An Investigation of the Implications and Effectiveness of Producer Responsibility for the Disposal of WEEE.

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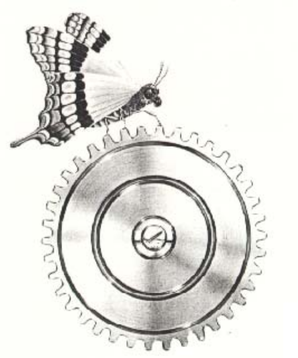

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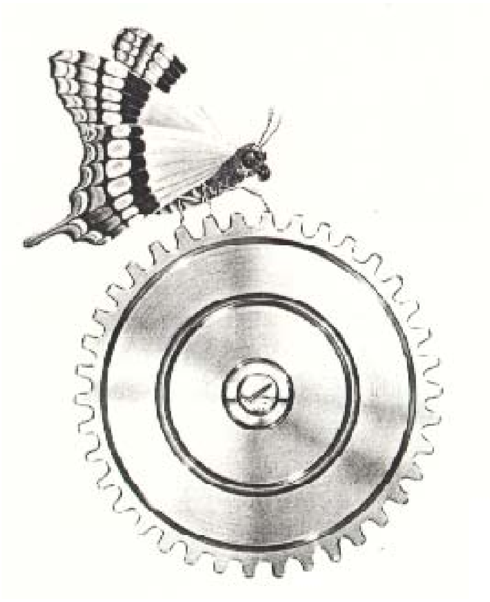

6 month report

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6 month report

Abstract

The intention of this review is to report on the progress of a four year EngD research project on Environmental Technology at Brunel University. The project is about producer responsibility and product take back within the electronics industry. The review has been undertaken in the context the industrial sponsor of the research, Hewlett-Packard Ltd (HP), a multi-national electronics manufacturer.

Initially the environmental context of producer responsibility and electronics waste is discussed as a background to the research project. The project itself, and the structure of this report is then explained. Government producer responsibility initiatives and legislative developments within the EU, Europe, the UK, and throughout the world are discussed with specific reference to wastes from electrical and electronic equipment, and the relevance of these to the research project is discussed. In order to detail existing developments for electronics take back and recovery, specialist end of life processing operations and recycling technologies, and existing voluntary industry Product Take Back (PTB) schemes have been reviewed, and their significance to the future of electronics take back discussed. Within this discussion, a distinctive process is outlined for electronic product recovery, plastic, printed circuit board, and cathode ray tube recycling technologies are described and evaluated, and the drivers behind voluntary industry schemes and common approaches of different electronics industry sectors are reviewed. The issue of product reuse is discussed, and presented as an area of increasing commercial and environmental interest. The adoption of the term "reverse logistics" to product take back is described, and two definitions for the term are evaluated. In respect of this project, the subject of reverse logistics is identified as important, is discussed in detail to support the proposed thesis, and defined with respect to producer responsibility. Finally, HP as a multinational corporation and a company within the UK is introduced, and specific product line organisations are described. Product take back operations world-wide, and within the UK are discussed, and the motivation behind, support for, and progress contributing towards this research project are given.

To conclude, the main findings and research arguments of each section are summarised before presenting the main thesis of this review. The expected future directions of this research are then suggested.

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1. Introduction

The Environmental Context of Producer Responsibility

Within the next 3 to 4 years, the European electronics industry could be made wholly responsible for the final destiny of waste electronic and electrical products. The European Union are currently considering whether to implement legislation to these ends while many European and Asian countries are already in the process of doing so. The electronics sector is not the only sector to be affected by this seemingly radical approach to waste management. Similar legislation on packaging and batteries has already been implemented throughout the EU, and is being considered for waste automobiles and tyres. This emergent approach to regulating waste management has been called *"producer responsibility"*.

It has been estimated that around 12 million items of electronic and electrical equipment reach *"end of life"[1] each year in the UK. This consists of "white goods"[2]* and around 100,000 tonnes of *"brown"[3] and "grey"[4] goods (these categories are far from being well defined). It appears to have been a general assumption that most end of life electronics will end up as waste sent for incineration, or in landfill, and that only a small fraction is currently recycled [b: DOE (1995) p 3].*

The primary reasons for addressing electronics waste streams in this manner are environmental. However, this is not a straight forward nor immediately identifiable rationale:

- * Electronics waste is not a problem in terms of relative quantities. The 100,000 tonnes of brown and grey electronics end of life goods arising in the UK each year make up only around 0.1% of commercial, domestic, and industrial waste streams, and only 0.02% of the total UK waste stream[5].

- * Although some potential environmental problems have been identified with end of life electronic products, there is little research conducted or evidence (in English or translated into English) to suggest end of life electronics actually cause significant environmental damage. For example, a printed circuit board may contain most

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1 [1] End of life (EOL) - the point in time at which a product is of no further use to its owner, and enters a phase of long term storage, is scrapped, or is disposed as waste to landfill or incineration.

1 [2] Domestic appliances such as washing machines and fridges.

1 [3] Electronic equipment for entertainment, such as TVs, videos, Hifi's and games consoles.

1 [4] Electronic equipment for communications and information processing, includes telecommunications, photocopying, and IT equipment, or office electronics equipment.

1 [5] Total UK waste: 435 million t/yr, of which domestic, 5%, commercial, 3%, and industrial 16% [b: DOE (1995) p3]

metals across the periodic table, and it has been shown that these may become mobilised under certain acidic conditions - such as in landfills (see section on recycling[6] printed circuit boards). However there is very little research to suggest that the quantities or relative toxicities of these metals contributes significantly to any contamination problems e.g. of landfill leachate.

* There is very little evidence to show that recycling electronic goods has environmental benefits over disposal, especially when the transport requirements of any proposed collection systems are taken into consideration.

To this extent the European Union have commissioned the consultants AEA Technology and the UK government has asked industry to provide more accurate information on the volumes of electronic waste arising each year, what happens to end of life electronics, and the relative environmental problems and benefits of product recycling and disposal.

The justification behind producer responsibility for electronic products does not appear to be based on any substantial evidence of the environmental impacts of end of life electronics disposal, but more on the acceptance of various fundamental principles and subsequent actions at government and international levels.

Firstly, in 1992, representatives from over 178 governments, including 100 heads of state, came together in a moment of history at Rio de Janeiro for what is known the *Earth Summit* [Grubb *et al* (1193)]. Two highly significant agreements were bought about as part of this event, the Rio Declaration, and Agenda 21. The Rio Declaration lays down the fundamental principles of sustainable development, i.e. *development in a manner that ensures that the needs of people today are met without compromising the ability of future generations to meet their own needs*[7]*. Agenda 21 lays down the practical steps that must be taken over the next century towards sustainability. Sustainability is fundamental to the future of the environment as it concerns the way in which humankind manages people, environment, and the economy to ensure the long term viability of life on earth.*

Although many of these agreements have not been met, both the Rio Declaration and Agenda 21 are global statements of intent, and their agreement has been the impetus behind environmental initiatives in many countries e.g. targets set in Canada's packaging stewardship protocol were to meet Agenda 21 solid waste management objectives to:

* Implement waste minimisation policies addressing specific waste problems
* Strengthen national recycling programmes by the year 2000.

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1 [6] The reclamation of *materials* from end of life products or waste streams, and their subsequent reuse as original virgin raw materials.

1 [7] There are many different definitions of sustainable development, this one appears the most commonly used - in the manner defined by Gro Harlem Brundtland, Prime Minister of Norway in 1982, who gave recommendations for the summit in Rio in the The Brundlandt Report [WECD (1987)].

Secondly, producer responsibility for waste is justified as a direct application of the *polluter pays principle*[8], as it was first defined by the OECD in 1975 [OECD (1975)]. Traditional government approaches to environment have come about through the use of direct instruments of government policy, namely legislation. This *command and control* approach has been employed to ensure that polluters or degraders of the environment are made responsible for paying for environmental damages caused or for preventing its initial occurrence. The concept has been expanded as regulatory authorities for environment, e.g. the UK Environment Agency, are required to recover their own costs from the parties they regulate e.g. industry. Without such mechanisms in place, producers are free to pollute and degrade common resources, such as rivers and the air, as the costs of any environmental damage caused are said to be *external* to the producers costs and market. Consequently, consumers respond to incorrect price signals that exclude environmental costs, and stimulate a form of misplaced demand for environmental damage.

It is preferable to make polluters pay for environmental pollution in this way as environmental costs of pollution are internalised to those that cause them. As costs of pollution or pollution prevention are passed on to consumers through service and product prices, they may respond by purchasing less environmentally detrimental products, either with more environmentally beneficial life cycles, or designed with environment in mind [Jacobs, M (1991) pp 149-150]. Producer responsibility can be defined with respect to the polluter pays principle:

> *The internalisation of the costs of waste management of a product or service at end of life into the costs of production.*

Agenda 21 endorses the use of market incentives and economic instruments such as "producer responsibility" within legal and regulatory frameworks to meet environmental objectives by supporting (paraphrasing part of the Agenda 21 text) [in Grubb *et al* (1993) p 112-113];

> *"the incorporation of environmental costs in the decisions of producers and consumers, to reverse the tendency to treat the environment as a "free good" and to pass these costs on to other parts of society, other countries, or to future generations,"*

.

Thirdly, in countries where landfill space is perceived as a critical environmental issue due to the shortage of available sites, and the circular flow of materials in the economy is seen as a critical stage along the path towards sustainability e.g. as in Germany, there is increased pressure from the public and non-governmental organisations for more widespread recycling activities, and for industry to design problems of waste and environment out of their products e.g. to use less packaging. Consequently governments have drafted and implemented legislation, especially in Europe. This has had a cascading effect as other countries have followed suite. The final step in the widespread move

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1 [8] Source, Richard Page MP (Industry), 1997.

towards producer responsibility for the electronics industry is expected when the EU finally implements a European wide directive to ensure consistent standards are applied between European member states.

Fourthly and finally, electronics products are considered to be durable goods (a category of goods that amongst others includes construction and transportation products, appliances, housewares, wire and cable, and toys). Around 10 million tonnes of durable goods arose as waste in the US in 1992 alone, with an annual increase of 4.6% to this amount. This total is expected to grow to 16 million tonnes by 2002 [Polymer News (1993) 19: 3: p 88]. A major concern over the loss of these goods as waste is the high quantity and quality of plastics that are lost, as there is no supporting infrastructure for recycling (most plastic recycling schemes have been set up for packaging), only 2.7% of waste durable goods are estimated to be recycled in the US.

End of life electronic products may also be of value not only in terms of materials such as precious metals, metals, and glass, but in reuse of product, components, and parts. Both industries and households are extremely reluctant to dispose of electronic products due to their perceived high value, it has been said that around 70% of electronic goods are held in long term storage. An electronic product arising as waste, especially if dumped by fly tipping, is an extremely visible component of waste streams (both in terms of bulk and attached "wasted value"). They also tend to be branded, and so are easily linked back to producers. Thus electronic wastes are viewed as a environmentally problematic waste stream (from the point of view of loss of embodied energy and high value materials), and a suitable candidate and target for producer responsibility initiatives.

Electronic products have been singled out as an individual problematic waste stream (electronic goods are perceived as having high embodied energy and materials which should not be wasted in the sustainable economy), suitable to be addressed by producer responsibility legislation (as a highly visible component as waste, and easily associated to a producer through branded products). The basis of this action appears to be international consensus on the combined need to develop national recycling and waste minimisation capacities, and to make polluters pay for the environmental degradation they cause. The impetus for action on producer responsibility was sparked by the actions of powerful economic countries in the early 90s in Europe (Germany) and Asia (Korea), who responded early to politically critical public and environmentalist concerns over the development of more sustainable national waste management and recycling programmes.

The Research Project

This research project is to investigate the effects of producer responsibility on the electronics industry, and research and propose appropriate responses in terms of the end of life management of products. The research is being conducted in the context of, and is later to be focused on Hewlett-Packard Ltd (the project's industrial sponsor), a premier multi-national electronics producer of computer products, networked systems, healthcare, and test and measurement equipment. The research project makes up a four year Engineering Doctorate (EngD) in Environmental Technology at Brunel University (the academic partner of the project).

The review is intended to inform the reader of the progress of research to date, and discuss background situation and literature to establish its context. It has also been exploited as an opportunity to formulate arguments, and to focus the research on particular areas.

The initial long term objectives for this research from the commercial (HP) perspective were to:

- Provide comprehensive information on all aspects of the end of life phase of electrical and electronic products
- To establish HP to be perceived as a major player in the field of product take back[9] logistics excellence.
- Join work with and represent industry focus in the development of state of the art solutions to producer responsibility objectives.
- To steer HP towards the most effective and timely end of life product take back strategy.

These commercially based objectives had to be synchronous with the academic objectives, which in the immediate term are perceived to be (longer term academic objectives resulting from this report are discussed in the conclusion):

- Completion of an extensive situational and literature review
- Determining an element research unique and relevant enough to be considered a contribution to knowledge, as required for a doctorate level research project.
- Ensuring that research shows consideration of environmental impacts of proposed solutions to the research problem.

The commercial research objective to provide comprehensive information on all aspects of the end of life phase of electrical and electronic products, and the academic objective of completing an extensive situational and literature review has been met through the completion of this report. Appendix 1 contains an draft outline process (with some keywords and search terms used in review of literature and internet materials) under which this review was undertaken, and some key research areas that were initially listed (non-exclusively) to scope the review process. This situational and literature review will continue to be developed on an ongoing basis throughout the 4 year research project in order to discuss any areas of research not yet covered or that are new.

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1 [9] Product take back describes the activity of collecting end of life or obsolete products form their point of origin for reuse or recycling.

The thesis of this research, discussed in later sections of this review, is:

> *Producer responsibility for products at end of life will require extensive reverse distribution networks to be organised and established. Therefore management practices, tools, methods, and models must be developed to enable producers to meet producer responsibility in a manner that is economically competitive and maximises benefits to the environment. Hewlett-Packard as an electronics producer will provide an ideal study situation to investigate this thesis further.*

Report Structure

The Introduction of this report aims to put forth the research topic, explain its environmental context, and describe the purpose and structure of the report. The first chapter on legislative pressures and government initiatives should give the reader a detailed insight into the history behind the development of the producer responsibility initiative as it relates to electronics products, and its status today within the UK, Europe, and throughout the world. The subsequent three chapters discuss the current status of elements of reverse logistics[10] processes e.g. end of life processing or recycling operations, recycling technologies, and the current status of industry-run programmes. The section on reverse logistics then attempts to pull the elements on end of life processing and product take back together, and presents the *concept* of reverse logistics. A research thesis is outlined in this section. The HP context for the research is then discussed both globally and within the UK, the drivers behind HP involvement in this is discussed, and relevant HP developments in product take back since the research started are given. Finally, the conclusions section highlights some of the main findings and arguments of the report, and discusses potential future research developments.

Reference to Hewlett-Packard has been kept to a minimum except in the section on the HP context of the research, and the conclusion section where future research is detailed. This was because the review is intended to be broad in respect of producer responsibility and the problems of the electronics waste stream, and future research is expected to focus on HP's specific situation as it relates to this broader situation.

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1 [10] For definitions, see chapter on reverse logistics.

2. Legislative Pressures and Government Initiatives Affecting End of Life Electronics Considerations.

The implementation of legislation at international and national levels appears inevitable to maximise the recycling of specific waste streams. Most European countries, the EU, and some Asian countries are considering producer responsibility legislation for electronics wastes, but have many uncertainties and inconsistencies between proposed approaches (see in Table 1). By resolving these uncertainties, impending legislation will set the scope for product take back e.g. which products should be collected, and to a large extent will determine the standards that affect how take back processes will be managed e.g. which elements of the supply chain will assume responsibility for take back and how take back will be financed.

Table 1: Current Areas of Uncertainty in Producer Responsibility for Electronic Wastes.

Area to be addressed by legislation	**Explanation**	**References**
Definitions	Current EU definition of waste does not help identify the stage in the product life cycle that electronic products become waste. This will be important in determining the scope of regulations. The proposed definition of electronic waste from priority waste streams group is:	
	"equipment using electricity or through which electricity flows, and / or which contains an electronic circuit, i.e., a circuit with active and passive components"	*[AEA (Jan 1997)]*
	alternativley proposed:	*[Eurobit (1996)]*
	"[electronic] products the end user wants to get rid of	

	without any trading (not the normal definition of waste - but suitable to PTB)	
Principles of responsibility	It has not been determined who in the product supply and use chain should assume responsibility for product at end of life. Centred around the debate over producer v shared responsibility.	*[Welkner et al (1996) Dec: pp 341-344]*
Targets	It is not known what volumes of electronic waste should be targetted for recycling, the dates by which this could be acheived, and what different product categories should be ectablished.	""
Marking	Clear consistent rules on marking of materials and components in electronic products for recycling are required.	""
Rules of "historical waste"	Approach taken with equipment arising as waste (that was produced before any legislative measures had been taken) needs to be decided	""
Co-ordination with existing rules	Any new measures need to be synchronuous with related legislation, e.g. on batteries and accumulators, and automobiles.	""
Financing	It is not known how collection and recycling should be financed, suggestions include through local taxes, a levy on product sale, and a disposal fee. Provisions for financing in other directives have been left for the main part for resolution by individual member states.	*[Eammon Bates (Jan 1996). p 27)*]

Legislation at both national and EU levels should clear up uncertainties in approaches taken, problematic inconsistencies have been approached in member states by:

- Determining categories and targets for recycling different electronic wastes (and therefore define equipment party to legislative control, and what an *"electronic waste"* is).
- Defining the point in time at which they become classified as waste (end of life).
- Deciding upon the appropriate allocation of responsibility for take back through endorsing "shared" and "producer" responsibility approaches across product supply chains.

Legislative developments and the state of affairs in the EU, throughout Europe, in the UK, and globally have been reviewed in detail below in an attempt to gain a better foresight and direction for ongoing research.

Progress in Europe

Only a few references were found to discuss progress on electronics take back initiatives in Europe in any detail [AEA (1997)][Eammon Bates (1996)][Eurobit (1996)][a: ICER (1996)][Welkner *et al* (1996). Dec: pp 342-344].Waste from Electronic and Electrical Equipment (WEEE) was first highlighted as being environmentally problematic in 1991 when the EU designated it as a priority waste stream (after recommendations made in the 1989 EU waste management strategy [SEC (89) 934 final]) along with 5 others listed below [a: DOE (1995): p 92]:

- End of life vehicles.
- Tyres
- Chlorinated solvents
- **Electrical and electronic equipment**
- Construction waste
- Healthcare waste

Open forum round table discussion groups were set up to examine these waste streams in detail, but failed to reach any useful or satisfactory conclusions. The priority waste streams programme was abandoned by the EU in June 1996 [WRF (1996) 50: pp 16-27].

Electronics waste remains an important environmental issue (despite the failure of the priority waste streams programme) due to the adoption of and support for producer responsibility initiatives to address specific waste streams within European countries. Germany was the first country to adopt legislation based on the principles of producer responsibility, when it implemented the German Packaging Ordinance in 1992, requiring manufacturers to pay for and even arrange take back and recycling of their packaging. The EU has now implemented directives covering take back and recycling of packaging [94/62 EC] and batteries [91/157 EEC], and have drafted similar legislation for automobiles.

Many countries within the EU and Europe are now in the process of adopting their own national legislation to govern the take back of electronic products (see Table 2). There appears to be no overall consistency or common direction in their approaches.

- Italy has been the first country to implement binding legislation for take back of electronic products. In September 1996 the Italian waste management Decree was implemented, which required producers to set up recycling collection schemes within 3 years of implementation or face surcharges of 10% on the price of new products. Other countries appear to be at different stages of implementing electronics take back legislation, and have dealt with areas of uncertainty in distinctively different ways.

- Denmark, the Netherlands, and Sweden are poised to implement legislation later this year, and Germany, Austria, Norway, and Switzerland are revising draft legislation to prepare proposals. Many countries have tried to encourage round-table voluntary responses from industry, and have had varying degrees of success (the EU priority wastes streams is an example that has failed in this respect). Finland and France, and Flanders (a region of Belgium) are still investigating the feasibility of voluntary schemes with minimum legislation, and Germany and Denmark have based their draft and proposed legislation on recommendations from successful voluntary industry groups. Remaining countries have still to draft legislation and develop a response e.g. UK, Luxembourg, and Greece are watching developments within the EU with keen interest. Countries such as Ireland and Spain have not yet approached the issues of electronics waste, and have no specific plans for legislation.

- Different approaches to the allocation of responsibility have been taken within each country. Sweden is to enforce responsibility for free of charge collections and recovery[11] of electronic wastes, regardless on the date of sale, entirely on producers and importers. In comparison, the Netherlands is adopting a strategy of shared responsibility amongst municipal waste management authorities, retailers, importers, and producers (however, even within this version of "shared" responsibility, the emphasis is on producers, as municipalities will only assume responsibility for equipment when the producer or importer no longer exists).

- The variety of waste electronic equipment covered, and the waste management obligations to be imposed on industry differs between countries. Italy's waste management Decree includes collection and recovery of refrigerators, televisions, computers, washing machines, and air conditioners and only requires that collection and recovery systems are established. In comparison, Sweden's eco-cycle proposal includes *"all"* electronic wastes, and proposes that these wastes should be managed in an *"environmentally responsible manner"*. Germany's draft Ordinance

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1 [11] In this context generally meaning salvage from end of life or waste streams for further processing. (interchangeable with reclamation).

only applies to end-of-life IT equipment, and does not stipulate any particular recovery or disposal arrangements.

It appears generally accepted that the EU will develop and implement legislation for take back of electronic products at end of life. The new EU waste management strategy (drafted June 1996 adopted December 1996) has re-addressed the issue of the priority waste streams. Within this new strategy, the EU has stated support for the principle of shared responsibility for specific waste streams, but also stated that shared responsibility is synonymous and compatible with producer responsibility e.g. as described above, the Netherlands have adopted a shared responsibility approach, with emphasis on the share of responsibility placed on the producer end of the product life cycle. The role of producer responsibility in design has been emphasised. Officially, the EU have no specific plans for legislation, and so the form of any potential directive is the subject of much discussion. However, the EU have commissioned AEA Technology to investigate and determine if the priority waste stream is a problem requiring further action by the EU. As more member states implement their own legislation, the EU will soon be empowered to take direct action and implement EU legislation under the Single European Act to ensure consistency in standards, and to prevent barriers to trade from developing, to facilitate free trade, and to minimise distortions in competition.

Producer Responsibility in the UK

Since the Environmental Protection Act (1990) set down some of the basic principles of current UK waste management law, recycling has been the subject of increasingly specific regulation and discussion within the UK. This *"intensification"* of waste management mirrors developments at the level of the EU (see above section). In 1995, recycling targets for separate waste streams (proposed in 1993 by John Gummer - the Environment Minister), were first outlined in the draft UK waste management strategy [a: DOE (1995) p 54].

It was envisaged at the time that various approaches would be employed to ensure these targets were met. These included regulatory, market, planning, promotional, and information based strategies. Producer Responsibility was considered a possible market strategy to ensure the recovery of waste products at the end of life stage.

Under the Environmental Act (1995), the secretary of state has powers to implement regulations enforcing producer responsibility. The regulations may currently cover:

* Identification of classes and descriptions of responsible parties upon which PR can be imposed.
* Setting of targets.
* Registration of schemes for exemption from obligations (voluntary schemes).

Except in cases where there is national requirement to comply with *"supra-national"* obligations e.g. EU directives, the Act gives precedent to the formation of voluntary industry schemes for take back of end of life products. Consequently, a number of bodies have been set up to represent the interests of industry with respect to producer responsibility initiatives. The work of these groups may include trials, pilots, initiatives, discussion papers, research, and proposals. Seven such groups within the UK are listed below:

ICER - Wastes from Electronic and Electrical Equipment
EMERG - Wastes from Electronic and Electrical Equipment
INCPEN - Packaging wastes
V-WRAG - Packaging wastes
BRMMA - Batteries
ECTEL - Mobile phones
ACORD - Automobiles

Without EU legislation, the UK government will only introduce legislation under the Environmental Act in instances where; it will result in increased reuse[12], recovery[13], and recycling[14], there are economic and environmental benefits, and burdens imposed on business are minimal to achieve targets. Although debate is ongoing, industry involved in developing packaging recycling schemes under the EU packaging directive have had some successes. They have agreed on a principle of Shared Producer Responsibility (SPR) for take back and recycling along the packaging supply chain, and have requested that regulations be bought in to prevent "free riding" (to stop any party from ignoring their voluntary obligations) [McMaster-Christie, A. (1995). 038: pp 33-36].

