to read resistance value

Note: Figure 4.15 and Figure 4.16 depicts the test procedure to identify faulty component within category 4 of electrical faults, damaged high voltage (HV) transformer and fuse (E4).

Damaged HV Capacitor (E5)

The high voltage doubler circuit consists of a high voltage capacitor and a diode. To test the functionality of the capacitor, a multimeter that sets to read the resistance value was used to measure the resistance across the capacitor terminals while the unit was unplugged. The resistance measured from terminal to terminal and from each terminal to the metal case of the capacitor. The value of the resistance should be infinite; if it reads other value than infinity, the capacitor is shorted and defective. The outcome of the test was documented.[34] Figure 4.17 depicts the arrangements for high voltage capacitor test using an ohmmeter.

The test of the functionality of the diode within the voltage doubler circuit was carried out. Once the diode disconnected from its circuit and the resistance was measured by an ohmmeter across the terminals of the diode. The measurement across functional diode should be greater than ten Mega ohms or infinity in one direction of the diode and zero or low at the other direction. Any measurement less than five Mega ohms across the diode recorded as defective diode [154].[35]

Defective Magnetron (E6)

To identify a defective magnetron, the researcher checked for any unexpected noise while carrying out the power test, and the outcome of the E1, E2, E3, E4 and E5 fault diagnostic categories to determine that the other components were functional and were

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[34] Due to health and safety, the defective capacitors were not replaced by functional spare capacitors in order to check functionality of the oven after replacement of the H.V. capacitor.

[35] Due to health and safety procedures the defective diodes were not replaced by a functional spare diode therefore further tests did not carried out

not responsible for malfunctioning of the unit. Furthermore, the oven cavity and filament connectors were visually inspected for any sign of spark or burn and food splashed into the coupling waveguide. Once it was established that the cause of malfunctioning of the unit is magnetron, the following tests were carried out in order to establish the magnetrons' functionality.

A multimeter that is sets to read resistance level was used to measure the resistance level between the filament terminals and the magnetron metal chassis. For a functional magnetron, the resistance level should be high or infinity (open circuit). The magnetron is faulty if there is a slight reading on the ohmmeter. Figure 4.18 depicts the arrangement of the magnetron test. Once it was established that the magnetron was not functional as well as the evidence of arcing, spark and burn within the cavity and food splashed into the coupling waveguide was observed, the relevant section of the survey sheet was marked as magnetron is defective. In the majority of cases, the magnetron was removed for further inspection. An example of an arcing magnetron is given in Figure 4.19.

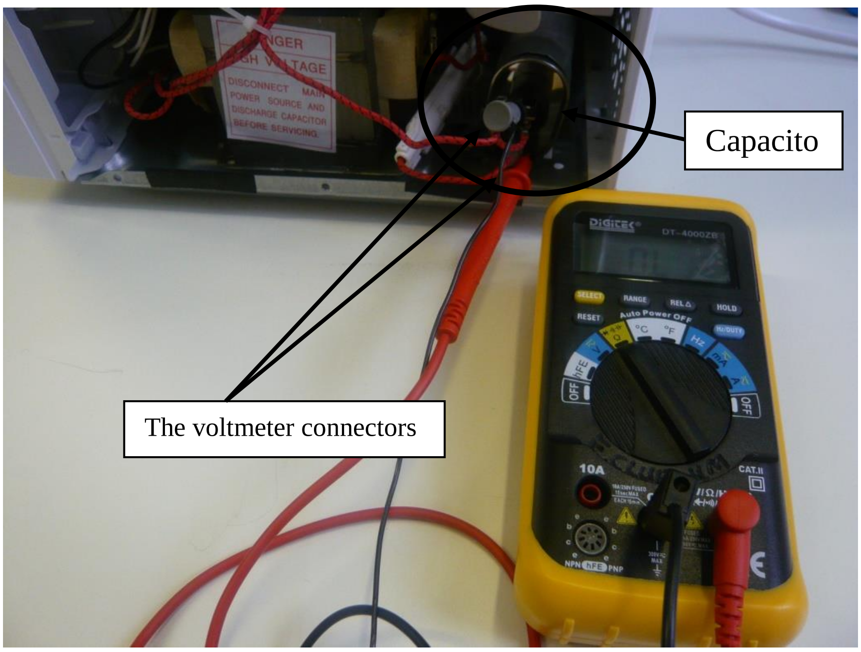

Figure 4.17: The arrangement of the HV capacitor (Voltage-Doubler circuit) test

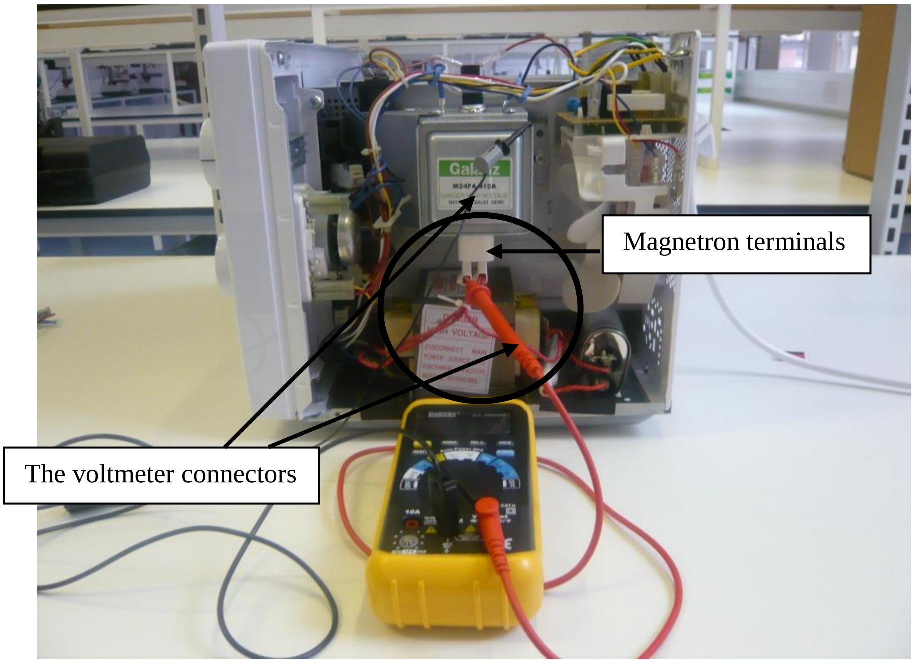

Figure 4.18: The arrangement of the magnetron test

Note: Figure 4.17 and Figure 4.18 depicts the test procedure to identify faulty component within category 5 and 6 of electrical faults respectively, damaged HV capacitor (Voltage-Doubler circuit) (E5) and Defective magnetron (E6).

Figure 4.19: An arcing magnetron

Note: Figure 4.19 depicts the test procedure to identify faulty component within category 6, Defective magnetron (E6).

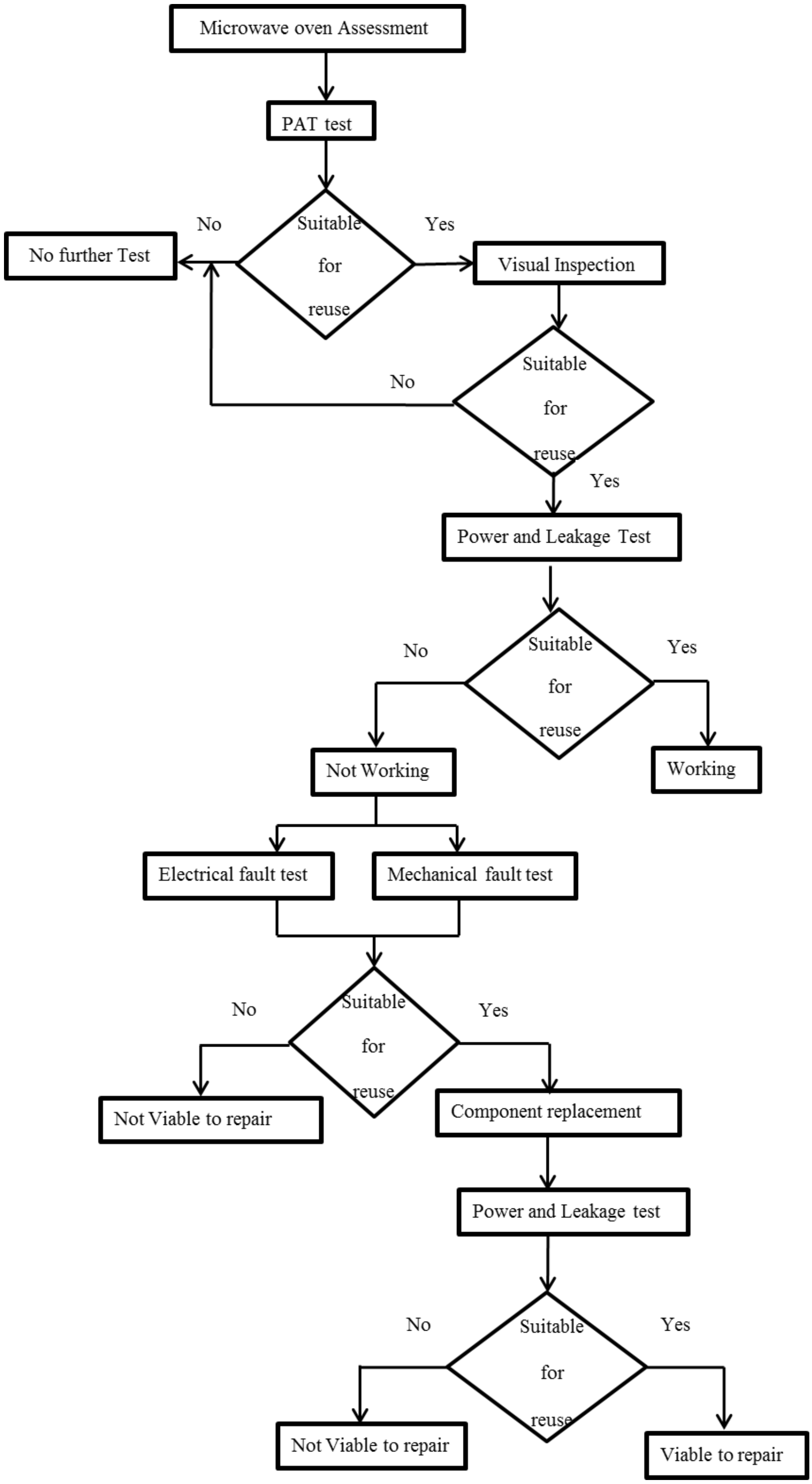

Figure 4.20: The test procedure work flow

4.5 Method for the Third Research Question

Research question 3: What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?

Following subsections provides methods that used to answer research question three in details.

4.5.1 Recommended Measures for Optimising Design and Facilitating Reuse and Life Span Extension

To fulfil the third objective of this research the third study was designed and conducted. The aim of this part of the study is to recommend measures for optimising design and facilitating reuse and life span extension based on the failure rate of the components and parts. The empirical data collected by research question two was used in order to lay the foundation to answer the research question three.

In order to lay the foundation, this part of the study began with an extensive literature review within the area of the design for remanufacture to uncover related studies. Furthermore, the hand dismantling of three microwave ovens was carried out. Three disposed/used microwave ovens from two different manufacturers were selected and dismantled (Bosch BM750PSL (800W-1200W) electrical control, Panasonic Inverter, NN-T5735BBPQ (900W-1300W) electro-mechanical control and Panasonic NNE205WBBPQ (800W-1100W)). The selection criteria were based on the type of the technology and the design of the ovens which were mostly tested to answer research question two as well as available disposed oven at the UoM at the time of dismantling survey. Two units were sourced from the CREATE UK and one unit was sourced from an employee of the University of Manchester. The following observations were documented throughout dismantling:

- The design differences between three individual units
- The design difference of individual components of each oven
- The time required to disassemble individual components of microwave ovens
- The units' easiness to disassemble, e.g., number of fasteners
- Easy access to individual components
- The composition of material within each component

4.5.1.1 Microwave oven Disassembly Method

This section explains the oven's manual disassembly method that has been employed at the University of Manchester by the author. The photos and manual notes were used as documentation techniques in this part of the study.

The tools used for disassembly of units are as follows. A selection of manual Philips and flat-headed screwdrivers in various sizes, safety screwdriver with various heads and sizes, and a pair of pliers were used. Furthermore, an electric screwdriver with various heads and sizes was available in case of need. However, during disassembly of the ovens the electric screwdriver was not used.

The individual parts were examined in order to identify interesting design features. Furthermore, components were examined visually for material composition. The disassembly process started with removal of the top cover. The visual inspection carried out in order to locate wiring connectors, fasteners and screws. Furthermore, based on the findings of the research question 2, the components with most fault rates were located and assembly and disassembly of those individual components were assessed, i.e., the magnetron or power cord. The following disassembly sequences were suggested to follow for three individual units. However, at some point due to design difference of units' adjustment to the disassembly sequences were made; the findings are reported in Chapter 5. In this study the disassembly sequences were as follow: 1- top case, 2- power cord, 3- filter circuit board, 4- control unit, 5- H.V. transformer, 6- H.V. fuse, 7- capacitor, 8- diode and case, 9- magnetron, 10- cooling fan and cooling fan case, 11- bulb, 12- thermostat, 13- door micro switches and casing, 14- entire door assembly, 15- bottom case, 16- black rubber stand, 17- rotating plate motor, 18- waveguide cover, 19- rotating roller, 20- rotating plate and 21- microwave chamber.

Furthermore, the researcher examined individual components of the three microwave ovens and the units as whole to suggest design changes in order to reduce the disassembly/assembly time, ease to disassemble and to facilitate and pro-long lifespan of the product. The recommendations on optimisation of the design of individual component or product to facilitate reuse or remanufacturing are given in Chapter 5 of this thesis.

4.5.1.2 Ease of Disassembly

To determine the ease for disassembly of the ovens, following criteria were assessed and documented.

- Number, type and size of screw used in the assembly of the oven,
- Ease of access to individual components without removing other individual component,
- Methods of components attachements, e.g., screw, metal clip or snaps fit, and
- Time required to disassemble individual components.

The results of the analysis of each of the microwave ovens are given in Chapter 5 of this thesis.

4.6 Data Analysis

This section presents the methods, which were used to analyse the findings of the three individual methods used to answer the research questions that presented in the previous sections.

4.6.1 Research Question One

The empirical data from research question 1 were loaded into the Microsoft Excel spreadsheet data management. The data that gathered from interviews were assessed and coded in terms of the questions that are given in Table 4.2. The data were coded in the format of ‘working=working’, ‘Not working=Not working’, ‘Yes=Yes’, ‘No=No’ and ‘Not answered=Not answered’ for each respondent. Furthermore, the comments and quotes were recorded additionally in a separate column accordingly (see, Appendix A9 for a snapshot of the spread sheet).

Table 4.2: The questions which data were assessed and coded accordingly.

Q1	Approximate date of purchase of the microwave oven	Date/Not Answered
Q2	Could you please tell us whether your discarded microwave oven is working	Yes/No/Not Answered
Q3	If the item is not working, are you able to pinpoint what is wrong with the product?	Yes/No/Not Answered
Q4	Are you replacing or updating this item with a more modern product?	
Q4.1	If the item is not working, are you replacing or updating this item with a more modern product?	Yes/No/Not Answered
Q4.2	If the item is working, are you replacing or updating this item with a more modern product?	Yes/No/Not Answered
Q5	Are you aware of other disposal options for your unwanted working items besides HWRC (e.g., donating, reuse organizations)?	Yes/No/Not Answered

Note: Q3 and Q4.1 were posed only to consumers, whose answer to Q2 was negative, Q4.2 only to consumers who answered positively.

The purpose of this study was to assess consumers' perception, knowledge and behaviour towards disposal of microwave ovens. Therefore, to analyse the data in this study the author decided to use an exploratory data analysis approach and employ descriptive data analysis techniques to cover such point as lifespan of units, in presenting the findings. Furthermore, this method is widely used in marketing, consumer and behavioural research [155] (e.g., See, reference [93]). This was done by counting the frequency of respondents who gave the same response to a particular question. The data are illustrated using percentages, tables and graphs. Section 5.1 of Chapter 5 presents the analysis of the data of the research question 1.

4.6.2 Research Question Two

The data collected for research question two were based on the fault diagnostic tests of 189 ovens. The data was checked for their accuracy by the researcher and the technician once the test was completed for that unit. Furthermore, the data were recorded using Microsoft Excel spreadsheet data management. The data was coded in the format of ‘Yes=1’, ‘No=Not applicable (N/A)’and ‘Not tested=Not tested’ for corresponding unit. Furthermore, the comments were recorded additionally in a separate column accordingly (see, Appendix A10).

The data was analysed in two phases. Phase one, consisted of identifying ‘working’, ‘not working’ and ‘not tested’ units. In phase two, the faults of the ‘Not working’ units were further analysed and categorised based on the viability to repair in order to reuse and remanufacture, based on the two criteria, time to repair and cost of parts. The two categories are namely ‘minor repair’ and ‘major repair’. In this study, a repair considered ‘minor repair’ if it could be accomplished with spare parts that retailed for less than £15 and would take no more than 15 minutes to complete (including disassembly, component replacement, reassembly and testing). The criteria were based on the CREATE UK practice and procedures on the white household goods and author’s communications and observations with CREATE UK engineers during field trips to their workshop. Furthermore, it was based on author’s observation of quality of remanufactured products at the CREATE UK retail floor. Prices used were those for spare parts available on the websites of specialist shops that cater to the repair industry as well as eBay UK. Repair times were based on recorded average repair times and opinions of participating technicians. The average price and source of the price that were used for each component are given in Appendix A13 (Tables A21-A25). Faults in categories E1, E3, E4, M2, and M4, and certain types of faults in M6, were considered minor, all others deemed major.

Exploratory data analysis was used to present the findings and frequency distributions of the faults [156]. This was done by counting the frequency of the fault in each category of faults. Furthermore, Pareto analysis of the identified failure modes has been carried out to prioritise and rank the frequency of component faults. Section 5.2.2 and Section 5.2.3 of Chapter 5 illustrates the data using tables and graphs.

4.6.3 Research Question Three

The empirical data from research question 3, was documented using Microsoft office word and also the photos were examined according to the notes that were taken during observation to verify their accuracy. Furthermore, the research supervisors and technicians at the UoM approved the analysis and recommendations. The recommendations were compared to those in the literature. Moreover, all recommendations were evaluated by colleagues at the UoM for feasibility, and by CREATE UK, a large, independent UK remanufacturer, for their usefulness in facilitating remanufacturing of the microwave ovens. Section 5.3 of Chapter 5, focuses on the analysis and recommendation based on the third research question.

4.7 Summary

The methods employed to answer each research question are given in this chapter. The details of semi-structured interview, faultfinding diagnostic tests set up and process in the research work presented in the thesis are given in this chapter. Comprehensive descriptions of arrangements for semi-structured interviews at the HWRC are given in this chapter. The set up and procedure of the fault diagnostic survey at the HWRC and at the University of Manchester are explained separately. Finally, the ovens hand disassembly method and tools used are outlined. Furthermore, the tools that were used to analyse the findings of three studies are given for each research study separately. The following chapter presents the findings of this study.

Chapter 5: Findings and Analysis

This chapter discusses the findings of the research questions outlined in Chapter 1. Section 5.1 describes and analyses the findings of the research question 1 “*What is the consumers’ knowledge and behaviours with respect to the functionality and disposal of microwave ovens?”* in detail. Section 5.2 focuses on the fault diagnosis with respect to the research question 2, “*What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?”*. The frequency and type of mechanical and electrical fault surveys are described and analysed in Sections 5.2.1 and 5.2.2 respectively. Section 5.3 addresses the findings of the research question 3 “*What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?”.* The time required to disassemble, ease of disassembly of individual components, material compositions of three microwave ovens are given in Section 5.3.1. Furthermore, the recommendations for facilitating reuse and life span extension of microwave ovens are given in 5.3.2. Summary of findings and analysis are presented in Section 5.4. Section 5.5 provides a general discussion on surrounding of the finding of this study. Finally, Section 5.6 gives a summary of this chapter.

5.1 Findings of the First Research Question

Research question 1: What are the consumers' knowledge and behaviours with respect to the functionality and disposal of microwave ovens?

As outlined in Chapter 1, one of the objectives of this research was to investigate and address the consumer knowledge of the functionality of the product at the point of disposal as well as their behaviour and perception towards microwave oven disposal at the point of disposal. Table 5.1, presents the overal findings of the Face to face Semi-structured interview of the consumers.

Table 5.1: Semi-structured interview of consumer behaviour related to disposal of microwave oven at the Longley Lane HWRC

	Yes	No	Not Answered	Total
Q2.	41 (50%)	39 (48%)	2 (2%)	82 (100%)
Q3.	16 (41%)	5 (13%)	18 (46%)	39 (100%)
Q4.1.	21 (54%)	0 (0%)	18 (46%)	39 (100%)
Q4.2	29 (71%)	2 (5%)	10 (24%)	41 (100%)
Q5.	19 (23%)	55 (67%)	8 (10%)	82 (100%)

Note: Five questions were asked of 82 consumers who disposed of microwave ovens at the HWRC in Greater Manchester. Q1- Approximate date of purchase of the microwave oven, Q2- Could you please tell us whether your discarded microwave oven is working (Yes)/not working (No)/Not Answered?; Q3- If the item is not working, are you able to pinpoint what is wrong with the product? Yes/No/Not Answered; Q4.1- If the item is not working, are you replacing or updating this item with a more modern product? Yes/No/Not Answered; Q4.2- If the item is working, are you replacing or updating this item with a more modern product? Yes/No/Not Answered; Q5- Are you aware of other disposal options for your unwanted working items besides HWRC (e.g., donating, reuse organisations)? Yes/No/Not Answered. Note that Q3 and Q4.1 were posed only to consumers, whose answer to Q2 was negative, Q4.2 only to consumers who answered otherwise. The answers to Q1 are eliminated from this table (see, Appendix A12).

For this purpose, 82 semi-structured interviews were conducted at the Longley Lane HWRC in the south of Manchester. The semi-structured interviews were analysed based on the six questions (Table 5.2 and Figure 5.1) and findings are given in this section. The overall response rate for 82 face to face semi-structured interviews was 100%.

Furthermore, observations during the semi-structured interviews revealed that most of those disposing of ovens were between 35 and 60 years old males, who owned cars. Moreover, the majority of consumers who disposed microwave ovens also disposed other household articles. For example, in one case a TV, a toaster and unwanted clothing, apart from a microwave oven were disposed by one consumer.[36] The following sections present the findings from semi-structured interview at the Longley Lane HWRC.

Q1: Approximate date of purchase of the microwave oven

The approximate age/date of purchase of the ovens was given by respondents which revealed the approximate age of the discarded ovens. Their answers were ranged from one to twenty five years and the average age of the used products were between six to seven years. Almost 60% of the ovens have been used for 6 years or less and half of those were used for 3 years or less before disposal. This confirms that the life span of the microwaves is relatively short, between 6-7 years, compare to other products in category one of WEEE directive e.g., washing machine. Furthermore, four interviewees (~5%) did not remember or did not know the approximate date of

[36] This information was concluded from the author`s conversation with HWRC staffs as well as author`s observations while presents at the recycling centre confirmed the information.

purchase of the microwave ovens, one interviewee stated *"just disposing for a friend"* and another stated that *"found the oven dumped outside of his driveway"*. The approximate life span of the 82 discarded microwave ovens which were stated by interviewees are given in Appendix A12, Table A 1.

Table 5.2: The 82 semi-structured interviews were analysed based on the five questions.

Q1	Approximate date of purchase of the microwave oven
Q2	Could you please tell us whether your discarded microwave oven is working
Q3	If the item is not working, are you able to pinpoint what is wrong with the product?
Q4	Are you replacing or updating this item with a more modern product?
Q4.1	If the item is not working, are you replacing or updating this item with a more modern product?
Q4.2	If the item is working, are you replacing or updating this item with a more modern product?
Q5	Are you aware of other disposal options for your unwanted (working) items besides HWRC (e.g., donating, reuse organisations)?

Note: Q3 and Q4.1 were posed only to consumers, whose answer to Q2 was negative, Q4.2 only to consumers who answered positively.

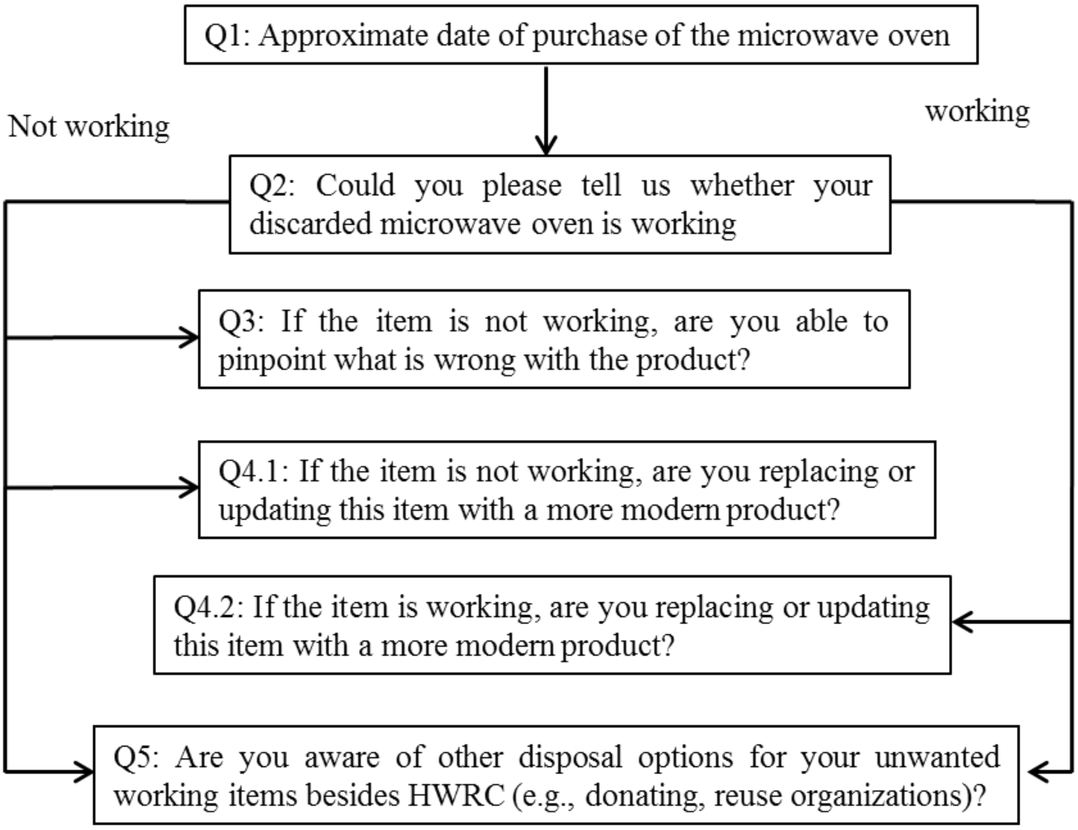

Figure 5.1: Semi-Structured questionnaire flow.

Q2: Could you please tell us whether your discarded microwave oven is working?

The interviewees were asked about their opinion on the functionality of their unwanted microwave ovens. It is revealed that 50% of respondents believed that their unwanted ovens were working, and almost 48% of respondents believed that their items were not working. Only two respondents (~2%) did not answer this question and it is most likely, as they stated that they did not have knowledge of the functionality of the units, furthermore following comments was given. One of the respondents stated that "*dropping off the microwave for a friend*" and the other one stated that "*found the oven dumped outside of the driveway*". Therefore, he/she did not know anything about the functionality of the product at the point of disposal. The overall consumers´ response to the question about their opinion on the functionality of their unwanted microwave ovens is shown in Table 5.3 below. However, the fault diagnostic survey indicated that, five of those ovens identified by owners as ‘not working’, were ‘working’ and one was ‘not tested’. Furthermore, one of the two units that respondents did ‘not answer’ the question was ‘not tested’ and another unit was ‘working’, for more on the functionality of the microwaves, see, Section 5.2. the findings show that the majority of the consumers had knowledge of functionalty of their units.

Table 5.3: The respondent's opinion of the functionality of their unwanted microwave ovens at the Longley Lane HWRC

	Number of respondants
Working	41 (50%)
Not working	39 (48%)
Not Answered	2 (2%)
Total	82 (100%)

Q3: If the item is not working, are you able to pinpoint what is wrong with the product?