Initiatives Towards Electronics Recycling in the UK[15]

ICER (**I**ndustry **C**ouncil for **E**lectronic **R**ecycling) was set up in 1992 by UK industry in response to a German Draft Ordinance on the recycling of electronics wastes, and the possibility for ensuing EC legislation. ICER bought together a broad range of interests, including raw materials suppliers, manufacturers, wholesalers, distributors, retailers, waste management companies, and recyclers. ICER's main objective is to facilitate a voluntary response from industry to end of life management of electronic products.

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1 [12] The utilisation of a product reclaimed from end of life or waste streams, in a manner that is consistent in some way with its original functions.

1 [13] In this context meaning the reclamation of *materials* from end of life products or waste streams, and their subsequent reuse to substitute lower value materials with similar physical, chemical, or other properties.

1 [14] There is a waste management hierarchy that infers a preference of reduction of waste over use, reuse over recycling, and recycling over recovery, and recovery over final disposal, based on both environmental and economic advantges from maintaining waste within the economic system at increasingly higher orders of use. This is supported by the EU, and by the UK government [b: DOE (1995) p 5]. Agenda 21 recognises the general principle, but states the need to consider specific and local conditions relating to any waste management arrangements [Grub *et al* (1993) p 134].

1 [15] Ascertained from correspondence between various organisations except where referenced in the text

Actual progress towards this objective has been relatively slow, which appears to be due to ICER's broad membership of diverse interest groups across the supply chain. In 1994, ICER presented a framework plan to the DTI [ICER(1994)] (that set down some of the principles for an electronics take back scheme in the UK), and initiated a recycling trial in selected areas of London and West Sussex. ICER's progress was not rapid enough for many members. In May 1995, 17 companies broke away from ICER and formed a separate organisation called EMERG (**E**lectronic **M**anufacturers **E**quipment **R**ecycling **G**roup), with the aim of setting up and developing voluntary industry electronics recycling schemes in the UK, that were environmentally sound and financially feasible. Approximately two years later, EMERG have completed a pilot electronics recycling scheme in the Lothian Region of Scotland [LEEP/EMERG (1997)], and are researching technologies for recycling printed circuit boards, cathode ray tubes, and contaminated plastics, and incinerating electronic scrap with heat recovery [EMERG (1997)]. A group known as the ECTEL Mobile Phones Take-Back Group (European Telecommunications and Professional Electronics Industries, Trade Association) was set up in 1995 within the UK [ECTEL]. ECTEL set up a pilot recycling scheme for mobile phones and batteries called *"Take Back"* in January 1997, a project officially welcomed by the DTI [DTI (1997)] as a *model* voluntary industry approach to producer responsibility initiatives in the electronics recycling.

ICER have now been requested to provide a status report to the DTI detailing the extent of the electronics waste problem, their proposed solution, and the research conducted that allowed them to reach their conclusions. ICER will present findings on design for recycling guidelines on 25/03/97, are soon to publish the results of the recycling trial, and are continuing to investigate the logistical problem of collection. Both ICER and EMERG represent the information technology industry at the level of the government, but neither has done much to resolve the issues surrounding and specific problems of electronics waste i.e. determining the need, potential, and possibility for electronics take back and recycling in the UK. It is clear that the DTI have now given ICER the role of completing this work by the end of 1997.

Producer Responsibility World-wide

World-wide it appears that only Asian and European countries have adopted environmental legislation covering producer responsibility (with the exception of Canada). Countries throughout the rest of the world appear to be watching these developments with interest.

Japan. Driven by an extreme shortage of landfill space [b:Resources Report (1997): IV: pp 2-3], Japan has developed and amended various recycling laws imposing responsibility for recycling on manufacturers. The principle of Extended Producer Responsibility has been fully introduced under the Environment Basic Law (1993) - These recycling laws have had limited success (on a voluntary basis) due to the weakness of markets for recycled materials. A deposit refund scheme was proposed to place economic responsibility for recycling legally on producers. Consequently a recycling finance bill was submitted to the government in Feb 1995 [Kursaka (1996). 8:2: pp 136-142]. Legislation to enforce the take back and recycling of packaging by producers was. submitted April May 1995. The *"Law for Promotion of Sorted Collection and Recycling of Containers and Packaging"* based on German and French recycling models, has now to be implemented in five phases. Responsibility for packaging waste is to be shared amongst consumers (sorting and collecting), local authorities (sorting and collecting), and manufacturers (recycling of a given percentage), although manufacturers may also choose to submit their own recycling plans for approval.

Korea. Korea was very early in implementing its own producer responsibility requirements in 1991 under the Waste Disposal Law. Under this law, requirements can be imposed on producers, processors, importers, and distributors to collect and properly dispose of their products, packaging, and other goods. In addition producers and importers can be required to pay contributions to a national waste management fund, determined by collection, disposal, and recycling costs. A unique feature of this law is that companies can claim back these payments if they collect more waste than they generate, and they may also claim for the extra costs of collection. This *"deposit refund"* system started in 1992, and covers several waste categories including home electronics (televisions and washing machines) which are charged at the equivalent rate of $0.04 (US) per Kg. In 1992 total deposits to the scheme were the equivalent of $34.9 million (US) from 297 companies, compared to refunds of $2.6 million (US) to 55 companies [Kursaka (1996). 8:2: pp 142-143].

Taiwan. In Taiwan, the concept of producer responsibility was introduced in 1991 when a deposit refund scheme was set up started for recycling of PET bottles. Under this scheme, soft drinks producers are required to ensure a fixed price for collected PET bottles [Kursaka (1996). 8:2: pp 143-144]..

Canada. In Canada, distinctive from European programmes, a much more holistic approach has been adopted by the government through the Canadian National Packaging Protocol ratified in 1991. This programme supports voluntary achievement of waste management targets through shared responsibility between producers, consumers, and governments. Targets cover the reduction, re-use, and recycling of packaging waste, and therefore support the waste management hierarchy. Between 1988 and 1992, Canada has already managed to reduce its packaging waste by 20% [a: Resources Report (1997): IV: pp 14-15]. The driver to meet this targets stems from the 1992 Rio de Janeiro "Earth Summit", in which nations of the world agreed to implement waste minimisation policies addressing specific waste problems, and to strengthen national recycling programmes by 2000.

It would be interesting to see if the US (who are considering policy on producer responsibility), will follow a European style approach, or adopt elements of the Canadian, Japanese, or Korean producer responsibility initiatives. It is expected that each country will develop new producer responsibility initiatives based on previous approaches. It therefore appears relevant to study parallel producer responsibility initiatives in countries outside of the Europe where governments have not addressed issues of electronics wastes.

As electronics manufacturers operate internationallly and multi-nationally, international developments may impose conflicting requirements on product flows, e.g. restrictions of product design - which may result in increasing country market / product specialisation of products. These developments will also affect whether this research is applicable in the UK only, or has broader applicability throughout Europe and the rest of the World.

3. End of Life Processing Methods

An initial part of the investigation for this research was to locate and research end of life electronics processing organisations, technologies, and capacities, which was considered essential information to ascertain available and developing end-of-life management opportunities for electronic equipment. This has been focused to date with the UK, with some limited enquiries made in the US and elsewhere in Europe. In total, 15 processors have been found. These are shown on the map in Figure 1. What happens to end of life electronics at present is an area of uncertainty, where little research has been undertaken. End of life electronics are said to enter *"grey markets"* (uncertain markets) once the first user has no more use for a product. This grey market consists of several routes that have been suggested and identified on the basis of assumptions, small scale investigations, and pilot studies. Although these routes exist, material flows have not been quantified.

Equipment from Domestic Sources:

Exchange between friends and family [assumption]
Storage [Pitts, G. (1996)]
Second hand dealers or exchanges [assumption]
Scrap merchants - shredding [c: ICER (1996)]
Landfill and incineration [assumption]

Equipment from Commercial Sources [The Corporation of London (1996)]:

Storage [Pitts, G. (1996)]
Sales to staff
Gifts to charity
Returns to suppliers or lessors
Sales to dealers
Sales via third party companies
Sales to scrap merchants and recyclers
Disposal as waste

Companies investigated as part of this specific research had *specialist operations for re-engineering*[16] *electronic equipment for reuse, beyond the stage that it could usually be considered an asset, or which prevented obsolete electronic equipment from being disposed. Therefore scrap metal companies operating granulators to recover precious metals and metals from waste electronic equipment, and asset management companies or dealers selling near to new equipment were not included. This was not because these parties didn't complete important work in the existing reuse or recycling chain, but*

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1 [16] Repairing and re-configuring products for reuse.

because they were perceived as "common" operations, not employing any specific new technology or increased service levels in the management of end-of-life electronics.

End of life electronics processors (working term):

"Organisations with specialist operations that specifically re-engineer electronic equipment for reuse beyond the stage that it could usually be considered an asset, or that prevent obsolete electronic equipment from being disposed of as waste."

Approach

Many organisations contacted were very reluctant to give out any information on themselves. Some even saw the dissemination of company brochures as a commercially sensitive activity. This was probably because electronics recycling is a new market with rapid growth potential, and high instability - information on market potential is extremely sensitive. Caution was exercised in all communications and visits e.g. any investigations or interviews were not recorded. This unfortunately limited the scope for research and investigation.

In order to gain better information on end-of-life processing operations, brochures were requested from various companies. In addition, those perceived as offering a high value services were visited where possible. To date 6 sites and 5 different companies have been visited out of the total shown in Figure 1.

Questions asked were very general (to facilitate discussion) and were based on the following questions which were deemed appropriate from literature:

Information Required of EOL Electronics Processors

[SWHWEC (1995)]

Number of sites.
Number of employees
Contact details
Turnover
Major customers
Company history and years of experience
Other business activities
Legal records
Environmental policy

Waste inputs to the process
Waste arisings and source collection
Transport used
Separation and sorting of waste

Destination of separated fractions
Organisation of the loading bay
Contingency measures
Process efficiency.

Information Required for Technology Evaluation

[Peavy *et al* (1985). p 626]

Capacities of technology
Demonstrable reliability
Service records
Efficiency
Environment
Health hazards
Aesthetics
Economics.

Operations and process review

Although these recycling companies were positioned in a rapidly growing and changing market where increasing diversification, specialisation, and individuality appeared evident[17], a common end-of-life electronics recovery process could be outlined within each operation. Description of this process is perceived as important in determining the flows and pathways of end of life electronic equipment. Within each stage of this process, companies could be differentiated and showed specialisation through the different technologies, approaches, and methods they employed.

Operations

Delivery

Goods were delivered by truck, lorry, or van and were unloaded into a goods in area (typically a large warehouse area) where they were *"logged in"*. This was either by assigning a number to each pallet load, by weigh bridge tonnage, or through listing an inventory of all equipment sent. One company went as far as assigning a micro-dot to identify each individual product through re-engineering and remarketing to *"second*

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1 [17] Most operators were actively expanding capabilities to handle recycling, reuse, and hazardous waste arisings from electronics wastes, but had also focussed on specifc unique handling abilities e.g. CRT recycling technologies. Each company also had a distinctive fundamental approach e.g. based of logistical efficiency, separate site specialisation in dismantling, recycling, and reuse, in increasing reutilisation of returned product, and increasing recycling of returned product.

life"[18]. Weigh bridge tonnages were quoted as +-10% accurate. Inventory lists (especially in combination with the micro-dot system) appeared to have greater accuracy for retaining detailed information on products and equipment sent for recycling, but did not give any indication of quantity (volume or weight).

Packaging and Containment

Equipment was delivered on wooden pallets (either plastic film wrapped, or in attached cardboard boxes), or in special stackable metal frames (e.g. see Plates 1 and 2) with either wire mesh cages, or large reinforced plastic industrial sacks. Metal containers had the advantage of being easily be reusable, and could be stacked high to save floor space and fill vans space more efficiently (wooden pallets could not be stacked). However they were initially expensive to purchase, and return transport had to be arranged for them to be reused. These containers were therefore best used in dedicated high volume operations.

Goods In

Each piece of equipment or product was then assessed for reutilisation potential and reselling value. If deemed of high enough value, it was passed on for testing and re-engineering for reuse. The remaining electronic equipment and products were sorted into separate categories for either continuous or batch specialist recycling and recovery processes.

Dismantling

Once sorted for recycling, electronic equipment must be dismantled to recover working components and material fractions for recycling (although these two activities may occur in different areas as electrostatic protection may be needed for specific components). This is completed using common household tools such as drills, manual and automatic screwdrivers, hammers, and pliers. Experienced labourers could dismantle bulky pieces of electronic equipment in a matter of minutes into several different material fractions.

Sorting

Sorting was generally carried out at the same point as dismantling. In order to move dismantled parts rapidly along recovery processes, trolleys, large carts, and conveyor belts were used. Trolleys and carts were cheaper and used less energy than conveyor belt processes, but were not as quick or efficient for handling large volumes of scrap

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1 [18] The period of extended or renewed use of a product or materials within the economy subsquent to end of life.

equipment as conveyor belts. Dismantled equipment and products were separated into several material streams for recycling or disposal:

Re-engineering for Reuse

- Products e.g. printers, computers, monitors.
- Components e.g. power supply units, memory cards, mother boards, disk drives.
- Parts e.g. memory chips, processor chips.

Recycling

- Plastic equipment housing
- Sheet metal casings
- Copper windings
- High value circuit boards (metals, precious metals)
- Low value circuit boards (metals)
- Non-ferrous metals
- Ferrous metals
- Cathode ray tubes
- Power supply units
- Wires and cables
- Circuit boards (where technology exists)

Disposal

- Circuit boards
- Cathode ray tubes
- Batteries
- PCB capacitors
- Mercury switches

Re-engineering

Once a product had been selected for re-engineering an assessment was made on its condition by specialist engineers. Equipment and products that were faulty, or not up to saleable standard were sent on for repair or upgrade. If the product could not be fixed, components were salvaged and repaired for resale as spare parts[19] or reuse in repairing and upgrading other products. Any remaining product or part of a product was passed on for material recycling (starting with dismantling).

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1 [19] Either to original manufacturers, to warranty 7and repair services, or to markets.

Once repaired, products were prepared for final testing and marketing e.g. new BIOS and other operating software was installed to PCs. Products were then *"soak tested"*, i.e. put to one side and left operational for a given time while diagnostic software and equipment ran tests on and checked the performance of products.

In more sophisticated processes, products were debadged and delabled using fine polishers, sanders, and hot air steamers in order to protect corporate identities from being identified with second user products. Products could also be rebadged under the recyclers own reconditioned brand name. If corporate identity is seen as a particularly sensitive issue, product could be even recased.

Outbound Products

Fully tested and working systems were then sold on to second user markets, either within the UK or internationally to third world and ex-eastern block companies eager for cheap IT equipment, or to original manufacturers or asset management companies as part of contractual arrangements.

Recycling

Sorted recycled materials were stored and processed continuously or in batches through various recycling systems (this is reviewed in more detail in the next section.)
Where internal recycling facilities or capacities did not exist, recyclable materials were stored in skips or bags for periodic collection by *"conventional"* materials recycling companies (see Plate 3).

This process (summarised in Figure 2.) has been suggested as being typical of most electronics recycling operations as a preliminary stage of this research. A knowledge of electronics recycling and reuse processes is essential in understanding end of life management options that are available. This process is a framework for understanding the flow of materials through recycling and reuse processes and the interrelationships and purpose of the various developing and available end of life electronics processing technologies. As this process also affects the flows of materials in any given return system, an understanding of it appears to be an essential part of understanding the entire reverse logistical chain in an integrated and holistic sense (holistic and integrated meaning not just considered from the perspective of developing collection and transportation networks and systems - see section on Reverse Logistics).

4. The Emergence of Electronics Recycling Technologies

Many academic and commercial interests appear to be developing technologies and processes specifically for the recycling of electronic wastes, and often in partnership together. 3 recycling vendors visited had recently or were currently working with academic partners on investigating the practical application of new processes and technologies. A Cathode Ray Tube (CRT) recycling process had been installed at one facility. Another had worked on a rapid plastics identification method for automobiles, and was applying the same approach to end of life electronics. Another was working on a method of using mulched printed circuit board material as a leachate filter medium in lining for landfill sites (which is a low value recovery).
It appears that recycling technologies may process electronics wastes in various ways depending on the outlet for the finished materials:

- for closed loop recycling back to manufacturers, e.g. plastics from keyboards may be recycled back into new computers, as with IBM.
- to be accepted by existing materials reclamation processes e.g. plastics and scrap metals (open loop recycling).
- to new and specialised materials with secondary low value economic functions to the original materials common applications e.g. recovered CRT glass may be used as a road filler (materials recovery) instead of glass for bottles, window panes, or even new CRTs.

Re-engineering and reuse technologies have not been included as these did not employ any specific large scale new technologies (and therefore the description given above for these activities is deemed as adequate). Technologies have been investigated for plastics, cathode ray tubes, and printed circuit board recycling as three common end of life materials from electronics wastes. A review of these technologies is given below.

Plastics Recycling

There are many different types and grades of plastic materials used in products, which tend to have the same aesthetic, tactile, and visible properties. These plastics have different chemical and physical properties and so are not all compatible in recycling operations, especially when plastics have to be recycled to high specifications, such as closed loop recycling. Therefore there is a requirement to separate plastic for recycling.

Various technologies have been developed to automatically sort high volumes of mixed plastics of various sizes from municipal waste streams into separate materials categories. These processes usually separate waste based on various physical and electrical properties of the plastic materials. For example:

- **Triboelectric separation** - a method dependent upon the relative electrostatic charging potentials of different plastic polymers. Plastics are separated from mixtures by applying a charge to the feedstock, which is then moved through a polarised field through gravity or suspension in a bed of air to separate out differentially charged plastics. Although these methods are highly accurate for mixtures of two different plastic polymers e.g. mixed Polyethylene and Polypropylene can be separated by up to 97-98%, they cannot separate more complex mixtures of plastics, and cannot separate large heavy pieces of plastic (such as that arising from electronic equipment wastes) [Stahl (1993)] [Inculet, Castle, & Brown (1994)]

- **Density Separation** - a method by which plastics are separated by their relative weight to volume ratios (density) in water, using hydro-cyclones or flotation units. This method is not accurate enough to separate high quality plastics to specifications required for high value plastic recycling (which could be described as plastic recycled into durable goods) in open or closed loop systems. It is also limited by the fact it cannot be used to distinguish between plastics with similar densities e.g. Poly Vinyl Chloride (PVC) from Polyethylene Terepthalate (PET) or Polyethylene from (PE) Polypropylene (PP) [Stahl (1993)].

Plastics identification is key to sorting plastics from electronics waste into separate material categories and grades accurately enough to meet high recycling specifications (with high value) for both open and closed loop recycling processes. Without the aid of highly sophisticated technology, the only means of plastics identification is to burn and smell fumes from a small sample. Obviously this has significant health and safety concerns, and is neither an accurate or efficient identification method[20].

Many new products have plastic components labelled with plastic types, however, many of these materials will not enter the waste stream for some years, and the recycling industry complains that on many occasions the labels are wrong.

Sophisticated spectroscopic techniques are employed to identify mixed plastics from in waste streams, e.g. cars, electronics, and toys. These include:

- **Near Infra-red Spectroscopy (NIR)** - Various workers have investigated the application of NIR spectroscopy to the identification of plastics for recycling [Scott and Waterland (1995)] [van der Broek (1996)] [Graham, Hendra, & Mucci (1995)]. Samples of plastic are illuminated using infra-red light between 0.75 to 2.5 μm in the electromagnetic spectrum. The NIR spectrometer measures the intensity of light from the surface of the sample, either continuously across the spectrum or at designated points. As different polymers absorb different wavelengths of light, each plastic polymer and grade has a unique pattern of light absorbance. Therefore plastics can be identified through various sophisticated mathematical techniques when compared against databases of known materials *"signatory"* absorbance

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1 [20] From discussions with electronics recycler: Intex Logistics.

spectra. NIR spectroscopy is rapid and reliable (even with slightly contaminated samples) but is limited to opaque and transparent plastic materials. Darker dyed plastics that may typically found in durable goods cannot be identified by NIR spectroscopy. Therefore NIR technologies have been mostly used for the identification of plastic packaging for recycling.

- **Mid-range Infra Red (MIR) Spectroscopy** - The role of MIR spectroscopy in the identification of plastics for recycling has also been highlighted by various workers [Intex Logistics & Nicolet Instruments (1996)] [Graham, Hendra, & Mucci (1995)]. The principles of MIR spectroscopy are very similar to NIR spectroscopy. MIR spectrometers use light in the range of 2.5 to 25 μm, which transfers kinetic energy (through absorption of energy in the form of infra-red radiation) to plastic molecules causing them to vibrate (generating heat). Each plastic polymer interferes with the MIR spectra in a unique manner (has a unique fingerprint or absorption spectra), a property by which the plastic can be identified. MIR spectroscopy has in the past been limited as samples typically (until relatively recently) needed substantial and timely preparation for analysis, and were destructively obtained from the source of material. With the application of sophisticated mathematical techniques such as the Kroners Kroning Transformation, and the introduction of new methods of recognising the absorption spectrum, sampling time has been substantially reduced. Today MIR spectroscopy provides an increasingly easy, rapid, and reliable method for plastics identification

- **Far Infra Red (FIR) and Raman Spectroscopy** - are unsuitable for plastics identification as the former has significant interference from water and carbon dioxide, where as the latter method requires expensive and powerful lasers, and cannot identify darker coloured plastics [Graham, Hendra, & Mucci (1995)].

Current methods used to identify plastic types in recycling using MIR spectroscopy have been time consuming and costly due to problems in preparation of samples. Recent developments of MIR spectroscopy have now enabled better and higher value recycling of plastics from durable goods.

Once identified, plastics can be manually sorted manually and recycled. Recycling occurs through relatively straightforward processes [Wogrolly (1994)]:

1. **Cleaning and decontamination:** using detergents, hand held scrapers, and steam tools to de-label products (contaminated plastics is a problem second in importance to identification in plastics recycling).
2. **Re-granulation:** Sorted plastics are granulated (using a granulator) into fine plastic granules which may be sold on as recycled material or further processed.
3. **Extrusion[21]: Plastic granules are heated and forced through a perforated plate to form plastic stands. These strands are broken by a mechanical arm**

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1 [21] Noted from visits to recycling companies

> **moving across the plate to form plastic pellets for recycling into new products e.g. plastic piping.**

Without identification and separation methods, plastics can be recovered in a mixed form to create new low grade specification substitute materials e.g. wood replacements, noise resistant materials, and wall cladding. These materials may be produced by a variety of methods, and have low value applications [Hauss (1994)]. Most electronics recyclers in the UK appeared to prefer higher value recycling of plastics, and 3 visited even operated their own plastics recycling processes. This was due to the high value of plastics from durable goods. One recycling company was quoted:

> *"..plastics from electronics equipment is second only to precious metals in terms of value."*

Printed Circuit Boards (PCBs)

Existing processes and the potential for the development of more advanced processes for the recycling of printed electronic circuit boards [Legarth *et al* (1995)] and the general extent of PCB recycling has been discussed [Metal Bulletin Monthly (1996)]. It appears that at present there are two main processes by which PCBs may be recycled; thermal and non-thermal processes.

Non-thermal Processes

Most companies reclaimed higher value materials (such as sliver and gold) from circuit boards manually by cutting away high value parts, e.g. gold pins. PCBs were then granulated and classified by air or water (over a vibrating table) to separate metal bearing fractions from lighter mixed fractions, and are then chemically treated to reclaim metals (by metal refining companies). It appears that most electronics recyclers in the UK have at present taken this approach to recycling PCBs.

Thermal Processes

Metals can also be separated through thermal treatment in an incinerator or furnace, and by processes known as pyrolysis, hydration, and metallurgy. Copper smelters commonly receive electronics scrap and recover elements such as Copper, and noble and base metals. PCB scrap is then mixed with flux (quartz and limestone) and coke and smelted in a shaft furnace with oxygen. Metals such as iron and aluminium can be recovered from a slag that forms in the smelter, and copper from "black copper" (80% copper), which is recovered through electrolytic processes. Zinc and lead from metal rich dusts from the furnace may also be reclaimed. One similar process for the recovery of precious metals and copper was visited in the UK, and another large scale smelting operation has been located in Belgium.

PCBs are very complex products for recycling as they contain most elements in the periodic table, intermeshed with plastic polymers, ceramics, and glass (see Table 3). Around 80% of metals available in PCB scrap can be reclaimed by existing copper smelting processes as described above. Remaining residues are sent for incineration or landfill. It has been suggested that some of the metals not reclaimed are very rare, in short supply, and used almost uniquely by the electronics industry e.g. tantalum, antimony, and gallium. No infrastructure has been set up or markets established to enable the recycling these materials to date, namely, it appears, because they occur in very low concentrations in PCB scrap. It has also been suggested that in many cases that these rare metals are enriched within particular electronics components e.g. tantalum in tantalum capacitors, and are diluted when mixed with other PCB scrap in conventional PCB recycling processes. Until recycling technologies and methods have been developed to reclaim these rare metals from components on circuit boards, and until new recycling markets have developed, valuable resources in short supply will continue to be wasted in landfill sites and incinerators.

Table 3: Material Breakdown of Printed Circuit Boards

Source: Computer scap arising. *Metal Bulletin Monthly*. (May 1996).pp 49.

Technologies are still developing for PCB recycling:

- One recycling company visited were investigating the feasibility of using PCB scrap as a landfill leachate filtration medium.

- NEC have developed a technology [Waste and Environment Today (1995)] that is capable of reclaiming circuit board components simultaneously for reuse and recycling, and pulverising remaining boards (minus solder which is abraded away) for separation of glass resin (which can be used to improve the expansion properties and strength of epoxy resins, and as a filler for other polymer products) and copper (which can be recycled) using gravity and electrostatic separation techniques.

There is still much potential for improving recycling of PCBs through developing technologies and markets for new materials. Reclamation processes should be developed for the rare earth metals found in electronics circuits as these are of the greatest concern in terms of environment and the conservation of natural resources.

Cathode Ray Tube (CRT) Recycling

CRTs make up the screens of televisions and computer monitors, and are an important component of the overall electronic waste stream. Various environmental concerns have arisen over disposal of CRTs in landfill sites:

* CRTs are coated with a fluorescent layer rich in metals (20% of CRT coating consists of Zn, Pb, Cd, and Al. Other metals include Yt, Fi, Ni, Cu, and Cr - although different estimates may vary) and phosphorous, which may be mobilised in acidic environments e.g. landfills [Metal Bulletin Monthly (1996)].

* From 1.4 to 2.2 kg of lead is used in the production of each CRT used for computer monitors (depending on size). Extrapolating from current and past trends in computer monitor consumption, it has been predicted that by the year 2005, 45,000 tonnes of CRT glass will be used to make computer monitors (without consideration of televisions) world-wide each year [Smith *et al*.(1996)].

* New monitors use 94% zinc sulphide and various rare earth metals such as europium and ytterbium, for which environmental effects are indefinite and recovery systems have not been established [Smith *et al*.(1996)].

The options for the end of life management of CRTs on a wide scale are very limited. Only one CRT recovery plant is operational in the UK, which is an expensive option costing around £4.00 to £10.00 per unit (according to 1996 figures) [Metal Bulletin Monthly (1996)]. It appears that other electronics end of life processors pack crushed end of life CRTs into drums for treatment and disposal as hazardous waste. An investigation by SONY [Smith *et al*.(1996)] revealed that end of life options for recycling and reuse of CRTs were limited. Reuse of CRTs is problematic (in terms of the need for specialist repair equipment to maintain a vacuum within the CRT), and also because computer monitors usually become obsolete (due to the demand for larger screens with better graphics capabilities) before they become functionally inoperable. Recycling CRTs is difficult because they consist of three glass types, that must be separated to be recycled into new glass due to their incompatibility in recycling processes. The funnel glass contains around 8% lead, the screen glass mostly barium, and a glass paste or frit is used to meld the two sections together and maintain the integrity of the vacuum inside the CRT.

The CRT recovery process in the UK (similar to operations elsewhere in the world) reclaims materials from CRTs by fragmenting and washing CRT glass in water with a unique specially cultured population of micro-bacteria to actively remove and absorb metal and phosphorous coatings. A metal rich organic sludge is extracted from the process after this stage from which metals may be reclaimed. The cleaned CRT cullet is then further classified using vibrating tables (for separating non-ferrous metals for recycling) and magnets (for extracting ferrous metals for recycling). Finally the CRT cullet is recovered for use as a road filling material or for lining incinerator furnaces (not very high value uses).

The best use of CRT glass is believed to be in closed loop recycling processes i.e. where old CRT glass is used to manufacture new. Unfortunately, specifications for virgin glass for use in CRTs are tightly controlled as the slightest variation can ruin a batch of CRT glass e.g. even mixing glass from different manufacturing sources. ZWEI (the German Electrical and Electronic Manufacturers Association) have developed a CRT materials specification [ZVEI (1996)] standard for Televisions that would facilitate European wide closed loop recycling of CRTs if followed consistently throughout the CRT manufacturing industry in the production of new television sets (research did not extend to computer monitors, but the same principles could apply). Existing end of life CRTs that have not been manufactured to these standards could be still be recycled in this way provided they still met the standard's requirements and sufficient volumes have been collected. Two end of life processors in the UK believed they could meet closed loop recycling specifications within the next year (1997).

CRTs present themselves as a problematic electronics waste fraction (they can arguably be considered a hazardous waste when crushed). There could be significant environmental benefits from recycling, including the opportunities to recycle rare earth metals, and include CRT glass in closed loop recycling systems.

5. Corporate Responses

Many major producers of electronic goods have initiated product take-back and reclamation[22] systems on a voluntary basis. In order to gain a perspective on the extent to which industry has risen to meet the challenge of producer responsibility, a view of existing reclamation practices has been conducted.

The extent of business led recycling schemes in the UK has been reviewed [b: ICER (1996)]. It was found that there were common elements between different industry approaches:

* Sources of electronic products included surplus production, faulty items, and returns from customers.

* The end of life products were either refurbished for resale, stripped of components and parts for reuse, or dismantled into material categories for recycling.

* The drivers behind these activities included the ability to:

- Meet customer requirements for environmentally responsible, secure, or convenient electronics disposal, to meet the challenge of producer responsibility.

- Enhance company environmental performance.

- Control sale of product on second hand markets (protecting the sale of new products on the market and to get rid of liability in resale by the company).

- Generate income from sale.

- Improve the design of new products by examining design faults of older generations of products, and to develop a new business activity or area.

It appears that many industry recycling schemes have developed from asset management processes that had been initially set up for financial and other business related reasons. Existing industry product take back and recycling systems can therefore be justified on the grounds of cost avoidance e.g. from better management of obsolescent stock with high market value, as a contribution to the companies' overall environmental performance, or protection of the customer base e.g. through offering equipment

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1 [22] In this context generally meaning salvage from end of life or waste streams for further processing (interchangeable with recovery this context).

collection services for old product on the sale of new and for customer returns. In general these findings appear consistent with the approaches various grey goods manufactures have taken, but significant differences in the scale and nature of business led schemes do exist.

Information Technology Manufacturers

* Siemens Nixdorf, a German IT manufacturer, appears to have set up the most sophisticated take back processes for IT equipment in Europe. The main driver behind their proactive position is the early development of German producer responsibility legislation. The company has already started to charge additional prices on selected new products in anticipation of future take back obligations. A network of 42 collection points (bring points) have been set up throughout Germany, all Siemens retail outlets will take back product from customers on a sale, and collections of old equipment will be arranged for larger commercial customers (using third party logistics companies). In total Siemens Nixdorf recycled 5400 tonnes of equipment in 1995, equivalent of 30% of sales from 5 years previously. 17% of this total was reused either as complete product or as components, both internally and through resale to second user markets, 69% was recycled, and 14% was disposed in landfill [BATE (December 1995) pp 5-7]

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* IBM in the UK have set up a closed loop recycling process whereby plastics from computer keyboards are granulated and used to mold new casings for computers at the Greenock plant. in Scotland[23]. Similar closed loop recycling operations can be found in other countries where other companies have manufacturing operations e.g. HP use 25% recycled plastics in the casings of selected printer models.

* Some manufacturers have offered a service to collect smaller amounts of IT equipment at a charge e.g. from households. Compaq charge roughly $20.00 to $30.00 for such a collection in selected markets, but found demand for this service insignificant at about 5 collections per month [Dillon (1996) pp 7-8]. IBM have also set up an *"Equipment Collection Offering"* scheme on a similar basis, and have also had negligible interest in this service[24].

* Most IT companies appear to work in partnership with third party electronics reprocessors (end of life processors) outside of major company locations, and have international recycling centres within Europe and the US e.g. HP has a centre in Grenoble, France[25], and in Roseville, California, IBM has a large components recovery process in Endicott[26], US, Digital in Contoocook, New Hampshire and

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1 [23] Source, IBM (UK) Ltd, 1997.

1 [24] Source, IBM (UK) Ltd,1997.

1 [25] Source, HP Ltd, 1997.

1 [26] Source, IBM (UK) Ltd, 1997.

Nijmegen, Netherlands [Merlot (1996)], and Siemens Nixdorf in Paderburn, Germany [Business and Environment (December 1995) pp 5-7].

Telecommunications Industry

Telecommunications companies have a large quantity of electronic equipment and waste to handle each year. In the case of Nortel [Dillon (1996) pp 29-30], 50% of this is from leased phones, customer returns, excess and obsolete inventory, and customer trade-ins and removals (BT [BT (1997)]also receives up to 2.5 million phones for remanufacturing and reuse, and recycling each year), and 50% originates as engineering wastes from the maintenance of large telecommunications system e.g. cable, switchboards, and telephone exchanges (BT have the task of recycling 7600 installed exchanges since 1995 when they were replaced with more modern digital and electronic exchanges). Nortel offer a suite of recycling services to customers in the UK and the US, and make a significant profit from these operations, returning up to 85% of revenue to Nortel business units.

Office Imaging Industry

The Imaging or document processing industry (manufacturing photocopiers, printing equipment etc.) could be said to be more involved in the end of life management of electronic goods than any other industry sector. This is chiefly due to the development of leasing options for products, in which the utility or service of the product is sold to the customer, and the leasing company retains ownership of the product. As a result, industries in this service sector have developed much more sophisticated asset management processes than most electronics manufacturers. Both Kodak[27] and Rank Xerox offer a range of product and service options, including new product sales, copiers re-engineered "as new", and copiers remanufactured for second users. Rank Xerox reclaimed 30% of their products in 1993 (representing 7200t of waste avoided), and 50% in 1995 through their plants in the UK, France, and the Netherlands [Maslennikova (1996)]. Rank Xerox continue to develop their remanufacturing capacities, with an objective of *"waste free products form waste free processes"*. Rank Xerox were initially driven as pioneers in product leasing by competitive pressures, and have now included greater environmental reasoning behind the further development of their already competitively successful leasing services [ENDS (1996) No. 261, pp 18-21].

The Issue of Reuse

It appears that many manufacturers have a reluctance to re-engineer their own products for resale to second user markets for reuse. This appears to be due to fears of supplying products to competing markets, and that a companies "badged" product would appear on

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1 [27] Source, the Eastman Kodak Company, 1997.

the market at an inferior quality. However, reuse of product offers significant advantages over recycling, including:

- * Better use of embodied energy and materials in a product - which arguably has greater environmental benefits.
- * High economic returns means profit can be made whereas recycling usually is a net cost.
- * Reuse markets for electronic products are by no means saturated, especially 3rd world markets, although this particular market raises some highly pertinent environmental and sustainability related questions e.g. what will happen to equipment sold to third world countries at end of life?
- * Acceptance of the growing market for reuse would allow manufacturers to be in a better position to control this market share (which could be a substantial percentage of total market) to their advantage, i.e. by increasing levels of product reutilisation, increasing overall market share, and using reconditioned products as a way of encouraging customers to buy new products or to expand profitable leasing service options (as examples).

As more end of life processors offer specialised services to corporations that are sensitive to these corporate concerns of market security and corporate image, e.g. sale to unrelated markets (overseas), and debadging and recasing operations, product reuse is becoming more attractive to corporations as an end of life option for electronic products. This trend is pushed further as returned products have less and less material value through material reduction in design, but is frequently returned before functional end of life and so with considerable reuse value. This trend has emerged as customers increasingly treat electronic products as consumable instead of durable goods by upgrading to new technology or responding to changes in fashion. For example, SONY now consider personal cassette players as disposable consumable goods and fashion accessories rather than durables[28], and Kodak (along with other film processors) are now producing disposable cameras. HP have also accepted the increasingly consumable nature of their products:

> *"People want to buy computers, printers and other electronic products as easily as they shop for groceries."*
>
> *-HP Computer Products Organisation.*[29]

It appears that more and more companies are accepting the idea of controlled reuse of end of life products. BT reused only 25% of telephones in 1994/95, but had increased this to over 70% in 1995/96 [BT (1996)]. In the future it could be easily conceived that any reluctance to accept product reuse by industry could significantly affect their competitive market positioning. Siemens Nixdorf is able to completely fund their take back processes through resale of 17% of returned products to second user markets.

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1 [28] Source, SONY 1997

1 [29] Source, HP 1997

An important question that still must be addressed is whether the reuse of electronic goods in unsaturated markets is indeed an appropriate end of life option from an environmental perspective.

It appears that there are consistent trends in electronic equipment manufacturer's responses to recycling of their products. It is clear that few manufacturers have anywhere near the capacity or ability to manage their end of life products in total, especially within the IT manufacturing sector (the office imaging sector being the best positioned to control the end of life management of their products). It also appears that as some companies have successfully developed schemes recovering large quantities of product without incurring significant costs (whereas others are limited by cost constraints) that electronics recycling is at least economically possible, and therefore offers significant competitive advantages to those companies that manage their end of life products well, and proactively.

6. Reverse Logistics - The Development of a Research Thesis

This section examines the current status of a concept known as reverse logistics as it is relevant to industry and producer responsibility. It is through this discussion and the setting out of some fundamental concepts that the research thesis is defined.

Reverse logistics is a term first coined by industry in reference to inbound returned product flows as opposed to outbound from manufacturing to market. Products are returned or become obsolete for various reasons:

* Returns for repair
* End of line product
* Ex-lease product
* Loan product returns
* Customer returns
* Ex-demonstration product
* Excess stock
* Ex-internal assets
* Product recalls.

As producer responsibility has become an issue, and as recycling has become an option for managing these various returned product streams, industry has used the term reverse logistics increasingly in reference to product recycling and reuse. Existing business led initiatives and developments in reverse logistics are therefore carried out on the basis of "good business practice" and described in terms of their significant economic and (modest) environmental benefits. Many such examples of this are given in the literature [Melbin (1995) pp 36-38] [b: ICER (1996)] [Guintini & Andel (1995) pp 97 - 98].

It can be assumed that quantities of obsolete product returned would be a small percentage of total product to market (except where in a few cases e.g. in office imaging and telecommunications industry where product is leased). Therefore most existing reverse logistics processes will not be nearly extensive enough or appropriate to be able to address the problems of total end of life product waste streams (as required by producer responsibility).

Reverse Logistics and Producer Responsibility

Reverse logistics has been defined in the context of producer responsibility as:

> *"The process of continuously taking back products and/or packaging materials to avoid waste disposal in landfill or high energy consumption through the incineration process."*
>
> [Linton (1996) pp 28-30]

and as:

> *"The retrieval and redisposition of a product after the customer is finished using it."*
>
> [{Bryne and Deeb in} Hiene (1993) pp 28-29]

Neither of these definitions appear to be satisfactory. The former incorrectly describes the environmental benefits of reverse logistics. Energy consumption is not an environmental impact associated with incineration (waste incineration processes produce net energy), the destruction of embodied energy and materials in products, and air pollution are more accurate assumptions of the major environmental problems of incineration. No consideration is given to the environmental benefits of reduced requirement for raw materials extraction and processing, and manufacturing through recycling and reuse, or the requirement to optimise and balance the environmental impacts of reverse logistics processes against the manner in which products are currently handled after end of life. Potential business or economic benefits or optimisation are also not included in the definition. The former definition has been considered insufficient as it does not specify *how* returned products should be managed e.g. in a manner that is both financially viable and environmentally acceptable[30], and because the "customer" is left open to interpretation (the customer at the point a product is first sold may not be the same as a customer of a reverse logistics service, as product may change hands many times during its life).

Two questions are key to understanding reverse logistics and reverse logistics processes [adapted from Linton (1996) pp 28-30]:

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1 [30] "Acceptable" meaning in a manner to meet standards applied - the appropriateness of the standards not currently being the topic of discussion

> 1. How does one collect products from widely dispersed (in time and space), possibly unknown, customers in a cost effective and environmentally efficient manner?
> 2. What does one do with the material after it has been collected?

As this report should have demonstrated, the detail that would be necessary to construct a response to the second question has been covered. Little appears to have been done to answer the first question e.g. no consideration was given to reverse logistics arrangements in the EU directive on packaging and packaging waste, but requirements were drawn up for recycling arrangements [Prendergast (1995) 8:3: pp 11-16]. It is this aspect of reverse logistics that incurs the greatest cost and raises significant environmental concerns (due to increased demand for transportation which has significant impacts such as air pollution and energy consumption leading to environmentally related problems such as global warming, photochemical smogs, acid rain, and non-renewable resource depletion, and requires that new roads must be built). It has been said that as the cost of distribution can be up to 30% of product price, and the cost of product take back[31] can be up to 8 times the cost of delivery.

The additional complications of reverse logistics processes as part of wider distributions systems are evident. For example, postal services throughout the world will deliver post direct to "doorstep", but only collect from more centrally located mail boxes or post offices. There may be many reasons for the inherent and developmental difficulties in reverse logistics processes for end of life product management:

> a) Current logistics infrastructure i.e. warehousing and lorry depots, and distribution systems, have been set up to handle the *"forward"* delivery of materials and products from manufacturers to a dispersed market (dispersed in time and space, retailers being dispersed in space, and customers buying from retailers at irregular, or dispersed intervals in time). A reverse of this process is bound to be inherently difficult, as without significant investment e.g. in a postal system, returning products could be described as "like trying to run the wrong way in a marathon!".
>
> b) Manufacturers have no control or guarantee of times and locations of product to be retrieved.
>
> c) Volumes of electronic products returned are presently very low, therefore economies of scale are unlikely to exist and any reverse logistics arrangement will be a expensive and by special arrangement.

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1 [31] Product take back being a description for a concept embodying the activities involved in reverse logistics processes, whereas reverse logistics is the specific management of processes or systems that can be used to take product back at end-of-life.

> d) Problems of matching volumes of returned products (which are indefinite and unreliable) against the demand for materials, and re-engineered components and products (which fluctuates). An electronics take-back process would not be working efficiently if volumes of product collected product exceeded technical and market reprocessing "capacities", or vice versa.

With the problem of end of life management of electronic products receiving increased attention, many manufacturers are now asking how producer responsibility will affect their business operations, how they can be proactive in areas of waste management which are not traditionally their area of core business, and how they can exploit producer responsibility as a competitive opportunity to reduce the environmental impacts of their products. Reverse logistics is the subject of study that will provide the answers to these questions.

The Research Thesis: The Organisation of Reverse Logistics Processes

The future organisation, management, and scope of reverse logistics processes as they will be developed to deal with returned electronic and electrical product flows under producer responsibility initiatives is the subject of this research. The elements of reverse logistics management required for a simple one product process (chemical drums) has been reviewed [Guintini (1996) pp 81-85]. The essential thesis of this research (as it has developed to date) is that:

> *Producer responsibility for products at end of life will require extensive reverse distribution networks to be organised and established. Therefore management practices, tools, methods, and models must be developed to enable producers to meet producer responsibility in a manner that is economically competitive and maximises benefits to the environment. Hewlett-Packard as an electronics producer will provide an ideal study situation to investigate this thesis further.*

It appears that the mainstream of academic thought has been taken from a literal interpretation of the meaning of reverse logistics. If a manufacturer distributes product to market (directly to either customers or retailers), then it should be relatively easy (at least conceptually) to reverse this flow so that product is bought back by manufacturers through the same network at end of life (see Figure 2). This is a perfect translation of producer responsibility into reverse logistics. Many people believe that expanding reverse logistics capacities will involve significant investment in two-way transportation systems, extension and adaptation of existing warehouse facilities for in and outbound product flows, and the setting up of materials sorting and reclamation lines within warehouses and manufacturing sites [Heine (1993) pp 28-29].

Figure 3. Reverse Logistics Through the Supply Chain.

From: Logistic Control Systems, Eindhoven University of Technology. *Welcome to Reverse Logistics*. http://www.tue.nl/ivo/lbs/main/revdist/revdist.htm (at http://www.tue.nl/ivo/lbs/main/).

There are many reasons why the organisation of reverse logistics by manufacturers in this way may be wholly inappropriate.

- Many manufacturing facilities of multi-nationals are located overseas from the markets. There would be no environmental or economic sense behind transporting products overseas (in these situations) for recycling that could just as easily be done local to the point of origin (in these cases, logistical implications mean that closed loop recycling is not necessarily desirable).

- Processing and collection requirements of end of life electronics are more akin to waste management and recycling operations. Waste management and recycling companies may be better placed to handle end of life products and materials, but are not part of the product supply chain.

- Electronic product life extends for several years, and products may change hands many times during this time. Therefore collection of end of life products at point of sale (exchange old products for new by retailers) may not be a sensible reverse logistics strategy.

There are many more approaches to reverse logistics that could be easily considered. It is proposed as part of this research that each approach is dependent on the roles and relations of 4 distinct entities within any given product take back process:

- Sources of electronic products e.g. domestic, commercial, and municipal locations.

- Transporting parties involved e.g. in collection from source, and to shipment of product between sites during processing.

- End of life processors involved, which is somewhat dependent of the processing requirements of an electronic product type and content e.g. CRTs form monitors could be considered hazardous wastes when crushed, PCBs form any electronic product could be recycled for precious metals content, and PCs could be re-engineered for reuse.

- The managing (but not necessarily the responsible) entities of the overall take back system e.g. manufacturers, industry collective schemes, importers of product, local authorities, and waste management and logistics companies.

In addition to these "key players", a common process can be envisaged for most reverse logistics operations (see Fig. 3):

- Collection: Materials must be collected from a variety of dispersed sources and taken to a local centralised collection facility.

- Consolidation: The bulk of goods is consolidated at the collection centre.

- Transfer: Larger vehicles are then used to transfer different consolidated end of life electronics "streams" to the most appropriate end of life processors.

- Processing: At the processing stages, materials are sorted and processed for final destination, which should be rentry into the economic system through reuse of product, components or parts or recycling of materials.

Reference is not given here to end of life electronics as this process could be common to most reverse logistics activities in that dispersed materials must be bought together in space and time. For example, expanding upon the example of postal systems, letters are collected from localised post boxes or post offices (dispersed sources of materials), transferred in small vans to a depot (collection). At the depot the letters are sorted according to general destination and packed (preliminary sorting and consolidation). Mail is then sent by train or lorry to a main depot (transfer) where the letters are sorted in detail according to final destination (final sorting and processing). From that point onwards the mail has been bought together, and could be considered to then enter a localised distribution system to be delivered to the doorstep.

Although this theoretical model does not appear to have been suggested in the literature, some theories behind waste management (and no doubt for logistics in post office systems) are used to evaluate the optimum areas that local collection centres should operate over (which can be calculated from the distance over which the cost of collection by van, foot, motor bike etc. per unit of a good exceeds the costs of transferring by larger vehicle arrangements e.g. train or truck - the distance at which another collection centre more locally placed would incur lower costs and therefore be more competitive) [Peavy *et al* (1985) pp 618-619].