The respondents to question 2 whom indicated that their ovens were ‘not working’ were further asked if they knew the reason why their microwaves had failed (see, Table 5.1). Nearly 46% respondents did not answer this question. However, 41% of respondents answered ‘yes’ to the question. Furthermore, some of the interviewees identified the problem with their microwaves in very general terms such as *“sparks inside the microwave”* or *“not heating”*. However, they were not able to pinpoint the source of the problem. In summary the respondents could identify the reason for non-functional unit as “*Start button broken (failure to start up)”, “The tube is shortened* *out-magnetron (unexpected noises)", "sparking when powered on", "non-working turntables", and "burnt out (rust)"*. Nearly 13% of respondents were unable to identify the source of the problem and answered 'No' to this question. For a list of reasons given by respondents see, Appendix A13.

Q4: Are you replacing or updating this item with a more modern product?

To gauge consumer attitudes towards the latest innovation and technological upgrades, the interviewees who answered question number two that the disposed oven is either 'working' or 'not working' further were asked whether they are replacing or updating the disposed item with a more modern oven. The responses were analysed as follows, for ease of presentation. Question 4.1 answered by those responded that their oven was 'not working' and question 4.2 answered by those responded that their oven was 'working'.

Q4.1: If the item is not working, are you replacing or updating this item with a more modern product?

Those consumers whom answered 'not working' in response to the question two further were asked whether they are replacing or updating non-functional units with a modern product.[37] 54% of respondents answered 'Yes' to this question which shows that more than half of the consumers who thought the disposed products were non-functional planning to purchase or already had purchased new functional modern

[37] In this study, a modern product referred to as a product with contemporary look and design with similar functionality (mechanical or electro-mechanical) as of the consumer has experience of understanding 'How does product work' from its functionality point of view. While asking this question the interviewer referred to the current disposing oven of the respondent to clarify the meaning of the modern oven.

products. Furthermore, 46% of the respondents did not answer this particular question, the author suspects that this could be for a variety of the reasons, one important reason could be that they either did not think of the functionality of the new unit to be purchased or were not able to remember the exact difference between the disposed oven and new purchased oven.

Q4.2: If the item is working, are you replacing or updating this item with a more modern product?

To gauge consumer attitudes towards the latest innovation and technological upgrades, the interviewees who answered to question two that the disposed oven is 'working' further were asked whether they are replacing or updating functional units with a modern oven. The respondents' answers are as follows. Nearly 72% were replacing or planned to replace their functional ovens with modern ovens. Some 5% of interviewees were responded that they "were not replaced or replacing" their functional units with modern units. This indicates that the consumers most likely replaced their functional units with the similar units and similar product characteristics such as make, model, colour and functionality. Furthermore, 25% of respondents did not answer this question. The author speculates that the respondent either had not replaced the unit or did not know the difference between new and disposed unit. However, further analysis shows that 11 (38%) ovens of the 29 ovens which owners stated that they were replacing or replaced with modern ovens had cosmetic failures such as crack cavity and dirt. It shows that cosmetic imperfection of the functional ovens can be one of the reasons consumers replaced their units with a modern product, i.e., stainless cavity instead of the enamel paint cavity. The findings are summarised in Table 5.4.

Table 5.4: The responses to the question 4.1 and 4.2.

	Replaced with modern unit	Not replaced with modern unit	Not answered	Total
Not working unit	21 (54%)	0 (0%)	18 (46%)	39 (100%)
Working unit	29 (71%)	2 (5%)	10 (24%)	41 (100%)

Note: 41 respondents believed that their units were functional at the point of disposal, 39 respondents believe that their units were defective and not functional at the point of disposal however 2 respondents did not answer this question whether the oven is working or not working.

Q5: Are you aware of other disposal options for your unwanted working items besides HWRCs (e.g., donating, reuse organizations)?

Respondents (82) were asked about their awareness of alternative end-of-life destinations for their unwanted functional products, the results are summarised in Table 5.5 below, according to the respondent's opinion on the functionality of the disposed oven and their awareness of other disposal option.

Table 5.5: The respondents' awareness of other disposal option according to their opinion on functionality of the disposed ovens

	Yes	No	Not answered	Total
Working oven	12(14%)	28(34%)	1(2%)	41(50%)
Not working oven	7(9%)	27(33%)	5(6%)	39(48%)
Not answered	0(0%)	0(0%)	2(2%)	2(2%)
Total	19(23%)	55(67%)	8(10)	82(100%)

Note: 23% of total respondents were aware of other disposal options and 67% of respondents were not aware of other disposal options furthermore, 10% not answered this particular question.

As Table 5.5 shows, almost same numbers of the respondents with both working and Not working ovens were not aware of alternative disposal options for their ovens.

Nearly 67% said they "*are not aware of alternative end-of-life destinations besides HWRCs*". Just 23% of respondents stated that they "are aware of alternative end-of-life destinations" such as donations to charities and sell through second hand outlets. However, some of those who answered 'yes' further commented as follow "*reuse, resale but it is dirty*", "*yes (aware of alternative option) but easier to come HWRC*", "*reuse and charity*". Furthermore, one of the respondents which stated that the oven is 'not working' further commented that "*yes (aware of) reuse, (however) repair is expensive*" and one other respondent commented "reuse, resale". One of those responded to this question as 'No' commented that "did not consider (another option)". Moreover, 10% of the respondents did not answer this question. The author speculates that the reason behind not answering this particular question could be such as the lack of time due to the location where that interview took place which have caused the respondent to not pay attention to the questions and consequently not answering this particular question.

5.2 Findings of the Second Research Question

Research question 2: What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?

To establish the functionality of the microwave ovens at the point of disposal, a questionnaire was prepared (Appendix A1) to be completed for each unit by the researcher under supervision of an experienced technician. Visual inspection of all items for missing electrical and mechanical components which may limit further tests were carried out prior to test begins. The test was carried out in five phases. For detail explanation of fault diagnosis procedures, refer to Chapter 4 of this thesis. In total 189 ovens from 40 different microwave oven manufacturers were tested such as Panasonic, Asda, Bosch and Belling. The brand names and models of the 189 microwave ovens manufacturers are given in Appendix A13 (Table A 12 and Table A 13).

The initial fault diagnostic test results show that, sixteen (8%) units either failed the PAT test or deemed not safe to test, i.e., missing entire control unit, missing high voltage transformer and broken window; therefore, further scheduled fault diagnostic tests were not performed and classified as ‘Not tested’. The reasons that caused the ovens not to be tested are given in Appendix A13, Table A14. Furthermore, 33 units (18%), found to be in perfect ‘working’ condition, could potentially be reused after cleaning, safety checks and without any servicing. The findings of the functionality test of 189 ovens are shown in Table 5.6, (Appendix A13, Table A15 and Table 16 presents the functional test of 82 microwave ovens collected directly from consumers and 107 ovens collected via CREATE UK respectively).

Table 5.6: The summary of functionality test of 189 microwave ovens

Microwave oven functionality test	
	No. of microwave ovens
Not tested	16 (8%)
Working	33 (18%)
Not working	140 (64%)
Total	189 (100%)

Note: Total of 189 ovens tested. Of those 16 not tested, either failed the PAT test or deemed not safe to test, i.e., missing entire control unit, missing high voltage transformer and broken window, therefore further scheduled tests were not carried out. 33 ovens categorised as working and could potentially be reused after cleaning, and without any servicing. 140 units classified as not working and further tests were carried out. Of those 70 units classified as minor repair in order to be remanufactured and remaining 70 ovens classified as major repair needed and deemed as not viable to be remanufactured.

The electrical and mechanical faults were classified as follows. Electrical faults: E1. Damaged cord, mains lead, or plug or blown fuse (top or internal); E2. No voltage at the filter circuit input; E3. Voltage supply unavailable at the control circuit input; E4. Damaged high voltage (HV) transformer and fuse; E5. Damaged HV capacitor; E6. Defective magnetron. Mechanical faults: M1. Faulty handle or door locking mechanism; M2. Faulty or broken door; M3. Defective or damaged controls; M4. Out of order rotating base; M5. Damaged display; M6. Other faults including dirt, worn out inside coating, small cosmetic imperfections, and damaged upper case.[38] The remaining 140 units presented cosmetic imperfections or exhibited electrical or mechanical faults. The electrical and mechanical faults further were classified into the minor or major repair categories (see, Section 5.2.1). In summary, a total of 70

[38]Category 6 of the mechanical faults refer to cosmetic imperfections.

units representing 37% of total units, were classified under ‘major repair’. Further 70 (37%) units were classified as ‘minor repair’ required in order being functional and economically viable for reuse such as replacement of a power cord or turntable plate. Summary of minor and major repair for 82 ovens and 107 ovens are given in Table 5.7.

Table 5.7: The summary of functionality test of 189 microwave ovens according to source of the units.

	189 Microwave oven Functionality Test		
	Functionality Test of 82 microwave oven	Functionality Test of 107 microwave oven	Total of Ovens
Not tested	4 (5%)	12 (11%)	16
Working	19 (23%)	14 (13%)	33
Minor repair	19 (32%)	51 (63%)	70
Major repair	40 (68%)	30 (37%)	70
Total	82 (100%)	107 (100%)	189

Note: in total 140 ovens test for their functionality and cosmetic imperfection. 82 ovens collected directly from consumer at the HWRC and 107 ovens collected by CREATE UK from two HWRCs. 59 of 82 ovens and 81 of 107 ovens found with minor/major faults.

5.2.1 Fault Types

Fault types were further classified according to gravity, that is, whether minor or major repairs were indicated. This classification was dictated by two criteria, time to repair and cost of parts. A repair was deemed minor if it could be accomplished with spare parts that retailed for less than £15 (excluding labour and transportation costs) and would take no more than 15 minutes to complete (including disassembly, component replacement, re-assembly and testing).[39] Prices used were those for spare

[39] In this case, based on the CREATE UK experience, the author assumed that the remanufacturing processes could be carried out by free labour under the training at the CREATE UK workshop.

parts available on the websites of specialist shops that cater to the repair industry as well as e-Bay and Amazon (see, Appendix A13, Tables A21 and A22); Table 5.8 summerises the average component price and estimated repair time that used as an indicator to minor repair (see, Appendix A13, Table A23 and Table A24 for detailed component costs of electrical and mechanical minor repair). The repair times were based on the recorded average repair times and opinions of participating technicians. The fault categories within minor and major repairs are given in Table 5.9. The 173 units were tested for electrical and mechanical faults, 33 of those found to be working therefore further tests were carried out for remaining 140 ovens.

Minor Repairs/Part Replacements

The minor repairs within electrical faults are as follows. Faults in category E1 are 'damaged mains lead/plug/blown plug top fuse/blown the internal fuse'. By simple replacement of the component or repair, the product can be reused. Faults in category E3 are 'mains supply not available at input of control circuit which can be solved by replacement of micro-switches such as primary and secondary interlock switches and monitor switch within the control circuit board or replacement of connectors. The faults in category E4 are 'damaged high voltage transformer and fuse'. Most of the faults within this category were identified as 'blown fuse' therefore, this fault simply can be solved by replacing defective H.V. fuse.

The minor repairs within mechanical faults are as follows. The certain type of faults within the category M2 'faulty or broken door' the most frequent fault within this category identified as faulty or misplaced door hinges and latches. Faults in category M4 were 'defective/damaged rotating base'; the units with missing or damaged rotating base roller and drive coupler were included in this category. Furthermore, the certain types of faults in M6 such as dirt, slight paint damage to cavity and slight case damage were considered minor. Summary of minor and major fault classification are given in Table 5.8.

Table 5.8: Summary of major and minor fault classification for remanufacturing purpose

Category	Major fault	Minor fault
Electrical	E2. No voltage at the filter circuit input; E5. Damaged HV capacitor (Voltage-doubler circuit); E6. Defective magnetron.	E1. Damaged cord, mains lead, or plug or blown fuse (top or internal); E3. Voltage supply unavailable at the control circuit input; E4. Damaged high voltage (HV) transformer;
Mechanical	M1. Faulty handle or door locking mechanism; M3. Defective or damaged controls; M5. Damaged display; M6. Other faults include worn out inside coating and major damaged case	M2. Faulty or broken door; M4. Out of order rotating base; M6. Other faults including dirt, small cosmetic imperfections, missing glass plate and slight damaged case

Note: The classification of the fault types was dictated by two criteria, time to repair and cost of parts. A repair was deemed minor if it could be accomplished with spare parts that retailed for less than £15 and would take no more than 15 minutes to complete (including disassembly, part replacement, re-assembly, and testing).

The average component price and estimated repair time to carry out each minor repair are given in Table 5.9. The minor mechanical and electrical faults can be solved simply by replacing faulty or missing components.

Table 5.9: The average component price and estimated repair time used as an indicator to minor repair

	Component	Cost of component	Time to repair	Ease of Access
E1	Mains, cable lead	£3	5-10 min	Worst
	13 A Fuse	£1.50	3-5 min	
E3	Micro-switches	£12	10-15min	Worst
	Wire connectors	£0.15	8-10min	Worst
E4	High voltage fuse	£9	12-15 min	Worst
M2	Latches or hooks	£9	10-15 min	Worst
	Hinges	£11	10-15 min	Worst
M4	Rotating base roller	£11	1-2 min	Best
	Drive coupler	£9	1-2 min	Best
M6	Glass plate	£15	1-2 min	Best
	Touch paint	£5	10-15 min	Worst
	Waveguide cover	£6	2-5 min	Best

Note: The approximate average component prices are given here were those for spare parts or similar universal spare parts available on the websites of specialist shops that cater for the repair industry (www.espares.co.uk, www.buyspares.co.uk and www.bec-components.co.uk), as well as e-bay.co.uk and amazon.co.uk. The websites were accessed between Jun 2011 and February 2012. The repair times were based on the recorded average repair times including dismantling, component replacement, assembly and test, and opinions of participating technicians. The ease of access to the components were categorised as worst and best based on the time and number of tools needed to access the individual component.

Major Repairs/Part Replacements

The major repairs on electrical faults are considered as follows. The category E2, the units that were identified with this fault were likely to have defective components on the circuit board or discontinuity on solders. In order to repair these faults a repair expert would be needed and replacement of the component would not be economical. The units with category E5 faults, no power to the capacitor (voltage doubler circuit), are also considered as major repair. Most units in this category had defective voltage doubler circuit which included defective capacitor or diode in most cases the replacement of components financially would not be viable and time consuming and a repair expert needed. The units with defective magnetrons, E6, are also considered as in need of major repair as the replacement of component financially would not be viable.

The major repair of mechanical faults is classified as follows. The unit with faulty handle/door locking mechanism (M1) including door lever and interlocks casing and the units with a defective/damaged control (M3) and damaged display (M5). However, the units with faulty handle/door locking mechanism, defective/damaged controls and damaged display could be repaired only by replacing faulty sub components or entire components which are considered as costly and time consuming. Furthermore, the cosmetic imperfection (M6) such as worn out cavity painting and severe damage to the outer case of oven were also considered as major repair for the same reason.

The results for units tested are as follows. Half of the examined units (70) required only minor repairs (e.g., replacing an internal fuse or external cable). Of these, 22 units (16%) had only minor cosmetic imperfections like external damage occasioned by transport, accumulated dirt or missing part i.e., turntable plate. Minor electrical faults found in 22 (16%) of tested units. 33 (23%) units had minor mechanical faults. Furthermore, 15 units had both minor mechanical and electrical faults. For example one unit in this category had category E1 (missing cable) fault as well as category M6 (dirt) fault. Major repairs required by the other half of the units included repairs such as replacing a non-functional magnetron. Table 5.9 below, summarises the results. Following sections provides the type and frequency of the mechanical and electrical faults in details.

Table 5.9: Quality of microwave ovens examined and sources of faults

Microwave oven fault categories			
	Minor repair	Major repair	Total
Electrical fault	22 (16%)	17 (12%)	39 (28%)
Mechanical fault	33 (23%)	34 (24%)	67 (47%)
Electrical and mechanical faults	15 (11%)	19 (14%)	34 (25%)
Total	70 (50%)	70 (50%)	140 (100%)

Note: Each of the 173 microwaves that redeemed as safe to apply further scheduled tests (16 ovens were not either passed the PAT test or classified as not tested for various reasons such as already dismantled parts or missing H.V transformer) was tested for six different electrical and mechanical imperfections. This table shows the results for the 140 microwaves that presented electrical and/or mechanical faults. The other 33 microwaves were in perfect working order.

5.2.2 Types and Frequency of Mechanical Faults

Mechanical faults are categorised into six different types of faults. Each of the 140 ovens is examined for faults within each category.

The type and frequency of the mechanical faults of 189 microwave ovens, according to their corresponding categories are given in

Table 5.10 (Appendix A13, Tables A17 and A18 present the type and frequency of mechanical faults of 82 microwave ovens and 107 ovens respectively, according to their corresponding categories).

Table 5.10: Major/Minor mechanical faults in 140 microwave ovens

Category	No. of oven with mechanical fault	% of faults
M1	3 (2%)	3%
M2	13 (9%)	11%
M3	14 (10%)	12%
M4	8 (6%)	7%
M5	5 (4%)	4%
M6	71 (51%)	62%

Note: As in Table 5.6, the 140 microwave ovens that passed the PAT test and were found to be defective are considered. 114 mechanical faults identified. Categories are the same as described in Section 5.2.1. This was a multiple fault diagnostic tests therefore; some items had multiple faults including both electrical and mechanical ones. For example, seven of the microwaves presented two mechanical faults, and two had three mechanical faults.

Furthermore, a Pareto analysis of the failure rate of components is given in Figure 5.2 (see, Appendix A 13, Table A 26 for the results obtained from Pareto analysis). The Pareto analysis of the diagnostic test results of mechanical faults identified the most faulty components within the categories as M6. Other faults including dirt, worn out inside coating, small cosmetic imperfections, and damaged upper case; M3. Defective or damaged controls and M2. Faulty or broken door with the total number of failures being 71, 14, and 13, respectively.

Moreover, some items had multiple faults including both electrical and mechanical faults. For example, seven of the microwaves presented two faults, and two had three mechanical faults. The test results are as follows.

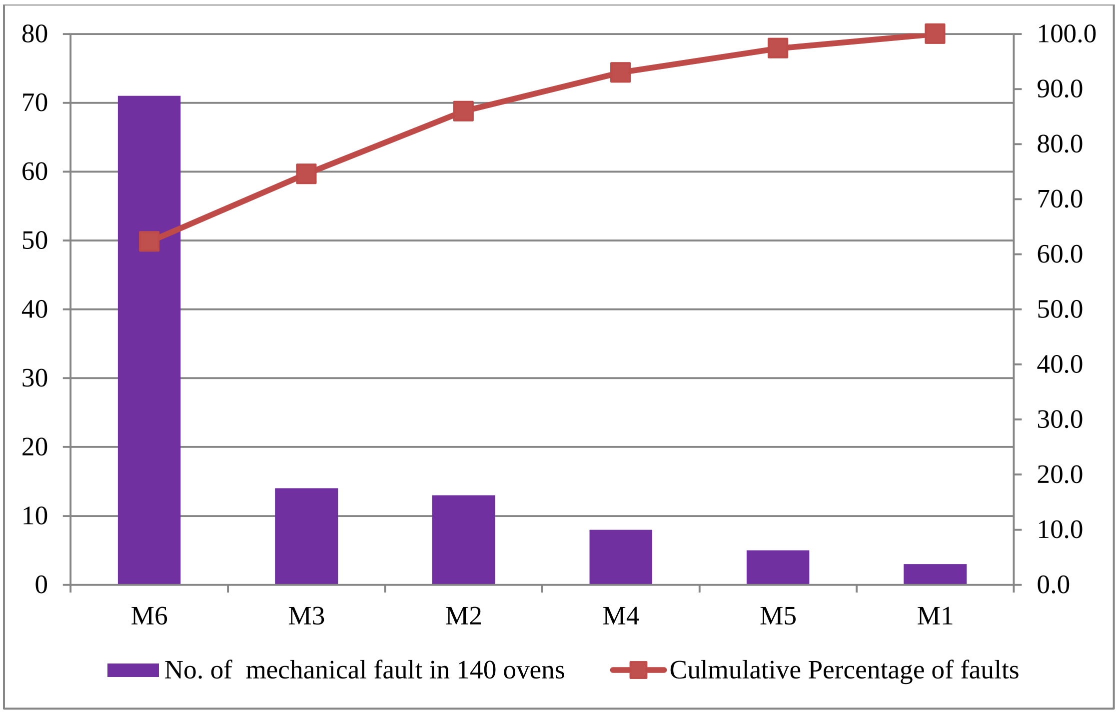

Figure 5.2: Pareto analysis of quantitative mechanical fault test results

Note: Pareto analysis of the mechanical faults of 140 ovens with 114 fault are shown in Figure 5.2. It shows that the most of the faults are caused by M6, M3 and M3 fault categories.

M1. Faulty handle/door locking mechanism

Only three units, representing ~ 2% of 140 ovens tested were identified with faulty handle or defective door locking mechanism.

M2. Faulty or broken door

Almost one tenth (13 units) of units found to have faulty or broken doors. Seven units sourced from CREATE UK (retrieved from recycling containers designated for collection and transported to the CREATE UK and then to the UoM) and 6 units collected directly from consumers. These faults can have several reasons, such as careless handling by consumers and HWRC and CREATE collection staffs. However, the author speculates that this fault could be avoided mostly by improving disposal and transport processes.[40]

M3. Defective or damaged controls

Defective or damaged controls have found in 14 ovens. Seven of those units were collected directly from consumers and 7 units delivered by CREATE UK. The faults were included missing parts or broken touch control units. The author speculates that these faults could be caused by extensive usage by consumers or mishandling of unit during transportation.

M4. Out of order rotating base

Almost 8 units or ~ 6% of the tested ovens was found to be defective, damaged or missing the rotating plastic ring and rotating base knob. The rotating plastic ring base was missing in five ovens and rotating base knob was missing in three ovens. The author expaculates that the missing components can be explaind partially by that the components can be seen as spare part for consumer`s new oven.

[40] Although the author cannot establish this difference to be statistically significant, observation and discussion with individuals working at the disposal sites confirm this finding.

M5. Damaged display

Only five units representing ~ 4% of the units were found with damaged or malfunctioning display. The author speculates that these faults could be caused by extensive usage by consumers or mishandling of unit during transportation.

M6. Other faults including dirt, worn out inside coating, small cosmetic imperfections, missing rotating plate and damaged case

Cosmetic imperfection was found in 71 units representing 51% of 140 units tested for faults. Cosmetic imperfection or other faults are included missing rotating glass plate and peeled off, burned, or damaged internal coating as well as damage to the external casing and scratch on the screen that might have incurred in handling and transport. However, the cosmetic quality of microwave ovens collected from the HWRC was superior to that of units received from CREATE UK this can be explained by the differences between methods that were used to collect products from two different sources, namely as directly from consumers and retrieved from recycling containers at the HWRCs. The author anticipates that most of the imperfections to the exterior have resulted from transportation to the recycling centres, and in the case of products obtained from CREATE UK, between the charity and university. Furthermore, some of the units had multiple cosmetic imperfection. Moreover, 66 of 71 units identified with worn or damaged cavities which is the most common internal faults were localised heating and thermal damage caused by food spillage and worn cavities as a result of the inferior quality of the painting process and material used by some manufacturers. 17 units had damaged external casing due to transport. 11 units were identified with missing glass plate, the author expects that the missing components can be explained partially by that the components can be seen as spare part for consumer`s new oven.

5.2.3 Types and Frequency of Electrical Faults

The electrical fault diagnosis tests carried out according to six sub categories of electrical faults. Each of the 140 ovens is examined for faults within each category.

The type and frequency of the electrical faults of 140 microwave ovens, according to their corresponding categories are given in Table 5.12 (see, Appendix A13, Tables A19 and A20 presents the type and frequency of the electrical faults of 82 microwave ovens and 107 ovens respectively).

Table 5.11: Major/Minor electrical faults in 140 microwave ovens

Category	No. of oven with electrical fault	% of fault
E1	44 (31%)	43%
E2	6 (4%)	6%
E3	5 (4%)	5%
E4	11 (8%)	11%
E5	14 (10%)	14%
E6	23 (16%)	22%

Note: As in Table 5.6, the 140 microwave ovens that passed the PAT test and were found to be defective are considered. 103 major/minor electrical faults identified. Categories are the same as described in Section 5.2. This was a multiple fault diagnostic tests therefore; some items had multiple faults including both electrical and mechanical ones. For example, four of the microwaves presented three electrical faults each.

Furthermore, a Pareto analysis of the failure rate of components is given in Figure 5.3 (Appendix A13, Table A27, describes the results obtained from Pareto analysis). The Pareto analysis of the diagnostic test results of electrical faults identified the most faulty components within the categories as E1. Damaged cord, mains lead, or plug or blown fuse (top or internal); E6. Defective magnetron and E5. Damaged H.V. capacitor (voltage-doubler circuit) with the total number of failures being 44, 23, and 14, respectively. Moreover, some items had multiple faults including both electrical and mechanical faults. For example, seven of the microwaves presented two faults, and two had three electrical faults. The test results are as follows.

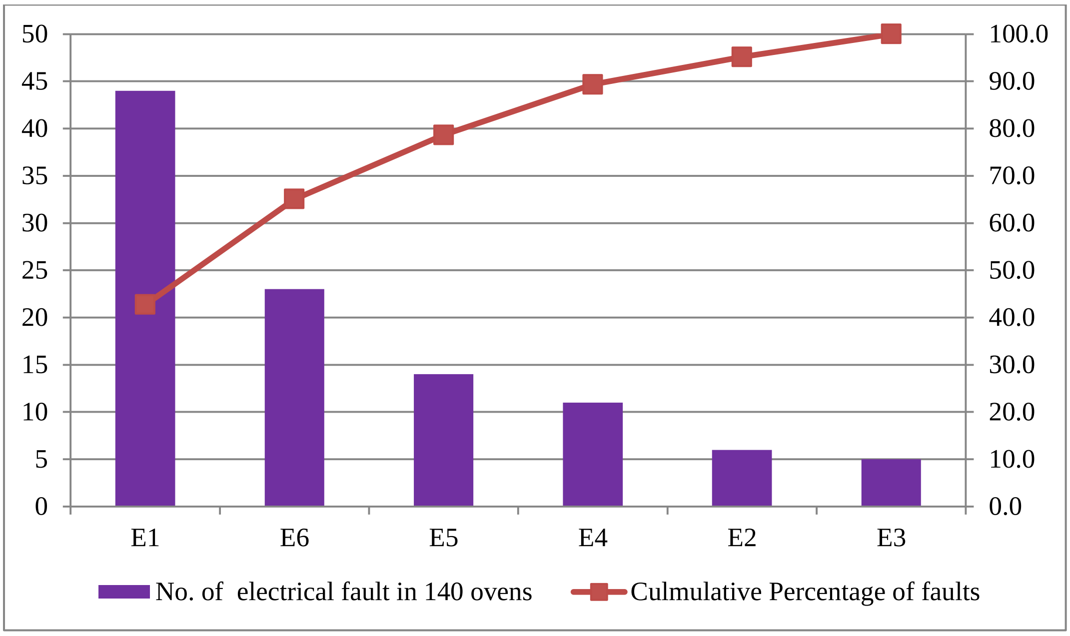

Figure 5.3: Pareto analysis of quantitative electrical fault test results

Note: Pareto analysis of the electrical faults of 140 ovens with a total of 103 faults are shown in Figure 5.3.

E1. Damaged cord, mains lead, or plug or blown fuse (top or internal)

The majority of the electrical faults within this category were missing plugs and leads. Almost 44 units comprising 31% of tested units were identified with 'missing plug and lead' or blown top fuse. Yet, interestingly, nearly one third of units collected directly from consumers at the HWRC reported with missing cords and plugs. This usually indicates that this electrical interface happens prior to disposing the microwave ovens at the local HWRC site by consumers. Therefore, many of the microwaves in this category were thus fully functional prior to disposal, and their reuse could be facilitated, at least to some degree, by simply making consumers aware that they are not liable for subsequent use of discarded items.[41]

E2. No voltage at the filter circuit input

The category 2 of electrical faults in the questionnaire is referring to the faulty filter circuit board or its components. The units in this category often had 'no voltage' at the filter circuit input or 'no voltage' at the filter circuit output. This could be due to shorting of the power supply to the board or loose component connection such as capacitors and resistors on the board. This category is the fifth most common fault diagnosed in this study, the six units representing ~ 4 % of tested microwave ovens were identified within this category.

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[41] This is confirmed by informal discussion with individual working at the site and supported by observation of the disposed other products such as TV, hair dryer, kettle, etc. during field work at the Longley Lane HWRC by the author.