Many different players (of the types listed as "key players" above) may be involved at each stage of a reverse logistics process. The choice and selection of key players, and the specific arrangements made for each stage is the subject of the organisation and management of reverse logistics. which should, of course, be optimal for environmental and economic advantage. It is not envisaged that one such arrangement would be optimum for all products and all producers, but rather that different reverse logistics options will be needed for different product types and sources, and that these processes will form more complex networks and interrelated systems that facilitate overall the return of products and materials to the economic system in a manner that is both logistically (in terms of cost and effort) and environmentally (in terms of environmental impacts minimised and benefits maximised) optimised.

With respect to the preceding discussion, and as it relates to producer responsibly, reverse logistics is defined as part of this research as:

> *"The collection of end of life goods (for reprocessing as products, components, parts, and materials) for re-entry to the economic system in a manner that is economically competitive and environmentally responsible."*

The title of this research is given as:

> ***"Managing End-of-Life Electronic Equipment - achieving logistical and environmental optimisation in closed economic cycles"***

Where closed loop economic cycles refers to the establishment of a more sustainable economy, based on circular flows of materials through widespread reuse, recycling, and recovery, as opposed to the non-sustainable linear flow of materials from natural resources to waste.

7. The Hewlett-Packard Context.

A Brief Introduction to the Hewlett-Packard Company.

The Hewlett-Packard Company (HP) is a multi-national corporation that designs, develops, manufactures, and markets a range of electronically based services and products for healthcare, testing and measurement, computation, and communication. In the 1995 fiscal year HP employed 108,300 people world-wide, and had an annual revenue of $31.5 billion. HP describes their purpose as:

> *"..to create information products that accelerate the advancement of knowledge and improve the effectiveness of people and organisations."*

The company's products and services are used in industry, business, engineering science, medicine, and education in more than 120 countries [HP (1996) p 13].

HP is made of several constituent yet autonomous organisations. The Computer Products Organisations (CPO) produces computers and peripheral equipment such as printers for consumer markets. The Test and Measurement Organisation (TMO) produce analytical equipment, and the Healthcare Organisation produces medical equipment such as foetal monitors. The company has a product range of over 10,000 with frequent new additions. The major product organisations are described by below[32]:

CSO

The Computer Systems Organisation's mission is to be the leading supplier of innovative information technology solutions to the top 100 global companies and Channel Partners. (Channel Partners are major HP customers that include software vendors, value-added resellers, distributors, systems integrators, etc.).

CPO

The Computer Products Organisation comprises of the LaserJet Printer Group, InkjJet Products Group, and the InkJet Supplies Business Unit. Collectively they manufacture and market laser printers, inkjet printers and supplies, plain-paper facsimile machines, integrated printer fax-copier products, large-format plotters, printers and scanners. HP created the market for desktop laser and inkjet printers and have sold more than 30 million.

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1 [32] Source HP, 1997

TMO

The Test & Measurement Organisation is the world's leading supplier of customised and standard test systems and equipment, instruments, components and accessories. Test & Measurement is also a provider of consultancy services including test equipment asset management. Its goal is to be the preferred provider of enabling technologies for the Information Age by applying its expertise in design, test and measurement to help its customers improve their business results.

HP grew into the world's leading manufacturer of electronic test and measurement instruments for engineers and scientists. These instruments measure the performance of electronic equipment as it is designed, tested, operated or serviced.

Engineers and scientists want instruments that provide even higher levels of precision, speed and reliability. HP's equipment tests and troubleshoots wireless products such as cellular phones, cordless telephones, pagers and two-way radios.

CAG

The Chemical Analysis Groups' mission is to create superior analytical instruments, systems, solutions and services that accelerate the advance of measurement in chemistry, enhance customer performance and enrich the quality of life.

Healthcare

HP's Medical products are targeted to healthcare professionals working in cardiology, critical care, surgery, obstetrics, hospital administration, health-maintenance organisations and physician offices. Its mission is to provide emergency medicine systems and integration of products and services that help customers improve patient outcomes, increase productivity and lower costs.

Components

HP's Components Group is the largest independent supplier of communication components in the world. The group's charter - to develop semiconductor component solutions that enable the information exchange revolution - advances such strategic technologies as the "information superhighway", the extended desktop and mobile information appliances. These technologies will significantly expand communications and information-management capabilities world-wide.

HP World-wide Product Takeback Programmes

HP policy on reuse and recycling within the Environmental Policy states [HP (1996)]:

> *"HP helps customers minimise waste and conserve resources by refurbishment and recycling obsolete or returned products."*

To date HP operates product-refurbishing centres in the US, Germany, and Austria, which take back obsolete HP products (mainly computers, peripherals, and test and measurement systems), and refurbish them for resale. In addition HP recycles or reuses more than 570 tonnes per year of material at product recovery centre in Grenoble, France, and Roseville, California. At these centres, components and parts are recovered for reuse or resale, and plastics, PC boards, and monitors are recycled.

A growing number of products (such as the HP Vectra range) have been designed to facilitate dismantling, e.g. by using "snap apart" fastenings for plastics and metals, and labelling and coding plastics components for material identification.

HP in the UK

The HP UKSR (UK Sales Region) is the geographic organisation responsible for the sale of HP product throughout the United Kingdom and Ireland (as a sub-region). The UKSR had a turnover of around £1.3 billion in 1994, which grew substantially to £1.7 in 1995, contributing to around 0.5% of the UK's GDP. The product line organisations operate through UKSR to sell their products to UK and Irish markets. Computation represents about 70% of revenue (with TMO and Healthcare making up the remaining share) from product sale to large UK retailers such as Dixons and PC World, and distributors who sell product and distribute wholesale to commercial and domestic consumers. In comparison, sales operations for other organisations are more direct to market e.g. the Healthcare Organisation sell even single units of product direct to hospitals.

Also operating within the UK and Ireland are four manufacturing locations aligned to the global product line organisations[33].

Bristol: Computer Peripherals Bristol (CPB) designs, develops, and markets data storage mechanisms and solutions. CPB are currently focused on Digital Audio Tape (DAT) drives IT products, and manufacture other Hewlett-Packard information storage products for the European marketplace.

Ipswich: Hewlett-Packard's Ipswich site houses the Fibre Optic Components Operation (FCO) which is part of Hewlett-Packard's Components Group. FCO designs, develops, manufactures, and markets high-speed optoelectronic components for fast growing global telecommunications marketplace.

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1 [33] Abstracted from HP Intranet information source

South Queensferry: The HP South Queensferry site houses many HP TMO product based organisations designing, developing, manufacturing, and marketing specialised test equipment for telecommunications systems and networks, microwave and video technology,

Dublin: A new manufacturing plant has been set up to manufacture Ink Jet cartridges at Dublin. The organisation is known as DIMO (Dublin Inkjet Manufacturing Organisation).

The HP Background Behind the Research.

Prior to the initiation of this research project, HP were a founding member of ICER in 1992. In January 1996 HP withdrew to associate membership of ICER as they felt it was not providing value for cost of membership. HP is also a founder member of EMERG (and is still an active member), the industry user group of a prominent recycling organisation. Although HP receive very few requests for product take back, and are not clear what happens to their products at end of life, several initiatives have been taken in view of impending producer responsibility legislation:

Parts are returned from reclaimed products (from HP asset management processes and form selected major customers) by the EOL electronics processor and returned to the asset recycling centre in Grenoble, France (HRE), where parts are tested and re-engineered for reuse by the HP Maintenance Division. Remaining product is recycled for valuable materials.

HP Motivation & Support

HP have 7 fundamental corporate objectives [HP (1989)]:

* To achieve sufficient profit
* Provide products and services of the highest quality to customers
* Participation in fields of interest
* Growth within limits of profitability, through developing innovative products
* Ensure people are happy and gain a sense of satisfaction and accomplishment from their work.
* Management through empowerment of individuals to have freedom of action in attaining well defined objectives
* Citizenship, to honour obligations to society.

Any business activity must contribute to these objectives. Environmental policy and related programmes help HP to meet their objectives of being "good" citizens (as well as various other objectives such as profitability arising from maintenance of longer term viability of the business through legislative compliance). Thus activities for recycling and refurbishing products can be justified from the perspective of environment. However, if environmental programmes prevent HP from meeting any other corporate objectives, especially profit, then support for them would not necessarily be forthcoming.

In relation to this research at present, HP in the UK will not develop new processes that incur significant costs without justification, and have implied that any take back systems must be self funding or even must make a slight profit. Although HP will have stated their concern for environment through policy, and make modest efforts to improve company environmental performance through good environmental management, costs and profit margins are considered to be primary drivers behind business activities.

It appears that HP have responded to the producer responsibility initiative and embarked upon this four year research project to:

* Take advantage of any competitive opportunities that may arise from producer responsibility, and minimise the impact it may have on HP business through proactive development of management systems and representation to government.

* Utilise environmental programmes to enhance corporate and brand image in terms of social responsibility which helps to strengthen HP markets in the long term.

* Develop take back services to meet the needs of "green" customers e.g. companies using "green" purchasing strategies and consumers.

* Ensure they will be able to meet the requirements of any legislation.

* To meet corporate environmental objectives as given by HP environmental policy.

Recent HP Developments

* The Logistics Services Organisation (LSO) that currently manage many of HP's internal asset management processes, including the consignment of electronics scrap to the EOL electronics processor, is planning to include HP product take back as a fundamental area for the attention of future business development. The LSO manager has also agreed to become second industrial supervisor for this work. It is the LSO that will be most immediately affected by the recommendations of this research.

* A virtual organisation[34], currently known as "EOLM inc." (End Of Life Management Incorporated) is to be set up within the LSO as a managing entity, responsible for the development of a HP end of life electronics management process. This is viewed as a long-term internal "business game".

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1 [34] An organisation made up through the commitment of its members (who are generally not involved in primary capacities), not officially recognised as a separate department or organisation within a company.

* Through discussion over the issues surrounding reuse of product, HP are reconsidering their position with regard to the reuse of products as and environmentally and economically preferable option to recycling.

* HP are actively seeking out additional partnerships with EOL processing and logistics organisations where it is of mutual benefit and the state of the art practices, methods, or technologies can be developed.

* HP withdrew membership entirely from ICER in January 1997 as it still was not perceived as providing sufficient value services for membership costs incurred.

* HP in Europe have realised the substantial costs involved in widespread product take back and recycling, and are now considering the need to start accruing costs for products now that may have to be recycled in a few years time when electronics take back legislation has been fully enforced.

* In early March, HP Ireland became officially included in the scope of this research project.

* HP have become involved as a partner in a EU project known as RELOOP. The aim of this project is to set up an internet based tool (using a series of databases) that can be used by "key players" involved in managing reverse logistics processes to gain expert advice on aspects such as the best locations to set up recycling organisations, optimum collection arrangements, and design guidelines for products in optimised logistics systems, in exchange for user information to feed back to the database to support future enquiries. Substantial resources for research into reverse logistics and highly useful information sources are available through the RELOOP partnership, and may be of substantial benefit to this (EngD) research project.

* Through initial investigation of asset management practices within HP, it is evident that there are many processes that ensure obsolete product are retained for reuse before being consigned for recycling. These include product leasing, high level remanufacturing , lower level reconditioning, and remarketing operations managed by the Finance Division and Finance and Remarketing Division (FRD) on behalf of the product line organisations. These processes may provide useful avenues for product returns in the future. It was also noted that little had been done to fully integrate these processes with asset recycling, which represents an immediate opportunity for process rationalisation and improvement. It was also found that asset recycling processes were of low priority, and received little management attention. Consequently they could be operating at unnecessary cost, e.g. distribution orientated logistics services were used to transfer waste electronics from point of source direct to the electronics EOL processor. Waste management or recycling logistics companies should prove cheaper options of transferring these products for recycling.

Conclusions

1. Electronics wastes make up a fractional percentage of overall UK waste arisings, but are perceived as environmentally problematic because:

- Printed circuit boards (PCBs) and cathode ray tubes (CRTs) typically incorporate a variety of toxic metals that can become mobilised under acidic conditions e.g. in landfill, and contaminate the environment.
- Electronic products have a lot of embodied energy and high value materials such as precious metals, rare earth metals, and plastics that are lost when disposed at end of life.
- The problem of high value durable goods (such as electronic products) arising as waste has not been addressed.

2. Within the next 3-4 years, the electronics industry could be made responsible for their products at end of life due to the implementation of producer responsibility legislation based on the polluter pays principle and the need to manage waste more sustainably (by building economies based on circular flows of materials).

3. Governments in many countries in Europe and Asia are considering producer responsibility legislation for electronic products. The EU are currently investigating the need for a directive, while countries such as Korea and Italy have already implemented legislation, and Denmark, Sweden, and the Netherlands are about to implement legislation.

4. The UK government has asked the electronics industry for a voluntary response to producer responsibility, but have threatened to legislate if no solution is forthcoming. The industry representative group, ICER (Industry Council for Electronic Recycling), have been given the task of facilitating industry consensus and to produce recommendations to the DTI (Department of Trade and Industry) within the year.

5. Currently, end of life electronics are either exchanged to be reused multiple times, are stored, are sent for materials reclamation and recycling, or are disposed as waste. The specific quantities or percentages of end of life products arising, and passing into existing end of life "pathways" have not been established.

6. Specific electronics recycling and reprocessing operations have been set up throughout the world, and are developing at a rapid rate. A distinctive process has been outlined for these reprocessing operations, including; dismantling, sorting, re-engineering, and recycling stages. It was suggested that an understanding of this process is essential if producers are to be able to manage end of life electronic products efficiently.

7. The capability of electronics processors to recover maximum value from end of life electronics is currently dependent on the available technology, and the willingness of

markets to accept reclaimed products, components, and parts, and recycle reclaimed materials. Considering the low volumes of waste electronics the arise, and the generally high value of reclaimed materials, the availability of markets for recovered end of life electronics is not a major concern. There are however important issues that future technological developments should address, including:

* The identification, separation, and decontamination of high grade plastics.
* The recovery of rare earth metals from CRTs and PCBs, e.g. Ybttrium.
* Closed loop recycling of materials e.g. CRT glass.

8. Many major producers of electronic goods have put forward voluntary electronic product take back and reclamation schemes. These tend to be justified from business and environmental perspectives as most have been set up to manage obsolete product (arising along the supply chain) more efficiently. These schemes (with the exception of schemes operated by the telecommunications and office imaging sectors, in which product ownership is retained by the producer after sale as part of leasing agreements) have not been set up to handle higher volumes of returned product that arise as waste from society.

9. The reuse of product is likely to become a critical issue in the end of life management of electronic wastes. Reuse appears to present a more economic and environmentally sound route to waste prevention, yet most producers appear reluctant to adopt this approach. The environmental implications of widespread reuse in unsaturated markets should be investigated further.

10. Reverse logistics is a term increasingly used in reference to producer responsibility. It refers to the way in which products are collected at end of life, returned, and reclaimed (for reuse, recycling, or recovery). Reverse logistics processes are determined by managing products at their end of life stage, which includes facilitating the involvement of four key entities (product sources, transferors, processors, and organisers/managers) in the reverse logistics chains (including collection from source, sorting and consolidation, transfer, and end of life processing operations). These processes are currently perceived as inherently problematic in relation to "forward" logistics processes due to low economies of scale, lack of infrastructure, lack of control over product returns markets, and difficulties in establishing "entry points" of returned materials and products to the economic system.

11. HP (the industrial sponsor and subject of this research), has been described as a multinational electronics manufacturer. An account of HP has been given as it operates globally, (including descriptions of product line organisations), and within the UK and Ireland. More specifically existing product take back arrangements, the drivers and motivation behind the research project, and related new developments have been reviewed.

Overall Conclusion

The management of reverse logistics is important if producers are to meet the challenge of producer responsibility, and utilise opportunities to create competitive advantage from environmental improvements. Ultimately producer responsibility is a step towards the attainment of more sustainable economies based on the circular flow of materials.

It is unlikely that one reverse logistics process arrangement will be suitable for all products form all sources. It is envisaged that end of life management will involve the organisation, arrangement, and selection of options (based on a balance of their relative environmental and economic benefits), within larger emergent reverse distribution systems (formed from complex networks and interrelationships between various key players and stages of reverse logistics processes). Thus the thesis of this research is that:

> *Producer responsibility for products at end of life will require extensive reverse distribution networks to be organised and established. Therefore management practices, tools, methods, and models must be developed to enable producers to meet producer responsibility in a manner that is economically competitive and maximises benefits to the environment. Hewlett-Packard as an electronics producer will provide an ideal study situation to investigate this thesis further.*

and ***reverse logistics*** is defined for producer responsibility as:

> *"The collection of end of life goods (for reprocessing as products, components, parts, and materials) for re-entry to the economic system in a manner that is economically competitive and environmentally responsible."*

Hewlett-Packard Ltd will be used as a longitudinal case study and research environment, in and through which hypotheses will be tested, and the thesis of the research will be further developed.

Next Research Steps

1. New developments in producer responsibility legislation and related initiatives, end of life processing operations, technologies, and in reverse logistics thinking should be followed through continued situational assessment and literary review.

2. At the end of four years (the end of this research project), a reverse logistics or end of life management method consisting of tools, processes, management models (non-mathematical), and approaches should have been developed and tested with regards to HP products and processes. This management method should enable HP to select the best end of life product options and arrange them in such a way to maximise environmental benefits and balance economic costs and revenues with respect to HP business objectives.

3. There are two dimensions into to which future research may enter. Firstly, as the exact details of legislation for electronics take back has not been determined, this research may influence developments in the UK and the EU through HP. Secondly this research will effect the specific arrangements made for product take back within HP. Ultimately, this research has academic freedom to test many different hypotheses, and explore many new areas. HP will be restricted by legislation, and will choose the end of life product management strategy that will best suit them within these limitations. Thus the effectiveness of policy and legislation developed nationally and internationally, and the final end of life product management approach adopted by HP may be critically evaluated as part of this research.

4. Some of the environmental problems of end of life electronics have been outlined in this report. This area has not been covered greatly by research to date. It is important if product take back systems are to be "environmentally optimised" that they are comparably better (on well researched environmental grounds) to current processes and alternative options (which must be identified and quantified). There are various assessment techniques and tools that may be used to list or make inventories of quantifiable environmental impacts, and make valued comparative environmental assessments between different options e.g. Life cycle assessment (LCA), waste management (based on site evaluations and investigation of the applicable validity of the waste management hierarchy), through the application of the Best Practicable Environmental Option principle (BPEO), through systems analysis, and through other sustainability principle based approaches.

5. In the immediate term, the following areas will be researched to develop the research thesis further:

- HP product types, typical components and materials, product markets (current and future), and the geographic distribution of sales and potential end of life product returns.
- Industry responses to other producer responsibility initiatives, e.g. packaging, batteries, tyres, and automobiles.

* Transport and environment.
* HP organisations and processes involved in the management of obsolete products.
* Factors affecting the selection of a location for and current trends in end of life processing operations.
* Reverse logistics processes and management.

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Appendix 1: The Review Process

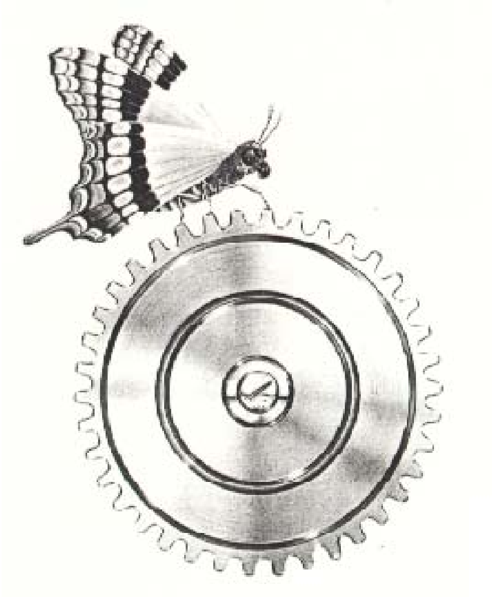
Keywords Used in BIDS British Library BLII Search.

1. Reverse logistics
2. Electronics recycling
3. Producer responsibility
4. Metals leaching
5. Metals in waste
6. Electronics waste
7. Plastics separation
8. Recycling & printed circuit boards
9. Metals & printed circuit boards
10. Electronics & environment
11. Computer scrap
12. Computer recycling
13. Computer waste
14. Landfill contamination
15. Landfill & metals
16. Plastic & recycling
17. Plastic & identification

Brunel and Surrey Engineering Doctorate Programme in Environmental Technology

Chapter 2, Vol. 2

An Investigation of the Implications and Effectiveness of Producer Responsibility for the Disposal of WEEE.



12 month report

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Contents

Executive summary

This 12-month report covers academic progress made over the last 12 months, reviews progress on specific objectives set out in the last 6-month report, describes how the research project will be focussed, and outlines future objectives and timeframes for work.

The literature review was a crucial stage in the development of the research project over the last year. It covers a “broad-brush” analysis of the environmental context for producer responsibility, legislative developments and government initiatives, recycling technologies and processes, industry recycling schemes, reverse logistics, and the role of Hewlett Packard in the research project.

The 5 objectives set out in the literature review have either lead to the development of new research ideas, been investigated in greater detail, or are now believed to be of lesser importance. These progressions are explained further in section 2.2.

Over the last year, around 2-3 months have been spent completing 6 modules and related assessments. These have been very useful in developing both business skills and relevant areas of research.

A wide variety of issues have been highlighted through the literature review. These include the problems surrounding electronics wastes, the extent and problems of existing recycling operations, environmental impacts of recycling and disposal of electronic wastes, and the role of reverse logistics management in providing solutions to electronics recycling (which forms the basis of the research thesis).

A variety of avenues could be followed in developing the research. Reverse logistics presents a major cost obstacle to electronics recycling. Therefore the purpose of this research is to analyse and put these costs into perspective, alongside evaluation of environmental impacts.

At present three specific research areas have developed, the investigation of a proposed qualitative model of end-of-life for IT products, environmental evaluation of different electronics recycling and logistical arrangements, and further study of existing arrangements incorporating elements of reverse logistics.

The major academic work over the next 6 months will be on researching these areas, and preparing related papers for publication in academically vetted journals.

1. Introduction

This 12-month report is a requirement of the Engineering Doctorate program on Environmental Technology and Brunel University. It is intended to describe progress towards objectives set out in the previous 6-month report (see section 3) and to develop and refine the objectives of the work for the next six to twelve months (see section 4). In particular, this report summarises the overall findings of the literature review stage (see section 2 & 3), and sets out the specific focus of the future EngD research project (see section 3).

No academic references are given in this report. Academic arguments presented are supported by other documents, which have been included in the project portfolio, or will be written within the next six months and submitted to the portfolio. A glossary of working definitions for terminology is provided at the end of the report.

2. General progress review

Over the last 12 months, the most important progress on academic research has been made with the completion of the literature review, and six taught modules with assessments. Detailed discussion of this is documented in the minutes of each supervisor meeting (see supervisors meetings minutes 1 to 5 – included in the portfolio).

2.1 Literature review

The literature review (completed on 4th April 1997) was a crucial stage in the development of the research project over the last year. It constituted a *"broad-brush"* analysis of the environmental context of product take-back, product take-back within HP, and product take-back in a broader sense at international and national levels, as specified in the first supervisor's meeting minutes. Specifically it was split into eight sections;

- **Introduction:** covering environmental context of producer responsibility, details of the research project, and report structure.
- **Legislative pressures and government initiatives affecting and-of-life electronics considerations:** Progress on legal and policy issues in Europe, worldwide, and in the UK.
- **End-of-life processing methods:** overview of electronics recycling processes in the UK
- **The emergence of electronics recycling technologies:** review of technology for plastics, printed circuit board, and cathode ray tube recycling.
- **Corporate responses:** electronics recycling by information technology, office imaging, and office imaging manufacturers. Competitive pressures over the reuse of products.

- **Reverse logistics:** A definition and review of *reverse logistics* from the perspective of producer responsibility. The development of a research thesis on the organisation of reverse logistics processes
- **The Hewlett-Packard context:** Introduction to HP, worldwide and UK product take-back programs, HP background to research project, and recent developments.
- **Conclusions:** Overall conclusions for literature review and each section within it, the research thesis and definition of reverse logistics, and 5 steps for future research.

The literature review was produced after an extensive analysis of relevant literature (including 52 specific references), networking and discussions with "experts in-the-field" and representatives from various organisations, and attendance at conferences and other "information-rich" events. The literature review was referred to as more of a "situational review". This was because elements of knowledge based on expert and practical experiences were incorporated as important background (these are referenced by 34 footnotes in the review). A process was developed to ensure that a vigorous approach was used to investigate, identify, validate, and record sources of information. This was appended to the review (Appendix 1).