E3. Voltage supply unavailable at the control circuit input

Defective control circuits are found in five units representing nearly 4% of tested units. The units in this category often did not respond to the control panel/knob. This could be due to shorting of the power supply to the board or loose connection between power and interlock and monitor switches as well as loose components such as capacitors and resistors on the board. This fault in category 3 is the sixth most common fault diagnosed in this study.

E4. Damaged high voltage (H.V.) transformer and Fuse

Defective high voltage transformer and defective high voltage fuse are the fourth most common fault diagnosed in this study. In summary, 10 units representing 8% of tested units are diagnosed with category 4 faults. Of those, six units were identified with defective high voltage fuse and the rest were with either defective high voltage transformer, or defective wire connectors to the magnetron and circuit doubler. The cause of the defective H.V. fuse might be a shorted H.V. capacitor, magnetron and shorted wires of the high voltage circuit.

E5. Damaged H.V. capacitor(voltage-doubler circuit)

The third most commonly diagnosed electrical fault was a failure of the capacitor or voltage-doubler circuit. 14 units representing 10% of tested ovens were diagnosed with this fault. The failure can cause a variety of other faults such as in some cases the shorted H.V. capacitor might blow H.V. fuse and an open H.V. capacitor will result in no heat and malfunctioning of the magnetron.

E6. Defective magnetron

The second most common electrical fault in testing microwaves was the failure of the principal component, the magnetron. In most of the cases the magnetron has suffered internal damage due to overloading or the grease of contaminating food stuff causing drying and breakdown where they could produce arcing and damage the magnetron. Furthermore, repeated heat exposure of food left in microwaves can burn the waveguide cover and damage the magnetron. Furthermore, the damaged filament and wire connectors can cause malfunctioning of the magnetron. 23 units, representing ~ 15% of microwave ovens diagnosed with such fault.

5.3 Findings of the Third Research Question

Research question 3: What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?

5.3.1 Disassembly of Microwave Oven

Information regarding types of component, individual weight, material composition and design of individual components are scant and are often withheld by OEMs. In order to gain knowledge of the design difference of individual components within the ovens and the unit assembly the following data was documented through dismantling of three used/disposed microwave ovens. The differences in their designs were examined and documented. The design and assembly of individual components were observed and documented. The time required to disassemble the individual components from ovens were recorded.

It was documented that it required 30, 37 and 24 minutes to dismantle the microwave oven I, II and III respectively.[42] It was documented that 37 minutes required to dismantle oven II to its component level, this was due to the higher number of screws that were used in the assembly of the unit as well as the less ease of access to the individual components, i.e., cooling fan casing and the magnetron. It was observed that the oven III was designed to disassemble easily compare to oven I and II, moreover it was observed that the use of less screw types and easy access to the components were helping to ease of disassemble of the oven III, which only three tools were used, two sizes of Philips screwdriver and one pair of Pliers. To dismantle the oven I, five tools (e.g., two Allen keys, safety screw driver, two sizes of Philips screwdriver and one pair of Pliers) and to dismantle the oven II, four tools were used (e.g., two sizes of Philips screwdriver, safety screw driver and one pair of Pliers). The times taken to dismantle three individual units are given in Table 5.12.

The composition of material within each component are visually examined and documented see, Table 5.13. It has been observed that Ferrous (steel and stainless steel) and non Ferrous (aluminium, copper, gold, silver and lead) metals, plastic and glass are used in the composition of the ovens. For example a typical transformer consists of copper and iron, the cavity wall is made of steel and aluminium or stainless steel and aluminium.

[42] The specification of the three ovens is as follows. Microwave oven I: Bosch BM750PSL (800W-1200W) electro-mechanical control, Microwave oven II: Panasonic Inverter, NN-T5735BBPQ (900W-1300W) electrical control and Microwave oven III: Panasonic NNE205WBBPQ (800W-1100W) electro-mechanical control.

The analysis of disassembly data of individual microwave ovens revealed interesting information regarding the design of the ovens and its components, and further resulted in recommendation for change in the design of the components to facilitate reuse and remanufacturing of used ovens in Section 5.3.2 of this Chapter.

Furthermore, by dismantling the units and their components observation were made about the difficulty of disassembly of the units and ease of access to the individual components. The reason behind this was to find out whether low skilled labour for example disadvantage adults placed at the CREATE UK would be able to carry out the disassembly and remanufacturing of such units. It was documented that disassembly of the following components were not easy in three ovens, e.g., H.V Transformer (Inverter), H.V capacitor, diode, magnetron and metal beam, cooling fan motor and rotating plate motor. The reason behind this is as follows. The level of access to the individual components without disassembly of other components as well as the number and different type of the fasteners that used in the assembly of the components which consequently leads to increase of the time to remanufacture ovens.

Design differences between three ovens were documented, for example the waveguide cover in the oven III was made of plastic while the waveguide cover of oven and I and II was a type of mica. Furthermore, the method of attachment to the cavity wall was different; i.e., the waveguide cover in oven II was attached with a screw as well as tabs places in slots while the waveguide cover in the oven I attached with only by tabs placed in slots. Figure 5.4 depicts the differences between three waveguide cover given above.

It was observed that the access to the magnetron of the oven II was difficult due to partial involvement of other components. However, in the ovens I and III screws were attached from the top of the magnetron. Access to the screws compare to the oven II were relatively easy. To dismantle magnetron in the oven II one must dismantle the metal beam and the plastic case holder. Figure 5.4 depicts the differences of assembly of individual magnetron of the three ovens.

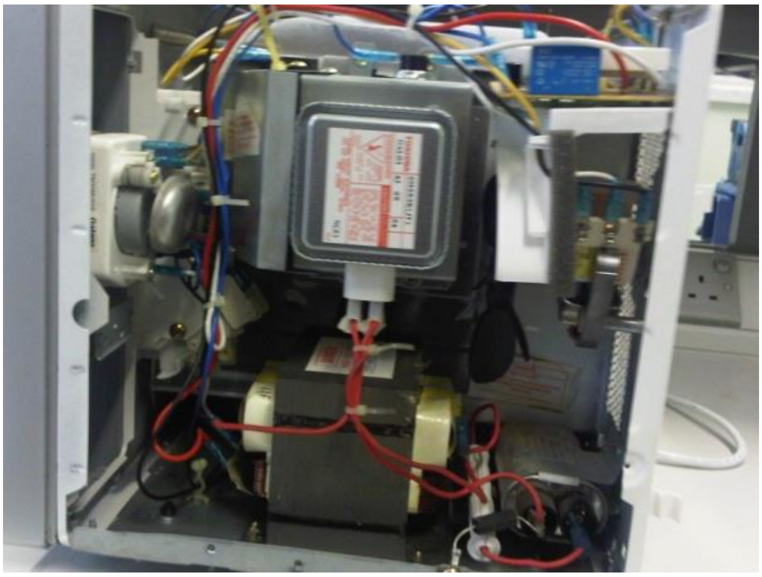
Furthermore, Table 5.12 summarises the data of disassembly of the three ovens as well as the time required to disassemble, the number of screws used in the assembly, types of screwdriver used in disassembly and overall ease of disassembly of the three ovens. For individual disassembly data of the three units refer to Appendix A14, Tables 32, 34 and 36.

(a) Oven I

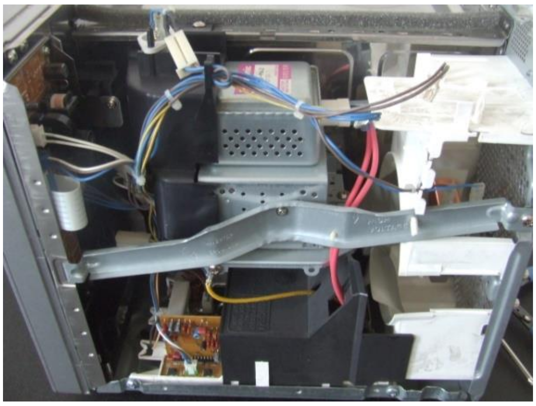
(b) Oven II (c) Oven III

Figure 5.4: The differences in waveguide cover design

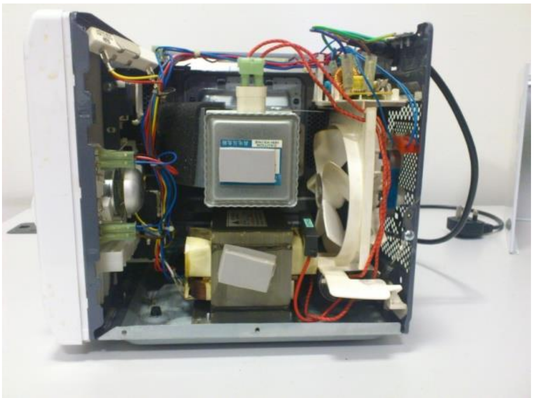
Note: Figure 5.4 (a) and (b) shows the waveguide cover made of mica in the oven I that attached only by tabs placed in slots. And oven II the cover was attached to the cavity wall by a screw as well as two corner tabs placed in slots. (c) Shows the waveguide cover in the oven III made of plastic which is used tabs placed in slot technique to attach to the cavity wall.



(a) Oven I



(b) Oven II



(c) Oven III

Figure 5.5: The differences of assembly of the magnetron of the three ovens

Note: Figure 5.5 (a) within the assembly of the magnetron in the oven I, seven screws provided access to the magnetron (b) in the assembly of the magnetron in the oven II, seven screws with two sizes were used. The access to the bottom screw was not easy and the beam and plastic casing had to be removed first to access to the screws (c) to disassemble the magnetron in the oven III, seven screws (most of them on top of the magnetron) were unsecured in order to access and disassemble.

Table 5.12: Summary of the disassembly of the three ovens, the time required to disassemble, the number of screws used in the assembly, types of screwdriver used in disassembly and overall ease of disassembly of the ovens.

	Microwave oven I	Microwave oven II	Microwave oven III
No. of Screw	38	42	34
No. of tools	4-Screwdrivers 1-Pliers	3-Screwdrivers 1 pair pliers	2-Screwdrivers 1 pair pliers
Type of Screwdriver	Type I-Philips Screw Medium head Type II-Philips Screw Small head Type III- safety screw driver Type IV-two Allen keys	Type I-Philips Screw Medium head Type II-Philips Screw Small head Type III- safety screw driver	Type I-Philips Screw Medium head Type II-Philips Screw Small head
Time to dismantle in minutes	30	37	24
Ease of disassembly	Worst	Worst	Best
Type of component involved in ‘not ease to disassemble’	H.V Transformer H.V Capacitor Diode Magnetron Rotating plate motor Entire door assembly	H.V Transformer (Inverter) Magnetron and metal beam Wave guide cover Cooling fan motor Interlock switches Rotating plate motor	H.V Transformer H.V Capacitor Diode Rotating plate motor

Note: The specification of the three ovens is as follows. Microwave oven I: Bosch – BM750PSL (800W-1200W) electro-mechanical control, Microwave oven II: Panasonic Inverter, NN-T5735BBPQ (900W-1300W) electrical control and Microwave oven III: Panasonic NNE205WBBPQ (800W-1100W) electro-mechanical control. The two of the ovens were sourced from CREATE UK and one was sourced from an employee of the UoM.

Table 5.13: The components composition based on the author's observation of the three dismantled ovens.

	Component	Visible material
1	Outer case and Bottom case	Aluminium
2	Power cord	Non-Ferrous, Plastic
3	Filter circuit board	Non-Ferrous, Plastic
4	Control Units	Non-Ferrous, Plastic
5	H.V fuse	Non-Ferrous, Plastic, Glass
6	H.V Transformer	Ferrous and Non-Ferrous
7	Capacitor, Diode and case	Non-Ferrous, Plastic
8	Magnetron	Non-Ferrous
9	Cooling Fan and casing	Non-Ferrous, Plastic
10	Cooling fan motor	Ferrous, Non-Ferrous, Plastic
11	Bulb	Glass, Plastic
12	Thermostat	Non-Ferrous, Plastic
13	Rotating plate motor	Non-Ferrous, Plastic
14	Wave guide cover	Plastic, Mica
15	Entire Door assembly	Non-Ferrous, Plastic, Glass
16	Door Micro switches and casing	Non-Ferrous, Plastic
17	Resistor, plastic cable fastner	Non-Ferrous, Plastic
18	Black Rubber Stand	Plastic
19	Wiring	Non-Ferrous, Plastic
20	Rotating plate	Glass
21	Microwave Chamber	Aluminum
22	Screws	Ferrous
23	Rotating Roller	Plastic

5.3.2 Recommended Measures for Facilitating Reuse and Life span Extension of the Microwave Oven

This Section is based on the analysis and results of the study reported in Section 5.2 and Section 5.3.1 of this thesis and focuses on the recommendations for facilitating reuse and remanufacture of microwave ovens. However, it was observed that many microwave ovens were disposed not because of the obsolescence and one fifth of the ovens have strong potential to be reused. The following sections present the ways to facilitate reuse, making remanufacturing process easier and affordable.[43] Furthermore, the modifications to improve the durability of the product, which would also contribute to longer life spans, are proposed.

The recommendations presented in the following sections are aimed at original equipment manufacturers (OEMs). Design recommendations are divided into two sections. Section 5.3.2.1 presents recommended measures for facilitating reuse and remanufacturing and Section 5.3.2.2 presents recommended measures for facilitating lifespan extension of the ovens. A total of eight design changes is presented.

Furthermore, the proposed changes in design of the microwave ovens for DfRem are further considered for whether the proposed changes contradict the principles of design for manufacturing (DfM) (e.g., whether a change in design makes the microwave oven more difficult to manufacture or increase the cost of manufacturing). All recommendations were evaluated by supervisors and colleagues

[43] By making remanufacturing process easier and affordable the author refers to the time required to disassemble and assemble.

at the University of Manchester for feasibility, and by CREATE UK, a large, independent UK remanufacturer, for their usefulness in facilitating remanufacturing. Furthermore, requests made to one large microwave oven manufacturer in the UK to discuss the proposed changes which were unanswered and assumed it has been declined.

Moreover, the recommended changes (see, Section 5.3.2.1 and Section 5.3.2.2) are classified according to RemPro-matrix [62] and summarised in Table 5.15.

Table 5.14: Recommended changes in design according to the RemPro-matrix

	Recommendation	How	Remanufacturing process	RemPro classification
1	Change the design of mains cables and plugs	i.e., use standard detachable Kettle cable	Dissassebly/assembly	Ease of separation Ease of access, and Securing
2	Reduce the complexity of how printed control boards (PCBs) are assembled	Use more robust design i.e., only snap fit	Disassembly/assembly/ testing/ reprocessing	Ease of access, Separation, and Securing
3	Facilitate access to internal parts	Use less/unified screw or change of the fastening to i.e., nylon rivet	Disassembly/assembly/ inspection/testing/ reprocessing	Ease of access and Securing
4	Redesign how magnetrons are fitted to make them more easily accessible	Use less/unified screw or change of the fastening to i.e., nylon rivet	Disassembly/assembly/ testing/ reprocessing	Ease of access, Separation, and Securing
5	Change painting of internal cavity material	Use more durable paint technique and material i.e., stailess steel ot dark enamel paint	Cleaning	Wear resistance, Ease of cleaning*
6	Change material in waveguide covers to plastic	From mica to plastic	Cleaning	Wear resistance, Ease of access and Securing
7	Standardised the Light bulb housing and thermostat assembly	Use less/unified fastening techniques	Disassembly/assembly	Ease of access and Securing
8	Reduce the number of different designs of mechanical parts	Use robust and unified design between brands	Disassembly/assembly	Affordable parts*

Note: * "Ease of cleaning" and "Affordable parts" are not included in the RemPro-matrix.

5.3.2.1 Recommended Measures for Facilitating Reuse

This section concentrates on the recommendation in order to facilitate the reuse as well as making the remanufacturing process easier and affordable. The changes are as follows. Changes such as ‘change the design of the mains cable and plug’ ‘reduce the complexity of how printed control boards (PCBs) are assembled’, ‘facilitate access to internal parts’, ‘re-design how magnetrons are fitted to make them more easily accessible’, ‘standardised the light bulb housing and thermostat assembly’ and ‘reduce the number of different designs of mechanical part’ are recommended in order to make the remanufacturing process easy and affordable furthermore to increase the reusability and remanufacturability of the ovens.

Change the design of the mains cable and plug

The disposed microwave ovens are frequently found with defective cables, which, although affordable, cannot be easily replaced. The analysis in Section 5.2.3 shows that the majority of ovens with defective cable are working; however, a simple design change would facilitate remanufacturing process affordable and less time consuming. Figure 5.6 depicts a microwave oven with a fixed cable, which have been cut by consumer before disposal. This could be remedied by a simple design change; namely, making cables removable (like a kettle's cable).[44]

[44]Currently, non-removable "cloverleaf" cables are used.

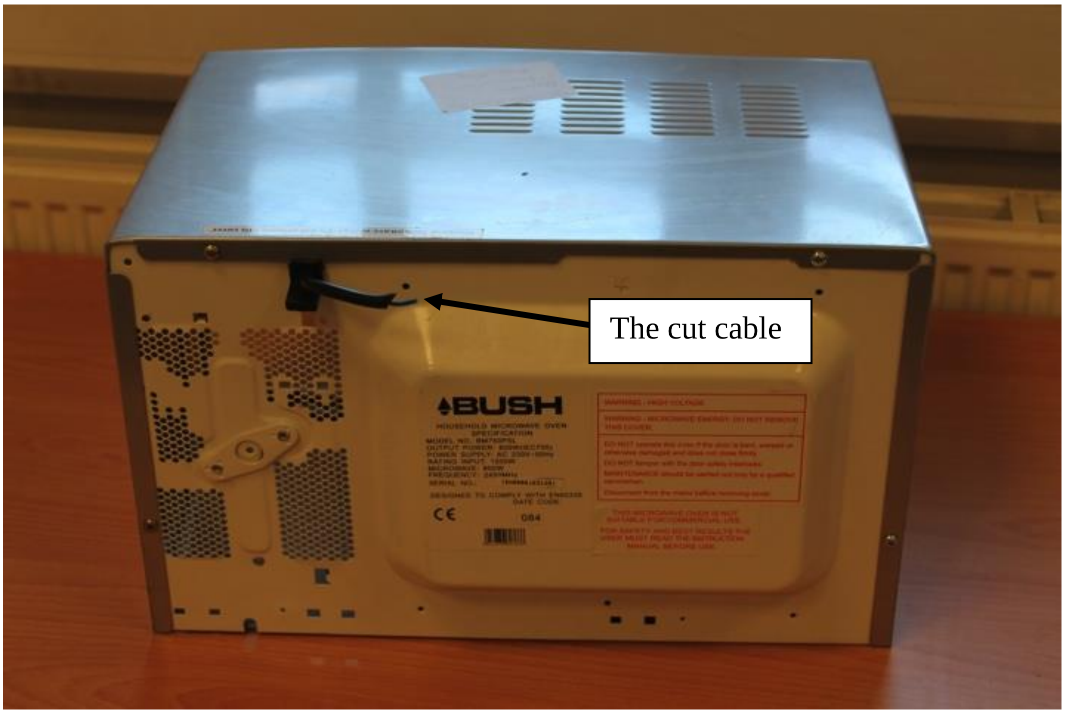


Figure 5.6: Microwave oven with fixed cable (cut)

Figure 5.7 depicts a removable cable (left) and the current attached cable used in ovens (right). Consumers and remanufacturers could either buy a replacement cable or have one installed for a small fee, no specialised labour being required. Utilising moulded cables like the 13A UK main plugs, which are generally available and retail for less than £2 would further improve effectiveness by enabling independent remanufacturers to reuse cables from machines disassembled for spare parts. [45,46] However, the author believes that further investigation is required to understand the design change implication on the DfM in terms of cost and complication of the current manufacturing layout.

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[45]The cost of the replacement is of those found at the specialised retail websites.

[46]The author`s experience suggests that independent remanufacturers commonly hold inventories of parts removed from returned products.

Figure 5.7: Removable cable (left) and current attached cable used in ovens (right)

Note: The cable on the right in Figure 5.7 is an example of the current design of a typical microwave power cable. The cable on the left is an example of moulded cable with 13A UK main plugs.

Reduce the complexity of how printed control boards (PCBs) are assembled

The way PCBs are fitted was found to vary substantially across microwave models and manufacturers. Manufacturers used screws (of different types and sizes), snap-fits, or plastic supports, and in many cases a combination of these, to mount PCBs to the chassis. This complicates retrieval of the control boards, as every removal is unique. An electrical circuit diagram, usually affixed to the inside of the case unit, was found in very few of the microwaves inspected. This rendered repair/remanufacture even more challenging. In summary, replacement of printed circuit board is time consuming, requiring careful dismantling of the board and other components as well as connector cables.

Of the microwaves investigated, the two mountings that rendered PCB removal the least time consuming were the snap-fit and plastic support. Utilising these instead of screw mountings would facilitate, in less time, reuse/remanufacturing of the filter circuit board (E2) and control circuit board (E3). Figure 5.8 illustrates a PCB board mounted with snap fits. With respect to design for manufacture (DfM), the unified design of the mounting of the PCB to the chassis would increase the current cost of manufacturing however reducing the numbers and types of the assembly would decrease manufacturing complexity. However, the author suggests that integrating the design suggestion for future oven design will facilitate ease to remanufacture in terms of time required to disassemble and assemble and will increase the interchangeability of the PCBs within the same categories of the ovens.

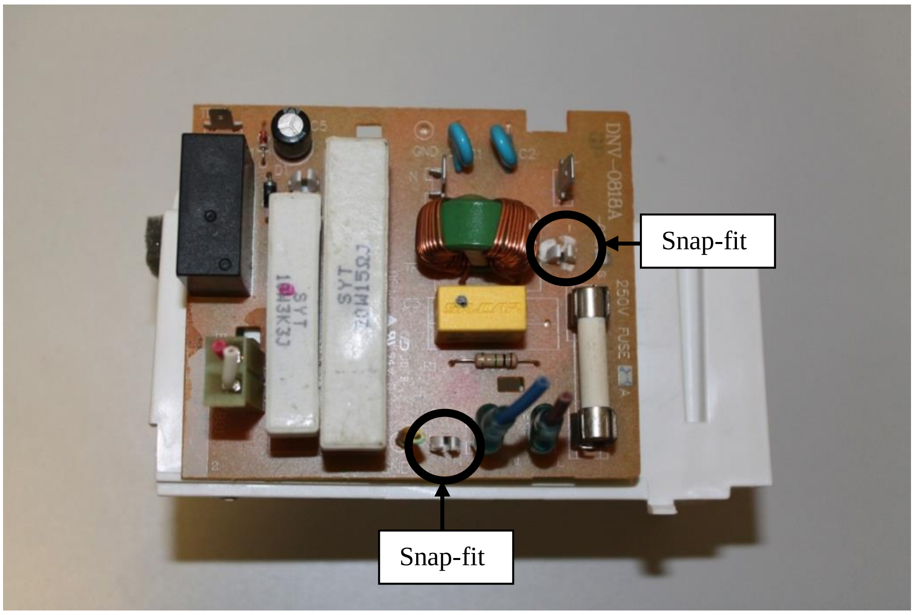
Facilitate access to internal parts

The problem of component accessibility, alluded to in [157], persists in some of today's home appliances [62]. To open a microwave oven case involves removing several screws (typically between six and eight), often of different types and sizes. Screws of different types and sizes may necessitate changing tools, which is time consuming, and screw removal in older machines can be complicated by rust and corrosion. These problems are exacerbated during the reassembly process because the technician needs to keep track of the right position of each screw. Furthermore, screws and screw holes may have been damaged during the disassembly process. A sample of different screws collected from a single microwave oven is shown in Figure 5.9.

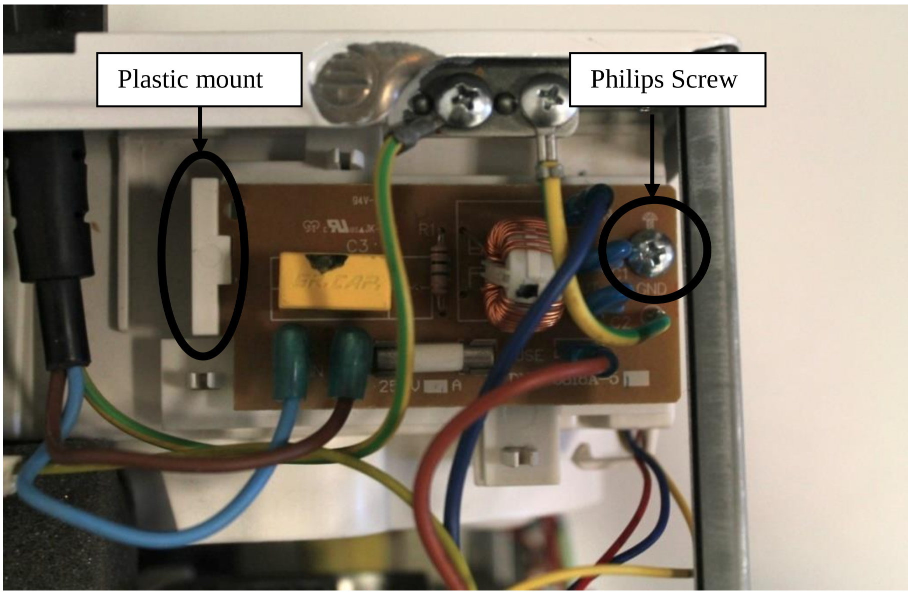
There are two solutions to this problem. The first is to design the product with fewer screws all of the same size and type, the second is to eliminate the use of screws altogether. An alternative solution is the use of nylon screws or rivets. The design optimisations of fastener (the use of nylon screws or rivets) were recommended by the researcher and Dr. A. Haigh and further produced by Dr. A. Haigh, a research fellow of the School of Electrical and Electronic Engineering, at the University of Manchester.

Figure 5.10 shows nylon rivets produced at the University of Manchester that require little effort to remove, don't rust, and are as solid and secure as metal screws. The specification and a simple sketch of the rivet are given in Figure 5.11 and Figure 5.12. The rivet is intended to reduce costs and time of assembly and disassembly. The advantage of the rivet is as follows: (i) it is cheaper than a plated metallic screw (ii) reducing assembly time; it requires only a pneumatic magazine tool to store and insert the nylon rivet and (iii) reducing removal time during remanufacturing of the oven by nylon rivet being drilled out.

With respect to design for manufacture (DfM), the author doesn't believe that reducing numbers and types of screws increases manufacturing complexity or cost, although introducing nylon rivets may. However, more indepth research and tests are anticipated to incorporate the nylon rivets to the design of the ovens preferably with manufacturers cooperations for the viability of the recommended deign change in operation.



(a) Type of PCB assembly with mounted using snap-fits



(b) Type of PCB assembling connected to the chassis with plastic mount (bottom, left) and Phillips screw (top, right).

Figure 5.8: Different fittings of the PCBs

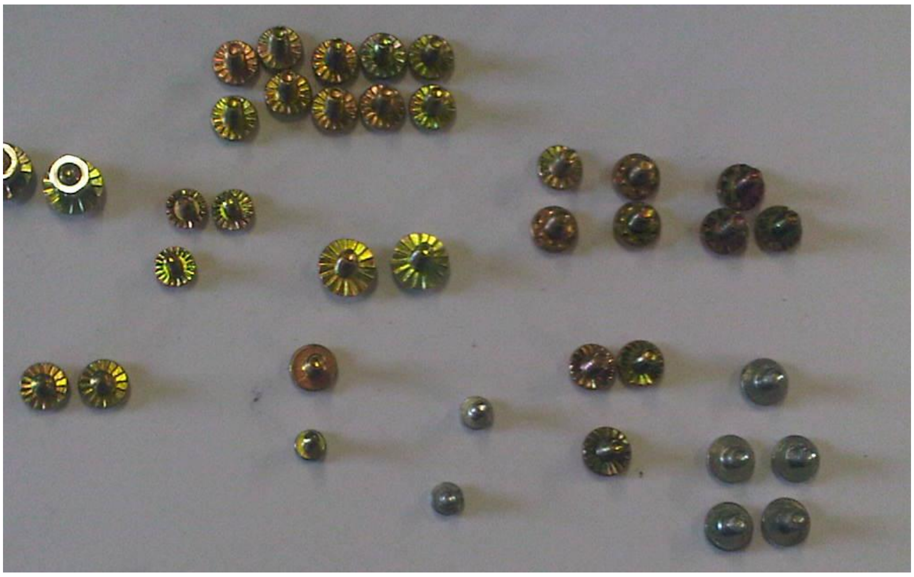


Figure 5.9: Screws of different shapes and sizes collected from a single microwave oven

Note: In total, this microwave contained 38 screws of 12 different types and sizes.

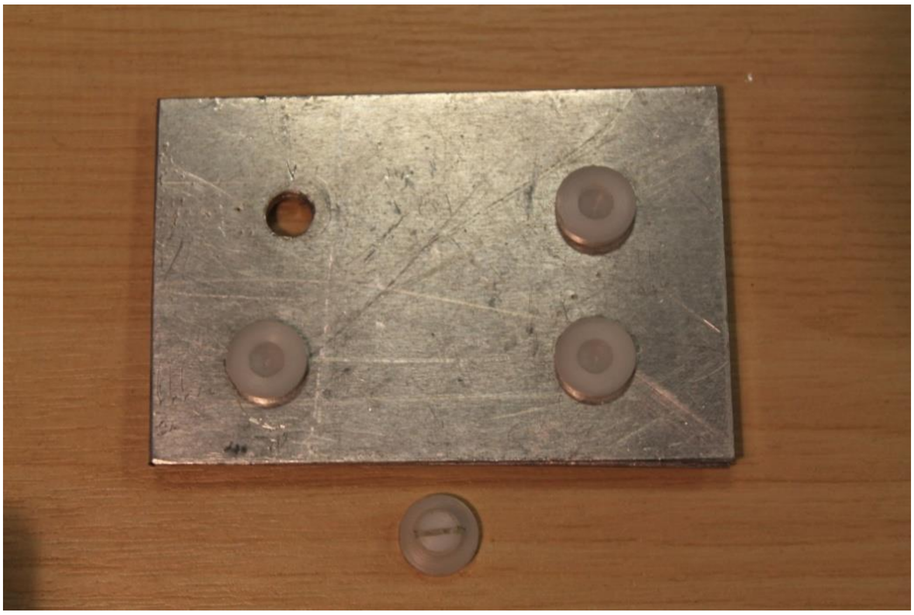
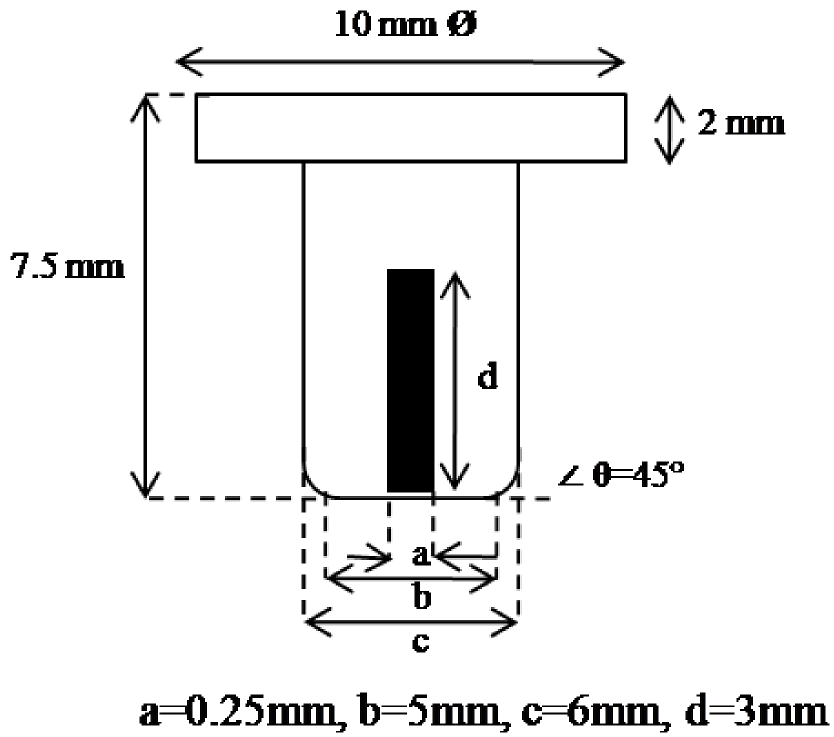
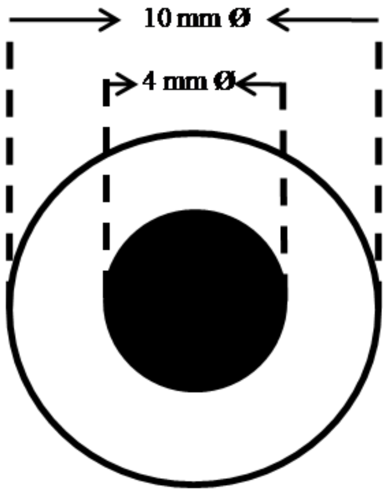


Figure 5.10: Nylon rivets produced at the University of Manchester



(a) The rivet is 7.5mm long; the head of the rivet is 10 mm diameter and 2 mm thick. The insertion part of the rivet is 6 mm diameter and 5.5mm long. At the end of the 6 mm diameter a chamfer 0.25 mm long at 45 degrees reduces the insertion force.



(b) The head of the rivet from (top view)

Figure 5.11: The sketch of the Nylon rivet

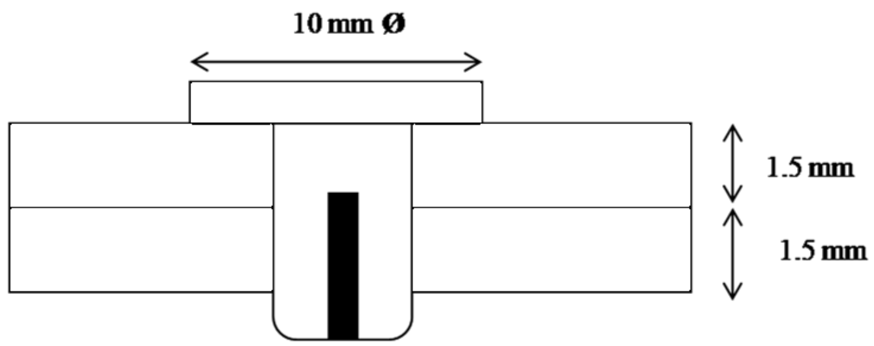


Figure 5.12: The sketch of the rivet inserted into the two pieces of aluminium sheet material

Note: Two pieces of aluminium sheet material are 1.5 mm thick; the holes in the aluminium are 6 mm in diameter.

Redesign how magnetrons are fitted to make them more accessible

The magnetrons, the second most common source of electrical faults, are produced by only a handful of manufacturers also facilitates the reuse of parts. For a number of units investigated, however, removal of the magnetron was complicated by, among other factors such as access and wiring issues, the need to remove a large number of screws to open the microwave case. In fact, the magnetron was in most models one of the most difficult parts to remove. Making magnetrons more accessible would facilitate their replacement or reuse. Sundin et al., [70] show that small changes in design can facilitate access to parts, and propose changes in the design of, among other home appliances, washing machines and refrigerators to facilitate ease of remanufacture.

Figure 5.13 depicts the magnetron disassembled and the screws of six different sizes (disassembled using three different type of tools i.e., Philips screw driver, safety screw driver and pliers) that needed to be removed to extract the magnetron from the case. Figure 5.14 depicts the position of a magnetron within a microwave oven with connecting cables and screws. Therefore, for ease of disassembly and reduce disassembly time the design change of fixing the magnetron with less screws of fewer types is suggested.

Reduce the number of different designs of mechanical parts

The most common sources of mechanical faults; defective controls, doors, and locks, because their design is used to achieve brand differentiation, are significantly less homogeneous than the parts responsible for most electrical faults. Whereas, for example, only a few models and specifications of magnetron exist, the number of doors is nearly equal to the number of different microwave models. Making components interchangeable across different product types and brands is thus more difficult for more mechanical than for electrical parts and consequently would increase complexity and cost of manufacturing. As a result, reuse of mechanical parts by independent remanufacturers is thus largely restricted to same product substitution. However, the author believes that OEMs should consider the homogeneous and more robust design across their own ovens and facilitate the availability of the affordable spare parts across their own products.[47]

[47] Design changes to the mechanical parts such as door, door handle may also help to facilitate life span extension for example by designing more robust and interchangeable components across ovens as well as using more robust design will decrease the likelihood of the damage might be accur during use phase.

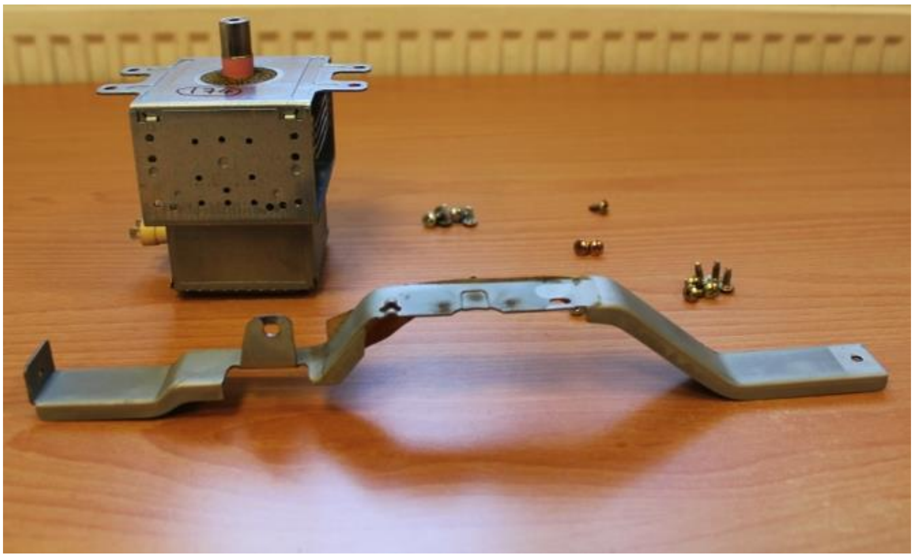


Figure 5.13: The disassembled magnetron from an oven and the screws used for its assembly

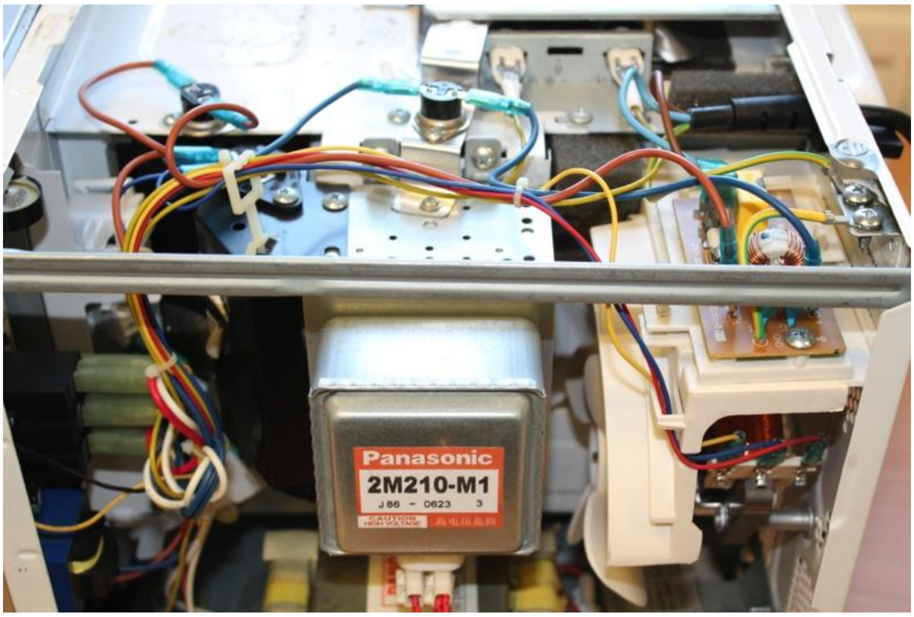
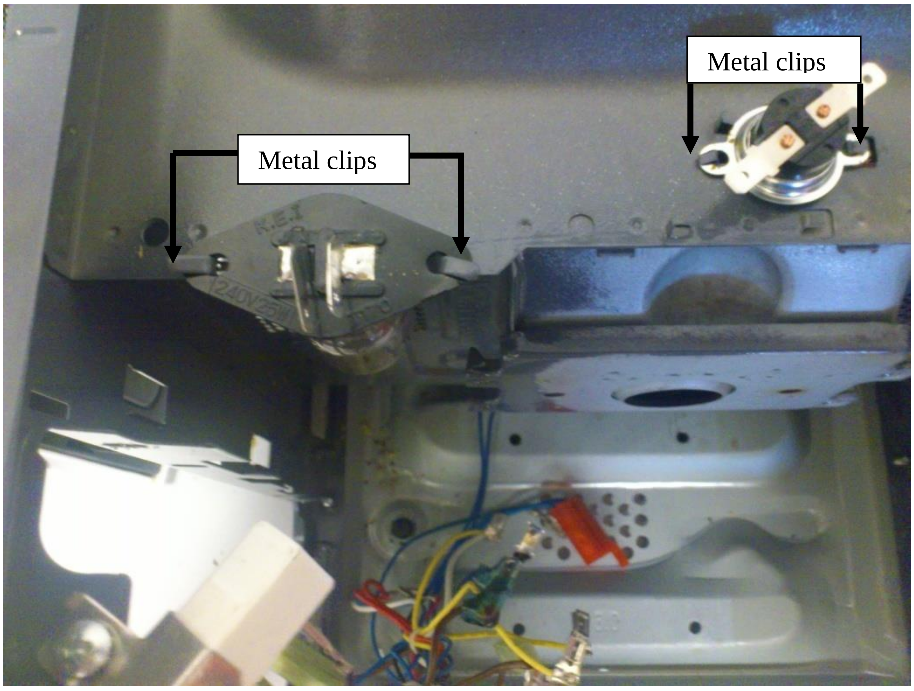


Figure 5.14: The position of a magnetron within a typical microwave oven with connecting cables and screws

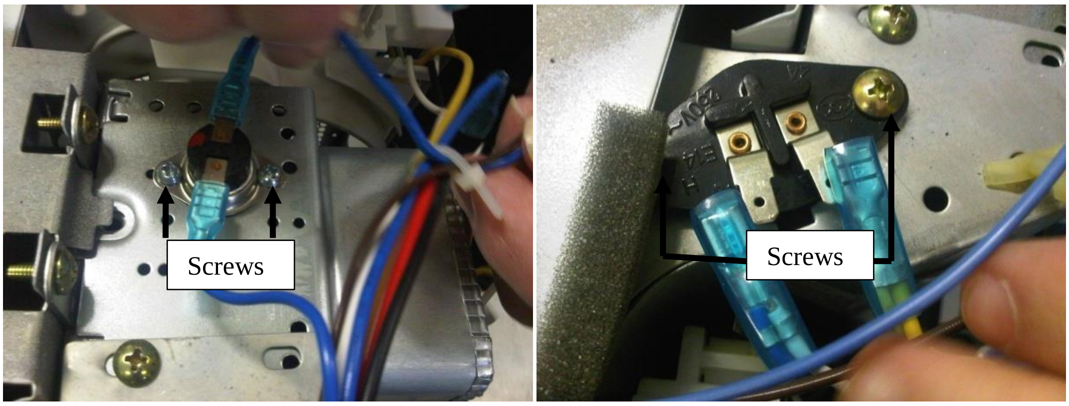
Note: The picture at the top shows the magnetron dismantled. In total, 18 screws of 6 types had to be removed to retrieve the magnetron. The picture at the bottom shows the way magnetron assembled within a typical microwave oven. The dismantled magnetron pictured in Figure 5.13 is from a microwave oven other than the microwave oven pictured in Figure 5.14.

Standardised the Light bulb housing and thermostat assembly

Two types of designs were identified in this study. One which attached with two identical screws and the second one with metal clips mounted directly to the chassis to support the bulb holder and thermostat. The author believes that the latter design would facilitate easy and cost effective remanufacturing due to less time involved in disassembly of the faulty bulb, bulb holder and thermostat. Figure 5.15 depicts the two different designs for attachment of the bulb holder and thermostat that identified in this study.



(a) Bulb holder (left) and thermostat (right) attached by metal clips



(b) Bulb holder (right) and thermostat (left) attached by two identical screws

Figure 5.15: Two different designs for attachment of the bulb holder and thermostat

Note: Figure 5.15 (a) shows a bulb holder and a thermostat which attached by two metal clips and (b) shows a bulb holder (right) and a thermostat (left) which attached by two identical screws of different sizes. The first attached method is recommended for ease to remanufacture.

5.3.2.2 Recommended Measures to Facilitate Life Span Extension

This section concentrates on the recommended measures to facilitate life span extension of the ovens. The changes are as follows. The ‘change painting of internal cavity material’ and ‘change material in the waveguide cover to plastic’ are recommended to increase the lifespan and to manufacture more durable ovens. [48]

Change the painting of the internal cavity material

The most common cosmetic mechanical fault was rust, the result of the internal cavity paint peeling off and the exposed surface becoming oxidised. This was often caused by the turntable wheels wearing down and lifting the floor surface. To reduce this fault, manufacturers need to (i) change the design of the stirrer belts and wheels, (ii) improve the painting in the internal cavity, or (iii) use stainless steel in the cavity.

With respect to changing the design of stirrer belts and wheels, it has been observed that older models that used fixed wheels did not present this problem. This study does not recommend reverting to the older design, as it increases the complexity of the manufacturing process and makes cleaning more difficult.

This problem can also be mitigated by changing the material and/or colour of the internal cavity. The peeling was more frequently observed in cavities painted with light acrylic/enamel colours and infrequently observed in cavities without paint (stainless steel) or painted in dark colours. However, with respect to the change of the material to the stainless steel the author believes that the proposed changes would

[48] Note that these changes may also facilitate ease and affordable remanufacturing process.

increase the manufacturing cost or complexity. Furthermore, the cost of the brand new microwave oven with stainless steel cavity is higher than the cost of the oven with acrylic/enamel painted cavity. The change of the material and/or colour used in the cavity of the ovens is anticipated to facilitate the extension of lifespan as well as ease of cleaning and consequently result in the affordable remanufacturing process. Figure 5.16 shows the current different cavity paint designs and Figure 5.16b, depicts the problem in a microwave with enamel white painted cavity.

(a) (b) (c) (d)

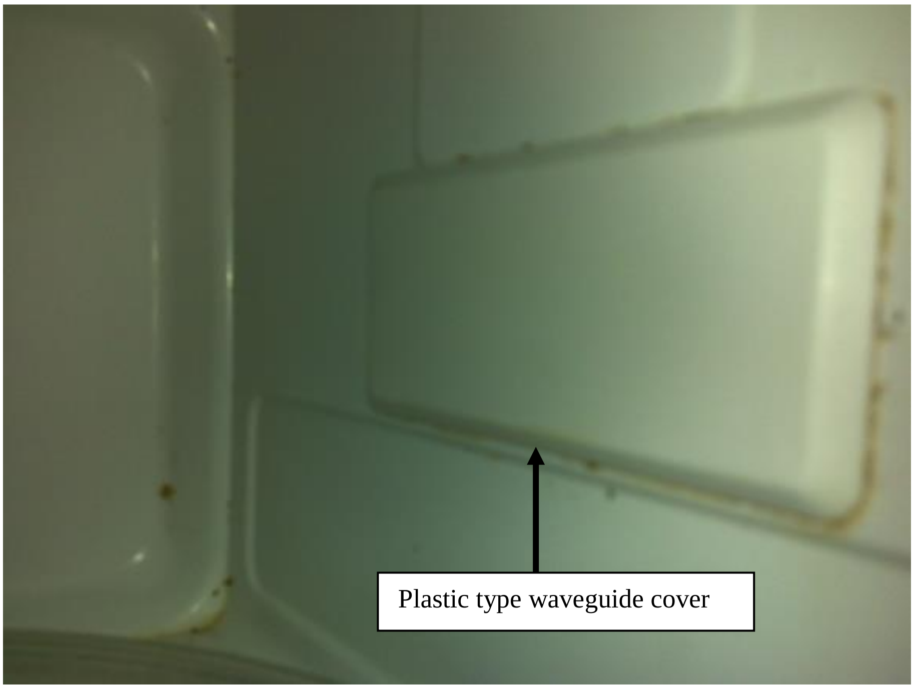
Figure 5.16: Different microwave oven cavity paint and design.

Note: Figure 5.16(a) shows cavity with stirrer wheels attached to the surface (b) shows oven cavity rust caused by the turntable wheels wearing down and lifting the floor surface, (c) depicts an oven with stainless steel cavity and (d) shows an oven cavity with dark/grey paint.

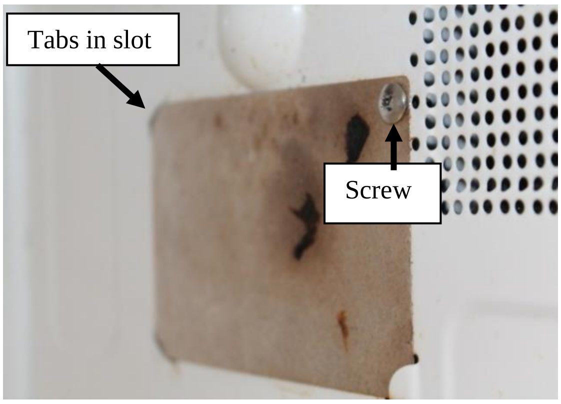
Change of material in waveguide covers to plastic

More recent, especially low-end, microwave ovens use a removable mica waveguide cover. Food grease and food spillages adhere more readily to paper, which, when heated, can be more easily damaged. Microwaves with a fixed plastic form of waveguide cover have been observed to be easier to clean and to have longer life spans.[49] The author hesitates to extrapolate these findings to all microwaves, however, believing more research to be needed to establish whether plastic is more durable than paper waveguide covers. Furthermore, the way that the mica waveguide cover attached to the wall of the cavity was different within the tested ovens. Two types of the attachment methods were observed, one attached with one or two screws as well as tabs in the slots and the second one with only by tabs placed in slots. The author believes that the latter design would facilitate ease to remanufacture by reducing the time to disassemble and assemble the damaged waveguide cover. Figure 5.17, illustrates a plastic waveguide cover (on the top) and the deterioration of a mica type waveguide cover (on the bottom) with different design of attachment to the chamber.

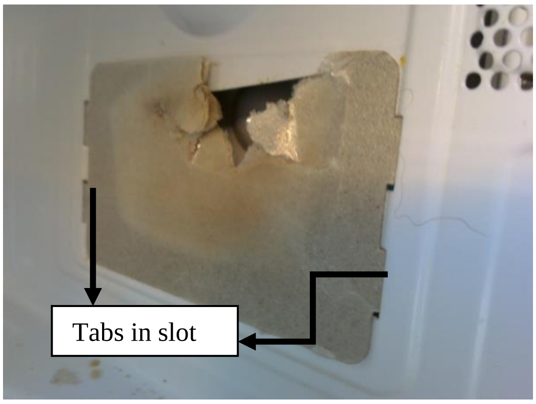
[49] The change of the design of the waveguide cover would also facilitate ease of remanufacturing as only cleaning of the waveguide cover would be necessary thus would make remanufacturing less expensive.



(a) A plastic type waveguide cover attached by tabs in slots



(b) A broken mica type



(c) A broken mica type

Figure 5.17: Plastic and mica waveguide cover

Note: Figure 5.17 (a) shows a tab in slots plastic type waveguide cover, (b) shows a broken mica type waveguide cover attached to the chamber with screw and by three tabs in slots and (c) shows a broken mica type waveguide cover attached to the chamber by tabs in slots. The latter attached method is recommended for ease to remanufacture.

5.4 Summary of Findings and Analysis

The focus of the following sections is on the summary of the finding and analysis of the following research questions.

Research Question One: *What are the consumers' knowledge and behaviours with respect to the functionality and disposal of microwave ovens?*

Research Question Two: *What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?*

Research Question Three*:* *What is the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?*

5.4.1 Research Question One

The overall response rate for face to face interviews was 100% (see, Table 5.1). The respondents revealed the age of the discarded appliances that was ranged from one to 25 years and the average age of the used products was between six to seven years. Moreover, most of those disposing of microwave ovens were between 35 and 60 years old, male, owned cars.

The interviewees were asked about their opinion on the functionality of their unwanted microwave ovens at the point of disposal. 41% of respondents could identify the problem with their microwaves in very general terms such as failure to start up, unexpected noises, sparking when powered on, non-working turntables, and rust. However, most were unable to effectively repair or even identify the source of the problem (e.g., some stated that their microwaves were making strange noises). The interviewees did not know why their microwaves had failed (they were not able to pinpoint the source of the problem). Furthermore, nearly 13% of respondents were unable to identify the source of the fault with their non-functional ovens.

It is revealed that almost half of the respondents believed that their unwanted ovens were working, and further 48% of respondents believed that their items were not working with only two respondents (~2%) did not answer this question.

To gauge attitudes towards the latest innovation and technology upgrades, the interviewees were asked whether they intended to replace their discarded products with similar or updated versions. More than half of those disposing of defective items planned to purchase replacement products with modern look and the same functionality, and most of those disposing of products in working condition to purchase updated products with modern look and the same functionality. The findings of these questions, which are summarised in Table 5.4, thus call into question the widely-held belief that e-waste is caused by a desire for the latest technology. And finally, only one fifths of interviewees were aware of alternative end-of-life destinations for their unwanted products (e.g., charities and reuse organisations).

5.4.2 Research Question Two

In total 189 ovens from 40 different microwave oven manufacturers were tested for their functionality and cosmetic imperfection at the point of disposal. Sixteen units were not tested for various reasons such as failed PAT test or had missing components and 33 units (17%), found to be in perfect working condition, could potentially be reused after cleaning, safety checks and without any servicing. The remaining 140 units presented cosmetic imperfection, electrical and mechanical faults. Almost half of these were suitable for reuse. The remaining units (70) required major repairs such as replacing a non-functional magnetron.

Mechanical faults are divided into six categories according to the components and failure types. Cosmetic damage (M6), by far the most frequently recorded failures, encompasses missing rotating glass plate and peeled off, burned, or damaged internal coating as well as damage to the external casing incurred in handling and transport. The author speculates that some of these imperfections to have resulted from transport to the recycling centres, and in the case of products obtained from CREATE UK, between the charity and university. The most common internal faults were localised heating and thermal damage caused by food spillage and worn cavities, a result of the inferior quality of the painting process used by some manufacturers as well as consumer`s use habits that may be mitigated by giving precise information how to clean and how often clean the cavity of the oven to consumers by OEMs in order to increase the life span of the ovens. Damaged doors being found mostly in items collected from CREATE UK suggest that this fault could be avoided by improving disposal and transport processes. The overall cosmetic quality of microwave ovens collected from the HWRC was superior to that of units collected from CREATE UK because the former were received directly from consumers rather than retrieved from designated recycling containers at the two HWRCs.

The electrical faults were classified according to the six categories. The majority of electrical fault was missing plugs and leads (E1). Nearly one third of units collected directly from consumers at the HWRC identified with missing cords and plugs. Furthermore, consumers reported cutting the cables before transporting their products to the recycling centres to prevent reuse, fearing that they were still liable for the discarded products. Many of the microwaves in the E1 category were thus fully functional prior to disposal, and their reuse could be facilitated, at least to some degree, by simply making consumers aware that they are not liable for subsequent use of discarded items. The second most common electrical fault in microwaves was the failure of the principal component, the magnetron (E6), usually due to overloading or spillage (repeated heat exposure of food left in microwaves can burn the waveguide cover and damage the magnetron). The third most commonly diagnosed electrical fault was a failure of the capacitor (E5). In this study approximately two-thirds of all electrical faults thus involve only three parts, cables, magnetrons, and capacitors. And finally some items had multiple faults including both electrical and mechanical ones.

The Pareto analysis of the quantitative test results of mechanical and electrical faults identified the most frequent faulty components (Figure 5.2 and Figure 5.3). The components in category M6, M3 and M2 for mechanical and E1, E6 and E5 for electrical are the most faulty with the total number of failures being 71, 14, and 13 for mechanical and 44, 23 and 14 for electrical, respectively.

In summary, the quality of discarded microwaves being high and cost of replacement electrical parts low, the potential for reuse and, consequently, product life span extension is good.

5.4.3 Research Question Three

Three ovens were dismantled and the differences in their designs and assembly of individual components were observed and documented (see, Figure 5.4 and Figure 5.5 and Appendix A14). The time taken to disassemble the individual components from ovens was recorded. It was documented that it was required 30, 37 and 24 minutes to dismantle the microwave oven I, II and III respectively. It was documented that time required to dismantle the ovens to component level were dependent on their individual design of fastening, the number of screws that were used in the assembly of the unit as well as the difficulty of access to the individual components, i.e., cooling fan casing and the magnetron.