The literature review was comprehensive and has helped to develop a clear understanding of the complex scientific, technical, practical, commercial, political, and social issues involved in producer responsibility for electronics wastes. It is intended that it will be continually updated and revisited as new articles and papers are written and found.

2.2 Progress on six month report objectives

At the end of the literature review (which incorporated the six-month report), 5 areas were detailed to indicate possible future research directions. Several of these have now developed into new ideas, or have been investigated in more detail. Some are now believed to be of lesser importance. These progressions will now be explained and justified.

1. Continued situational assessment and literary review of developments related to producer responsibility, end-of-life processing technologies, and reverse logistics.

Review of developments related to producer responsibility has continued. The paper included in the portfolio entitled *"Meeting the "producer responsibility" challenge – the rationale and future for the electronics industry"* (submitted to the 1997 Engineering Doctorate conference) was based recent developments in legislation, and on discussion on legislative pressures and government initiatives in the literature review. It argued that although there were many inconsistencies and uncertainties between different approaches to producer responsibility in Europe, that there were common issues and approaches identifiable within each. Work and reading on end-of-life processing technologies and operations continues through further visits to recycling operations and investigation of available technologies (see sections on "End-of-life processing methods" and "The emergence of electronic recycling technologies" in the literature review). The subject of logistics management needs to be investigated in much greater depth. This will help develop understanding of how industry logistics competencies could tackle producer responsibility problems. This will be undertaken through wider reading, networking, and potentially through taught academic courses.

2. The development of new tools, models, novel approaches, and environmental assessment techniques to reverse logistics management for producer responsibility.

This objective is central to the development of the research thesis (first outlined in the sections on "*Reverse Logistics*" and the "*Conclusions*" in the literature review). Development of the research is discussed in further detail in the *"Focussing the research"* section of this report.

3. The effects of the implementation of government policy on research direction.

The issue of how product take-back schemes are to be set up and managed could be determined largely by government policy decisions, as discussed extensively in the 1997 EngD conference paper. This research project is focussed on operational elements of product take-back, and not on the efficacy of government policy. However as producer responsibility policies require industry to set up voluntary schemes, policy decisions could be based on knowledge gained from practical and academic experience. Therefore the implementation of government policy is relevant to this research through its affects on the practical operation, management, and environmental impacts of producer responsibility schemes.

4. Evaluation of Best Practicable Environmental Options for electronic wastes

The environmental impacts of electronics recycling and disposal were only covered very briefly in the introductory chapter of the literature review. This was in reference to perceived environmental problems such as potential metal contamination, volumes, and the benefits of recycling over disposal and concluded that it was not clear if there were indeed any significant environmental impacts of electronics wastes. Subsequent to further literature review and visits to operations (discussed in section 3 of the conference report and in the assessment for the environmental measurement module) it appears that electronics wastes may cause significant (if somewhat difficult to identify) environmental problems. The recycling of electronics waste has been placed high on the political agendas internationally due to social concerns and public pressures. This area has now developed into a separate area of research covered in section 3.2 of this report.

5. *Specific research areas for the intermediate term*

- HP product types and volumes and weights can be tracked through two HP databases, *“DLS pack”* and *“product file”*. However, the geographic distribution of HP product sales and markets has not been investigated. This was because this area of interest has developed into a much broader research project, based around a proposed model of product “end-of-life” in society and commerce. Specific research into HP markets is becoming increasingly important as legislation approaches – and will be needed to calculate appropriate strategies in combination with other research information on the nature of the product end-of-life phase.

- Other producer responsibility initiatives are currently being reviewed. This includes draft and final legislation on batteries, packaging, and automobiles in Europe and the UK. This provides useful background information on development of policy e.g. it is possible that the European Union will transpose the draft automobile directive to electronics wastes.

- A course has been attended on transport and the environment, and extensive literature references built up. This information will be essential background reading in the evaluation of the environmental impacts alternative logistical solutions to producer responsibility (see section 3.2 for an outline of future research on evaluation of environmental impacts).

- Existing HP processes for managing obsolete electronic products have been reviewed in detail as part of the industrial work of the doctorate. In combination with discussions with other industries and the section entitled “corporate responses” in the literature review – an academic paper is being drafted on the relevance of existing corporate and commercial product take-back and recycling schemes to producer responsibility and the existing dependency on or need for reverse logistics management. It is hoped that this will be published in an appropriate academically vetted journal.

- Work on identifying factors that influence site of location in the recycling industry has not been followed extensively, accept to say a broad correlation has been noted between the location of existing sites, population, and industry. This will provide some useful background information in developing reverse logistics models and management approaches.

- Work on the development of reverse logistics tools models, and management approaches continue (see section "*Reverse logistics – development of a research thesis*" in the literature review). Several case studies are being prepared of processes that appear to have reverse logistics functions i.e. they bring products distributed across space and arising at different times together (see Glossary). This research s outlined further in the section 3 -"*Focussing research*" - in this report.

2.3 Modules and assessments

Considerable time has been spent completing various compulsory taught modules and assessments (approximately 3 months). There have been six modules to date, which are listed below.

Modules attended September 1996 to September 1997

Module	**Grade**
Teamwork and presentation skills	A
Project management and life cycle assessment	A/B+
Social research methods	B
Risk perception	B
Environmental measurement	?
Environmental auditing	?

Where possible, best use was made of assessments by focussing them on particular aspects of the research project. The project management, and team working and presentation skills courses and assessments helped develop essential interpersonal skills necessary to work within a business environment. The social research methods assignment was used to outline the problem of investigating the end-of-life phases of electronic products. A refinement of the proposed approach (which was originally too broad) has since lead to the development of a model for the end-of-life phase for electronic products. Market and social research projects are currently underway to investigate this model further (see section 3.1). The environmental measurement assignment was used to determine a basis for evaluating different recycling operations on a comparable basis. These written assessments can be found in the portfolio under the titles of *"A proposal for the study of Hewlett Packard's potential future markets for end-of-life electronic equipment"* and *"Environmental performance measurement in the UK electronics recycling industry"* respectively.

3. Focusing research

Various interesting issues have been discussed in the literature review, including some rough hypotheses that could all equally be investigated by subsequent research projects. However, it is necessary to develop a specific research focus so that a contribution to an area of knowledge can be defined and made in respect to doctoral level research (this was discussed and decided upon within the 6th supervisors meeting – see minutes in portfolio). The discussion below summarises the broader context of research understanding and general arguments to date (including the proposed thesis). Following this discussion, the future focus of the research problem is outlined and the thesis and project title redefined with respect to this. Finally specific research areas already underway are discussed.

3.1 Summary of research findings and arguments to date through literature review

The following summary of the main research arguments developed to date has been put together from the conclusion sections of the literature review, the conference paper, the social research methods and environmental measurement course assessments. Academic references to support these arguments can be found within these documents within the portfolio.

The problem of electronics wastes:

Electronics wastes only makes up a fractional percentage of total waste volumes. It has been placed high on the political agenda through social and environmental concerns over the contamination of waste streams, and over the loss of products and materials that potentially can be recycled.

In next 3-4 years, manufacturers of electronic products will be made responsible for the collection and recycling of their waste products throughout Europe and in the UK due to the adoption of producer responsibility policies. The UK government has requested voluntary industry responses, but legislation will be employed in absence of any response.

At present electronic products are either exchanged several times or stored before finally becoming part of general waste from domestic and commercial facilities. Very little information is available on how or why electronic products arise as waste at any particular stage, or on how commercial or domestic waste disposers would respond to any particular recycling arrangements.

Existing recycling operations:

Many major producers of electronic goods operate voluntary product recycling and reuse schemes. These tend to be justified for business and environmental reasons as most have been set up to manage redundant and obsolete products.
Commercial electronics recycling operations have already been established and employ a variety of traditional basic and new novel technologies to recycle metals, plastics, and cathode ray tube glass from electronic appliances.

Electronics recycling in the UK is at best an initial material sorting and low volume recycling or processing stage, followed by larger scale materials recycling.

The main obstacles to recycling materials from electronics products are the identification, separation, and decontamination of high grade engineering plastics, the recovery of rare earth metals, and the closed loop recycling of specific materials e.g. plastics and CRT glass.

Environmental impacts:

The most important environmental issues surrounding electronics recycling are the release of specific dioxins during smelting and shredding, metal contamination of groundwater, watercourses, or surrounding land, energy consumption, and verification of quantities of materials recycled.

Both industry and government need to know and demonstrate which are the Best Practicable Environmental Options (BPEO) for electronics recycling. Appropriate standards could be developed through a holistic evaluation or “life-cycle” investigation of environmental impacts of alternative recycling and disposal options. This would include impacts of recycling stages and transport or logistical arrangements.

Solutions:

Reuse of products should be fully considered by industry and government as part of widespread producer responsibility schemes as it appears to be a better economic and more environmentally sound route to waste prevention than materials recycling.

Reverse logistics involves the management of end-of-life products from source, collection, consolidation, storage, and transfer, to recycling. Reverse logistics processes are inherently more difficult than “forward “ the equivalent processes, reverse logistics costs can be 60 to 100% of total recycling costs[1]. This is due to low economies of scale, a lack of infrastructure, a lack of control or influence over product return volumes at end-of-life, and obstacles to returning products and materials to the economic system through recycling.

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[1] Source - Hewlett Packard 1997.

The development of reverse logistics management capabilities and skills by industry logistics functions will be essential in creating competitive opportunities from the producer responsibility challenge for electronics wastes.

Hewlett-Packard (the sponsors of this research project) is a multi-national electronics manufacturer that imports most of its products to the UK. HP will provide an ideal situation to test hypotheses and further develop the central thesis of the research.

Initially proposed thesis:

"Producer responsibility for products at end of life will require extensive reverse distribution networks to be organised and established. Therefore management practices, tools, methods, and models must be developed to enable producers to meet producer responsibility in a manner that is economically competitive and maximises benefits to the environment. Hewlett-Packard as an electronics producer will provide an ideal study situation to investigate this thesis further"

3.2 Defining the scope of future research

As can be seen above, there are many possible avenues of research, all of them equally relevant. Only one of these should be chosen if research to be in enough depth for doctoral level research. These areas are depicted in Fig.1 and include:

- Product design for recycling, dismantling, and elimination of hazardous components
- Product distribution and sale to commercial and domestic markets.
- Waste management of end-of-life electronic products

- Life cycle assessment of electronics wastes and electronics recycling
- Reverse logistics
- Electronics recycling technologies and markets.

Due to the potential environmental problems that electronics wastes could cause, producers will be made responsible for increased electronics recycling through substantial social and political pressure. Reverse logistics presents a major obstacle to electronic recycling schemes; it can account for around 60% to 100% of costs (accounting for transport, administration, storage, and consolidation). The purpose of this research is to understand, analyse, and put these costs into perspective to eliminate barriers to recycling.

This research will focus on the management of end-of-life or waste electronic products through reverse logistics, with specific emphasis on information technology products. This will involve development of novel approaches to logistics management, and will incorporate appropriate environmental evaluation methods. Reverse logistics solutions should be well matched and integrated to the systems under study. Therefore if end-of-life electronics are to be managed effectively, full consideration should be given to the end-of-life phase of products (the point at which an electronic product is removed from use in society or commerce) through market and social research. Full consideration should also be given to the possibilities, requirements, and constraints introduced to reverse logistics through material and product recycling operations and markets. Other areas outside of this scope, such as design for environment (DfE), will only be researched to a limited extent where there are significant implications for the study of reverse logistics. The wider context of electronics recycling has and will continue to be investigated through periodic literature and situational review as background to this research.

Research will be undertaken from the perspective of a multi-national IT producer, Hewlett-Packard Limited. Specific resources have been allocated to this work through direct project involvement in the Environment, Health, and Safety Department (EHS), the Logistics department (LSO – Logistics Services Organisation), and through a long-term business development team working to provide business solutions to producer responsibility under the project title “EOLM” – *End-of-Life Management*. In addition, research has already, and will continue to be completed in partnership with other organisations involved in the issue of producer responsibility for electronics recycling e.g. electronic recycling companies, academics, local authorities, and other producers such as ICL and IBM.

In view of the discussion above, the research title has been changed from:

Managing and-of-life electronic equipment – achieving logistical and environmental optimisation in closed economic cycles.

To:

Managing waste electronic products. Improving the logistical efficiency and environmental evaluation of electronics recycling systems.

And the research thesis has been revised to:

Producer responsibility for waste electronic products will require substantial development of collection and recycling infrastructures. These must be established and organised in a manner that is economically competitive and maximises benefits to the environment. If industry is to meet their obligations, novel approaches to logistics management must be developed which incorporate methods of environmental evaluation. Hewlett-Packard (a multi-national electronics producer) will provide an ideal study situation within the IT industry sector to investigate this thesis further.

3.3 New research projects

After the literature review was completed at the sixth month stage, and during the completion of much of the academic modules and conference paper and presentation – three research areas have developed that are central to future research. These are:

- The investigation of a proposed model of electronic products end-of-life phase
- The determination of an appropriate method for evaluating environmental impacts of different recycling and disposal options comparatively.
- Research on existing approaches to reverse logistics (as defined generally – see Glossary) through literature and case studies.

These areas are discussed in more detail below.

Important developments have occurred through the acceptance of a European Union project on reverse logistics called RELOOP, which HP is a major partner in. This (Engineering Doctorate) research will benefit through broader application in a European context, and from a wider pool of knowledge of other project partners. A summary of the project is provided in Appendix 1.

Investigation of product end-of-life

A number of electronics recycling schemes have failed in the UK due to a lack of understanding of the markets and societies in which schemes operate. This includes the ECTEL take-back scheme for mobile phones, and some areas of the ICER recycling trial with various local authorities. Based on a few existing small-scale non-academic research projects and on consultation with different industry sectors, a qualitative model describing these issues has been developed (see Fig. 2). During its use, a product may pass through various complex stages and various sectors of society and commerce before the end of its functional life and disposal as waste. This has significant implications for reverse logistics, as there may be many misunderstood, unknown and even powerful economic and social forces at work that can disrupt any collection and recycling arrangements. This model is now being verified and investigated amongst different sectors of society, mainly commercial and domestic sectors.

At present a study of the commercial sector is fully underway, and is scheduled to finish in mid January (see Table 1). This has involved 500 of the UK’s largest businesses by employees through a combined telephone and mail survey. A full methodology and results report and an academic paper will be written on this specific project – and included in the portfolio by mid-January and late February respectively.

Broader research on the domestic sector is currently being initiated, with various other potential commercial, academic, and local government partners. This project will use observational social research techniques such as unstructured interviews of selected households, which could be used to develop well-founded assumptions for a second stage of research involving more structured mail surveys of wider populations based on well founded assumptions. It is expected that this project will run from mid-November to mid-June, and may be extended subject to available resources and the research methodology involved. A full methodology and results report will be included in the portfolio and an academic paper should be written towards the end of this project.

Finally, in order to complete the verification of the model, further investigation will be necessary of commercial recycling operations, and waste management arrangements for electronic products disposal by local authorities, and of existing schemes run by electronics manufacturers, distributors, and retailers. This will be completed through discussion and collation of data from a range of industry contacts between mid-October to mid-December, and possibly through smaller scale research projects between April and August 1998.

By September 1998, the end-of-life product stages model should have been fully researched. The model could then be established as a significant contribution to knowledge by publishing an article in an appropriate academically vetted journal. This research will provide a strong basis for the development of reverse logistics models in future research.

Reverse logistics case studies

Reverse logistics has not been developed for IT products in the UK (an argument which will be investigated through further research on the IT sector). Various schemes do operate conversely to conventional logistics processes. In this context reverse logistics can be given a functional definition:

> *The bringing together of materials or products that are highly distributed in space and become available at different points in time for centralised processing.*

Within the electronics sector Rank Xerox operate substantial lease programs for photocopiers, and Black and Decker run trade-in programs at retail outlets for old products that have required two-way distribution systems to be established. The waste management and recycling industry has long operated reverse logistics processes for waste collection, recycling and disposal. Courier and postal services, door-to-door milk deliveries with empty bottle returns, and surplus newspaper and magazine collection from newsagents all involve elements that could be defined as reverse logistics as defined above. It is possible that substantial reverse logistics knowledge already exists in these operations. This knowledge could be bought together and developed into effective reverse logistics management and modeling tools that could be usefully applied to producer responsibility recycling schemes. Over the next 7 months these assertions will be researched in detail through literature review and case studies of various industries. Models and tools developed through this research will then be tested through application to Hewlett Packard’s existing and expanding recycling schemes.

Assessment of environmental impacts

Within the assessment for the Environmental Measurement module, the major environmental impacts of electronics recycling were described in relation to recycling processes. These included:

- Metal contamination of groundwater, surface water, and soils.
- Release of certain dioxins from incineration and granulating of plastics
- Energy consumption of recycling processes
- Verification of actual quantities of materials recycled through complex life cycles.

In addition, assessment of Best Practicable Environmental Option (BPEO) would require full consideration of the pathway through various processors and transport systems involved. Accounting for this, the 1997 EngD conference paper argued that a holistic life cycle approach was needed to evaluate appropriate logistics, recycling, and disposal standards. Such a study would need to ensure that logistics and recycling systems were evaluated on a comparable basis. Results would have to be relatively simple to reach (as compared to a full-blown life cycle assessment), but in enough detail to be meaningful measures and representative of the system under study.

From January to August 1997, the environmental impacts of Hewlett Packard’s recycling schemes will be evaluated using a life cycle approach. This will allow areas where there is insufficient data to be outlined. The environmental evaluation method will be incorporated into reverse logistics tools and models to ensure environmental factors and standards are taken into account during decision making.

4. Future planning

4.1 The next 6 to 12 months

Following the previous discussion on progress and the need to focus research, the objectives for the next six months of this project are described below. A rough plan of research for the next year is provided in table 1.

- Investigate the management and capability of existing recycling schemes and reverse logistics arrangements to handle significant increases in product returns in UK IT companies
- Scope with respect to research focus, develop methodology, pilot, and begin research on domestic end-of-life products.
- Research approaches and methods used to manage existing processes that incorporate elements of reverse logistics through literature review and case study investigations.
- Finish research on end-of-life products in the commercial sector, and write report on methodology and results interpretation.
- Evaluate environmental impacts of Hewlett Packard reverse logistics arrangements for product returns and recycling to test appropriate evaluation methods.
- Write academic and philosophical justification for research focus for the clean technology module assessment, or as an extension to the literature review.
- Complete course on logistics management
- Update literature review with new articles and background within the next 6 months.
- Publish three journal articles based on the1997 EngD conference paper, an analysis of the IT sector’s ability to meet the producer responsibility challenge through reverse logistics, and on commercial arrangements for end-of-life products.

4.2 Planning research for the next 3 years

A rough plan of general research areas is provided in table 2. This can be summarised as:

Year 1:	Investigation of background and development of research ideas.
Year 2:	Investigation and formulation of scenario planning, cost management, and environmental evaluation techniques for reverse logistics management models.
Year 3:	Testing development and application of tools and models to real situations.
Year 4:	Continued test, development and application of tools and models. Inclusion of more in depth research on areas of particular interest e.g. the use of information technology to manage and model reverse logistics processes. Final project write-up.

The detail of this rough plan will be built up over the next few months, and reported in more detail in the 18-month report.

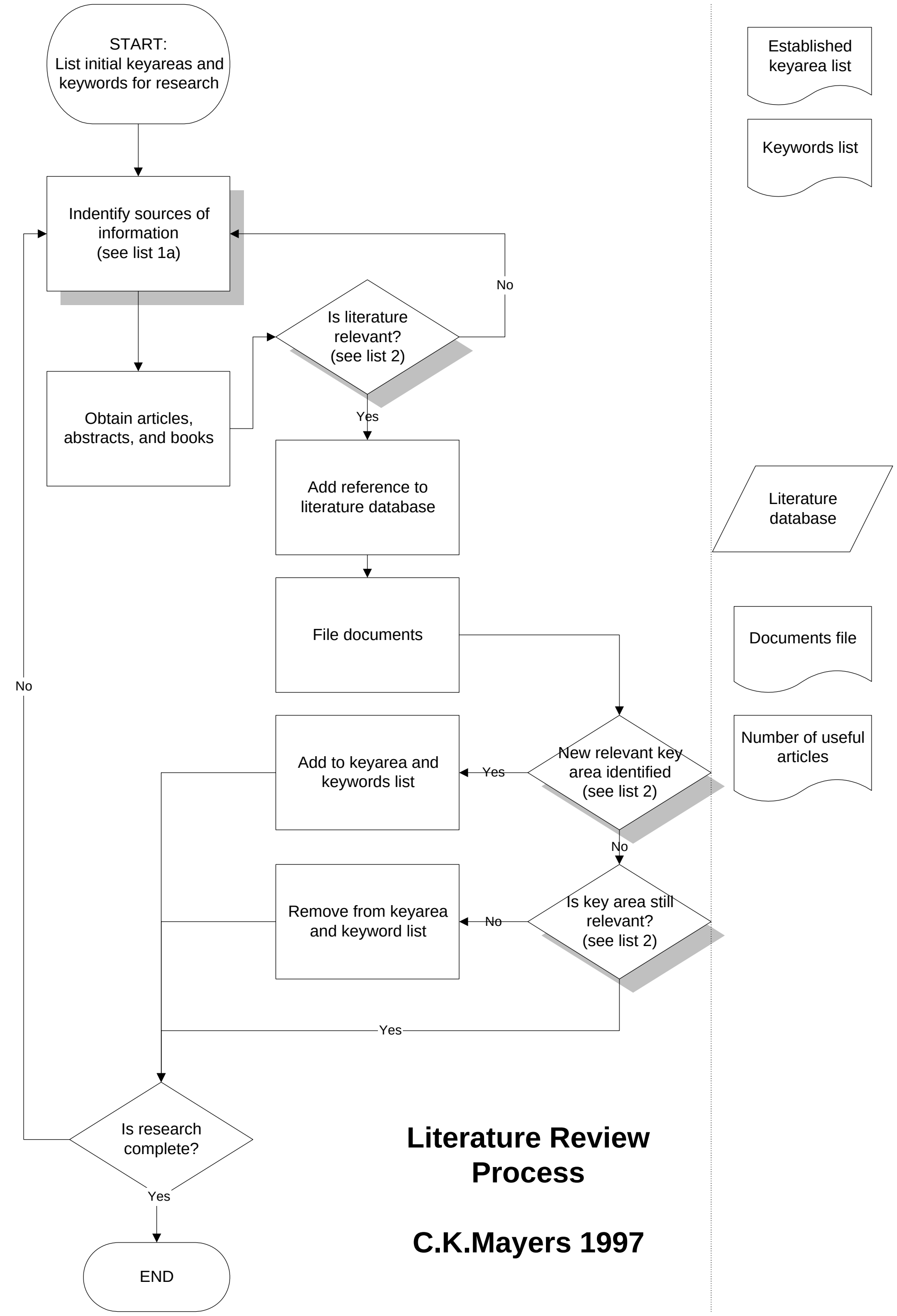
Glossary

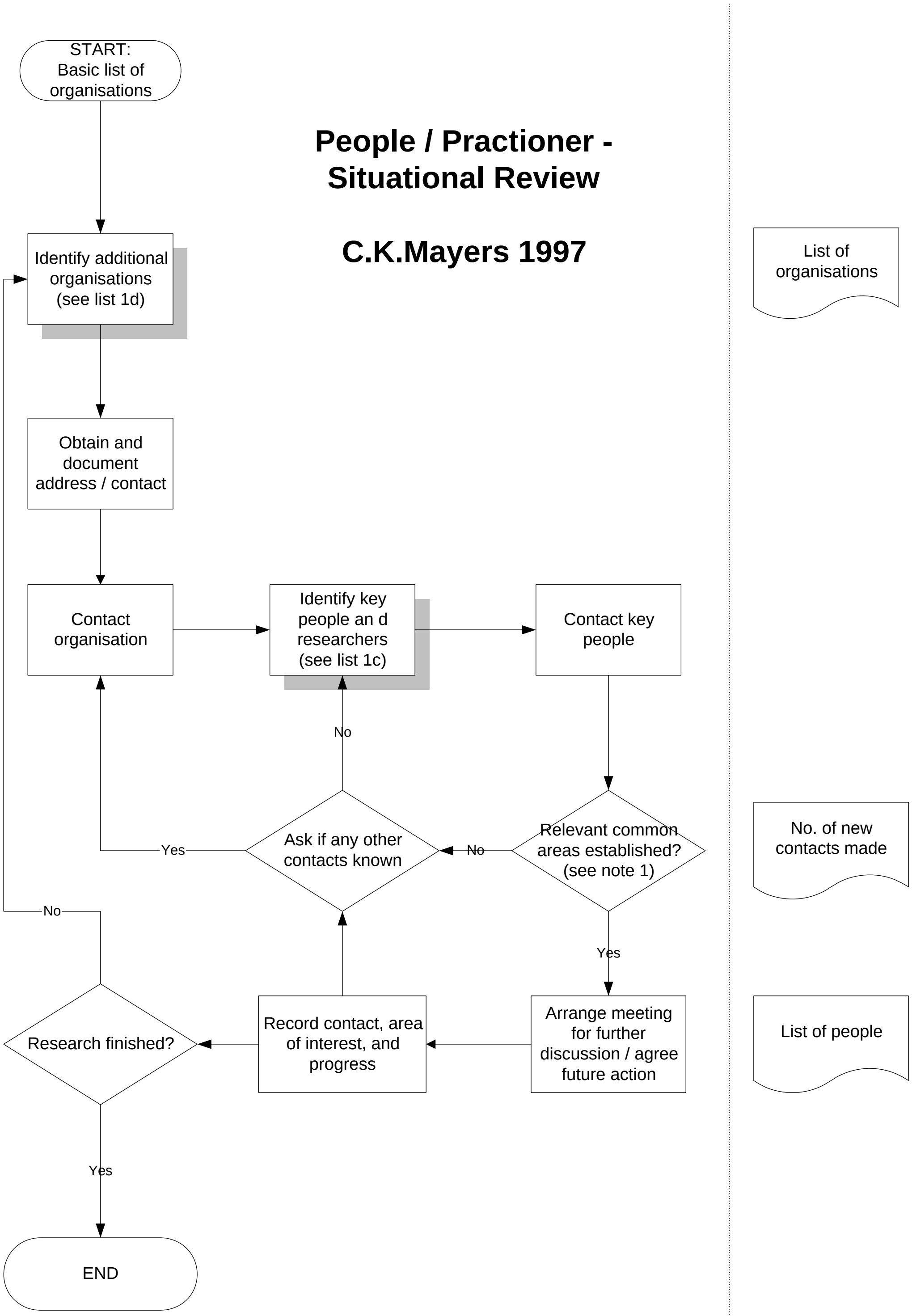
Glossary of terms: The following list of terms is defined in the context of this article.