The composition of material within each component (i.e., Ferrous (steel and stainless steel) and non-Ferrous (aluminium and copper, gold, silver and lead) metals, plastic and glass) were visually examined and documented. For example, a typical transformer consists of copper and iron.

It was documented that disassembly of the following components was not easy in three dismantled ovens for instance, H.V transformer (Inverter), H.V capacitor, diode, magnetron and metal beam, cooling fan motor and rotating plate motor. The reason behind this is two folded. First, the level of access to the individual components without disassembly of other components. Second, the number and different type of the fasteners that were used in the assembly of the components which consequently leads to increase of the time to remanufacture ovens. The recommended design changes to facilitate ease and affordable reuse and remanufacturing process as well as the modifications to improve the durability of the product, which would also contribute to longer life spans, are summarised in Table 5.15.[50] The recommendations presented in this Chapter are aimed at original equipment manufacturers (OEMs). All recommendations were evaluated by supervisors and colleagues at the University of Manchester for feasibility, and by CREATE UK, a large independent UK remanufacturer, for their usefulness in facilitating remanufacturing.

[50] In this study by making remanufacturing process easier and affordable the author refers to the time required to disassemble and assemble faulty component.

Table 5.15: The summary of the recommended eight electrical and mechanical design changes to facilitate ease and affordable reuse, and remanufacturing process and improve the durability of the product.

	Recommendation	Ease to Remanufacure	Improve the Durability
1	Change the design of mains cables and plugs	Yes	N/A
2	Reduce the complexity of how printed control boards (PCBs) are assembled	Yes	N/A
3	Facilitate access to internal parts	Yes	N/A
4	Redesign how magnetrons are fitted to make them more easily accessible	Yes	N/A
5	Standardised the Light bulb housing and thermostat assembly	Yes	N/A
6	Reduce the number of different designs of mechanical parts	Yes	N/A
7	Change painting of internal cavity material	Yes	Yes
8	Change material in waveguide covers to plastic	Yes	Yes

5.5 General Discussion of Findings

This section provides a general discussion of findings of this research. This research has investigated the quality of the discarded ovens at the HWRCs in the UK and it has found that the good proportion of these products are suitable for reuse. The Section 5.5.1 discusses the benefits of the remanufacturing from the social and environmental point of view. Furthermore, the findings of this research show that the current design of the ovens is hindering the reuse of ovens. The section 5.5.2 provides discussion on surrounding of this issue.

5.5.1 Social and Environmental Benefits

Increasing the life span and reuse opportunities for microwave ovens would have an impact on both socio-economic development and environmental protection.

With respect to social-economic development, remanufacturing, being a labour intensive activity, has generated numerous jobs in the United Kingdom and elsewhere. For example, the employment figures provided by Bryson, a white goods refurbishment enterprise in Northern Ireland, shows that within one year, fourteen full-time staffs and two trainees (subsidised by Northern Ireland's Department of Education and Learning) were employed [14]. However, the potential for job creation within this sector has not been yet fully exploited means that more jobs might be created in the sector if governments and manufacturers work together to support product reuse [158], [159]. Moreover, the remanufacturing industry annually produces products worth billions. In the United Kingdom, alone, the industry is worth £5 billion per year as well as the remanufacturing can create many more jobs and it can generate even more value to the UK economy than it does today [160].

Remanufacturing commonly employs a layer of society, the long-term unemployed, for which permanent jobs are difficult to secure. A local charity located in the northwest of England, for instance, has trained nearly 500 long-term unemployed and placed them in permanent jobs with local and multinational manufacturers, such as Jaguar. According to the local police, the number of trained long-term unemployed who committed criminal offences after finding a permanent job was but a small fraction of what would be expected from a group with the same profile [76].

E-waste has become an increasingly serious concern in the United Kingdom largely due to the limited capacity of landfills and concerns about the release of toxic materials [10]. Reusing and extending the life span of microwave ovens also reduces the amount of e-waste that needs to be processed as well as reduce the quantity of the toxic materials to enter the waste stream especially as e-waste contains a myriad of toxic substances such as lead [7]. Furthermore, a microwave is made of on average 15kg of ferrous and non-ferrous metals as well as plastic and glass, by reusing and extending the life span of the ovens saving of the raw materials and energy can be achieved which is important to tackle the material scarcity in the world.

With respect to global emissions, although measuring emissions savings that might occur to remanufacturing is beyond the scope of this thesis, however according to the study by Quariguasi-Frota-Neto and Bloemhof on eco-efficiency of remanufactured personal computers and mobile phones [53] the author speculates that remanufacturing consumes substantially less energy than manufacturing and accounts for lower emissions per microwave oven. It is difficult to say, however, whether the cumulative energy demand (CED) through the entire life cycle of the product is lower for remanufactured products, as new products tend to be more energy efficient [14]. A further research is needed to answer the above points.

5.5.2 Design for Remanufacture

In the case of the ovens, in this thesis, the technical possibilities of increasing reuse, or in other words, the "how" question is discussed. Equally important, however, is to analyse the question as to why OEMs are so dis-engaged with the design for reuse and remanufacturing. The dis-alignment of incentives between manufacturers and remanufacturers and its effects on the (dis) engagement of OEMs with respect to DfRem has been previously documented in a study by Hatcher, Ijomah and Windmill [33]. In this case the OEMs do not profit, at least directly, from reuse, and moreover the OEMs have little incentive to design products in ways that facilitate reuse [33]. Although, the work presented in this thesis has not directly investigated this issue, the author speculates that based on the study by Hatcher, Ijomah and Windmill [33] the design change that could potentially reduce e-waste, are not implemented due to the reasons as follows.

First, manufacturing and remanufacturing of microwave ovens, as in many other electrical appliances, is generally carried out by two different types of organisations, original equipment manufacturers (OEMs) or their appointed remanufacturers and independent remanufacturers. This reduces the incentive for manufacturers to design for reuse, as such changes will only benefit remanufacturers, and may even hurt OEMs, e.g., better design for remanufacturing contributes to an increase in the number of products being remanufactured, which in turn will compete with new manufactured products. Second, unlike other environmentally friendly initiatives like improvements in energy efficiency, which consumers do consider when purchasing new products, there is no direct incentive for microwave manufacturers to design their products to be reusable, i.e., government grants.

Furthermore, the incipiency of the second hand market can reduce the remanufacturing of the products. In this case the lack of a strong secondary market for microwave ovens is conspiring against reuse and can be partially explained by first, the lack of appropriate reuse channels for this type of the product as well as the cost of available spare parts. For instance, the quantity of the other products such as IT equipment and washing-machine available on offer, e.g., eBay UK or direct from remanufacturers, is higher compared to the microwave ovens. Second, the lack of consumer willingness and awareness to buy second hand products for various reasons, e.g., lack of awareness of the quality of the second hand products.

5.6 Summary

This chapter discussed the findings of the research questions outlined in Chapter 1. Section 5.1 described and analysed the findings of the research question 1 "*What is the consumers' knowledge and behaviours with respect to the functionality and disposal of microwave ovens?"* in detail. The focus of the Section 5.2 was on the fault diagnostic tests with respect to the research question 2, "*What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?"*. The frequency and type of mechanical and electrical fault surveys were described and analysed in Sections 5.2.1 and 5.2.2 respectively. Section 5.3 focused on the findings of the research question 3 "*What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?".* The time required to disassemble, ease of disassembly of individual components, material compositions of three microwave ovens were given in Section 5.3.1. Furthermore, the recommendations for facilitating reuse and life span extension of microwave ovens were outlined in 5.3.2. Summary of findings and analysis are given in Section 5.4. The general discussions on surrounding of the finding of this study were given in Section 5.5. The following Chapter presents the major conclusions, discussions and future works of the research.

Chapter 6: Conclusion and Further Work

This chapter discusses the conclusions in relation to the objective of this thesis, which have been described in Chapter 1. In this thesis, the primary objective was *" to explore and analyse the functionality and quality of the microwave ovens at the point of disposal and its impact on the remanufacturing and reuse ".*

Using microwave oven case study, the primary objective of the study was translated into the following three research questions (RQ):

RQ1: "*What is the consumers' knowledge and behaviours with respect to the functionality and disposal of microwave ovens?"*

RQ2: "*What are the quality of, functionality and costs of remanufacturing, microwave ovens discarded in the United Kingdom?"*

RQ3: "*What are the likelihood of the design changes to increase opportunities for reuse and remanufacturing of microwave ovens?"*

The research findings based on the research questions were analysed and discussed in Chapter 5. The remaining of this Chapter is organised as follows. Section 6.1 provides a summary and contributions of the empirical research findings. The limitations of this study are given in Section 6.2. The contributions of the research are crystallised in Section 6.3. Finally, Section 6.4 concludes this chapter by suggesting the possible scopes of further research.

6.1 Summary of the Empirical Findings

This thesis has investigated the quality of microwave ovens discarded in the United Kingdom and consumer attitudes regarding the disposal of this product. It also has examined the current design of the ovens that might hinder the life span extension and reuse and further proposes changes, aimed at OEMs, to the current design of the ovens to facilitate reuse and life span extension. The significant contributions of this thesis towards our understanding of the objective of the thesis are as follows.

First, it is found that more than half of discarded (103) ovens to either be in perfect working order or have only minor faults, and a high percentage to be candidates for reuse or remanufacture.

Second, the author argues that the cost of spare parts needed to repair most of the items to be, on average, small, and found a few parts to be responsible for most of the electrical and mechanical failures, which were in many cases repairable.

Third, it is noted that despite the significant potential of the discarded ovens at the HWRCs in the UK, reusability of the ovens is seriously hindered by designs that do not fully embrace the concept of the manufacturing for reuse or DfRem. It is observed that the more reliable products, i.e., stainless cavity, may only partially solve the problem of short life spans. Furthermore, simple changes in the design of the ovens could significantly improve their lifespan. Moreover, it found that the re-designing microwaves to accommodate repairs of simpler faults, i.e., change of material of the waveguide cover, and make repairs of more complex faults by specialised shops more economical in terms of time and spare cost could substantially increase product life spans and re-usability of the ovens. However, this study found that even with existing designs it is technically (but not necessarily economically) viable to safely reuse most of the discarded ovens.

Fourth, this study found that few of those disposing of microwave ovens at the HWRC had knowledge of how electronic appliances could be reused. It was revealed that almost half of the respondents believed that their unwanted ovens were working; therefore, awareness of other disposal option for functional products may have increased the collection for reuse of the ovens. This finding highlights the importance of awareness of the consumers on the other disposal options available through the local authorities in the UK. In general, because the disposal process can significantly damage working items. This study recommends that, to maximise reuse, functional ovens must be identified and collected prior to disposal. Therefore, to increase collection of the functional products the recyclers and stakeholders involved in collection of cores are encouraged to engage in an appropriate collection network to avoid potential functional products being discarded at the point of disposal. Moreover, the proposed arrangements may help to avoid cosmetic or other damage to otherwise re-useable units in recycling containers or during handling and transport. In this study, most cosmetic damage to casings, doors and windows, control parts, and plug mains leads occurred during the transport of microwaves from consumers` premises to the HWRC site or from two HWRCs to the CREATE UK storage site and to the University of Manchester. These observations clearly highlights that the collection methods of the end of use products has a great impact on the primary destination of the items as previously pointed out by Alexander et al., [161].

The majority of interviewees did not know why their microwaves had failed. The majority of those disposing of defective items planned to purchase replacement products with the same functionality, and most of those disposing of products in working condition to purchase updated products with modern look and the same functionality. In a general sense, the design of the ovens which facilitate the reuse and life expansion may have influenced the decision of those consumers with defective ovens to perform simple repairs or conveniently obtain shop repairs at an attractive price. On the other hand it may not affect the decision of those consumers who disposed of their functional ovens.

And finally, based on the findings and observations of this study the design changes to the ovens were proposed to facilitate reuse and remanufacture and consequently facilitate the life span extension of the ovens. Furthermore, if e-waste is to be reduced, microwaves need to be re-designed with reuse in mind to last longer, and inventories of spare parts made available at affordable prices by OEMs.

In summary, the empirical study presented in this research shows that the quality of the disposed ovens at the HWRCs is good and the reuse and remanufacture of such products are viable. This result supports prior findings of the WRAP study [71] that the quality of the disposed WEEE at the UK HWRCs is superior and has resale value. However, the major factor preventing reuse is the current design of this product, which makes repairing difficult and onerous, as well as the receptiveness of the market for second hand items resulting from these functional products being discarded.

6.2 Limitation of the Research

Finally, a number of important methodological and generalisability limitations need to be considered.

6.2.1 Methodological limitations

First, this research was limited on the number of the microwave ovens that have been examined. Also the characteristics of the sample were broad, containing a variety of makes and models (up to 40 makes such as Bosch, Asda, Daewoo, Tesco, Samsung, Panasonic and Sanyo). This was due to the nature of the HWRCs business model as they accept all products that are listed within the ten categories of the WEEE directive and is not limited to the specific make and model of the products. However, the available make of the ovens in the UK market is limited to those makes that the sample was taken.[51]

Second, the current investigation was limited by the location of the HWRCs that ovens were collected. The ovens were sourced from three different HWRC sites within the Greater Manchester area, the location of the HWRC sites within the neighborhood might have had an influence on the quality of disposed ovens that were

[51] The available makes and models on the UK market revealed by online research and electronic outlet in the UK via their websites.

tested. An issue that was not addressed in this study was whether the HWRC location has influence on the quality of discarded ovens.

Third, the fault diagnostic tests were solely based on the available technician knowledge and expertise as well as the available literature and databases and it might influence the findings of the research. However, care has been taken by asking second and in some occasion's third expert opinion to limit the error on fault diagnostic tests.

And finally, the recommended design changes to facilitate reuse and life span extension based on analysing the functionality and cosmetic imperfection of the discarded ovens in the UK were approved for their usefulness and technical feasibility, to apply on the design of new ovens, by colleagues and research supervisors at the UoM. Furthermore, the recommended design changes were approved by CREATE UK, an independent reuse organisation in the UK, although the recommendations were for OEMs.

6.2.2 Generalisability limitations

First, because of the difficulties involved in the fault finding tests described in Chapter 3, the limited availability of experienced technician and the time involved, as a direct consequence, 189 microwave ovens from a variety of makes and models were tested in this research. Therefore, care should be taken when drawing conclusions for the functionality and cosmetic imperfection of the disposed ovens at the HWRCs in general.

Second, for the same reason described in Chapter 3, time and resources, 82 face to face semi-structured interviews took place at a particular HWRC. Furthermore, as any behavioural research study, using face to face interview method, the risk of response and non-response bias was foreseen. To mitigate the risk of response bias and non-response bias to the questions the following precautions were employed. First, the educational purpose of the research explained to the respondent. Second, the anonymity of the respondents and confidentiality of the answers by respondents ensured (the personal information of the respondents were not collected). However, with a small sample size and considering the location of the HWRC caution must be applied, as the findings might not be transferable to the entire consumers in the UK.

And finally, this thesis is the first, based on the empirical study conducted by academia and limited, attempt at analysing the functionality and quality of disposed microwaves based on the voluntary or drop off returns at the Greater Manchester based HWRCs, and therefore conclusions may not hold for the whole UK. However, this study lays the foundation for future studies in this area.

6.3 Contribution of the Research

The main contribution of this research is an increased understanding of the quality of the discarded products in particular microwave oven at the UK household waste recycling centres for the purpose of reuse and remanufacture. The HWRCs in the UK are the first collection point that is set up by government and local authorities in compliance with the EU WEEE directive, and can be seen as point of supply of good quality core for reuse to reuse organisations. The main beneficiaries of this research are OEMs, policy makers and reuse organisations. Following paragraphs discusses the specific contribution of this research.

- *Assesses consumers' intentions and behaviours with respect to the disposal of microwave ovens,*

This thesis contributes to the understanding of the consumer intention and behaviour towards disposal of the products, especially functional ovens, that are the important factor to achieve sustainable consumption and consequently reuse and remanufacture. The results can aid the stakeholders such as government, local authorities and waste prevention managers to design a network and campaign to increase the awareness of other disposal option for unwanted functional products among the consumers. Furthermore, it can also provide information to the decision makers to identify functional equipment at the earliest stage possible opportunity for instance, by allocating a separate storage area for an unwanted functional product, as this study revealed that the the majaroty of consumers knew of the functionality of their disposed ovens, that consumer return to the HWRCs.

- *Investigates the quality of, and the costs of remanufacturing, microwave ovens discarded in the United Kingdom*

This thesis contributes to the understanding of the quality and factors that influence the remanufacturability of the discarded ovens at the HWRC in the UK. Furthermore, analysis of the empirical data can potentially help stakeholders such as local authorities, waste managers and reuse organisations focus on the ways to reclaim these products, which has great potential for reuse at the earliest possible and divert them to reuse channels and increase the reuse rate of the e-waste. Moreover, these results could help the decision makers at the reuse organisations to expand their reuse activities to include microwave ovens to their product portfolio as a potential remanufacturable product.

- *Proposes design changes intended to increase opportunities for reuse and remanufacturing.*

The design changes intended to increase opportunities for longer lifespan and reuse and remanufacturing are proposed to original equipment manufacturers. It is shown that by minor design changes the life extension of the ovens is possible. Furthermore, the empirical results could help and influence governments and decision makers to further support the design for remanufacture within the design stage of the products and to develop and introduce the stronger incentives for OEMs (e.g., tax break for those products designed to be remanufacturable) and other players within the field in order to promote reuse and life extension of electronic products from the early stages of the manufacturing.

6.4 Suggestions for Further Research

This section identifies and describes the scope of future research based on the research work presented in this thesis.

This thesis empirically investigated and documented the opportunities that exist for reuse and remanufacturing of microwaves in the United Kingdom and proposes ways that re-use can be facilitated by OEMs. However, other technical and strategic issues have not been addressed, but deserve attention in future research. These include the antecedents of participation in product take-back, for example, why do some organisations engage in reverse logistics and other not? What are the opportunities and how the stakeholders within the closed loop supply chain can collaborate to increase the collection of core, given the importance of the quality core for remanufacturing and relatively high quality of disposed products at the HWRCs in the UK?

Equally important is to investigate why, given the low cost of and a strong financial case for remanufacturing microwave ovens, are OEMs not currently engaging in such activity (e.g., maybe fear of cannibalisation or image damage [14]). Also how might governments make the remanufacturing and reuse business case even stronger. One important question to be addressed is: How national and international legislations can encourage better design for manufacture?

From consumer perspectives, how do consumers perceive remanufactured products and what affects consumers' willingness-to-pay for these products? The impact of the new UK BSI-PAS141 reuse specification on the consumer perception and demand for the remanufactured products needs investigation. Furthermore, would the assurance of quality of the remanufactured products via national and international standards result in an increase of demand for such products?

Furthermore, within this thesis, design changes to the ovens were proposed to facilitate the reuse and life span extension of the ovens. There is an opportunity to investigate the cost of implementation and its impact on the environmental benefits of the design changes to the OEMs, in the short and long term, by close collaboration with OEMs.

As mentioned before, the focus of this thesis is on the supply side of the closed loop supply chain, however in order to increase the reuse of e-waste the following issues need to be addressed in the future research. First, the role of incentives from governments such as providing tax breaks to OEMs for those products that are designed to ease to remanufacture in order to increase reuse and remanufacture. Second, the market for second hand products. For instance, the government could address the problem of a weak market for remanufactured products by creating mechanisms to include remanufactured products in its procurement strategy as well as increase awareness of potential environmental damage of e-waste and encourage reuse of products among consumers.

A future study investigating the social and environmental benefits of the reuse of microwave oven and its impact on the global emissions would be very interesting.

And finally, this research is focused on the microwave ovens but same research can be applied to other products within the WEEE categories. More information on the functionality and cosmetic imperfection of the disposed products at the HWRCs and their designs that hinder reuse and life span extension would help all stakeholders (e.g., OEMs, policy makers, NGOs, academia, etc.) to establish a greater degree of accuracy on this matter.

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Appendices

A1: The face to face semi-structured interview questionnaire

A2: Fault find Questionnaire

A3: Longley Lane Household Waste Recycling Centre (HWRC), Sharston- Viridor Laing (VLGM) waste Prevention Leaflet

A4: Viridor Laing (Greater Manchester) Limited (VLGM)

A5: Dates which the research team was present and the number of the oven tested at the Langley Lane HWRC site

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A9: A snapshot of the interview data spreadsheet

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A11: The University of Manchester Health and Safety Risk assessment- Survey of the general public and fault find test

A12: Summary of findings to research question One

A13:Summary of findings to research question Two

A14: Summary of findings to research question Three

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A1: The face to face semi-structured interview questionnaire

Section 1 - General small electrical/electronic waste. **Questionnaire Number………**

Date of disposal:	
Approximate date/year of purchase:	
Electrical item to be disposed:	
Make and model:	
Rated Power:	**Recorded power:**

Reason for disposal:

If the item is NOT WORKING are you able to say what may be wrong with the product?	YES/NO
Reported fault details:	
If the item is WORKING/Not working are you replacing or updating this item for a more modern product?	YES/NO
Are you aware of other disposal options for recycling? i.e. GMWDA, charities, specialist recycling centres.	YES/NO
Other (consumer) comments:	

Section 2 - Fault Diagnosis Report for microwave ovens
(To be completed by University technician)

Electrical Faults:

Damaged cord/mains lead/plug/blown plug top fuse/internal fuse	YES/NO
Mains supply voltage available at input of filter circuit	YES/NO
Mains supply available at input of control circuit	YES/NO
Power to HV Transformer	YES/NO
Power to Capacitor	YES/NO
Power to Magnetron	YES/NO

Mechanical Faults

Faulty handle/door locking mechanism	YES/NO
Faulty or broken door latch/interlock	YES/NO
Defective/damaged controls	YES/NO
Rotating base working	YES/NO
Damaged display	YES/NO
Other faults:	

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1824

The University of Manchester

A2: Fault finding Questionnaire

Section 1 - electrical/electronic waste **Questionnaire Number………**

Date of Test:		
Approximate date/year of Manufacture:		
Microwave Oven		
Make and model:		
Input Power:	**Output power:**	
Start Temp:	**Finish Temp:**	**D.T.:**
Time: 60 s		
Mass of Water: 200 ml.		

Section 2 - Fault Diagnosis Report for microwave ovens
(To be completed by University researcher)

Electrical Faults:

Damaged cord/mains lead/plug/blown plug top fuse/internal fuse	YES/NO
Mains supply voltage available at input of filter circuit	YES/NO
Mains supply available at input of control circuit	YES/NO
Power to HV Transformer	YES/NO
Power to Capacitor	YES/NO
Power to Magnetron	YES/NO

Mechanical Faults

Faulty handle/door locking mechanism	YES/NO
Faulty or broken door latch/interlock	YES/NO
Defective/damaged controls	YES/NO
Rotating base working	YES/NO
Damaged display	YES/NO
Other faults:	

A3: Longley Lane Household Waste Recycling Centre (HWRC), Sharston

Address: South Manchester, Longley Lane, M22 4RQ

Distance from the University of Manchester: 8.5 miles

Tel: 0161 428 4963

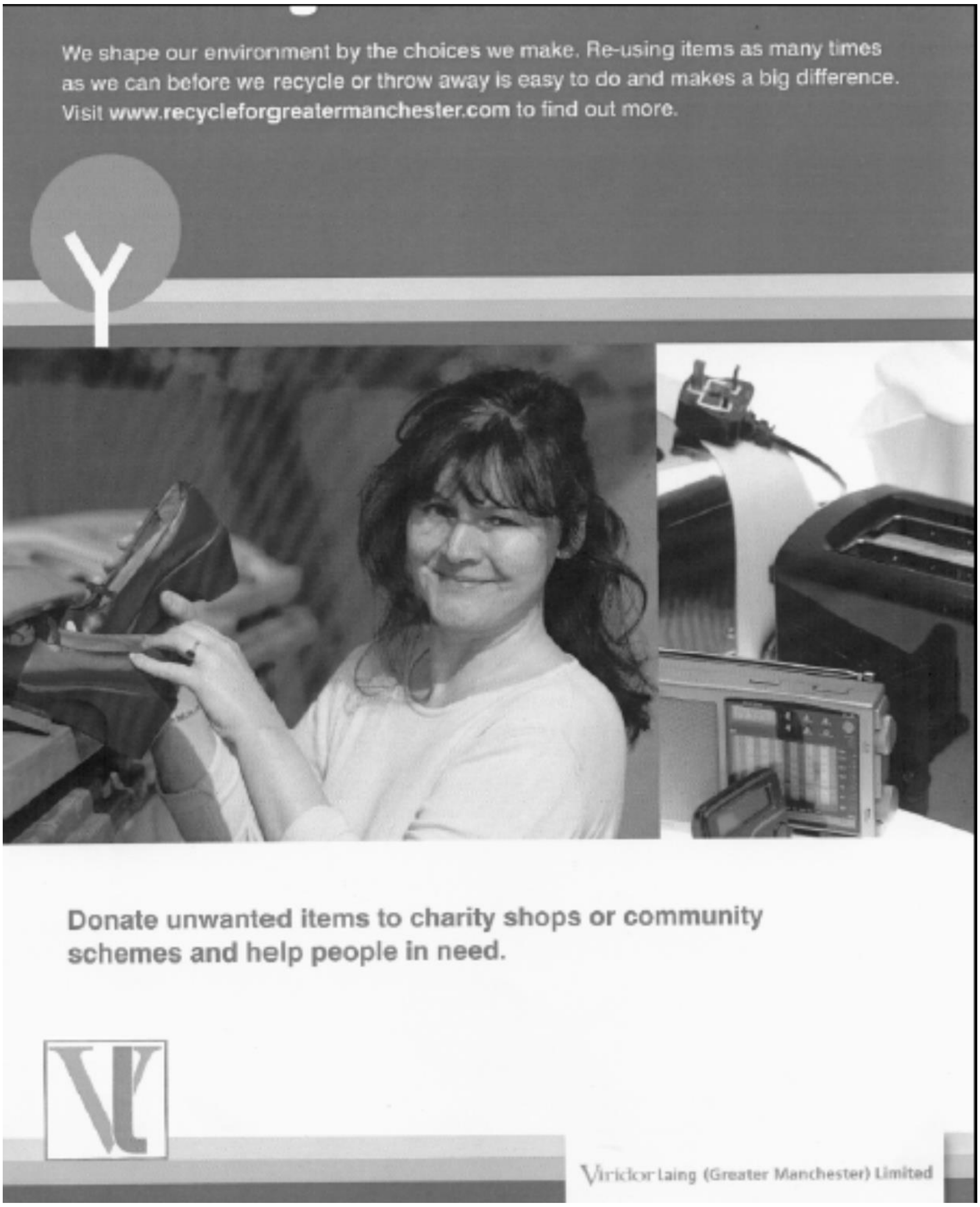
Opening Times: Summer - 8:00am – 8:00pm

Winter - 8:00am – 6:00pm

Accepted Items:

Asbestos, Batteries, Books, Cans, Cardboard, Carpets, Cell Batteries, Chemicals, Computer Monitors, Fluorescent Tubes, Fridge/Freezer, Gas Bottles, Glass, Green Waste, Non Ferrous Scrap, Oil (engine and cooking), Paper, Plasterboard and Gypsum, Plastic bottles, Rubble, Scrap Metal, Textiles, TVs, Tyres, WEEE (Waste Electrical and Electronic Equipment), furniture and Wood.

Viridor Laing (VLGM) waste prevention leaflet



Donating Unwanted Items

Unwanted Clothes, CDs and Books

Donate unwanted clothes or perhaps look at purchasing clothes from charity shops. There are many unwanted items that we can donate to a local charity shop across Greater Manchester. Our clothes, furniture, books, CDs and DVDs are just some of the items accepted. Take advantage of charities that collect clothes and textiles door-to-door. They usually post a plastic sack through your letterbox and provide you with a collection date.

To find out more about donating to charity shops or to locate your nearest one, visit **www.charityshops.org.uk**

Unwanted Furniture and White Goods

There are many community and voluntary organisations across Greater Manchester who accept donations of unwanted household items such as beds, sofas and washing machines. They often repair items if necessary and either sell or pass them on to people in need. The collection from your doorstep is usually free of charge. All you have to do is contact them. Only items in good condition or working order will be accepted at the collector's discretion.

To find out more about donating unwanted furniture simply visit the Community Waste Network North West directory online to see what organisations are local to you.
Visit **www.crn.org.uk/region/north_west** to access the online directory or call on **0161 2736976**.