Closed loop:	Systems or economies based on circular flows of energy and materials.
Electrical products:	Products relying on the supply of electricity e.g. vacuum cleaners.
Electronic products:	Products containing integrated circuitry e.g. computers.
Electronic wastes:	Abbreviated and convenient term for WEEE used in this article.
End-of-Life (EOL):	Redundant products destined for disposal. Not a clear cut stage.
End-users:	Users of a product at EOL.
Recovery:	(1) The use of certain properties of materials reclaimed from waste or at EOL for a useful purpose e.g. for heat recovery or composting. (2) Broadly applied term for recycling, reuse etc.
Recycling:	The reuse of materials reclaimed from waste or at EOL e.g. plastics & metals.
Reverse distribution:	Collection and transportation systems for EOL products
Reverse logistics:	The collection of End-of-Life goods for re-entry to the economic system in a manner that is economically competitive and environmentally responsible.
Reuse:	The effective re-deployment of functional components and products reclaimed from waste or at EOL e.g. microchips & second-hand washing machines. .
Take-back:	The physical activity of collecting and transporting products from end-users.

Appendix 1

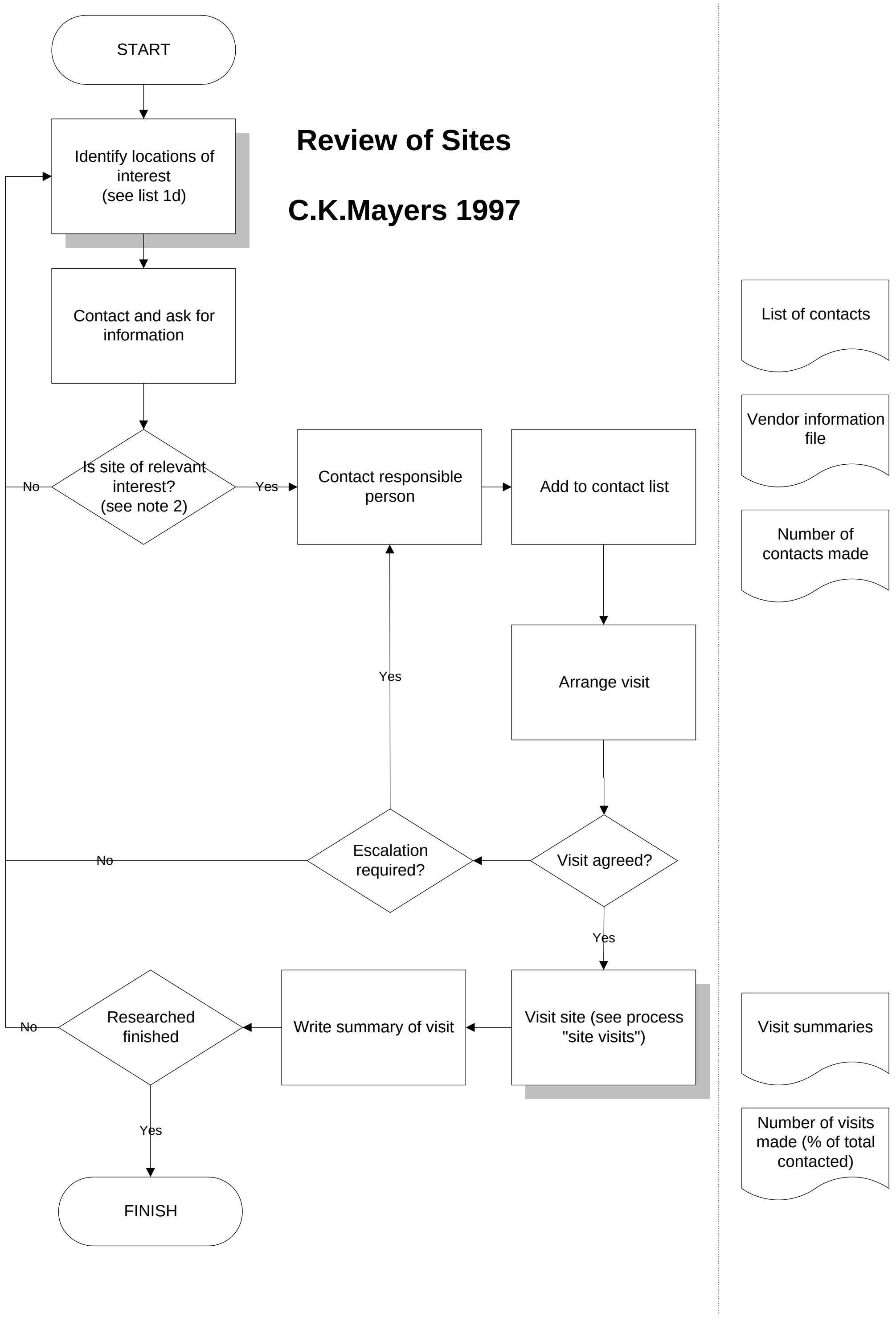
The following diagrammes have been provided as examples of the processes used during the literature and situational review.





People / Practioner - Situational Review

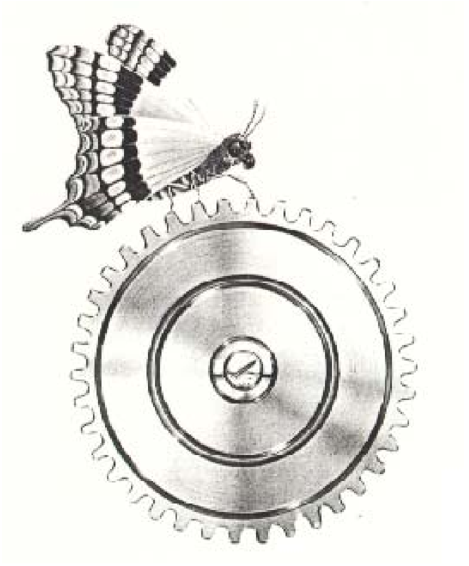
C.K.Mayers 1997


START
Identify locations of interest (see list 1d)
Review of Sites
C.K.Mayers 1997
Contact and ask for information
Is site of relevant interest? (see note 2)
No
Yes
Contact responsible person
Add to contact list
Arrange visit
Yes
Escalation required?
No
Visit agreed?
Yes
Researched finished
No
Write summary of visit
Visit site (see process "site visits")
Yes
FINISH
List of contacts
Vendor information file
Number of contacts made
Visit summaries
Number of visits made (% of total contacted)

Brunel and Surrey Engineering Doctorate Programme in Environmental Technology

Chapter 3, Vol. 2

An Investigation of the Implications and Effectiveness of Producer Responsibility for the Disposal of WEEE.



18 month report

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NB: Not all Appendices have been supplied with this report.

Contents

Executive summary

In this six-month report general progress and progress against objectives set out in the last six-month report are reviewed. A research focus is discussed in preparation for the two-year dissertation, and an outline of time-scales objectives, and deliverables is given.

Several objectives set out in the last six-month report have now been refined and restated, and time-scales for completion have shifted both forwards and backwards. The main areas of research progress are:

- Three specific research projects are underway or almost complete (investigating end-of-life in commercial and domestics sectors, and best practice in reverse logistics)
- An academic paper on the rationale and industrial implications of producer responsibility legislation will be ready for publication by the end of May
- Two EngD modules have been completed
- The literature review has been extended
- Applied research within Hewlett-Packard is under development

The initial thesis, set out as a guide to research in previous reports, is not sufficient to support doctoral level research. Therefore research ideas need to be developed further. A possible research focus is the effective management of end-of-life electronics products. This may include the investigation of problem areas, and the development of management solutions that lead to a reduction in environmental impacts and cost, and could provide added-value customer services. Before the two-year dissertation, a detailed research thesis, expected end-results, and contribution to knowledge will be developed. The literature review will also be updated by the end of May.

Time-scales and planning needed to complete this work is discussed in section 4. A detailed research plan will be developed for the two-year dissertation giving details of research for the remainder of the project. Detailed time-plans for the next six months are currently under negotiation – especially in relation to the specific research projects. MS project 98 is being used to help co-ordinate all project work. A list of objectives and deliverables for the next six months are given in section 4.2.

1. Introduction

It is a requirement of the Engineering Doctorate Programme to produce six monthly progress report describing progress towards research objectives and deliverables, refining and restating the objectives of the work, and including updated project management plans. The six-month reports are very useful in that they provide an opportunity for regular reviews of the work and possible future directions.

Previous six-month reports (submitted on 4th March 1997, and 1st April 1998) have:

- Explored the background and context of research through an initial literature review
- Described progress on compulsory modular components of the course
- Discussed progress against defined research objectives
- Discussed a possible research thesis and focus
- Proposed possible research projects or areas
- Outlined timeframes and objectives for future research

These reports will be an important part of the project portfolio and so together must provide a coherent overview of research development. This report will be used to:

- Review general progress and progress on objectives set out in the last six-month report.
- Explore and discuss a research focus for the two-year dissertation
- Outline future timeframes, objectives, and deliverables.

2. General progress review

2.1 Research progress

A general overview of academic progress for the last six months is available through minutes of supervisor meetings (see Appendix 2) and informal bi-weekly email updates (starting November 1997 - see Appendix 1). These include periodical reports on project planning, specific research projects, idea development, professional development, research focus, and possible academic papers. A re-occurring theme throughout the year has been the need for an agreed research focus and direction. After guidance in the seventh progress meeting, the author is developing improved professional and time-management skills to keep pace with supervisor's performance expectations (see minutes of Supervisors Meeting No. 7 in Appendix 2).

Progress against defined objectives

Several of the objectives set out in the last six-month report ([b: Mayers 1997; 23] / excerpt given in Appendix 2 for convenience) have been restated and refined and timeframes for completion have shifted. This is explained for each objective below.

<u>Objective 1:</u> A specific research project on product-take-back in the IT sector was not completed. Substantial information on this topic is already available through existing industry contacts and observations, and research completed a colleague (Cheryl Rodgers – Portsmouth University) which will be included in an update to the literature review. A rationale for the role of electronics manufacturers in product-take-back has been argued in a working paper soon to be submitted to an academically reviewed journal (Mayers and France 1998), and will be further investigated through studies on best practice in reverse logistics.

Objectives 2, 3 & 4: Progress on the three research projects on commercial and domestic end-of-life products, and on reverse logistics best practice case studies is discussed below.

Objective 5: A study of environmental impacts has not been possible due to redevelopment of Hewlett-Packard's electronics recycling processes. Alternatively environmental standards and supplier selection are being investigated, and a survey of UK electronics recyclers has been completed. Some of this applied research will be drawn together and advanced as a major component of the future research plan to be included in the dissertation (see section 2.2).

Objective 6: Further justification and discussion of the research has been incorporated into this report in preparation for the two-year dissertation.

Objective 7: A suitable logistics course has not been found, and specific knowledge needs are not yet known. Alternatively a variety of articles and books on logistics and reverse logistics have been used to build knowledge in this area. This has been useful in developing some research ideas and will be used to update the literature review by the end of May.

Objective 8: The literature search has been extended to include over 50 new references. These will be incorporated into the literature review when the scoping and preliminary reading phases of the two new research projects are complete (during April and May)

Objective 9: A working paper has been authored jointly with Dr. Chris France [Mayers & France 1998] on the rationale of producer responsibility policy for electronics wastes and reviewing implications for the electronics industry. This was based on the 1997 EngD conference paper [a: Mayers 1997], and has involved extended research and analysis. The paper will be submitted to a relevant academic journal by the end of May. Other papers will follow the completion of specific research projects (within four months following completion). The role of electronics manufacturers in end-of-life management will be the focus of this research (see section 3.1) and will be further investigated through a best practice study over the next six months.

Although timeframes and objectives set out in the last six-month report were useful starting points, they were not based on a fully defined research focus or a detailed work plan. The objectives set in this report will be more relevant and achievable, however it is always likely that objectives will be refined through the course of research, and the six-month report will be used to restate and explain any significant deviations.

Research Projects

<u>End-of-Life IT waste in the commercial sector</u> [b: Mayers 1997;18]: This project is now drawing to a delayed close. Although progress has been sluggish due to practical problems in increasing labour resources for survey work, 99 responses have been received to date, on-target for a minimum target of 100 (estimated total of 120-130 by end of project). Preliminary results have been evaluated, and a detailed scoping and methodology report has been drafted (which will include results and be included in the portfolio by the end of August). A realistic finish date for the project is mid-August (see Gantt Charts in Appendix 3). This will allow time for completion of follow-up research, data analysis, and final reporting.

<u>The E-SCOPE survey</u> (**<u>E</u>**lectronics Industry – **<u>S</u>**ocial **<u>C</u>**onsiderations **<u>o</u>**f **<u>P</u>**roduct **<u>E</u>**nd-of-Life)[b: Mayers 1997;19]: This project has begun with an initial budget of £10,000 from four commercial sponsors (Intex, Philips, Domestic and General, and Hewlett-Packard). An established academic researcher at Sheffield Hallam University (Tim Cooper) has also committed time to this project. The Executive Summary of the project proposal is included in Appendix 5. At present additional funds are being sought through ENTRUST (landfill tax), and new commercial partners, and the available literature is under review. The survey will probably use a series of exploratory focus groups, followed by face-to-face interviews with around

300 selected households. A detailed project report will be included in the portfolio by the end of the project (planned for September).

Reverse Logistics Best-Practice Case Studies (see p.20): Additional resources have been made available to extend this study internationally through the EU project on Reverse Logistics, RELOOP (first mentioned in the previous six month report [b: Mayers 1997; 18] – see summary in Appendix 6). It will now be completed in partnership with a researcher at the University of Stuttgart – Evelyn Bettac. The research objective has been defined as:

"To explore issues in reverse logistics "chain management" by identifying strategies, structures, and methods to give an overview of best practice and effective performance management."

Specific individual contributions to this project will be agreed in writing before any findings are disseminated. At present a detailed work programme is being developed and a preliminary literature review is almost complete. Specific case studies will be researched through reading and face-to-face interviews. Timeframes have been dictated by the RELOOP project for completion by July. It seems unlikely that this deadline will be achieved (see resource allocation sheets and Gantt chart in Appendix 4). Full records of this project have been kept, and a project report will be included in the portfolio by the end of the project.

Modules

Two modules and assessments have been completed in the past six months:

Clean Technology: The Clean Technology module covered a variety of areas such as environmental economics, environmental ethics, and clean technology, and used workshops for open discussion on issues covered. The assessment was highly useful as it allowed reflection on personal interpretations and understanding of Environmental Technology. This was a critical step towards understanding what the contribution to knowledge of this research could be.

Risk Communication: The Risk Communication module examined important relationships between decision-makers, the media, and the public. While this module was very interesting, it was not of core relevance to the research. It has helped develop understanding of public perceptions and concerns over the management of electronics waste.

From available results the average module mark is B+ to date, which is satisfactory within the requirements of the EngD programme. To improve these grades the balance between extensive literature review and intelligent analysis should be improved, and assessments should be submitted well in advance of hand-in dates.

2.2 Applied research

A substantial proportion of time (based on records of work completed in February 1998) is spent on developmental or applied research “in the field”. This included:

- Consultation and lobbying on UK and European product-take-back policy.
- Consultation and development of Hewlett-Packard’s electronic recycling processes
- Investigating customer needs for product-take-back
- Representing Hewlett-Packard Limited on the EU project on reverse logistics, RELOOP (see summary in Appendix 6).

Deleted:

In some cases this research has led to significant changes internally and externally to Hewlett-Packard, which could be counted as additional contributions to knowledge. This applied research offers rapid access to resources and information, and will ultimately become the most important element of the project. The two-year dissertation will include a discussion of current contributions to knowledge in this area, and a research plan detailing how this will develop.

3. Research focus

The next six-month report will be in the form of a two-year dissertation, which must include the literature review, a discussion of the project from start to expected end-result, and most importantly a well-defined thesis(es). This 18-month report is an important “staging post” for planning this work.

3.1 Development of a research thesis(es)

The last six-month report contained a useful discussion on the direction and possible *foci* of future research [b: Mayers 1997; 15-17]. The purpose this work was been previously described as *“to understand and place into perspective costs of reverse logistics to eliminate barriers to recycling”* [b: Mayers 1997; 16], which excludes important environmental or customer service dimensions of product-take-back. The initial thesis pursued in this work was that:

“*Producer responsibility for waste electronic products will require substantial development of collection and recycling infrastructures. These must be established and organised in a manner that is economically competitive and maximises benefits to the environment. If industry is to meet their obligations, novel approaches to logistics management must be developed which incorporate methods of environmental evaluation. Hewlett-Packard (a multi-national electronics producer) will provide an ideal study situation within the IT industry sector to investigate this thesis further.”*

This is not sufficient for a doctoral thesis. It does not state the specific research focus, hypotheses, or contribution to knowledge. Therefore the ideas and direction of the research must be developed further. A research focus is needed to determine the appropriate direction and scope of the project. This was agreed and discussed in the seventh supervisors meeting (see minutes in Appendix 2). As indicated in the initial thesis, the focus of the research is on how electronic manufactures can manage their products at end-of-life effectively (in particular HP and the IT sector). Two measures to determine "effectiveness" are cost and reduced environmental impact. A third measure could be enhanced customer service. Product end-of-life services could be used not only to add-value to after-sales support, but also to create innovative new service concepts such as approved second-hand dealer networks.

The purpose of this research is to investigate and develop, management solutions for products at end-of-life. "Management solutions" could include strategic and tactical approaches, environmental management methods, and cost models. In addition the nature of "the problem" must be understood if effective solutions are to work. To date "the problem" has been researched through social and market surveys on end-of-life products, and by evaluating and rationalising the basis for industry strategy on producer responsibility. Elements of "the solution" have been investigated through applied research and best practice case studies. Therefore the scope of research currently includes:

- Government policy and business strategy on producer responsibility
- The nature of product end-of-life.
- Methods of product collection, treatment, and recycling.
- Investigation of effective management approaches.

The possible scope of future research is discussed further below:

- *Empirical and operational research:* At present qualitative and empirical research is being conducted by the author e.g. on government and business strategy, and on product end-of-life processes. As legislation is developed and Hewlett-Packard extends its product-take-back processes, quantitative or operational research methods are likely to be used. Such a mix of empirical and operational research is important in management and logistics research [New & Payne 1995], and also in determining how end-of-life products are best managed.

- *IT products and other electronics:* Although the principle interest has been managing End-of-Life for IT manufacturers, collection of a mixture of goods from domestic sources would require consideration of other categories of electronic goods.

- *Recycling chain management and materials handling:* Recyclers internal material handling arrangements could affect the structure of recycling chains, and so could be important factor in the management of end-of-life products. This will be investigated through the best practice study.

- *Markets for second-hand products and recyclates:* Most studies of reverse logistics and recycling emphasise that a lack of market demand for second-life materials and products is a major obstacle to cost effective recycling. Therefore these limitations are important considerations in the management of end-of-life products.

- *Product design and end-of life:* As part of Producer Responsibility manufacturers will either be given incentives through market mechanisms or legally required to design products that consume less natural resources during production, and can be recycled and treated safely and easily at end-of-life. Product design is therefore another significant factor that should be considered in the management of end-of-life products.

All areas of current and future research must be planned in detail and linked together to support an overall project focus and thesis. The next section summarises important steps to achieving this within the next six months.

3.2 Next steps

In order to develop the research thesis for the two-year dissertation, a work plan is presented below:

- Define the end-results of the research
- Identify why this research is a contribution to knowledge in Environmental Technology
- Develop a thesis that will result in contribution(s) to knowledge.
- Develop a detailed plan.
- Update the literature review to explore the arguments for the research focus in more detail.
- Summarise important elements of the above points in a succinct and clear research summary.

The organisation of these tasks is considered in the section 4.

4. Future planning and Time-scales

4.1 Planning research for the next two and a half years

A detailed research plan must be developed over the next six months, which will help prove or disprove final research thesis(es). An initial idea of future avenues of research and possible time frames was given in the last six-month report [b: Mayers 1996; 24]. These have been refined and are presented below. A detailed plan for work over the next six months is given in the next section.

- **Year 1:** Literature review and development of research ideas

- **Year 2:** Investigation of factors affecting product management at end-of-life, and best practice in product take-back; including:
  - The scope of producer responsibility policy for electronics waste
  - Development of product recycling operations
  - Product end-of-life processes
  - Best-practice in reverse logistics

- **Year 3:** Development of management methods, which could include;
  - Strategic and tactical approaches
  - Environmental management methods (verification of standards)
  - Cost management models

- **Year 4:** Analysis of final results, time for additional research, and final write-up.

At present it will not possible to develop detailed research plans for years 3 and 4 until:

- A more detailed research thesis and end-result has been defined and agreed with project stake-holders.
- The scope of producer responsibility legislation is more clearly defined by draft EU directive (to be sometime after Easter 1998).
- Hewlett-Packard Limited has re-established its electronics recycling processes
- Results from the 3 research projects are available (even if preliminary).

It is also highly likely that there will be overlap of research in these areas. The role of Information Technology in reverse logistics (suggested in the previous six-month report) should be investigated through the reverse logistics best practice case studies and other related projects, rather than designated as an independent research project.

4.2 The next six months

MS Project 98 has been used to help manage and track research progress in detail. This is a very versatile package that can be used to manipulate time scales, view critical paths, and allocate and monitor planned time use quickly and easily. Detailed project plans under development for the three academic research projects, modules and other academic work such as completion of the two-year dissertation, and holiday (see Appendix 3). Individual project plans have been consolidated into one overall project plan, which can be used to plan daily workloads and manage time allocated to different tasks. Ceilings can be set for time allocation, and provisional time set-aside for unexpected tasks. It is expected that the best practice study will demand a large share of time, and that time scales and resources for this project will have to be negotiated with the project co-ordinator.