For more information on how you can reduce your waste please contact :
Sheridan Hilton | Waste Prevention Manager | Viridor Laing (Greater Manchester) Ltd. | Unit 4 Hurstwood Court Raikes Lane Industrial Estate | Bolton | BL3 2NP | T : 01204 374221 | **M** : 07795 171708 | **E** : sheridan.hilton@viridor-laing.co.uk

Viridor laing (Greater Manchester) Limited

A4: Viridor Laing (Greater Manchester) Limited (VLGM)

In April 2009, Greater Manchester Waste Disposal Authority signed a 25 year recycling and waste contract with Viridor Laing (Greater Manchester) Limited (VLGM); a partnership between Viridor and John Laing plc.

The £3.8 billion contract is Europe's largest ever waste deal and includes a £631 million construction programme, creating a network of state-of-the-art facilities to treat Greater Manchester's waste.

VLGM provides facilities and services to manage household waste across nine districts of Greater Manchester, in an environmentally and economically sustainable manner. This involves the reception, treatment and disposal of waste to increase levels of recycling, composting and recovery and reduce waste sent to landfill.

A network of new and redeveloped recycling and waste management facilities are being introduced across Greater Manchester. Many Household Waste Recycling Centres (HWRC's) have now been developed and offer an increased range of recycling opportunities as well as improvements to their layout.

Greater Manchester Waste Disposal Authority (GMWDA) provides recycling and waste disposal services for 1,009,815 households in Bolton, Bury, Manchester, Oldham, Rochdale, Salford, Stockport, Tameside and Trafford. It handles around 5% of national municipal waste.*

*Source:http://www.viridor.co.uk/about-us/our-customers/greater-manchester/

A5: Dates which the research team was present and the number of the oven tested at the Langley Lane HWRC site

	Date of Visit to HWRC and test	Day of the week	No of ovens
1	21.06.2010	Monday	0
2	17.09.2010	Friday	16
3	01.10.2010	Friday	13
4	15.10.2010	Friday	20
5	02.11.2010	Tuesday	20
6	26.11.2010	Friday	13
Total			82

A6: Dates of the face to face interview at the Langley Lane HWRC site

Date of interview	Day of the week	No. of oven
Unknown. 09.2010	Unknown	10
17.09.2010	Friday	6
18.09.2010	Saturday	8
20.09.2010	Monday	5
08.10.2010	Friday	2
10.10.2010	Sunday	8
11.10.2010	Monday	6
12.10.2010	Tuesday	4
23.10.2010	Saturday	7
24.10.2010	Sunday	4
25.10.2010	Monday	2
31.10.2010	Sunday	1
01.11.2010	Monday	6
10.11.2010	Thursday	5
11.11.2010	Wednesday	2
12.11.2010	Friday	2
13.11.2010	Saturday	3
16.11.2010	Tuesday	1
Total		82

A7: CREATE UK Organisation

CREATE Stands for: Community Recycling Environment And Training Enterprise. CREATE Was formed in 1995 by an amalgamation of social and commercial enterprises on Merseyside, CREATE is a registered charity and a social enterprise that is based in Speke Liverpool.

CREATE's aims

- To provide guidance, support and training for adults who have barriers to employment, helping them move into meaningful work and sustainable employment.
- To protect the environment and to reduce waste in the community, by appropriately reusing and finally recycling white goods and furniture that would have historically gone to landfill.
- To supply quality reused and fully refurbished goods back into low-income families within the local community, so as to improve their quality of life, health and well-being.

In 2011 Create UK had 24 full time staffs at their workshop.

CREATE's Success

- In 2011, CREATE has an annual turnover of £ 1.2 million, employs 24 full time staff – comprising engineers, trainers, drivers, administration clerks, retail and sales staff, support workers and management - and up to 30 previously long term unemployed adults on short term paid work and training contracts in Speke Liverpool.
- Between 2010 and 2011 they successfully trained 117 long term unemployed and disadvantage adults and successfully place them at the local car manufacturer into the full time employment
- CREATE currently brings in around 1,500 used machines every week from retail groups, local councils and manufacturers. CREATE reuses about 35% of these products and supplies UK charity refurbishers around the country. CREATE itself refurbishes approximately 10% of those products and sells them to low income households through our own charity shops and in partnership with other charities. Since 1995 CREATE has moved 700 previously unemployed adults into sustainable employment.
- CREATE is seen as a model of sustainable social enterprise. More than 98% of its income comes from the sale of its products and its recycling and training contracts. The Company receives less than 2% of its income from grant funding. It strives to make a surplus each year to reinvest in its charitable aims and its business development

Operational Procedure within Create UK

CREATE is an Environmental Charity with regards to its reuse and recycling operations the sole purpose of operating a waste transfer station (WTS), two designated collection facilities (DCF's) and a large approved authorised treatment facility (AATF) is to gain access to end of life white goods for reuse. CREATE's operations are solely funded by its commercial collection operations, three refurbishment workshops, recycling operations and sales through our own and other partnership charities.

CREATE accepts bulky household collections of end of life white goods commonly known as waste electrical and electronic equipment (WEEE). CREATE sorts these appliances on arrival into two categories by appliance type. The first are the goods that are likely to be able to be refurbished (Reuse) and second is goods that are fit to be destroyed (Recycled). These groups are then categorised as hazardous or non hazardous and coded into the different WEEE categories they belong to.

All incoming products are individually entered on our database and are give a unique identifier (Barcode). At this point a barcode sticker is printed from the system and attached to the appliance; this barcode will remain on the appliance and drive the refurbishment process which will be discussed latter.

As the database has now been told what type of appliance it is, a Furniture Reuse Network (FRN) protocol weight is assigned to the appliance for the purpose of reporting incoming weights to the producer compliance scheme (PCS).

Any products that CREATE do not refurbish or fails during the refurbishment is forwarded onto an end of line AATF for re-processing. These organisations weigh the goods sent from CREATE on arrival and send back weigh bridge tickets and issue dummy evidence notes. CREATE uses this information to record outgoing weights and levels of final recovery.

CREATE does not carry out any direct recycling techniques on WEEE in either the hazardous or non hazardous categories'. CREATE therefore relies on the end of the line re-processors to satisfy the Recycling and Treatment element of BATRRT.

Goods In

As the goods/appliances are received by CREATE they are immediately assessed by trained engineers to see if they are suitable for Reuse. This assessment criterion includes cosmetic looks, age of appliance, type of appliance and a manual check to check for excess wear/damage to the main drum spider. All incoming appliances are entered onto our database and issued a unique identifier (barcode) regardless of suitability for Reuse; CREATE only print out barcode labels for appliances that have a chance of passing through the strict refurbishment process. The barcode once attached to the appliance drives the refurbishment process and allows for a full audit trail, this proves invaluable latter on in order to satisfy the requirements of the AATF independent auditor to prove not only Reuse but also the refurbishment process the appliance has passed through. This process turns the appliance from WEEE back into EEE suitable and fit for purpose.

All appliances that fail the selection process are sent to end of line AATF's for recycling, these AATF's report back to CREATE the weight of WEEE recycled and the percentage of materials recovered. This is reported back to CREATE on a "dummy" evidence note which is in the same format used on the WEEE settlement centre.

All of the appliances now destined for Reuse are sorted by manufacturer and then palletised, they are then stored in a dry warehouse until they are called on by the refurbishment teams at each of the CREATE refurbishment workshops. These workshops are located at Speke Hall Road Liverpool, Wallasey Wirral and HMP prison Liverpool.

Failed appliances are treated with appropriate duty of care and loaded onto trailers to be sent onto end of line UK AATF recyclers.

Reuse Workshops/Reuse Process

The trained engineers at our refurbishment workshops call on the warehouse team to supply them with product that has been pre-selected by them for Reuse.

Once the appliance is transferred the refurbishment can begin, the appliances have already been given a unique ID when they were booked onto the CREATE database. The key to this process is that it has been entered by not only the source it came from but by appliance type. This means that when our engineers enter the unique ID into the system and move the appliance from goods into refurbishment, the database prints out a process control sheet designed to match the appliance type. CREATE splits its refurbishment workshops into three simple categories "Wet" for laundry appliances, "Cold" for refrigeration appliances and "Hot" for cooking and drying appliances. Each of these three areas then takes its own product type through a four stage process.

Stage one is check and preparation this stage is vital for health and safety as we do not know what has been done to the appliance prior to its arrival at CREATE.

Stage two is initial test and fault diagnosis it is at this point that we attach power to the appliance and the required tests are performed and checked off by the engineer.

Stage three includes any repairs that need be carried out and full functional and electrical testing.

Stage four of the process is all about quality assurance and making sure the product is of a high enough standard to be presented to the sales team for sale.

Spare Parts/Scrap Salvage

Any appliances that do not make it through the refurbishment and quality control process are not just scrapped and sent for recycling. Every effort is made to get the full Reuse element out of the product before it is sent for recycling.

The backbone of the CREATE refurbishment process is the stores which supply the engineers with all the resources they need to Reuse the appliances. The stores are stocked with spare parts that have been recovered from failed machines as part of a scrap salvage process. It is important to note at this point that any appliances that fail are ultimately scrapped on the system and are sent back to the warehouse as “goods in”. This makes sure that there is no chance of any appliance being “double counted” as WEEE evidence.

The stores at CREATE makes a wish list of the spare parts that are required by the three refurbishment workshops. The scrap salvage team then source these spare parts from failed appliances, all the spares that are removed are bar-coded and assigned a part number and then consigned to the stores core stock.

As an engineer calls on a spare part he brings to the stores his process sheet. The bar-code on the process sheet is then scanned as is the spare part, the database then assigns the spare part to the appliance it is to be used on. As the engineer has also logged onto the database we now have a full audit trail showing what spare part was fitted by each engineer on each the appliances they are refurbishing.

Quality Control

Once the refurbishment process is complete the senior engineer from each department re-checks that all of the work has been completed satisfactorily he then again uses a portable appliance tester (PAT) for the final time to ensure the appliance is safe. He then completes the bar-code label with the PAT readings and then signs the appliance off as complete and fit for purpose. It is at this point that CREATE then treats the appliance as EEE and not WEEE.

CREATE was a member of the steering group in 2009 for WRAP’s guidance document for the best collection and treatment processes for WEEE, CREATE is currently representing the Community Recycling Network (CRN) on the steering group for the BSI PAS 141 which is to be the new reuse standard for WEEE. CREATE is already adapting its reuse processes to meet these new standards.

CREATE makes every effort to ensure that these appliances can now be sold to low income families in the community, as part of this concerted effort CREATE has introduced a further quality control measure.Appliances are chosen at random by management and are re-tested in a separate quality control bay, a quality control sheet is completed by an independent engineer, and if the appliance passes the QC sheet is placed in the appliance to reassure our customers of the efforts we undertake to ensure quality.If the appliance fails the QC sheet is passed back to management for review and the results are fed back to the engineering team so as to further improve the quality process.

Sales and After Care

Once the appliance reaches the sales team it is checked over by the sales staff to ensure that the appliance is cosmetically aesthetic, the sales team have to accept the appliance from the refurbishment department on the database before they can assign the sales details. Once the appliance has been sold it is delivered out to the customer.

All of the refurbished appliances that CREATE sells are guaranteed. CREATE has enough confidence in its Reuse and Refurbishment process that it gives a full 12 months guarantee on every appliance it sells. Any appliances that require after sales care are attended by one of our two full time service engineers in the customer's home.

Why Create did not survive?

In May 2012 the Create UK falls into administrations following reasons were provided:

- The high value of scrap metal which it claims has made the re-use and refurbishment of products unviable, particularly against a background of low-cost imports on easy-payment options.
- Government funding cuts in training

Read more: Liverpool Echo: http://www.liverpoolecho.co.uk/liverpool-news/local-news/2012/05/16/speke-recycling-scheme-create-in-liquidation-100252-30976397/#ixzz2Hsy1pIMI

Source: Author Visit and Intervirew with CEO of CREATE UK and staff, and available internal reports and documents provided by CREATE UK.

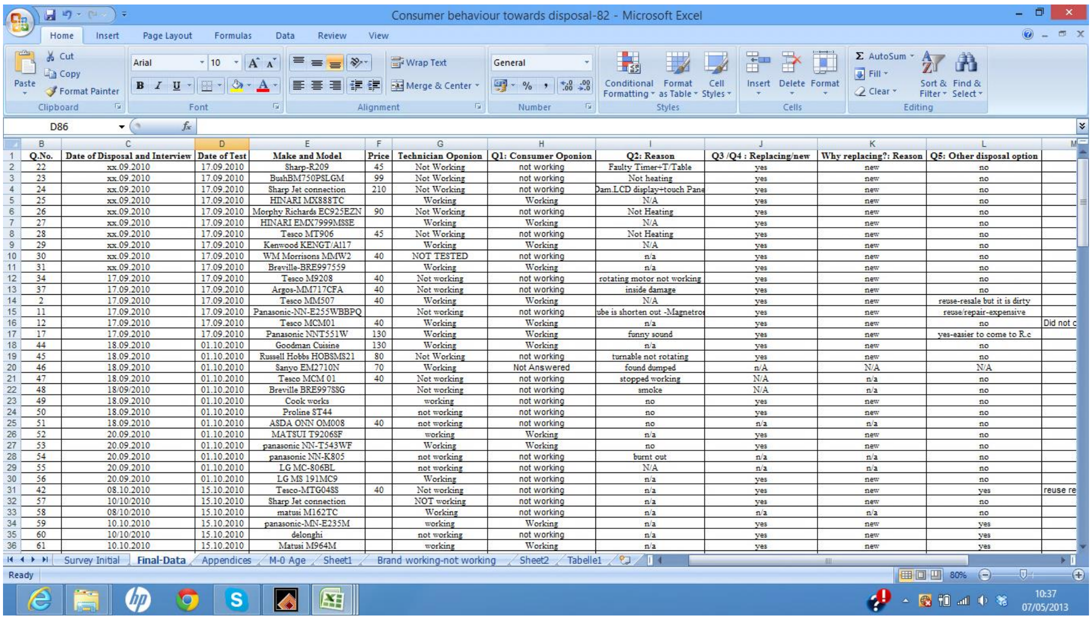
A8: Specification of 328 Digital LCD Multimeter

Manufacturer : **Rapid**

A digital multimeter with large 4½ digits LCD display. The multimeter provides high accuracy, measuring of capacitance and frequency.

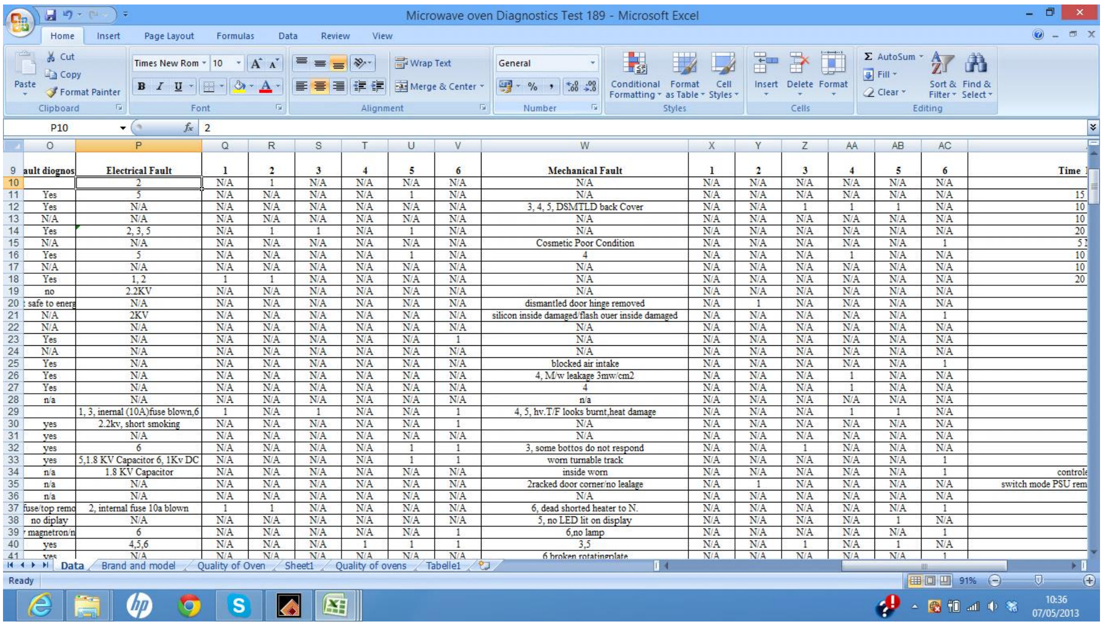
- Display: 30 x 60mm LCD, max. reading 1999 counts
- DC Voltage: 200mV ±0.05%, 2/20/200V ±0.1%, 1000V ±0.15%
- AC Voltage: 2V ±0.5%, 20/200V ±0.6%, 700V ±0.8%
- DC Current: 2m/20mA ±0.5%, 200mA ±0.8%, 20A ±2%
- AC Current: 2m/20mA ±0.8%, 200mA ±1.2%, 20A ±2.5%
- Resistance: 200 ±0.5%, 2K/20K/200K/2M ±0.3%, 20M ±0.5%, 200M ±5%
- Capacitance: 2000p/20n/200n/2u/20uF ±4.0%
- Frequency: 20KHz ±1.5%
- Continuity checking with buzzer
- Diode check: Test current 0.8mA, test voltage 3V
- Power source: 1x 9V
- Product dimension: 91 x 189 x 31.5mm
- Product weight: 310g (including battery)

A9: A snapshot of the face to face interview data spreadsheet



	Q.No.	Date of Disposal and Interview	Date of Test	Make and Model	Price	Technician Oponion	Q1: Consumer Oponion	Q2: Reason	Q3 /Q4 : Replacing/new	Why replacing?: Reason	Q5: Other disposal option	
2	22	xx.09.2010	17.09.2010	Sharp-R209	45	Not Working	not working	Faulty Timer+T/Table	yes	new	no	
3	23	xx.09.2010	17.09.2010	BushBM750PSLGM	99	Not Working	not working	Not heating	yes	new	no	
4	24	xx.09.2010	17.09.2010	Sharp Jet connection	210	Not Working	not working	Dam.LCD display+touch Pane	yes	new	no	
5	25	xx.09.2010	17.09.2010	HINARI MX888TC		Working	Working	N/A	yes	new	no	
6	26	xx.09.2010	17.09.2010	Morphy Richards EC925EZN	90	Not Working	not working	Not Heating	yes	new	no	
7	27	xx.09.2010	17.09.2010	HINARI EMX7999MSSE		Working	Working	N/A	yes	new	no	
8	28	xx.09.2010	17.09.2010	Tesco MT906	45	Not Working	not working	Not Heating	yes	new	no	
9	29	xx.09.2010	17.09.2010	Kenwood KENGT/A117		Working	Working	N/A	yes	new	no	
10	30	xx.09.2010	17.09.2010	WM Morrisons MMW2	40	NOT TESTED	not working	n/a	yes	new	no	
11	31	xx.09.2010	17.09.2010	Breville-BRE997559		Working	Working	n/a	yes	new	no	
12	34	17.09.2010	17.09.2010	Tesco M9208	40	Not working	not working	rotating motor not working	yes	new	no	
13	37	17.09.2010	17.09.2010	Argos-MM717CFA	40	Not working	not working	inside damage	yes	new	no	
14	2	17.09.2010	17.09.2010	Tesco MM507	40	Working	Working	N/A	yes	new	reuse-resale but it is dirty	
15	11	17.09.2010	17.09.2010	Panasonic-NN-E255WBBPQ		Not working	not working	ube is shorten out -Magnetro	yes	new	reuse/repair-expensive	
16	12	17.09.2010	17.09.2010	Tesco MCM01	40	Working	Working	n/a	yes	new	no	Did not c
17	17	17.09.2010	17.09.2010	Panasonic NNT551W	130	Working	Working	funny sound	yes	new	yes-easier to come to R.c	
18	44	18.09.2010	01.10.2010	Goodman Cuisine	130	Working	Working	n/a	yes	new	no	
19	45	18.09.2010	01.10.2010	Russell Hobbs HOBSMS21	80	Not Working	not working	turnable not rotating	yes	new	no	
20	46	18.09.2010	01.10.2010	Sanyo EM2710N	70	Working	Not Answered	found dumped	n/A	N/A	N/A	
21	47	18.09.2010	01.10.2010	Tesco MCM 01	40	Not working	not working	stopped working	N/A	n/a	no	
22	48	18/09/2010	01.10.2010	Breville BRE997SSG		Not working	not working	smoke	N/A	n/a	no	
23	49	18.09.2010	01.10.2010	Cook works		working	not working	no	yes	new	no	
24	50	18.09.2010	01.10.2010	Proline ST44		not working	not working	no	yes	new	no	
25	51	18.09.2010	01.10.2010	ASDA ONN OM008	40	not working	not working	no	n/a	n/a	no	
26	52	20.09.2010	01.10.2010	MATSUI T9206SF		working	Working	n/a	yes	new	no	
27	53	20.09.2010	01.10.2010	panasonic NN-T543WF		Working	Working	no	yes	new	no	
28	54	20.09.2010	01.10.2010	panasonic NN-K805		not working	not working	burnt out	n/a	n/a	no	
29	55	20.09.2010	01.10.2010	LG MC-806BL		not working	not working	N/A	n/a	n/a	no	
30	56	20.09.2010	01.10.2010	LG MS 191MC9		Working	not working	n/a	yes	new	no	
31	42	08.10.2010	15.10.2010	Tesco-MTG04SS	40	Not working	not working	n/a	yes	new	yes	reuse re
32	57	10/10/2010	15.10.2010	Sharp Jet connection		NOT working	not working	n/a	yes	new	no	
33	58	08/10/2010	15.10.2010	matusi M162TC		Working	not working	n/a	n/a	n/a	no	
34	59	10.10.2010	15.10.2010	panasonic-MN-E235M		working	Working	n/a	yes	new	yes	
35	60	10/10/2010	15.10.2010	delonghi		not working	not working	n/a	yes	new	yes	
36	61	10.10.2010	15.10.2010	Matusi M964M		working	Working	n/a	yes	new	yes	

A10: A snapshot of the fault finds survey data spreadsheet



	ault diognos	Electrical Fault	1	2	3	4	5	6	Mechanical Fault	1	2	3	4	5	6	Time
10		2	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
11	Yes	5	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	15
12	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3, 4, 5, DSMTLD back Cover	N/A	N/A	1	1	1	N/A	10
13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10
14	Yes	2, 3, 5	N/A	1	1	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	20
15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Cosmetic Poor Condition	N/A	N/A	N/A	N/A	N/A	1	5 I
16	Yes	5	N/A	N/A	N/A	N/A	1	N/A	4	N/A	N/A	N/A	1	N/A	N/A	10
17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10
18	Yes	1, 2	1	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	20
19	no	2.2KV	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
20	: safe to energ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	dismantled door hinge removed	N/A	1	N/A	N/A	N/A	N/A	
21	N/A	2KV	N/A	N/A	N/A	N/A	N/A	N/A	silicon inside damaged/flash ouer inside damaged	N/A	N/A	N/A	N/A	N/A	1	
22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
23	Yes	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
25	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	blocked air intake	N/A	N/A	N/A	N/A	N/A	1	
26	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4, M/w leakage 3mw/cm2	N/A	N/A	N/A	1	N/A	N/A	
27	Yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4	N/A	N/A	N/A	1	N/A	N/A	
28	n/a	N/A	N/A	N/A	N/A	N/A	N/A	N/A	n/a	N/A	N/A	N/A	N/A	N/A	N/A	
29		1, 3, inernal (10A)fuse blown,6	1	N/A	1	N/A	N/A	1	4, 5, hv.T/F looks burnt,heat damage	N/A	N/A	N/A	1	1	N/A	
30	yes	2.2kv, short smoking	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
31	yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
32	yes	6	N/A	N/A	N/A	N/A	1	1	3, some bottos do not respond	N/A	N/A	1	N/A	N/A	N/A	
33	yes	5,1.8 KV Capacitor 6, 1Kv DC	N/A	N/A	N/A	N/A	1	1	worn turnable track	N/A	N/A	N/A	N/A	N/A	1	
34	n/a	1.8 KV Capacitor	N/A	N/A	N/A	N/A	N/A	N/A	inside worn	N/A	N/A	N/A	N/A	N/A	1	controle
35	n/a	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2racked door corner/no lealage	N/A	1	N/A	N/A	N/A	N/A	switch mode PSU rem
36	n/a	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
37	fuse/top remo	2, internal fuse 10a blown	1	1	N/A	N/A	N/A	N/A	6, dead shorted heater to N.	N/A	N/A	N/A	N/A	N/A	1	
38	no diplay	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5, no LED lit on display	N/A	N/A	N/A	N/A	1	N/A	
39	magnetron/n	6	N/A	N/A	N/A	N/A	N/A	1	6,no lamp	N/A	N/A	N/A	N/A	N/A	1	
40	yes	4,5,6	N/A	N/A	N/A	1	1	1	3,5	N/A	N/A	1	N/A	1	N/A	
41	yes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6 broken rotatingplate	N/A	N/A	N/A	N/A	N/A	1	

A11: The University of Manchester Health and Safety Risk assessment- Survey of the general public and fault find Test

SCHOOL OF E&EE RISK ASSESSMENT

Location: Viridor Laing, Longley Lane Recycle Centre, Sharston.

Activity: Survey the general public as they are disposing of small electrical items.

Risk Assessment: Survey_EEE_09_06_10_SD1

WORK ACTIVITY/ WORKPLACE (WHAT PART OF THE ACTIVITY POSES RISK OF INJURY OR ILLNESS)	HAZARD (S) (SOMETHING THAT COULD CAUSE HARM, ILLNESS OR INJURY)	LIKELY CONSEQUENCES (WHAT WOULD BE THE RESULT OF THE HAZARD)	WHO OR WHAT IS AT RISK (INCLUDE NUMBERS AND GROUPS)	EXISTING CONTROL MEASURES IN USE (WHAT PROTECTS PEOPLE FROM THESE HAZARDS)	WITH EXISTING CONTROLS: SEVERITY	LIKELIHOOD	RISK RATING	RISK ACCEPTABLE	MEASURE REQUIRED TO PREVENT OR REDUCE RISK (WHAT NEEDS TO BE DONE TO MAKE THE ACTIVITY AS SAFE AS POSSIBLE)	PERSON RESPONSIBLE FOR ACTIONS AND AGREED TIMESCALES TO ACHIEVE THEM	WITH NEW CONTROLS: SEVERITY	LIKELIHOOD	RISK RATING	RISK ACCEPTABLE
Researcher conducting an on site questionnaire	Movement of traffic, public vehicles and Viridor site vehicles	Crushing Severe injury	Researcher/ Technician/Public	Researcher/Technician to wear high viz vest at all times and remain vigilant. No UoM staff to remain in the Viridor side of the compound while Viridor site traffic is in operation UoM Staff to remain within the areas as specified by Viridor.	5	2	10	No	Appropriate signs to be displayed informing motorists a survey is in progress	Sheridan Hilton Prior to any UoM survey	5	1	5	YES
	Weather Sun, Rain, Wind, Temperature	Sun burn Hypothermia	Researcher/ Technician	Suitable clothing to be worn that is appropriate for the weather conditions, hard hat water proofs, fleece, and safety shoes.	3	1	3	YES	Uom to provide PPE	Stephen Duffy Prior to any UoM survey	3	1	3	YES
Collection of microwave ovens	Lifting	Back injury Crushing or trapping of feet	Researcher/ Technician/Public	Wherever possible allow member of public to carry the microwave into the storage cage. Only trained UoM person to lift microwaves.	4	2	8	No	Training in manual handling required for researcher	Stephen Duffy Prior to any UoM survey	4	1	4	YES
	Slips trips and falls	Minor injury	Researcher/ Technician/Public	Work area to be kept clear of trip hazards	3	1	3	YES	Additional care to be taken when working in wet conditions.					
Pedestrian access and egress to the recycling centre site	Movement of Traffic Public Vehicles and Viridor site vehicles	Crushing Severe injury	Researcher/ Technician	Researcher/Technician to wear high viz vests at all times and remain vigilant. Always make use of designated pedestrian routes.	5	1	5	YES	UoM Staff to sign visitors book on arrival and on exit	Sheridan Hilton to advise Prior to any UoM survey	5	1	5	YES

1

SCHOOL OF E&EE RISK ASSESSMENT

WORK ACTIVITY/ WORKPLACE (WHAT PART OF THE ACTIVITY POSES RISK OF INJURY OR ILLNESS)	HAZARD (S) (SOMETHING THAT COULD CAUSE HARM, ILLNESS OR INJURY)	LIKELY CONSEQUENCES (WHAT WOULD BE THE RESULT OF THE HAZARD)	WHO OR WHAT IS AT RISK (INCLUDE NUMBERS AND GROUPS)	EXISTING CONTROL MEASURES IN USE (WHAT PROTECTS PEOPLE FROM THESE HAZARDS)	WITH EXISTING CONTROLS				MEASURE REQUIRED TO PREVENT OR REDUCE RISK (WHAT NEEDS TO BE DONE TO MAKE THE ACTIVITY AS SAFE AS POSSIBLE)	PERSON RESPONSIBLE FOR ACTIONS AND AGREED TIMESCALES TO ACHIEVE THEM	WITH NEW CONTROLS			
					SEVERITY	LIKELIHOOD	RISK RATING	RISK ACCEPTABLE			SEVERITY	LIKELIHOOD	RISK RATING	RISK ACCEPTABLE
Driving personal vehicle when gaining access to the recycling centre site	Movement of other traffic public vehicles and pedestrians	Crushing Severe injury	UoM Staff/ Public/Viridor staff	Maintain site speed limit, observe directional signs and notices Park in designated area	5	1	5	YES	Viridor to provide a designated parking area	Sheridan Hilton to arrange prior to any UoM survey	5	1	5	YES
Access to welfare facilities	Lack of facilities	Abandon survey	Researcher/Technician	Viridor to provide access to the on site welfare facilities Toilets & refreshment area	2	1	2	YES						
Site Safety awareness	Traffic, waste.	Unidentified Hazards	Researcher/Technician	Local Safety Induction for UoM Staff	5	2	10	NO	Local Safety Induction for UoM Staff Viridor SoP & Risk Assessments to be followed	Sheridan Hilton to arrange prior to any UoM survey	5	1	5	YES

RISK ASSESSOR	NAME: Stephen Duffy School Safety Advisor	SIGNED:	DATE:	THIS RISK ASSESSMENT WILL BE SUBJECT TO A REVIEW NO LATER THAN: (MAX 12 MTHS)
Project Supervisor	NAME: Professor A.Gibson	SIGNED:	DATE:	REVIEW DATE: 08/08/11
Researcher	NAME: Azadeh Dindarian	SIGNED:	DATE:	

2

SEVERITY VALUE = Potential consequence of an incident/injury given current level of controls.

5 Very High Death / permanent incapacity / widespread loss
4 High Major Injury (Reportable Category) / Severe Incapacity / Serious Loss
3 Moderate Injury / illness of 3 days or more absence (reportable category) / Moderate loss
2 Slight Minor injury / illness - immediate 1st Aid only / slight loss
1 Negligible No injury or trivial injury / illness / loss

LIKELIHOOD = what is the potential of an incident or injury occurring given the current level of controls.

5 Almost certain to occur
4 Likely to occur
3 Quite possible to occur
2 Possible in current situation
1 Not likely to occur

The multiple of Likelihood with Severity is the risk classification value.

RISK SCORE Key:

1- 5 **LOW - Tolerable** - Monitor and Manage

6 - 10 **MEDIUM** - Review and introduce additional controls to mitigate to "As Low As Reasonably Practicable" (ALARP).

12 - 25 **HIGH** - Intolerable Stop Work and immediately introduce further control measures

		Severity				
		1	2	3	4	5
Likelihood	1	Low	Low	Low	Low	Low
	2	Low	Low	Medium	Medium	Medium
	3	Low	Medium	Medium	High	High
	4	Low	Medium	High	High	High
	5	Low	Medium	High	High	High

MANCHESTER 1824

The University of Manchester

SCHOOL OF E&EE RISK ASSESSMENT

Location: Viridor Laing, Longley Lane Recycle Centre, Sharston.

Activity: Fault Diagnosis of Microwave Ovens.

Risk Assessment: Fault Diagnosis_EEE_09_06_10_SD1

WORK ACTIVITY/ WORKPLACE (WHAT PART OF THE ACTIVITY POSES RISK OF INJURY OR ILLNESS)	HAZARD (S) (SOMETHING THAT COULD CAUSE HARM, ILLNESS OR INJURY)	LIKELY CONSEQUENCES (WHAT WOULD BE THE RESULT OF THE HAZARD)	WHO OR WHAT IS AT RISK (INCLUDE NUMBERS AND GROUPS)	EXISTING CONTROL MEASURES IN USE (WHAT PROTECTS PEOPLE FROM THESE HAZARDS)	WITH EXISTING CONTROLS				MEASURE REQUIRED TO PREVENT OR REDUCE RISK (WHAT NEEDS TO BE DONE TO MAKE THE ACTIVITY AS SAFE AS POSSIBLE)	PERSON RESPONSIBLE FOR ACTIONS AND AGREED TIMESCALES TO ACHIEVE THEM	WITH NEW CONTROLS			
					SEVERITY	LIKELIHOOD	RISK RATING	RISK ACCEPTABLE			SEVERITY	LIKELIHOOD	RISK RATING	RISK ACCEPTABLE
Technician conducting an on site inspection of microwave ovens	Movement of traffic, public vehicles and Viridor site vehicles	Crushing Severe injury	Researcher/ Technician	Researcher/Technician to follow all control measures as identified in the "Survey_EEE_009_06_10_SD1" risk assessment & Viridor SoP for HWRC Operatives	5	1	5	YES						
Manual handling	Moving of multiple microwave ovens in a confined space	Slips trips, falls	Researcher/ Technician	Only trained person to handle/lift ovens Work area to be kept clear of debris	2	2	4	YES						
Manual handling	Sharp edges.	Cuts, infections	Researcher/ Technician	Oven to be visually inspected prior to moving	2	2	4	YES	First aid kit to be available on site Appropriate safety gloves to be provided and worn when moving & testing ovens.	UoM to provide gloves & First Aid Kit prior to any UoM survey Report to Viridor First Aider	2	1	2	YES
Manual handling	Falling Heavy ovens	Crushing Severe injury	Researcher/ Technician	Steel Toe Capped Safety Shoes to be worn at all times. Ovens not to be stacked more than 4 high	3	3	9	NO	Weather conditions to be monitored additional caution particularly when wet	UoM to provide safety shoes prior to any UoM survey	3	1	3	YES
Testing	Exposed voltages	Electrocution	Technician	Only trained competent technician to conduct fault finding	5	3	15	NO	RCBO protection used in line of the supply voltage. Technician to be isolated from Earth when mains voltages are applied	UoM to supply suitable portable petrol generator with Residual Voltage detection and Over Current protection (Max 13a). Prior to on site survey	5	1	5	YES

1

SCHOOL OF E&EE RISK ASSESSMENT

WORK ACTIVITY/ WORKPLACE (WHAT PART OF THE ACTIVITY POSES RISK OF INJURY OR ILLNESS)	HAZARD (S) (SOMETHING THAT COULD CAUSE HARM, ILLNESS OR INJURY)	LIKELY CONSEQUENCES (WHAT WOULD BE THE RESULT OF THE HAZARD)	WHO OR WHAT IS AT RISK (INCLUDE NUMBERS AND GROUPS)	EXISTING CONTROL MEASURES IN USE (WHAT PROTECTS PEOPLE FROM THESE HAZARDS)	WITH EXISTING CONTROLS				MEASURE REQUIRED TO PREVENT OR REDUCE RISK (WHAT NEEDS TO BE DONE TO MAKE THE ACTIVITY AS SAFE AS POSSIBLE)	PERSON RESPONSIBLE FOR ACTIONS AND AGREED TIMESCALES TO ACHIEVE THEM	WITH NEW CONTROLS			
					SEVERITY	LIKELIHOOD	RISK RATING	RISK ACCEPTABLE			SEVERITY	LIKELIHOOD	RISK RATING	RISK ACCEPTABLE
Testing	Exposed voltages	Electrocution	Technician	Only trained competent technician to conduct fault finding	5	3	15	NO	No insulating guards or terminals will be exposed during the fault finding procedure Ovens to be PAT tested	No live electrical testing will be conducted unaccompanied.	5	1	5	YES
Testing	Explosion/Fire from petrol generator & stored fuel	Burns, severe injury	Technician, researcher, Viridor Staff	Max 5 litre approved petrol container to be used. No naked flames Fire Extinguisher	4	1	4	YES	Spare petrol to be stored in approved Viridor location.	Arrange with local site supervisor S Duffy Prior to on site survey	4	1	4	YES
Testing	Microwave leakage	Exposure to microwaves	Technician	Only trained competent technician to work in the vicinity of the microwaves when energised.	5	3	15	NO	Microwave leakage detector to be used to check for leakage	UoM to supply suitable leakage detector Prior to on site survey	5	1	5	YES
Testing	Microwave leakage	Exposure to microwaves	Technician	Only trained competent technician to work in the vicinity of the microwaves when energised.	5	3	15	NO	No protective covers, interlocks or screens will be removed or bypassed during the fault finding process.	Technician will carry out testing in accordance with SoP & Testing Methodology, appendix 1 e-waste proposal document	5	1	5	YES

RISK ASSESSOR	NAME: Stephen Duffy School Safety Advisor	SIGNED:	DATE:	THIS RISK ASSESSMENT WILL BE SUBJECT TO A REVIEW NO LATER THAN: (MAX 12 MTHS)
Project Supervisor	NAME: Professor A.Gibson	SIGNED:	DATE:	REVIEW DATE: 09/06/11
Researcher	NAME: Azadeh Dindarian	SIGNED:	DATE:	

2

SCHOOL OF E&EE RISK ASSESSMENT

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RISK SCORE Key:

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6 - 10 MEDIUM - Review and introduce additional controls to mitigate to **"As Low As Reasonably Practicable"** (ALARP).

12 - 25 HIGH - Intolerable Stop Work and immediately introduce further control measures

Likelihood	Severity 1	2	3	4	5
1	Low	Low	Low	Low	Low
2	Low	Low	Medium	Medium	Medium
3	Low	Medium	Medium	High	High
4	Low	Medium	High	High	High
5	Low	Medium	High	High	High

3

A12: Summary of Findings to Research Question One

Table A 1: Approximate life span of 82 microwave ovens given by respondents

No.	Life span	Approx.Year of Purchase	No.	Life span	Approx. Year of Purchase
1	6	2004	42	7	2003
2	5	2005	43	2	2008
3	5	2005	44	6	2004
4	6	2004	45	12	1998
5	2	2008	46	4	2006
6	5	2005	47	3	2007
7	Not Answered	Not Answered	48	9	2001
8	3	2007	49	6	2004
9	Not Answered	Not Answered	50	1	2009
10	2	2008	51	3	2007
11	1	2009	52	2	2008
12	2	2008	53	15	1995
13	3	2007	54	25	1985
14	10	2000	55	3	2007
15	7	2003	56	17	1993
16	5	2005	57	1	2009
17	7	2003	58	2	2008
18	7	2003	59	5	2005
19	12	1998	60	1	2010
20	10	2000	61	2	2008
21	5	2005	62	11	1999
22	4	2006	63	Not Answered	Not Answered
23	14	1996	64	5	2005
24	6	2004	65	1	2009
25	5	2005	66	10	2000
26	4	2006	67	4	2006
27	12	1998	68	25	old
28	10	2000	69	3	2007
29	12	1998	70	3	2007
30	3	2007	71	7	2003
31	10	2000	72	19	1990
32	8	2002	73	9	2001
33	4	2006	74	20	1990
34	9	2001	75	6	2004
35	7	2003	76	10	2000
36	4	2006	77	2	2008
37	14	1996	78	5	2005
38	11	1999	79	11	1999
39	2	2008	80	2	2008
40	9	2001	81	6	2004
41	2	2008	82	Not Answered	Not Answered

Note: The calculation is based on the approximate purchase date and disposal date, e.g., Sep, Oct and Nov 2010.

Figure A1: The approximate age of the disposed ovens

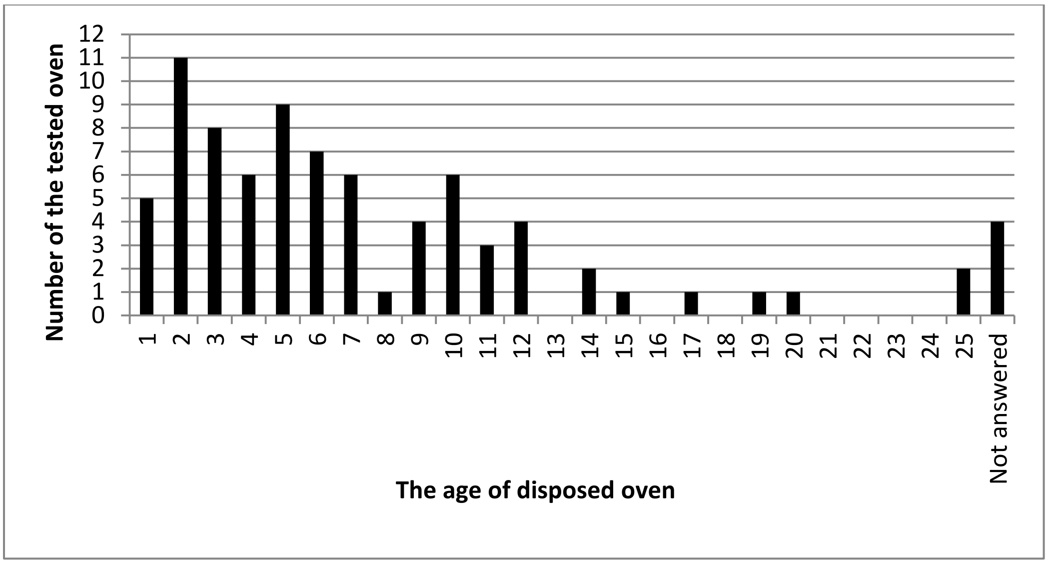


Table A 2: Respondents‘ opinions on the functionality of the disposed ovens at the point of disposal

Respondent`s opinion	No. of respondents
Working	41
Not working	39
Not answered	2
Total	82

Table A 3: Summary of the fault-finding diagnostic test of those ovens that interviewees believed were not working

Fault find diagnostic findings to Not working answer	No. of ovens
Not working	32
Working	5
Not tested	2
Total	39

Table A 4: Summary of the fault-finding diagnostic test of those ovens that interviewees believed believed were working

Fault find diagnostic findings to working answer	No. of ovens
Not working	0
Working	40
Not tested	1
Total	41

Table A 5: Summary of the fault-find diagnostic test of those ovens that interviewees did not answered

Fault find diagnosis findings to Not answered answer	No. of ovens
Not working	0
Working	1
Not tested	1
Total	2

Table A 6: Summary of the responds to the question: If the oven is not working can you identify the cause?

If the oven is Not working can you identify the cause	No. of respondent
Yes	16
No	5
Not answered	18
Total	39

Table A 7: Summary of the responds of those consumers stated that the oven is not working but is being replaced with modern oven

Consumer said NOT working but replacing with modern oven	No. of respondent
Yes	21
No	0
Not answered	18
Total	39

Table A 8: Summary of the responds of those consumer stated that the oven is working but replacing with modern oven

Consumer said working but replacing with the modern oven	No. of respondent
Yes	29
No	10
Not answered	2
Total	41

Table A 9: Summary of the response of those consumers that not answered/not known the functionality of disposed oven that is being replaced with a modern oven

Not answered but interviewer assumed that oven is working and asked a subsequent question of are you replacing item with modern oven	No. of respondent
Not answered	2
Replacing with new items	0
Not replacing with new items	0
Total	2

Table A 10: Reason for replacement of working ovens given by respondents which believed that the disposed oven was not working

Reason for disposal	No. of respondents
Funny sound	1
Old	3
Door rusty inside	1
New one	2
Updating model	2
Total	9

Table A 11: Summary of the failure identified by respondents believed that the disposed ovens were not working

Failure identified by respondents	No. of respondents
Faulty Timer and Turn Table not working	1
Not Heating	5
Damaged LCD display+touch Panel	1
Rotating motor not working	1
Inside damage	1
The tube is shortened out –Magnetron	1
Turn table not working	1
Stopped working	1
Smoke	1
Burnt out	1
Inside door shortens	1
Start button broken	1
Total	16

A13: Summary of Findings to Research Question Two

Table A 12: The 40 tested microwave ovens manufacturers‘and retailers name

	Manufacturer or retailer of tested ovens	No. of ovens		Manufacturer or retailer of tested ovens	No. of ovens
1	Argos	1	21	NAIKO	1
2	ASDA	3	22	NEXT	1
3	Belling	4	23	Pacific	3
4	Breville	3	24	Panasonic	14
5	Brother	1	25	Prestige	1
6	Bosch	4	26	Pro-line	4
7	Cookworks	7	27	Russel Hobbs	7
8	Cuisinart	1	28	Sainsburys	1
9	Daewoo	8	29	Saisho	2
10	De‘Longhi	6	30	Samsung	7
11	Delta	1	31	Sanyo	16
12	Duraband	3	32	SHARP	25
13	Gold star	3	33	Siemens	1
14	Goodman Cuisine	1	34	SWAN	6
15	Hinari	12	35	Tesco	15
16	Kenwood	3	36	Toshiba	1
17	LG	5	37	TRICITY	1
18	Matsui	8	38	Whirlpool	4
19	Mellisa smart	1	39	WM Morrisons	1
20	Morphy Richards	1	40	WOOLWORTH	2
			Total	40	189

Note: Argos, ASDA, NEXT, Sainsbury`s, Tesco, WM Morrison and Woolworth are retailer and rest are OEM manufacturers.

Table A 13: 189 tested ovens from 40 different makes and variety of models

No.	Make and Model	No.	Make and Model
1	Argos-MM717CFA	36	DeLonghi DMX30
2	Asda ONN OM 011	37	De'longhi EM821 AAN
3	ASDA ONN OM008	38	De'longhi-WP800L20-5S111
4	ASDA P70 B17P-C6	39	Delta
5	Belling	40	Durabrand DBM001
6	Belling	41	Durabrand DBM001
7	Belling BEL-CT211	42	Durabrand XB2316
8	Belling BEL-STW25	43	Gold star MA6515E
9	Breville -BR799GMSSE	44	Gold star MA-651ME
10	Breville BRE997SSG	45	Gold star-MA6905E
11	Breville-BRE997559	46	Goodman Cuisine
12	Brother ER6321SW	47	Hinari
13	Bosch	48	Hinari EMX 911 CGTCSS
14	Bosch BM750PSL	49	Hinari- EMX7505S
15	Bosch BM750PSL	50	HINARI EMX7999MSSE
16	Bosch BM750PSLGM	51	Hinari life style MX315
17	Cookworks	52	Hinari life style MX-704 CCR
18	Cookwork- EM 717 CKL	53	Hinari life style MX707 TCSL
19	Cookworks	54	Hinari life style MX708 TCSL
20	Cooksworks- EM717CKL	55	Hinari lifestyle MX745GL3L
21	Cookwoorks -MM717CKA	56	Hinari MX 731 SSE
22	Cookwoorks -MM717CKA	57	Hinari MX888TC
23	Cookworks	58	Hinari Lifestyle
24	Cuisinarts	59	Kenwood KENGT/Al17
25	DaeWoo	60	kenwood KGJAL31
26	DaeWOO -KOR 63A5/WH	61	Kenwood-KEN ST/AL25
27	DaeWOO KOR 6L15	62	LG
28	DaeWOO KOR63F7	63	LG intellowave
29	DaeWOO kor-63F7	64	LG MC-806BL
30	DaeWOO KOR-63MCSL	65	LG MS 191MC9
31	DaeWOO- KOR6L15	66	LG MS-1905CBL
32	DaeWOO- KOR6L15SL	67	Matsui
33	De'Longhi	68	Matsui M160
34	De'Longhi	69	Matsui m162tc
35	De'Longhi DMX30	70	Matsui M964M

The table continues from previous page

No.	Make and Model	No.	Make and Model
71	Matsui T9206SF	106	Russell Hobbs- sjs21
72	Matusi M162TC	107	Russle hobbs
73	Matsui M181TC	108	Sainsburys
74	Matusi M964M	109	Saisho MW2000
75	Mellisa smart	110	SaishoMW2000
76	Morphy Richards EC925EZN	111	Samsung M1712N-7MAW604634J
77	NAIKO	112	Samsung M1713N
78	NEXT-mx704corg!nxt	113	Samsung M1713N
79	Pacific	114	Samsung M1733N
80	Pacific PM-001W	115	Samsung M6247
81	Pacific PMW 2700	116	Samsung M633
82	Panasonic	117	Samsung M759S
83	Panasonic	118	Sanyo
84	Panasonic Dimension 3 Turbo Bake	119	Sanyo
85	Panasonic inverter	120	Sanyo
86	Panasonic MICRO & browner	121	Sanyo
87	Panasonic NN - V659W	122	Sanyo EM S35 &&S
88	Panasonic nn6307b	123	Sanyo EM-2416
89	Panasonic NN-E225MB BPQ	124	Sanyo EM2710N
90	Panasonic NN-K805	125	Sanyo EM2710N
91	Panasonic NN-T543WF	126	Sanyo EM-51065S UK2
92	Panasonic NNT551W	127	Sanyo EM-G3597B
93	Panasonic NN-V672SBBPQ	128	sanyo EM-S1055SUK2
94	Panasonic-MN-E235M	129	sanyo EM-S1055UK2
95	Panasonic-NN-E255WBBPQ	130	Sanyo EM-S155as
96	Prestige GS25	131	Sanyo EM-S155as
97	Pro-line SM12 WH	132	Sanyo-EMS105AS
98	Pro-line 3906 02657	133	Sanyo-EMS10655SUK 2
99	Pro-line SM12WH	134	SHARP COMPACT R-230A(W)M
100	Pro-line ST44	135	SHARP
101	Russel Hobbs - HOB GTS23	136	SHARP
102	Russell Hobbs	137	SHARP
103	Russell Hobbs HOBSMS21	138	SHARP
104	Russell hobbs RHM1701	139	SHARP
105	Russell hobbs- RHM2009S	140	SHARP

The table continues from previous page

No.	Make and Model	No.	Make and Model
141	SHARP	176	Tesco MT906
142	SHARP carousel II	177	Tesco MTG06
143	SHARP Carousel II R-6270	178	Tesco-MTG04SS
144	SHARP carousel II R-7360	179	Tescos MCM01
145	SHARP Jet connection	180	Tescos MTG06
146	SHARP Jet connection	181	Toshiba er-672
147	SHARP R-1336 (50602108)	182	TRICITY-TMC209
148	SHARP R-202(W)M-00342258	183	Whirlpool UKm110/wp/wh
149	SHARP R202WM	184	Whirlpool MOD-AVM 683/WH
150	SHARP R-206	185	Whirlpool
151	SHARP R-254(SL) M	186	Whirlpool
152	SHARP R5541	187	WM Morrisons MMW2
153	SHARP R5960	188	WOOLWORTH 17L 1276D4110
154	SHARP Sens n Cook R-360A	189	Woolworths
155	SHARP-R-202(BL)M		
156	SHARP-R209		
157	SHARP-R242(BL)M		
158	SHARP-R3G58(W)M		
159	Siemens		
160	SWAN		
161	SWAN SM 2040W		
162	SWAN SM2045W		
163	SWAN- SWM 900C		
164	SWAN SWm800G		
165	SWAN-SM1110		
166	Tesco		
167	Tesco		
168	Tesco M9208		
169	Tesco MCM 01		
170	Tesco MCM01		
171	Tesco MCM01		
172	Tesco MM07		
173	Tesco MM507		
174	Tesco MT 08		
175	Tesco- MT07		

Table A 14: The list of determined reasons why 16 ovens were classified as not tested

	Reason		Reason
1	Not safe to test, no plug	9	Not safe to test
2	Pulled apart before transport	10	Failed PAT
3	Bad condition	11	Failed PAT
4	Control panel missing	12	Not safe-Brocken window
5	Not safe-Brocken window	13	No reason determined
6	Very rusty, Dirty, not safe	14	No reason determined
7	Not safe to test	15	Door hinges damaged-not safe
8	Not safe to test	16	H.V transformer missing

Table A 15: The functionality test of 82 microwave ovens

82 Microwave oven Functionality Test		
	No. Of microwave oven	%
Not tested	4	5%
Working	19	23%
Not working	59	72%
Total	82	100%

Note: 82 ovens were collected directly from consumers part of face to face interview at the Longly Lane HWRC.

Table A 16: The functionality test of 107 microwave ovens

107 Microwave oven Functionality Test		
	No. Of microwave oven	%
Not tested	12	11%
Working	14	13%
Not working	81	76%
Total	107	100%

Note: 107 ovens were collected by CREATE UK from two HWRCs and delivered to the UoM for functionality and cosmetic imperfection faultfinding tests.

Table A 17: Major/Minor mechanical faults in 59 microwave ovens

Major/Minor Mechanical Fault of 59 Ovens		
Category	No. Of oven with mechanical faults	% of fault
M1	2 (2%)	4%
M2	6 (7%)	11%
M3	7 (9%)	13%
M4	7 (9%)	13%
M5	5 (6%)	9%
M6	27 (33%)	50%

Note: Major/minor mechanical faults within 82 microwave ovens are given in table above. 59 ovens tested for major/minor mechanical faults and 54 major/minor mechanical faults are identified.

Table A 18: Major/Minor mechanical faults in 81 microwave ovens

Major/Minor Mechanical Fault of 81 Ovens		
Category	No. Of oven with mechanical faults	% of fault
M1	1 (1%)	2%
M2	7 (9%)	12%
M3	7 (9%)	12%
M4	1 (1%)	2%
M5	0 (0%)	0%
M6	44 (54%)	73%

Note: Major/minor mechanical faults within 107 microwave ovens are given in table above. 81 ovens tested for major/minor mechanical faults and 60 major/minor mechanical faults are identified.

Table A 19: Major/minor electrical faults in 51 microwave ovens

Major/Minor Electrical Fault of 59 Ovens		
Category	No. Of ovens with Electrical faults	% of fault
E1	12 (20%)	24%
E2	4 (7%)	8%
E3	4 (7%)	8%
E4	4 (7%)	8%
E5	10 (17)	20%
E6	17 (29%)	33%

Note: Major/minor electrical faults within 82 microwave ovens are given in table above. 59 ovens tested for major/minor electrical faults and 51 major/minor electrical faults are identified.

Table A 20: Major/minor electrical faults in 81 microwave ovens

Major/Minor Electrical Fault of 81 Ovens		
Category	No. Of ovens with Electrical faults	% of fault
E1	32 (30%)	62%
E2	2 (2%)	4%
E3	1 (1%)	2%
E4	7 (6%)	13%
E5	4 (4%)	8%
E6	6 (6%)	12%

Note: Major/minor electrical faults within107 microwave ovens are given in table above. 81 ovens tested for major/minor electrical faults and 51 major/minor electrical faults are identified.

Table A 21:: Summary of estimated average minor repair cost from websites

Mechanical Components				Electrical Components			
	Component	Estimated range of spare component cost*	Average Cost*		Component	Estimated range of spare component cost*	Average Cost*
1	Plastic Roller	£4.49-£19.49	£11	1	13 A fuse	£0.20-£2.75	£1.50
2	Rotating Knob	£7.99-£10.00	£9	2	Plug and mains	£1.00-£6.45	£3
3	Glass plate	£9.35-£18.99	£15	3	H.V fuse	£1.99-£13.99	£9
4	Cavity touch up paint	£4.49-£6.19	£5	4	Wire connectors	£0.10-£0.20	£0.15
5	Door hinges	£4.14-£14.25	£11	5	Micro-switches	£3.49-£28.04	£12
6	Waveguide cover	£5.00-£7.99	£6				
7	Door Latches	£1.99-£10.99	£9				

Note: Prices are in pound Sterling (£) in case of available price from overseas websites e.g in US dollar, were exchanged at the rate of approximate 1$=1.50£. * The estimated average spare component cost is based on the minimum and maximum advertised price of individual components available on the websites of specialist shops that cater to the repair industry as well as e-bay and Amazon.