Objectives (and deliverables) for the next 6 months:

- Update the literature review to include new references and discussion to support research focus
  - Literature review updated by end of May.

- Complete assessments and other compulsory work well in advance of hand-in dates
  - Submit assessments within 4 weeks of attending a module
  - Submit reports for review by supervisors on an agreed date
  - Submit compulsory work least one day before the submission date.

- Publish working papers relevant to research focus in academically vetted journals.
  - Research papers prepared and ready for submission at latest four months after finish of three research projects.
  - Finalised paper on the rationale for producer responsibility submitted to an agreed journal by end of May.

- Fully defined research focus, thesis, and detailed research plan discussed submission in the two-year dissertation.
  - Draft dissertation submitted for review by supervisors (Date to be confirmed).
  - Final dissertation submitted (11th September 1998)

- To verify and investigate why products reach end-of-life in commercial and domestic sectors through social and market research.
  - Ensure full project reports are submitted to the portfolio by the end of each research project.
  - Finish commercial research project by mid-August
  - Finish domestic research project by end of September

- To complete a study of best practice in take-back logistics through selected case studies
    - Ensure full project report is submitted to the portfolio by the end of project.
    - Finish project by July or August (to be agreed)

Detailed project plans to support these objectives have been put together using Microsoft Project 98. Gantt charts have been included as evidence of this work in Appendix 3 and an overview of timeframes used for planning at present is given in Table 1.

5. Conclusions

A research thesis must be written and agreed before the two-year dissertation. This will clearly define the research focus and specify contribution to knowledge. The focus will also determine the scope of the project, which will be supported in the breadth of the literature review.

While at present a number of external factors are being investigated through in-depth review and analysis, and empirical research, future research will be more applied and may use more quantitative methods e.g. operational research models. A detailed research plan will be included in the two-year dissertation.

MS Project 98 has been used to develop detailed work plans for the next six months. During this time three research projects will be finished, an academic paper will be submitted to an appropriate journal, and work necessary for the two-year dissertation will be completed.

Glossary of terms

The terms in the following list are defined in the context of this article.

ABS:	Acrylonitrile-butadiene-styrene
Brown goods:	General term for entertainment electronics e.g. HI-FI, televisions, & video.
CFCs:	Chloro flouro carbons- responsible for the depletion of the ozone layer.
Closed loop economies:	Systems or economies based on circular flows of energy and materials.
Closed loop recycling:	Recycling of waste materials for same product applications
Cycle deficit:	A negative balance of costs and revenues in a closed loop system
Dioxins:	A group of carbon based compounds, some of which are disputed to be highly carcinogenic.
Durable goods:	US terminology. Includes construction, furniture, electronics etc.
EEE:	EU definition "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" [DG XI.E3/FE D(97)].
Electrical products:	Products relying on the supply of electricity e.g. vacuum cleaners.
Electronic products:	Products containing integrated circuitry e.g. computers.
Electronic wastes:	Abbreviated and convenient term for WEEE used in this article.
End-of-Life (EOL):	Redundant products destined for disposal. Not a clear cut stage.
End-users:	Users of a product at end-of-life.
Grey goods:	General term for IT electronics e.g. computers, photocopiers, & phones.
PCBs:	Poly-chlorinated bi-phenyls
PVC:	Poly-vinyl chloride
Recovery:	(1) Broadly applied term for recycling, reuse etc. (2) To reclaim something of potential value from a waste stream
Recyclate:	Feedstock for a recycling process (as opposed to waste for disposal)
Recycling:	The reuse of materials or even products (when used more ambiguously) reclaimed from waste or at end-of-life.
Reverse distribution:	Collection and transportation systems for end-of-life products
Reverse logistics:	The collection of End-of-Life goods for re-entry to the economic system in a manner that is economically competitive and environmentally responsible.
Reuse:	The effective re-deployment of functional components and products reclaimed from waste or at end-of-life e.g. microchips & second-hand washing machines.
Second-life:	Refers to materials or products sold and used for a second time
Take-back:	The physical activity of collecting and transporting products from end-users.
White goods:	General term for convenience electronics e.g. refrigerators & kettles.
WEEE:	Waste from Electrical and Electronic Equipment – official EU working term. European definition of waste applies to EEE (defined above) in the definition of WEEE

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b: Mayers, C.K. *12 Month Report*, 1997, Portfolio Report held at Department of Manufacturing and Engineering Systems, Brunel University.

Mayers, C.K. and C. France “Meeting the ‘Producer Responsibility’ challenge: A rationale for the future of the of the UK and European electronics industry”. *Working Paper*, 1998, Centre for Environmental Strategy, University of Surrey.

New, S. J. and P. Payne, “Research frameworks in logistics. Three models, seven dinners and a survey” in *International Journal of Physical Distribution and Logistics Management*, Vol. 25, No. 10, 1995, pp 60-70.

Appendix 1: Supervisor email updates.

Appendix 2: Research Engineer / Supervisor meeting minutes

Meeting number 5 - 29/10/97

Meeting number 6 - 12/12/97

Meeting number 7 – 17/03/98

Appendix 3: Objectives from the last 12-month report.

1. Investigate the management and capability of existing recycling schemes and reverse logistics arrangements to handle significant increases in product returns in UK IT companies
2. Scope with respect to research focus, develop methodology, pilot, and begin research on domestic end-of-life products.
3. Research approaches and methods used to manage existing processes that incorporate elements of reverse logistics through literature review and case study investigations.
4. Finish research on end-of-life products in the commercial sector, and write report on methodology and results interpretation.
5. Evaluate environmental impacts of Hewlett Packard reverse logistics arrangements for product returns and recycling to test appropriate evaluation methods.
6. Write academic and philosophical justification for research focus for the clean technology module assessment, or as an extension to the literature review.
7. Complete course on logistics management
8. Update literature review with new articles and background within the next 6 months.
9. Publish three journal articles based on the1997 EngD conference paper, an analysis of the IT sector's ability to meet the producer responsibility challenge through reverse logistics, and on commercial arrangements for end-of-life products.

Appendix 4: Project Management Gantt Charts.

Appendix 5: Electronics Industry – Social Considerations of Product End-of-Life Survey (E-SCOPE): Executive Summary

Within the next few years producer responsibility will make electronics producers responsible for their products at end-of-life. Very little is known about what happens to end-of-life electronics, and the infrastructures available for treating and recycling these wastes are underdeveloped. Although various pilot projects have been set up in the UK to investigate the feasibility of different product-take-back arrangements, many of these have been unsuccessful due to unforeseen market and sociological factors (especially for the domestic sector). Some research has been conducted into sociological and market factors affecting end-of-life electronics, but this is limited to specific product types, regions, or sectors of society.
Hewlett-Packard Limited and Intex Logistics Limited have initiated a joint market and social research project to investigate product end-of-life in different sectors of society. This research is essential for anyone involved in establishing product-take-back operations.
This proposal relates to stage 2 of this research project, and is about end-of-life electronics in the domestic sector (stage one focussed on the commercial sector – see Appendix I). Broadly the research will address 3 questions:

1. Why do people stop using their products?
2. What do people do with old equipment and why?
3. Which solutions would lead to effective waste reduction?

This will be investigated in 2 parts, using focus groups in part 1, and more detailed in-house interviews in part 2. Six potential commercial partners have been approached for inclusion in this second stage (inclusive of original project partners). Two academic researchers with a good background in closely related areas (from Portsmouth and Sheffield Hallam Universities) have also invited to participate in the project, in addition to the author of the proposal who is based at Brunel University and Hewlett-Packard Limited. A research consultant will be contracted to complete most of the survey work. Details of the involvement of each partner are given in section 4 of the proposal and in Appendix II.

The project would be managed through 4 management meetings, and 3 academic meetings (more details of project management and deliverables are given in section 5). It is expected that the project will run from February to late August 1998, and commercial partners would fund it. The cost of the project will be only £2500.00 per partner (not including the use of the company's own resources). The ideal number of contributors would be six, providing a budget of £15,000 for completion of the project (see page 14 for a breakdown of costs).

Appendix 6: Summary of the RELOOP project

Reverse Logistics Chain Optimisation in a Multi-User Trading Environment

SUMMARY

WHAT? The objective of RELOOP is to provide the solution for the **optimisation of Take-Back Logistics** (TBL) on a European scale from both an **economical and environmental** point of view. Therefore **models and a WWW-based, multi-user engineering tool** will be developed to help the businesses employed in the reycling process chain (manufacturing, collection, recycling and logistics companies) to closely co-operate and optimise costs and environmental impact of TBL. After project end all European companies can easily make use of the network tool after paying a minor subscription fee covering the administration.

The entire recycling chain will benefit in terms of increased business and reduced cost. RELOOP will

- **optimise TBL in terms of cost**. This will result in an **increase of recycling activities driven by market forces**. RELOOP will lower the financial burdon of European manufacturers connected to future product take-back and recycling and give **guidelines** to design products suitable for efficient TBL.
- **optimise location planning** within Europe for new recycling company subsidiaries, Better planning capabilities will result in an additional reduction of the total recycling cost.
- **improve the logistic chains** from the last end-user of the product to the most optimal disassembly and recycling locations, considering **trade-offs between ecological impact and cost**.

Reductions of about 10% in **environmental impacts** per ton of transported recycling products due to the RELOOP tool are expected, due to better planning and higher efficiency.

WHY? Next to legislative force the **ultimate incentive for recycling is money**, generated by an end-of-life product value reclaimed through recycling. **TBL contributes up to more than 50%** of the overall recycling cost of a product, being a **major hurdle** for cost-efficient recycling.

Circular economies will result in **extensive logistics** between locations for the entire collection, disassembly and recycling of products, modules and fractions. Therefore an optimisation is crucial in order to lower both cost and environmental impact. However, this **optimisation is extremely difficult** for European markets and varying distributions. Huge amounts of data from logistics chain options, logistics service providers, recycling companies and highly fluctuating and differing prices require **extensive updates of the database at runtime**. An easy-to-use Internet-tool using standardised sets of data and providing algorithms and models for monetary and ecological route optimisation based on alternative recycling strategies is required, linking and integrating all sources of data.

Finding the **most appropriate recycling strategies**, such as decentralised partial disassembly to reduce product volume, is practically impossible with today’s means, since no tool provides the required support for the inclusion of logistic aspects into the optimisation.

RELOOP contributes to the establishment of **circular economies** as well as to a **sustainable development** and the **protection of the environment**.

RELOOP focuses on the electronics industry since **take-back laws are expected** in that area in Germany in the year 1997. Other European nations will follow, encouraged by European environmental legislation, such as the **Environmental Management and Auditing Scheme**

WHO? RELOOP involves seven partners from six European countries. A European effort is vital due to the international markets and the fact that environmental issues may not be tackled on a regional level. The complementary character of the consortium is secured by partners from the targeted user categories electronic products manufacturer (HP (GB)), recycling (MANN (GB)) and logistics (Logic Line (F)). All three user groups will provide system requirements, know-how and data.

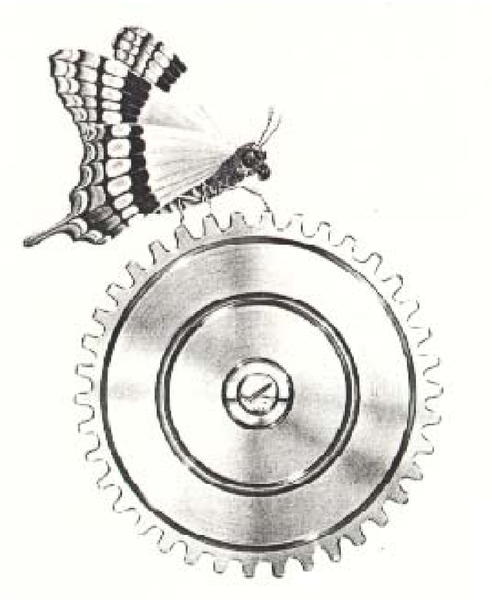
The acquired knowledge will be formalised by the R&D partners into a method (WTCM (Belgium)), a model, the required database and the specification list for the Internet-based tool (IAT (Germany)). Methods for the environmental evaluation are contributed by tme (NL), an environmental consulting company. Implementation is done by the system developer PROGIS (A), who is able to market a stand-alone version as well as the Internet tool.

To ensure European wide use of the system, all partners intend to act in the first stage as information brokers and points of contact for their region and will provide access to the RELOOP system for European industry. After project end companies from all three user categories act also as content providers.

Brunel and Surrey Engineering Doctorate Programme in Environmental Technology

Chapter 4, Vol. 2

An Investigation of the Implications and Effectiveness of Producer Responsibility for the Disposal of WEEE.



24 month report

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Abstract

European Union legislation has been drafted that will make producers of electrical and electronic goods responsible for the management of their products after they have become waste. This “Producer Responsibility” legislation is a market-based approach that aims to encourage industry to improve “voluntarily” the environmental impacts of their products and processes through redesign, reuse, and recycling.

In this dissertation it is argued that the aims of this legislation will not be easily achieved. There is very little evidence to show that the wholesale collection, recycling, and specialist treatment of end-of-life electronics will either harm or benefit the environment. It is argued that the overall environmental impacts of these processes would be better understood by adopting a life-cycle perspective e.g. by completing Life-Cycle Assessments. In addition current producer-led attempts to collect and recycle these products have been limited by poorly understood behavioral patterns of use and disposal. It is concluded that there is a lack of knowledge on the best way for producers to develop and direct their own End-of-Life Management processes to meet legislative targets.

Here, an outline End-of-Life Management (EOLM) system is proposed to assist producers in the management of their end-of-life electrical and electronic products. This system uses the concept of “reverse logistics” in which logistics approaches are applied to recycling and waste management problems. By combining logistics cost management and environmental Life-Cycle Assessment, this research aims to test and develop this system for the management of end-of-life “channels” based on best practice, market needs, and legislative opportunities and constraints. Progress to date on the development of this system and on background research is reviewed. Finally a long-term research plan is given.

Contents

Introduction

Within the next 3 to 5 years it is likely the UK *"electronics"* [1] industry will be made responsible for the collection and recovery of electronic and electrical products currently disposed of as waste. The European Union (EU) is developing a Directive including such requirements (DG XI.E3/FE D [97], WEEE-21/4/98, WEEE-27/7/98), and many countries throughout Europe, East Asia, and the Americas are already drafting and implementing national legislation. These changes are being bought about by a new approach to waste management called Producer Responsibility. Under this approach producers must collect, treat, and recycle a minimum proportion of their products as they arise as waste, either voluntarily or under legislative mandate. The EU has already implemented directives under Producer Responsibility for packaging (94/62 EC) and batteries (91/157 EEC). Discussions are also underway over the potential regulation of automobiles, tyres, construction, and healthcare wastes.

It has been estimated that around 12 million items of electrical and electronic equipment are discarded in the UK each year (DOE 1995). Estimates of the total weight of electronics waste arising in the UK vary between 0.65 and 0.9 million tonnes per year (ICER 1998 [a]). Electronics has become one of the fastest growing business sectors in the world, and is predicted to become the largest in the new millennium (Berry and Towill 1992). Consequently the quantities of waste electronics are likely to rise. The cost of meeting producer responsibility legislation will be substantial. In 1991 it was estimated that these costs would be over £100 million in the UK alone, which can be calculated as 0.4% of the total market value at that time (Roy 1991). This could significantly affect the industries' profit margins.

This two-year dissertation has been completed for the Engineering Doctorate programme in Environmental Technology. It includes a literature review and states the research focus, key questions, research aim, methodology, and long term objectives for the following two years. The dissertation has been arranged into the following sections:

1. <u>Environmental concerns over electronic wastes.</u>

   Describes the environmental impacts of electronics waste disposal and recycling, and discusses the usefulness of environmental Life-Cycle Assessment.

2. <u>Producer Responsibility.</u>

   Explains the background to the global development of Producer Responsibility policies, and discusses its implementation for waste management in the UK, and electronics waste in Europe.

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[1] For an explanation of terminology used please see Glossary

3. Patterns of use and disposal of electronics products.

   Discusses the patterns of disposal of electronics products in the UK, and summarises the results of and progress on related market and social research studies already completed or underway as part of this project.

4. Electronics End-of-Life Management process.

   Outlines existing processes and technologies used for managing electronic products at end-of-life.

5. Producer Responsibility in practice.

   Discusses examples of producer led initiatives in the management of end-of-life electronics products for different industry sectors.

6. End-of-Life Management and reverse logistics

   States the research focus, key questions, and thesis, and describes the use of logistics management techniques in managing electronic products at end-of-life.

7. Methodology, progress, and long-term research plan

   Describes a system for the management of end-of-life electronics products proposed as part of this research, outlines research methodologies to be used, reviews progress since the previous six month report (Mayers 1998 [a]), and provides long-term project objectives.

Throughout the dissertation the central concept of End-of-Life Management (EOLM) is developed. As producers of electronic equipment must arrange the collection, treatment, recycling, and disposal of their waste equipment at so-called *“end”* of product *“life”*, the expression EOLM (End-of-Life Management) is used to describe these activities. The concept of EOLM is the focus of the research, and is developed in more detail in Sections 6 and 7.

1. Environmental concerns over electronics wastes

The EU first highlighted Waste from Electrical and Electronic Equipment (WEEE) as a potential environmental problem in 1991, when it was designated as a priority waste stream alongside end-of-life vehicles, tyres, chlorinated solvents, construction wastes, and healthcare wastes (DOE 1995). The reasons given for this included (ENEA 1995):

- Future increases in the volume of electronic wastes going to landfill or incineration
- Loss of valuable materials as waste
- Harmful and hazardous materials that could be released on disposal

Estimates for total quantity of waste electronics arising in the UK vary between 0.65 - 0.9 million tonnes/yr. (ICER 1998 [a]), which can be calculated from Department of Environment waste statistics as only 1.3 - 1.7% by mass of industrial, commercial, and domestic wastes (DOE 1995). Consequently it could be argued that recycling would make little difference to the overall environmental impacts of the production and use of electronic products. Other UK waste streams could perhaps therefore be more effectively tackled by Producer Responsibility legislation e.g. the unrestricted disposal of hazardous wastes more generally from households. Some arguments have been advanced to suggest that the disposal of electronics wastes poses significant environmental problems.

- <u>CFCs:</u> CFCs can be released to the atmosphere from old refrigerators at end-of-life.

- <u>PCBs and PCPs</u> Carcinogenic PCBs and PCPs used in older electronic capacitors and transformers can contaminate waste streams in incinerators and landfill (Niemeyer and Woldt 1997. Poll 1993).

- <u>Metal contamination:</u> Evidence has been published which suggests that printed circuit boards and cathode ray tubes (in televisions & VDUs) could cause heavy metal contamination problems in waste (Voute 1994, Yang 1993).

The EU has proposed that the use of lead, mercury, cadmium, hexavalent chromium, and halogenated flame-retardants should eventually be phased out of electronic products (WEEE-27/7/98). It has also proposed that electronics wastes should be treated to remove a long list of hazardous substances before recycling or disposal. A major environmental concern over the disposal of electronics equipment is the loss of the high value, precious, and rare materials they may contain. In addition many products disposed of may still function, and so could be reused:

- <u>Reuse:</u> Many companies re-utilise or resell electronic products to second-hand markets, especially in the IT, telecommunications, and white goods sector. For example, British Telecom recovers around 2.5 million' phones for reuse each year (BT 1996).

- Resource consumption: Large quantities of non-renewable resources are consumed in the production of electronics products each year. For example it has been estimated that around 7% of plastics consumed in Western Europe are used in the production of electronic products (Wogrolly 1994) and that by the end of 1998 around 85,000 tonnes of lead will have been consumed in the production of computer monitors (Smith *et al* 1996).

- Recycling: Many of the materials used in electronic products are recyclable. For example electronic product casing is often made from metals such as aluminium or steel, or lightly coloured engineering grade plastics such as ABS, which can be valuable as recyclates.

- Precious and rare metals: Various electronic components such as printed circuit boards have parts and coatings containing valuable and precious metals e.g. gold, copper, and palladium. Some rare metals found in these components are used almost uniquely by the electronics industry, and have virtually unknown environmental effects e.g. tantalum, antimony, and gallium (BifA 1997, Legarth *et al* 1995).

The treatment and recycling of electronics wastes can therefore help to conserve resources and reduce environmental impacts of raw materials production and waste, and could be of benefit the environment. However, this should not be concluded in all cases as electronics recycling can also have significant detrimental impacts on the environment:

- Energy consumption: Metal shredders and granulators used in the recovery of metals from wastes consume large quantities of energy. It has been estimated that this could be as much as 37 kWh / tonne of waste processed (ICER 1998 [b]).

- Metals contamination: The diverse range of metals found in parts such as printed circuit boards (BIfA 1997, Legarth et al 1995), batteries, and cathode ray tubes (Metal Bulletin Monthly 1996) can become mobilised in the environment through recycling processes. Airborne metal rich dusts and fumes can “fall-out” from granulation and smelting operations onto surrounding land (*op cit* 1998). Aqueous metal-rich wastes from “wet” recycling processes could be discharged to local watercourses or sewers. Ground water can become contaminated from metals leached from semi-processed shredder material stockpiled around a site, or from “wet” recycling processes.

- Dioxins: Dioxins are a group of persistent and potentially carcinogenic organic chemicals that form when hydrocarbons and chlorine react together at temperatures below 1000^{o}C (O'Neill 1993). As these conditions are found in small smelters (Bifa 1996), shredders, and granulators (Danish Environmental Protection Agency 1997) dioxins can form from plastics (notably PVC) contained in electronics appliances during recycling.

- CFCs: It has been estimated that 75-90% of “white goods” (ICER 1998 [b]) are recycled by scrap shredders. Although ozone depleting Chloro-Fluoro Carbons (CFCs) have now been eliminated from production, older appliances may still contain these gases as a coolant or within insulation foams (Poll 1993, Niemeyer & Woldt 1997). An increasing number of refrigerators are now treated before disposal. However, it has been suggested that up to 1,100 tonnes of CFC are still released to the environment from waste refrigerators in scrap recycling operations every year in the UK (Friends of the Earth 1991 *in* Poll 1993).

- PCBs and PCPs: Carcinogenic and highly toxic PCBs and PCPs in capacitors found in older appliances can contaminate the “dirt” fraction of shredder residues. As PCBs have been restricted and phased out of production since the late eighties, the extent of contamination in shredder residues has fallen from around 44 mg/kg in the late eighties to 16 mg/kg in the early nineties (Poll 1993).

- Transport: The fuel consumed and pollution caused by collection and transportation of equipment could outweigh the benefits of treatment and recovery, especially for smaller electronics products (such as kettles and irons). This is due to the need for collecting sufficient bulk of material for recycling.

- Trans-frontier shipment of wastes: Export of second-hand products to countries without equivalent restrictions on the sale and disposal of electronic equipment may simply transfer waste management problems.

Electronics recycling operations present significant potential for environmental degradation. Consequently many industry bodies have proposed electronics recycling standards (The Nordic Office and IT Organisations 1998, CYCLE 1995, ICER 1997). The proposed EU directive includes obligations both on recyclers and waste processors. However, these standards will not guarantee that electronics recycling is of net environmental benefit i.e. from a “life-cycle” perspective.

Unlike Life-Cycle Assessment methodology, Producer Responsibility is not intended to address the full life cycle of a product (from extraction and generation to final use, recovery, and disposal - “cradle-to-grave”) as it largely excludes manufacturing and use stages. The EU has proposed other market approaches and broad-based regulations to address these areas of concern, such as voluntary eco-label schemes e.g. as proposed for Personal Computers (Atlantic Consulting 1997), and an Integrated Pollution Prevention and Control Directive (91/61/EC) for manufacturing operations. The effectiveness and overall integration of these disparate policy initiatives is an important area of concern, but is not covered further in the scope of this dissertation. The adoption of a life-cycle perspective and the use of Life-Cycle Assessment in the management of electronics waste would allow different product design (an important element of Producer Responsibility legislation) and waste management options (including incineration and landfill) to be compared and considered together. This would ensure that the best environmental options are identified and efficient recycling schemes established, as Graedel and Allenby (1995) have observed,*“The efficiency with which cyclization [recycling] occurs is highly dependent on the design of products and processes”*.