Table A 22: Summary of estimated major repair cost from websites

Mechanical Components			Electrical Components		
	Component	Estimated spare component cost*		Component	Estimated spare component cost*
1	Door frames	£14.99-£63.99	1	Magnetron	£31.49-£288.25
2	Door assembly	£43.99-£99.99	2	H.V transformer	£50.25-£164.25
3	Door handles	£23.99-£34.99	3	Control PCB	£35.00-£99.99
4	Control panel	£26.99-£147.99	4	Filter PCB	£43.00-£63.95
5	Cavity	£23.99-£270.00	5	Capacitor	£30.99-£34.25
6	Interlock mechanisms	£7.49-£19.99	6	Diode	£10.94-£22.94

Note: Prices are in pound Sterling (£) in case of available price from overseas websites e.g in US dollar, were exchanged at the rate of approximate 1$=1.50£. * The estimated average spare component cost is based on the minimum and maximum advertised price of individual components available on the websites of specialist shops that cater to the repair industry i.e. e-bay.co.uk, bec-components.co.uk, espares.co.uk and buyspares.co.uk

Table A 23: Summary of type of electrical minor repair and cost from websites

	Electrical Component	e-bay.co.uk and amazon.co.uk		bec-component.co.uk		espares.uk and buyspares.co.uk		
		Min. Cost(£)	Max Cost(£)	Min. Cost(£)	Max. Cost(£)	Min. Cost(£)	Max. Cost(£)	Average(£)
1	13 A fuse	0.2	0.3	-	-	2.1	2.75	1.50
2	Plug and mains	2	3	6.45	-	1	1.99	3
3	H.V fuse	1.99	7.59	5	13.99	10.25	13.75	9
4	Wire connectors	0.1	0.2	-	-	-	-	0.15
5	Micro-switches	4.5	14.5	5	28.04	3.49	19.99	12

Note: Prices are in pound Sterling (£) in case of available price from overseas websites e.g in US dollar, were exchanged at the rate of approximate 1$=1.50£. * The estimated average spare component cost is based on the minimum and maximum advertised price of individual components available on the websites of specialist shops that cater to the repair industry and ebay.co.uk and amazo.co.uk. Some information regarding the price of those compoenets in given websites were eghther unavailabe or unreliable marked with “-“ sign in the table.

Table A 24: Summary of type of mechanical minor repair and cost from websites

	Mechanical Component	e-bay.co.uk and amazon.co.uk		bec-component.co.uk		espares.uk and buyspares.co.uk		
		Min. Cost(£)	Max Cost(£)	Min. Cost(£)	Max. Cost(£)	Min. Cost(£)	Max. Cost(£)	Average(£)
1	Hinges	4.14	14.25	-	11	-	13.75	11
2	Hooks	6.99	10.99	-	6.99	1.99	9.75	7
3	Plastic roller	4.49	9.99	9.99	13.99	9.49	19.49	11
4	Control knob drive	7.99	-	-	10	9.99	-	9
5	Paint	4.49	6.19	-	-	-	-	5
6	Glass plate	9.35	18.99	-	-	9.99	18.99	14
7	Waveguide	6.49	7.99	-	5	5.75	6.25	6

Note: Prices are in pound Sterling (£) in case of available price from overseas websites e.g in US dollar, were exchanged at the rate of approximate 1$=1.50£. * The estimated average spare component cost is based on the minimum and maximum advertised price of individual components available on the websites of specialist shops that cater to the repair industry and ebay.co.uk and amazo.co.uk. Some information regarding the price of those compoenets in given websites were eghther unavailabe or unreliable marked with “-“ sign in the table.

Table A 25: Assumption on the viability of remanufacturing of the tested ovens

	Repair cost Min-Max*	Criteria**: Average PRICE Viable to repair	No.of M/O In this criteria	No. of ovens NOT fit In this criteria	Total
Working	0	0	33	0	33
Not tested	1000	1000***	16	0	16
Repair	Between 1.00-363.00	Between 1-15.00	33	14	47
NOT working	Between 1.00-993.00	0	50	0	50
Cosmetic	Between 3.00- 293.00	Between 3.00- 15.00	37	6	43
Total			169	20	189

Note: Prices are in pound Sterling (£) in case of available price from overseas websites e.g in US dollar, were exchanged at the rate of approximate 1$=1.50£. *repair cost is based on the minimum and maximum advertised price of individual components available on the websites of specialist shops that cater to the repair industry as well as e-bay and Amazon. **the criteria in order to repair and remanufacturing viable in terms of cost were set as above. *** the price criteria set for not tested ovens at 1000.

Table A 26: Pareto analysis of mechanical faults of 140 microwave ovens

Category	No. of mechanical fault in 140 ovens	% Microwave ovens with mechanical fault (140)	Cumulative frequency	% of mechanical fault (114)	Cumulative Percentage of fault	Horizontal line value
M6	71	51%	71	62%	62.3	80
M3	14	10%	85	12%	74.6	80
M2	13	9%	98	11%	86.0	80
M4	8	6%	106	7%	93.0	80
M5	5	4%	111	4%	97.4	80
M1	3	2%	114	3%	100.0	80
Total	114					

Table A 27: Pareto analysis of electrical faults of 140 microwave ovens

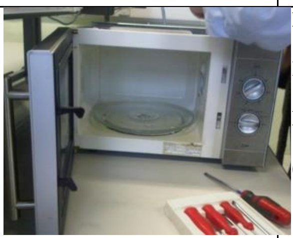
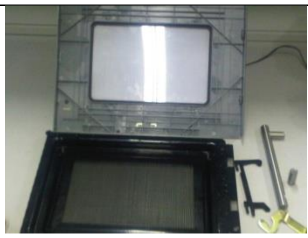
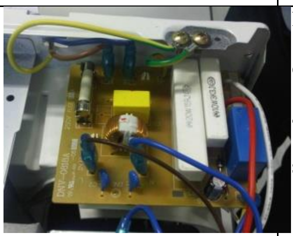
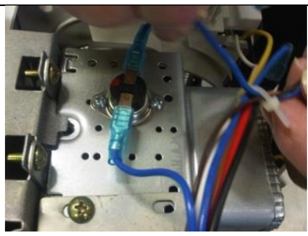
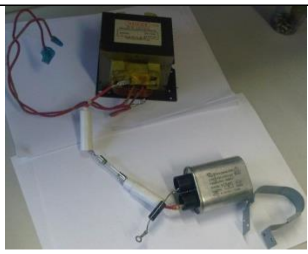
Category	No. of electrical fault in 140 ovens	% Microwave ovens with electrical fault (140)	Cumulative frequency	% of electrical fault (103)	Cumulative Percentage of fault	Horizontal line value
E1	44	31%	44	43%	42.7	80
E6	23	16%	67	22%	65.0	80
E5	14	10%	81	14%	78.6	80
E4	11	8%	92	11%	89.3	80
E2	6	4%	98	6%	95.1	80
E3	5	4%	103	5%	100.0	80
Total	103					

Table A 28: List of makes and models of microwave ovens identified with category 6 of electrical fault

	Make and Model		Make and Model
1	Panasonic-NN-E255WBBPQ	13	SaishoMW2000
2	Tesco MCM 01	14	LG Intellowave
3	Breville BRE997SSG	15	Whirlpool
4	Pro line ST44	16	Beling
5	ASDA ONN OM008	17	Sharp
6	Tesco-MTG04SS	18	SANYO EM-G3597B
7	Sharp Jet connection	19	Cooksworks- EM717CKL
8	De‘longhi	20	Cooksworks EM 717 CKL
9	Samsung M1713N	21	SHARP R-202(W)M-00342258
10	Sanyo EM2710N	22	Sharp R-254(SL) M
11	Bosch BM750PSL	23	Pacific PMW 2700
12	NAIKO		

A14: Summary of Findings to Research Question Three

Table A 29: Summary of the design differences: Microwave Oven I

	Image	Description		Image	Description
1		Microwave Oven I- Bosch – BM750PSL (800W-1200W)	6		Subcomponents of the door assembly, including, door handle, hinges, latch or hook, glass outer case and inner case.
2		Filter printed circuit board attached with a snap fit	7		The thermostat is attached using 2 identical Philips screws
3		Overview of the component assembly.	8		Assembly of the rotating motor including control plastic knob attached with two screws. To access the motor bottom case has to be removed ad unscrew the 5 screws of 2 sizes in length and diameter.
4		Dismantling of the door using a Philips Screwdriver, Spinner and 932 hexagon head screwSpinner and large screwdriver wereused.	9		High voltage Transformer, High voltage fuse, capacitor and diode used within the assembly of the Oven I.

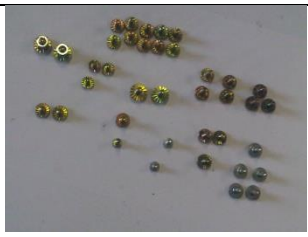
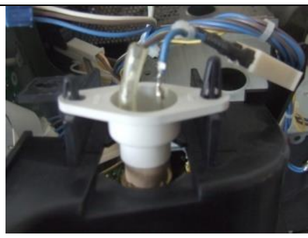
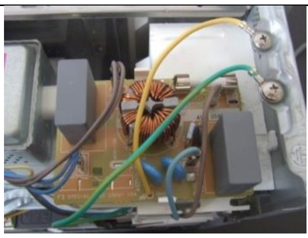
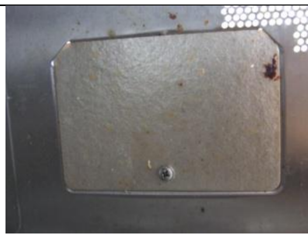
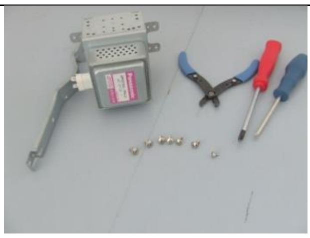
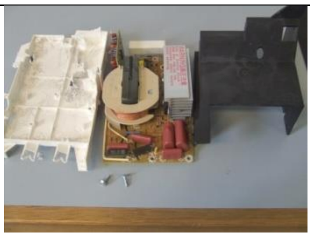
5		Lower door hinge attached with two 932 hexagon head screw	10		38 screws of 4 types in a variety of sizes in length and diameter were used in the assembly of the Oven I.

Table A 30: Summary of the design differences: Microwave Oven II

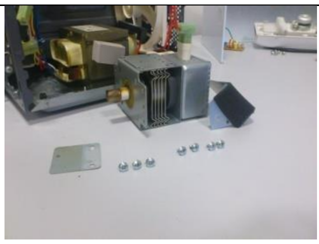
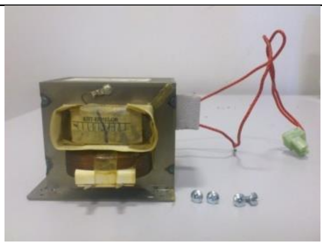
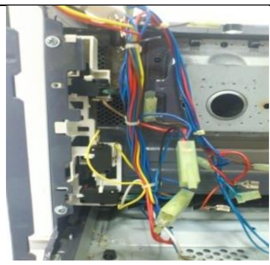
	Image	Description		Image	Description
1		Microwave Oven II- Panasonic NN-T5735BBPQ (900W-1300W)	11		Assembly of the bulb holder using plastic snap fit
2		The control unit/two scres and snap fit were used to assemble	12		Assembly of the microwswitches and casing attached with 2 screws to the case
3		Filter printed circuit board attached with two snap fits	13		Waveguide covers attached by a screw and slide through.

4		Overview of the component assembly.	14		The cavity is made of stainless steel
5		Magnetron attached to the chassi using 7 screws	15		The assembly of the door using two screws and pin.
6		High voltage Inverter attached to the chasse with two screws	16		Subassembly of the door
		Assembly of the motor fan and casing/the access to the motor fan is difficult due to casing.	17		Total of screws used within the assembly of the oven, crews of 3 types in variety of sizes in length and diameter
8		Motor fan is attached to the back panel of the oven by two screws	18		The oven II components

9		Assembly of the control panel.			The tools that were used in disassembly of the oven

Table A 31: Summary of the design differences: Microwave Oven III

	Image	Description		Image	Description
1		Microwave Oven III- Panasonic NNE205WBBPQ (800W-1100W)	9		Capacitor is fitted using 2 screw
2		The cavities of the oven made of steel and coated with grey enamel paint	10		The rotating motor s ftted using only one screw
3		PCB filter is attached by snap fit	11		The door is fitted without screws unlike other ovens

4		Overview of assembly of components	12		The door is fitted only by pin and hook integrated into the door design
5		Access to the screw of the control unit is easy	13		Assembly of the door
6		Thedissassembled magnetron from chassis, 7 screws removed	14		The components used with the microwave oven III
7		The tools which were used to dismantle te oven III	15		In the assembly of the oven II 34 screws of 2 types in variety sizes in length and the diameter were used
8		In order to remove the H.V transformer, magnetron had been removed first.	16		Assembly of the microwswitches and casing attached with 2 screws to the case

A15: The dismantling data of the three ovens

- **Microwave Oven I- Bosch –BM750PSL (800W-1200W)**

The make and model of the first microwave oven dismantled was Bosch – BM750PSL (800W-1200W) with electrical control, time taken to disassemble this unit to individual component was approximately 34 minutes. It is observed that a safety screw used within the outer case assembly of the unit. This type of screw is used to prevent non-professional intervention with the components within the unit. 38 screws were used in assembly of unit, 4 types of screwdrivers are used to disassemble the unit. The experiment shows that to dismantle some of the components, surrounding components need to be removed. It is observed that the knowledge of the design of the components is necessary to increase the disassembly and assembly time. The disassembly time including a number of screws and easy to disassemble of individual components of the Bosch–BM750PSL (800W-1200W) microwave oven (I) are presented in Table A 32. The material composition of individual components of the oven were examined. The analysis shows that the components consists of Ferrous and non-Ferrous metals; Plastic and Glass. The material compositions within oven are given in Table A 33.

- **Microwave Oven II- Panasonic Inverter, NN-T5735BBPQ (900W-1300W)**

The total time taken to dismantle the oven II was approximately 37 minutes. 42 screws were used in the assembly of components of the unit. Three types of Philips screwdriver with two different sizes, small and medium as well as a safety screwdriver were used to disassemble the oven. It was observed that 11 different screws in length size and thread were used in the assembly of the oven. Furthermore, the removal of magnetron reported to be time taken and needed of removal of metal hold a bar and plastic case of monitoring. It has been observed that the type of wire connector ending is making a huge difference on dismantling time. Access to the door latches was not easy, had they defected, the control unit has to be removed. The waveguide cover is attached with a Philips screw. In the assembly of door 4 screws are used. The disassembly and time to disassemble including a number of screws of Panasonic Inverter, NN-T5735BBPQ microwave oven (II) is presented in Table A 34.

The material composition of individual components of the oven are investigated. The analysis shows that the components are consists of Ferrous and non-ferrous metals Plastic and Glass. The material compositions within oven are given in Table A 35.

- **Microwave Oven III-Panasonic NNE205WBBPQ (800W-1100W)**

The total time taken to dismantle the oven III was approximately 24 minutes. 34 screws were used in the assembly of components of the unit, 31 Zinc plated and 3 Stainless Steel screws. One type of Philips screwdriver with two different sizes, small and medium; is used to disassemble the oven. It is observed 8 different screws in length size and thread are used in the assembly of the oven. It is observed that in order to remove one specific component, removal of other components was necessary e.g. disassembly of H. V transformer and cooling fan motor. It is noted that the separate assembly of micro switches from the control board unit is advantageous to disassembly, consequently reduces the time of remanufacturing of the oven. Furthermore, the design of complete door assembly was simple with none screw used within the assembly. Moreover, the author examined the design of the door assembly before dismantling of the unit in order to gain knowledge of the design. The disassembly and time to disassemble including a number of screws of Panasonic NNE205WBBPQ microwave oven (III) are presented in Table A 36.

The material composition of individual components of the oven were examined. The analysis shows that the components are consists of Ferrous and non-Ferrous metals Plastic and Glass. The material compositions within oven are given in Table A37.

Table A 32: Ease of disassembly and disassembly time of microwave oven I

Microwave Oven I- Bosch –BM750PSL (800W-1200W)								
	Component	Wire connection or snap fit	Ease to access	No. of Screw	Type of Screw	Tool	Comments	Time to dismantle
1	Outer case	None	Yes	7	6-Type I 1-Type III	Philips screw driver safety screw driver	None Time taken to find special screw driver at the workshop	120s
2	Power cord	2 Wire	Yes	1	1-Type I with locking washer	Philips screw driver pliers	None	30s
3	Filter circuit board	8 Wires Snap fit	Yes	1	1-Type I	Philips screw driver pliers	Twist, Pull	120s
4	Control Units	4 Wires Snapfit 1 screw	Yes	1	1-TypeI	Philips screw driver	Screw on top Movement, Pulled up to release from snap fit	80s
5	H.V fuse	2 Wires	Yes	None	None	pliers	Finding connectors Remove connectors with twist	60s
6	H.V Transformer	5 wires 4 screws	No	4	4-Type I	Philips screw driver Pliers	Magnetron need to take out to facilitate access to transformer	120s

7	Capacitor	1 screw 1 wire to Diode 1 wire to H.V transformer	No	1	1-Type I	Philips screw driver Pliers	Plastic casing of cooling fan first need to be taken out	90s
8	Fan casing	3 screws	Yes	3	3-Type I	Philips screw driver	None	60s
9	Diode	1 wire to Capacitor 1 screw to chassis	No	1	1-Type I Locking washer	Philips screw driver Pliers	Fan Casing need to be removed twist	40s
10	Magnetron	2 wires 7 Screw	No	7	7-Type I	Philips screw driver Pliers	Screws on top Change of position	180s
11	Cooling Fan and Motor	3wires 4 screws	Yes	4	4-Type I	Philips screw driver Pliers	Removed casing To access motor fan and motor has to removed together	120s
12	Bulb	2 wires	Yes	1	1-Type II	Philips Screw driver	None	30s
13	Thermostat	2 Screw 2 wire	Yes	2	2-Type I	Philips Screw driver pliers	None	60s
14	Rotating plate motor	2 Wires 2 screw	No	2	2-Type II	Philips Screw driver pliers	To access base need to be removed	90s
15	Wave guide cover	None	Yes	None	None	Flat head screwdriver	Pulled out	30s

16	Entire Door assembly	Metal hook	No	2	2-Type IV	Philips Screw driver Spinner 932 hexagon head screw	Spinner and large screwdriver used. To remove Push and pull technique used with help of technician Based removed Upper hinge difficult to remove, 932 hexagon head screw used	260s
17	Door Micro switches x3 and casing	2 Screw 6 wires Snap fit	Yes	2	2-Type I	Philips Screw driver pliers	Door micro switch is removed once entire control unit is removed, It is mounted to white plastic case with snap fits.	30s x 3=90s
19	Black Rubber Stand	Clips	Yes	None	None	None	Pulled using flat head screw driver	20s
20	Base	5 snap fit	Yes	None	None	Pliers	Difficult to dismantle , technician helped	180s
			Total	38				1780s ~ 30 min.
					Screw Types	Type I	Philips Screw Medium head	
						Type II	Philips Screw Small head	
						Type IV	932 hexagon head screw	
						Type III	safety screw driver	

Table A 33: The material compositions within oven I.

	Microwave Oven I- Busch –BM750PSL (800W-1100W)	
	Component	**Visible material**
1	Outer case and Bottom case	Aluminium
2	Power cord	Non-Ferrous, plastic
3	Filter circuit board	Non-Ferrous, plastic
4	Control Units	Non-Ferrous, plastic
5	H.V fuse	Non-Ferrous, plastic, glass
6	H.V Transformer	Ferrous and Non-Ferrous
7	Capacitor, Diode and case	Non-Ferrous, plastic
8	Magnetron	Non-Ferrous
9	Cooling Fan and casing	Non-Ferrous, plastic
10	Cooling fan motor	Ferrous, Non-Ferrous, plastic
11	Bulb and holder	Glass, Plastic
12	Thermostat	Non-Ferrous, plastic
13	Rotating plate motor	Non-Ferrous, plastic
14	Wave guide cover	Plastic
15	Entire Door assembly	Non-Ferrous, plastic, glass
16	Door Micro switches and casing	Non-Ferrous, plastic
17	Plastic cable fasteners	Plastic
18	Black Rubber Stand	Plastic
19	Wiring	Non-Ferrous, plastic
20	Rotating plate	Glass
21	Microwave Chamber	Stainless steel and Aluminum
22	Screws	Ferrous
23	Rotating Roller	Plastic

Table A 34: The ease of disassembly and disassembly time of oven II

	Microwave Oven II- Panasonic NN-T5735BBPQ (900W-1300W)							
	Component	wire connection or snap fit	Ease to access	No. of Screw	Type of Screw	Tool	Comments	Time to dismantle
1	Outer case	None	Yes	4	3-Type I 1-Type III	Philips screw driver Safety screw driver	Hard fasten to unscrew	180s
2	Power cord	2 Wire	Yes	1	1-Type I with locking washer	Philips screw driver pliers	No	60s
3	Filter circuit board and plastic cover	3 Wires Snap fit	Yes	2	2-Type I	Philips screw driver pliers	Twist, Pull	120s
4	Control Units	4 Wires 7 Snap fit 2 screw	Yes	2	2-TypeI	Philips screw driver pliers	Screw on bottom not easy to access, Movement, Pulled up to release from snap fit	60s
5	H.V fuse	Solder	No	None	None	None	Soldered to the Transformer PCB	0s
6	H.V Transformer (Inverter)	5 wires 3 screws	No	3	3-Type I	Philips screw driver Pliers		160s
7	Capacitor	Solder	No	None	None	None	Soldered to the Transformer PCB	0s
8	Fan casing	1 screws	Yes	1	1-Type I	Philips screw driver	Pulled,	120s

		3 Snap fit					Removed before Fan and motor	
9	Diode	Solder	No	None	None	None	Soldered to the Transformer PCB	0s
10	Magnetron and beam attached	2 wires 7 Screw	No	7	6-Type I 1-Type II	Philips screw driver Pliers	Screws on bottom not easy to access, the beam and plastic case removed first, Change of position	600s
11	Cooling Fan and Motor	3wires 2 screws	No	2	2-Type I	Philips screw driver Pliers	Removed casing To access motor fan and motor has to removed together	120s
12	Bulb	2 wires 2Snapfit	Yes	None	None	Pliers	None	30s
13	Thermostat	2 Screw 2 wire	Yes	2	2-Type I	Philips Screw driver Pliers	None	60s
14	Rotating plate motor	2 Wires 2 screw	No	2	2-Type II	Philips Screw driver Pliers	To access base need to be removed	60s
15	Wave guide cover	1screw	Yes	1	1-Type II	Philips Screw driver Pliers	Removed with care not to damage	60s
16	Entire Door assembly	4 screw	Yes	4	4-Type I	Philips Screw driver	Relatively easy to remove	1200s
17	Door Micro switches x3	2 Screw	Yes	2	2-Type I	Philips Screwdriver	The door micro switch is removed once the entire control unit is removed, without removing it is	20s x 3=60s

	And casing	5 wires Snap fit				Pliers	not possible to access micro switches and It is mounted to white plastic case with snap fits.	
19	Black Rubber Stand	2 Clips	Yes	None	None	None	Pulled using a flat head screwdriver with Pliers aid	20s
20	Base	5 Screw	Yes	5	5-Type I	Philips Screwdriver	None	120s
21	Plastic wire holder	2 screws	Yes	2	2-Type III	Safety Screwdriver	None	60s
			Total	42				2010s ~ 37 min.
					Screw Types	Type I	Philips Screw Medium head	
						Type II	Philips Screw Small head	
						Type III	Safety screw driver	

Table A 35: The material compositions within oven II.

	Microwave Oven II- Panasonic Inverter, NN-T5735BBPQ (900W-1300W)	
	Component	**Visible material**
1	Outer case and Bottom case	Aluminum
2	Power cord	Non-Ferrous, plastic
3	Filter circuit board	Non-Ferrous, plastic
4	Control Units	Non-Ferrous, plastic
5	H.V fuse	Non-Ferrous, plastic, glass
6	H.V Transformer	Ferrous and Non-Ferrous
7	Magnetron and holder	Non-Ferrous
8	Cooling Fan and casing	Non-Ferrous, plastic
9	Cooling fan motor	Ferrous, Non-Ferrous, plastic
10	Bulb and holder	Glass, Plastic
11	Thermostat	Non-Ferrous, plastic
12	Rotating plate motor	Non-Ferrous, plastic
13	Wave guide cover	Mica
14	Entire Door assembly	Non-Ferrous, plastic, glass
15	Door Micro switchesand casing	Non-Ferrous, plastic
16	Plastic cable fasteners	Plastic
17	Black Rubber Stand	Plastic
18	Wiring	Non-Ferrous, plastic
19	Rotating plate	Glass
20	Microwave Chamber	Stainless steel and Aluminum
21	Screws	Ferrous
22	Rotating Roller	Plastic

Table A 36: The ease of disassembly of microwave oven III.

Microwave Oven III- Panasonic NNE205WBBPQ (800W-1100W)								
	Component	Wire connection or snap fit	Ease to access	No. of Screw	Type of Screw	Tools	Comments	Time to dismantle
1	Outer case	None	Yes	7	7-Type I	Philips screw driver	None	60s
2	Power cord	2 Wire	Yes	1	1-Type I	Philips screw driver Pliers	None	30s
3	Filter circuit board	2 Wires Snap fit	Yes	None	None	Pliers	Twist, Position change	60s
4	Control Units	4Wires Snap fit 1 screw	Yes	1	1-TypeI	Philips screw driver	Screw on top Movement, Pulled up to release from snap fit	80s
5	H.V fuse	2 Wires	Yes	None	None	Pliers	Finding connectors Remove connectors with twist	60s
6	H.V Transformer	5 wires 4 screws	No	4	4-Type I	Philips screw driver Pliers	Magnetron need to take out to facilitate access to transformer	120s
7	Capacitor	1 screw	No	1	1-Type I	Philips screw driver	The plastic casing of cooling fan first need to	90s

		1 wire to Diode 1 wire to H.V transformer				Pliers	be taken out	
8	Fan casing	2 screws	Yes	2	2-Type I	Philips screw driver		60s
9	Diode	1 wire to Capacitor 1 screw to chassis	No	1	1-Type I	Philips screw driver Pliers	Fan Casing need to be removed Twist	40s
10	Magnetron	2 wires 7 Screw	Yes	7	7-Type I	Philips screw driver Pliers	Screws on top Change of position	180s
11	Cooling Fan and Motor	6 wires 4 screws	Yes	4	4-Type I	Philips screw driver Pliers	Removed casing To access motor fan and motor has to remove together	120s
12	Bulb	Metal snaps fit 2 wires	Yes	None	None	Pliers	None screw used Open metal snap fit with care	30s
13	Thermostat	Metal snaps fit 2 wires	Yes	None	None	Pliers	Open metal snap fit with care	30s
14	Rotating plate motor	2 Wires 1 metal snaps fit 1 screw	No	1	1-Type II	Philips Screwdriver Pliers	To access base need to be removed	60s

15	Wave guide cover	None	Yes	None	None	Flat head screwdriver	Pulled out	30s
16	Entire Door assembly	Metal hook	Yes	None	None	None	Bottom case removed Knowledge of design needed, To remove Push and pull technique used to help of a technician	240s
17	Door Micro switches x3 and casing	2 Screw 6 wires Snap fit	Yes	2	2-Type I	Philips Screwdriver Pliers	The door micro switch is removed once the entire control unit is removed, It is mounted in white plastic case with snap fits.	20s x 3=60s
18	Resistor	2 Wires 1 screw	Yes	1	1-Type I	Philips Screwdriver Pliers	Can be removed without touching other internal components	30s
19	Black Rubber Stand	Clips	Yes	None	None	None	Pulled using a flat head screw driver	20s
	Total			34				1400s ~ 24 min.
				Screw Types	Type I	Philips Screw Medium head		
					Type II	Philips Screw Small head		

Table A37: The material compositions within oven III

Microwave Oven III- Panasonic NNE205WBBPQ (800W-1100W)		
	Component	**Visible material**
1	Outer case and Bottom case	Aluminium
2	Power cord	Non-Ferrous, Plastic
3	Filter circuit board	Non-Ferrous, Plastic
4	Control Units	Non-Ferrous, Plastic
5	H.V fuse	Non-Ferrous, Plastic, Glass
6	H.V Transformer	Ferrous and Non-Ferrous
7	Capacitor, Diode and case	Non-Ferrous, Plastic
8	Magnetron	Non-Ferrous
9	Cooling Fan and casing	Non-Ferrous, Plastic
10	Cooling fan motor	Ferrous, Non-Ferrous, Plastic
11	Bulb	Glass, Plastic
12	Thermostat	Non-Ferrous, Plastic
13	Rotating plate motor	Non-Ferrous, Plastic
14	Wave guide cover	Plastic
15	Entire Door assembly	Non-Ferrous, Plastic, Glass
16	Door Micro switches and casing	Non-Ferrous, Plastic
17	Resistor	Non-Ferrous, Plastic
18	Black Rubber Stand	Plastic
19	Wiring	Non-Ferrous, Plastic
20	Rotating plate	Glass
21	Microwave Chamber	Aluminum
22	Screws	Ferrous
23	Rotating Roller	Plastic