Life-Cycle Assessments (focusing on the environmental impacts of raw materials production and waste processing of end-of-life electronic products, but largely excluding use and manufacturing) have been used to compare different waste management options. For example studies have been conducted on the take-back of mobile phones as part of a scheme in the UK and Sweden, covering energy use (McClaren et al 1997), and on plastic computer housing from IBM products in the USA (Brinkley 1994). These studies reinforced the orthodox view of the hierarchy of waste management i.e. that in descending order, reuse, recycling, and incineration with energy recovery are preferable to disposal in landfill. Although these studies provide interesting conclusions, they are only relevant to the specific electronic products and recycling systems under study. If it is to be generalised that the recycling of electronics waste is environmentally beneficial, this should be justified on the basis of more comprehensive environmental assessments. However, given the diversity of electronic products, and product design and process changes that may come about under Producer Responsibility (see section 2), such full-scale assessments may be impractical. This is due to the overwhelming number of variables to consider e.g. products types and product brands, scale of operation, collection methods, recycling processes, and country of operation. Life-cycle methodologies should be adapted and refined for use in the management and assessment of individual products and take-back processes. Legislation should support this approach by ensuring that End-of-Life Management processes meet acceptable government standards on a case-by-case basis.

Section 1 conclusions

In this section, it has been argued that Producer Responsibility legislation must ensure that recycling does not occur *"at any cost"* as this could be wasteful and counter-productive both economically and environmentally, a form of *"profligate environmentalism"* (Clift & Longley 1996). Ultimately, producers must be able to manage the environmental impacts (as well as cost) of their own product recycling operations. Life-cycle methodologies need to be refined and developed to focus on the determination and accurate assessment of overall environmental impacts of different end-of-life treatment, recycling, and disposal options. In the next section the development of Producer Responsibility for electronics waste is discussed.

2. Producer Responsibility

2.1 Producer Responsibility

Governments across the world have recognised the need to reduce levels of resource consumption and waste, and to make polluters pay for the pollution they cause. This has lead to the development of Producer Responsibility.

In 1992 two highly significant agreements were reached at the Rio “Earth Summit”, the Rio Declaration and Agenda 21 (Grubb et al 1993, UNCED 1993). These agreements endorsed the principle of sustainable development, i.e. development in a manner that ensures that the needs of people today are met without compromising the ability of future generations to meet their own needs (WECD 1987). Although many of the original targets have not been met, they are both global statements of intent, and have been the impetus behind waste management initiatives in many countries. For example targets were set in Canada's packaging stewardship protocol to meet Agenda 21 waste management objectives to (Resources Report 1997 [a], Grub et al 1993):

- Implement waste minimisation policies addressing specific waste problems
- Strengthen national recycling programmes by the year 2000.

The UK 1995 Sustainable Waste Management Strategy was also written in response to commitments made at the Earth Summit (DOE 1995).

Agenda 21 also supports the adoption of market based policy instruments complementarily to environmental legislation. It sets the following objective for the development of national policies:

> *“To incorporate environmental costs in the decisions of producers and consumers, to reverse the tendency to treat the environment as a ‘free good’ and to pass these costs on to other parts of society, other countries, or to future generations.”*
>
> UNCED 1993: 93

By internalising the external costs of environmental degradation to the costs of products and services, it is argued that consumers could be encouraged to adopt purchasing habits “better” for the environment and society (Jacobs 1991, Pearce 1992, Cairncross 1991). Hence it is argued that market mechanisms could be used to encourage more sustainable patterns of production and consumption. An example of one such market-based approach is the use of tradable air pollution permits in the US to control and reduce point source air emissions (Rees 1992).

Producer Responsibility is a market based policy instrument, and has been described as a direct application of the Polluter Pays Principle (OECD 1975) to waste management (COM (96) 399 final, DOE 1995). It has been assumed that the internalisation of waste management costs to the costs of production would give producers economic incentives to reduce waste by redesigning products, and establishing End-of-Life Management schemes (see Sections 4 and 5). It has been argued that this should lead to socially desirable and environmentally acceptable levels of resource consumption and waste. However, market based instruments must be developed and applied with due respect to the complexity and very specific details of the market conditions they aim to change (Pearce and Turner 1993)

Failure to consider electronics waste disposal and recycling from a life-cycle perspective could mean that price mechanisms might ignore important environmental impacts. Additionally, if pricing mechanisms are not adequately enforced or integrated into the market, they could be disregarded or result in little overall environmental benefit. Packaging is already subject to Producer Responsibility. There are fears that the UK packaging industry's system of "tradable permits" or "Producer Responsibility Notes" (PRNs) developed under this legislation will result in an overpricing of recycling services by the recycling industry, and very little increase in the volume of packaging recycled (ENDS 1998).

2.2 The development and adoption of Producer Responsibility

In the early nineties Germany, Canada, Korea, and Japan became the first countries to develop Producer Responsibility schemes. With the exception of Korea where home electronics, lubricating oils, batteries, tyres, plastics, and packaging were included, these early programmes only covered waste packaging (Sprenger 1997, Kursaka 1996, Resources Report 1997 [a] & [b]). These national initiatives came about due to concerns over shortages of landfill sites, and the perceived need to conserve resources and protect the environment (Kursaka 1996, Livingstone and Sparks 1994). This was followed by wider global adoption of Producer Responsibility across Europe, East Asia, and the Americas.

Producer Responsibility has been extended to cover an increasing array of product categories. Like Korea both Japan[2] and Germany[3] have introduced Producer Responsibility legislation that will eventually cover all waste streams through more specific future regulations. The OECD are to publish a manual in 1999 containing recommendations for governments implementing such broad-ranging Producer Responsibility legislation (AEA 1997).

The electronics industry response to Producer Responsibility has been cautious, advocating "shared responsibility" for electronics waste amongst manufacturers, distributors, retailers and consumers (Cramer and Stevels 1996, ORGALIME 1998). In the 1996 EC waste management strategy (COM [96] 399 final), the European Union parliament clearly defined the scope of producer responsibility:

> *"Considering the life cycle of a product from manufacture until the end of its useful life, producers, material suppliers, trade, consumers and public authorities share specific waste management responsibilities. However it is the product manufacturer who has a*

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[2] Through the Recycling Law in 1991 and the Environment Basic Act in 1993 (Kursaka 1996)

[3] Through the Recycling and Waste Management Act - Kreislaut Wirtschaus-und Abtalgesetz - in 1996 (Sprenger 1997)

> *predominant role since he takes key decisions concerning his product which largely determine its waste management potential."*
>
> CEC COM (96) 399 final: 1b

2.2.1 Producer Responsibility in the UK

In the past the UK government has given priority to voluntary Producer Responsibility initiatives (DOE 1995). However, prescriptive regulations may be implemented in support of Producer Responsibility under Section 93 of the 1995 Environment Act. In developing an electronics-recycling programme in the UK, approaches to be adopted elsewhere should be examined. Special note needs to be taken of European efforts that may influence the EU. It is less likely that approaches used for other waste streams in the UK will be adopted either because they are not appropriate for the management of electronics wastes, or not yet fully developed.

In the UK packaging regulations (SI 1997/648) manufacturers, distributors, and retailers have all been assigned individual recovery obligations irrespective of their role in the supply chain. Arguably such an approach would be impractical for electronics waste, as they are not as ubiquitous or easy to reclaim as packaging wastes. Targets set for newspaper and magazine recycling have been met voluntarily by the newspaper industry through investment into new paper recycling plants, such as the Aylesford Newsprint plant (DOE 1995). In comparison, proposals for a voluntary battery-recycling scheme are still to be put into effect to comply with the EU battery directive (91/156/EEC (b), S.I. 1994/232). The development of producer responsibility schemes for WEEE and automobiles are still under discussion.

2.2.2 The management of electronics waste in Europe

The EU abandoned the Priority Waste Streams programme (discussed in Section 1) in June 1996 after discussion groups (including industry and governments) failed to make sufficient recommendations to the European Commission (WRF 1996). Electronics waste has remained an important issue as various countries have proposed their own national Producer Responsibility programmes. Different approaches have been adopted or are under development in each country (AEA 1997, Welkner 1996). For example, there has been little agreement over the most appropriate classification of electronic or electrical waste. Italy's Waste Management Decree covers refrigerators, televisions, computers, washing machines, and air conditioning units. In comparison Sweden's Eco-cycle proposal includes "all" electronics wastes. Germany's draft Ordinance only applies to IT equipment. The EU proposed definition for electronic and electrical equipment (EEE) itself is very broad[4]:

> *"…equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for*

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[4] In the definition of WEEE, normal legal definitions of waste would apply, that *"waste shall mean any substance or object...which the holder discards or intends or is required to discard"* (75/442/EEC).

> *the generation, transfer and measurement of such currents and fields …and designed for use with a voltage rating not exceeding 1000 Volt for alternating current and 1500 Volt for direct current."*
>
> WEEE - 27/7/98

Differences between national programmes may be partially resolved through the harmonisation of standards by the planned EU directive.

The literature appears generally scant of detailed discussions on the specific role of Producer Responsibility in the management of electronics waste. In the few articles available, authors have focused on the roles of different stakeholders, such as the need for the European Union to harmonise standards between member states (Welker *et al* 1996) and the importance of industry consortia in electronics recycling (Rodgers 1995). Others have discussed the merits of different approaches, such as the need for "shared responsibility" (Cramer and Stevels 1996), the importance of increased product durability in the reduction of waste (Cooper 1994), and the need for open negotiation between government and industry in the reconciliation of their perspectives (ECTEL 1997).

Various existing Producer Responsibility schemes adopted or proposed for WEEE within Europe have been reviewed through the available literature (AEA 1997, Product Stewardship Advisor 2. 4-6, 5: 1997, Welker *et al* 1996)[5]. Five fundamental differences were identified:

1. Stage of development: Different countries are at different stages of setting up national electronics waste recovery schemes and a wide range of voluntary, mandatory, and combined approaches have been proposed (see Fig. 1). For example Italy was the first European country to implement binding legislation in September 1996, requiring producers to set up collection and recycling schemes within three years or face surcharges of 10% on the price of new products. At present a collection scheme for refrigerators has been developed using 12 national recovery centres. This is expected eventually to be self-funding and will extend to other product types (Product Stewardship Advisor 1, 5: 1997). In Switzerland a voluntary electronics-recycling programme has been in operation since 1994 (although supporting legislation was implemented in June 1998). Unusually products are collected via mainline train stations for subsequent recycling by manufacturers (Wäger *et al* 1997).

   It is planned that the EU working paper on WEEE will be finalised and put before the European Parliament during 1999. It is therefore unlikely that some member states will have implemented binding legislation until after the new millennium, despite actions by others enforcing shorter time frames. This will give industry time to respond voluntarily to the challenge of Producer Responsibility in countries with less advanced proposals or "wait-and-see" approaches, such as in the UK.

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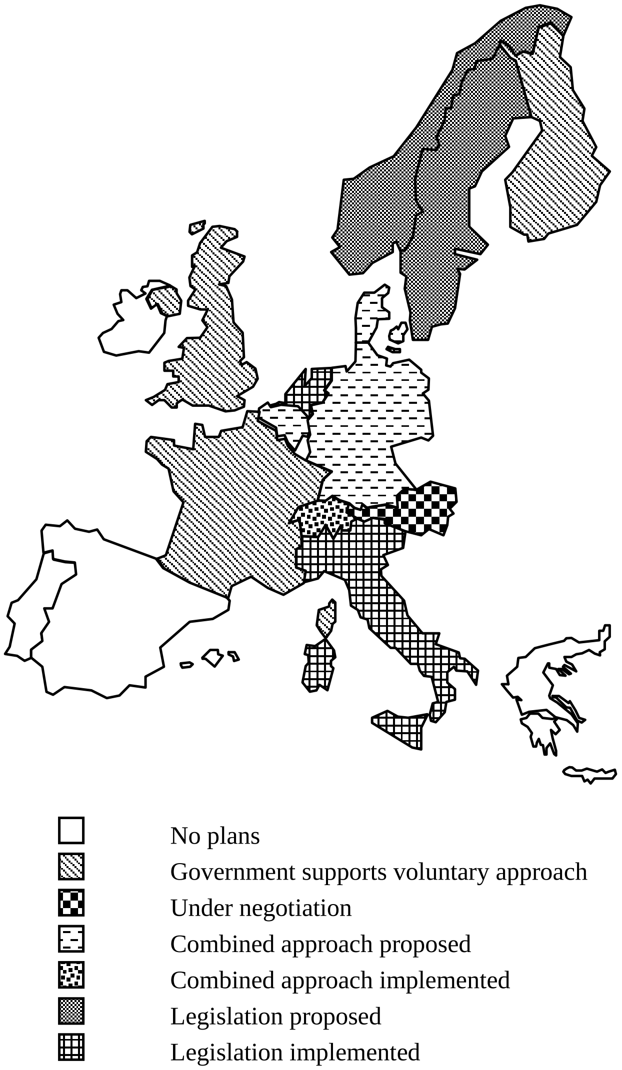
[5] Up to date (1997) information ascertained from Hewlett-Packard international sources.

Figure 1: The implementation of Producer Responsibility for WEEE in Europe



2. Collection methods: There appears to be three main approaches suggested for the collection of electronic products from end-users in European countries:

    - Municipal authorities establish collection systems at least partially integrated into existing domestic waste management and recycling schemes.
    - Retailers take-back old products from customers on the sale of new.
    - Industry establishes collection systems or take-back products directly as part of commercial agreements e.g. leasing or product trade-in arrangements.

    It appears that the majority of countries have allocated responsibility for collection on a combination of retailers and municipal authorities e.g. Denmark, the Netherlands, Norway, and Sweden. In some countries co-operative cross-industry schemes have been established to avoid increased costs of setting up duplicate collection systems for different products or brands e.g. ICT in the Netherlands, SWICO in Switzerland, CYCLE in Germany, and SITO in Sweden (AEA 1997).

As Producer Responsibility is a market-based approach, legislation should be relatively flexible over the development of specific collection methods

3. Allocations of responsbility: Given the variety of country specific proposals in Europe and in consideration of the EU proposals to date it is apparent that responsibility could be placed at three different levels:

   - *Financial responsibility*: e.g. the responsibility of paying for recycling costs is likely to fall on individual companies.

   - *Management responsibility:* e.g. industry consortia may manage recycling schemes on behalf of industry.

   - *Operational responsibility:* e.g. industry consortia may subcontract the operational responsibility of recycling to a recycling company.

   Most proposals within Europe to date have distributed responsibility by having:

   - Consumers take responsibility for segregation of wastes and delivery to collection systems
   - Retailers collect old products on the sale of new
   - Producers redesign products and services, and establish collection and recycling schemes.

4. Funding mechanisms: Three mechanisms for financing the collection and recovery of electronics waste from end-users have been proposed either separately or in combination (ICER 1996):

   - Fee administered to end-users disposing of electronics waste.
   - Cost included in product price (either directly or through a levy), and charged to customers on purchase of new products.
   - Local taxes charged to the general public.

   For example, Germany has proposed a combined approach with a fee to end-users to fund municipal collections, and increased product prices to fund industry recovery schemes. In Sweden's Eco-cycle proposal local authorities may recover their collection costs through charges to industry. Inclusion of collection and recovery costs in product price appears to be the best option as it would be equitable, and could provide the competitive price signals required to encourage appropriate design changes and efficient collection, treatment, and recycling systems to be established, which fits within the ethos of Producer Responsibility. However, the inclusion of costs for old products i.e. those sold before the implementation of a directive, as proposed currently by the EU

(WEEE-27/7/98) or other similar retrospective approaches requiring payment of collection and recovery costs at product end-of-life could distort price signals.

If legislation is to be retroactive and include older products sold before implementation, financial obligations for collecting and recycling these products should be met through other means e.g. such as a local waste tax as has been proposed in Germany.

5. Product recovery targets: The proposed European directive will do much to standardise product categories and targets. Collection targets of 4 kg per person per year on average (WEEE-27/7/98), and separate recycling targets ranging from 70% to 90% by weight are presently being negotiated by the European Commission. The Commission has proposed these targets to ensure that consistent and equivalent regulation is enforced across member states. However, much work has still to be done on developing EU targets if they are to be achievable, and make Producer Responsibility work in practice.

2.2.3 The development of a Product-Take-Back system in the UK

The development of a consolidated industry position and Product-Take-Back (PTB) system in the UK is dependent both on the industry becoming more proactive, and on the government developing an appropriate environment and providing the necessary impetus for change. It is unlikely that any voluntary initiative developed by industry will work well without a supporting legislative framework (to prevent less scrupulous companies from avoiding their responsibilities). The government must ensure that the remit of such legislation is twofold, that *well-defined price mechanisms* support the appropriate level of *environmental improvement*.

The electronics industry is clearly in an advantageous position to negotiate and even propose a product take-back system within the UK. The fundamental elements that must be decided in the development of a PTB system have been proposed in Table 1 along with the range of possible industry positions, and a proposed “best” position. Although the EU will specify certain elements within this, the development of an agreed UK PTB system model would provide a stronger basis for Member State representation and negotiation within Europe. A detailed analysis of Producer Responsibility for electronics waste in the UK has already been completed as part of this research (Mayers *et al* 1997 [c], Mayers & France 1998).

Section 2 conclusions

The development of effective and highly specific framework legislation will be critical to the success of future electronics recycling programmes. What is needed, and is indeed missing from the academic literature, is in-depth critique of the different practical methods and approaches currently proposed for this waste stream. Given the opportunity for the formation of voluntary solutions in the UK, the need to reconcile government and industry perspectives and agree areas of responsibility is fundamentally important. Critical academic review would provide a useful and objective evaluation of the best way forward for legislation and the development of future electronics waste recycling schemes. Such an evaluation has been already completed as part of this research project (Mayers *et al* 1997 [c], Mayers and France 1998). In the following three sections current patterns of use and disposal of electronic products, existing electronics recycling and disposal operations, and producer lead "take-back" processes are examined to determine how future waste-management operations may develop under Producer Responsibility and the need for further research.

Table 1: Fundamental Product-Take-Back system elements and industry positions

PTB system element	Range of possibilities	Proposed position
1. Environmental management	- Environmental standards - Environmental assessments	Life-Cycle Assessment to qualify best environmental options on a "case-by-case" basis.
2. Operational target date (s)	- Implementation prior to directive - Implementation subsequent to directive	Phased implementation prior to directive.
3. Implementation	- Mandatory - Voluntary - Combined	Combined mandatory and voluntary system to ensure cross-industry compliance and flexibility.
4. Goals and objectives	- Product classification - Design targets - Collection and recycling targets - Treatment standards	Further clarification needed, should be consistent across EU to avoid trade barriers and market distortions.
5. Funding mechanisms	- Charge to end-user - Local authority tax - Inclusion in product price	Non-retrospective inclusion in product pricing (levy or variable). Must be carefully designed to result in appropriate levels of environmental improvement.
6. Financial responsibility	- Collection - Processing & transport	Producer financially and ultimately responsible for transport and processing. Responsibility for collection shared amongst distributors, local authorities, and customers.
7. Management & operational responsibility	- Collection - Processing & transport	Flexible to allow industry based solutions to develop and evolve over time.
8. Collaborative structure	- Brand only - Market-segment - Industry wide	Flexible to allow individual companies to employ combinations of brand only, market segment, and industry wide solutions e.g. for different products.
9. Collection methods	- Retailer return - Local authority - Manufacturer - Other	Flexible for all parties and end-user friendly.

Source: Mayers & France (1998: 17)

3. Patterns of use and disposal of electronic products

"Electrical and Electronics waste" is a very broad categorisation. Unlike other waste stream categories such as packaging and automobiles it contains many different products with entirely different dimensions, constructs, and functions. It has been estimated that 46% by weight of electronics waste is made up of domestic appliances (such as refrigerators, washing machines, irons, and vacuum cleaners) or "white goods", and 45% by weight of data processing or communications technology or "grey goods". "Brown goods" include home entertainment products (such as televisions, HI-FI, and video) and make up only 6% of the estimated total waste stream. A more detailed breakdown has been provided in Fig. 2. These estimates are based on market volumes and average product life expectancies. Therefore they do not necessarily reflect the actual quantities of electronic appliances entering general waste streams for landfill or incineration.

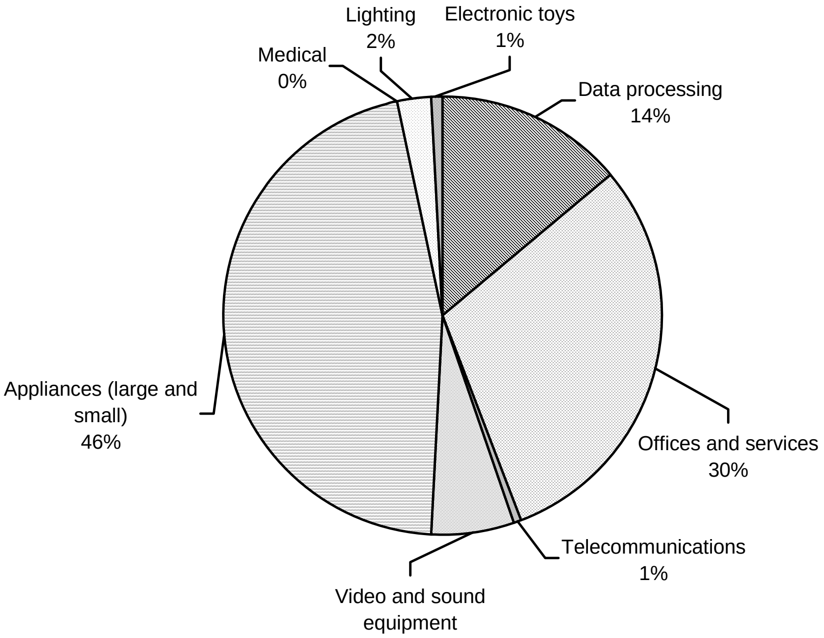


Figure 2: Electronic and electrical waste arising in the UK (percentage by weight)

ICER 1998 (a)

It has been estimated that approximately 75-90% of "white goods", 8% of "grey goods", and 6% of "brown goods" are presently recycled (ICER 1998, Poll 1993). It has been assumed that most other electronics wastes are either incinerated or sent to landfill, with only a small fraction being recycled (DOE 1995). In the United States it has also been suggested that up to 75% of electronic products are held in storage e.g.

in warehouses or homes before final disposal (Pitts 1996). The same could be applied to Europe. For example a recent survey on take-back of mobile phones in Sweden and the UK (see information on the ECTEL scheme below) showed that 55% and 47% of people (respectively) retained their old mobile phones after they had finished using them (ECTEL 1997).

Various organisations have developed pilot electronics recycling schemes in preparation for producer responsibility legislation in the UK. The results of these have been poor, rarely recovering above 1% of total estimated waste streams, which compares poorly to proposed European Union collection targets which can be calculated from a target of 4 kg / yr /inhabitant (WEEE-27/7/98) at about 25% to 35% by weight. These projects are summarised in Table 2 below.

Table 2: Electronics recycling pilots in the UK

Scheme	**Location**	**Project duration and date**	**Products collected**	**Coverage**	**Quantity recovered (tonnes)**	**% of waste arising**	**References**
ECTEL (European Telecommunications and Professional Electronics Industry)	UK and Sweden	6 months (1997)	Mobile phones	110 retail outlets in the UK	5633(UK) 879 (Sweden)	<1%	ECTEL 1997
EMERG (the Electronic Manufacturers Recycling Group)	Lothian region and Edinburgh	15 months (1996)	Mainly IT and office equipment. Some domestic appliances.	128 workplaces, 5 civic amenity sites	107	<1%†	LEEP 1996
ICER (the Industry Council for Electronic Recycling)	West Sussex and Croydon	19 months (1995 to 1997)	Mainly domestic appliances.	Civic amenity sites, and doorstep collections using grey bags.	27	Approximately 2%†	Information provided by ICER 1998.
SWAP (Save Waste and Prosper)	Leeds, Bradford, and the Humber	6 months (1998)	Information technology	Larger organisations and companies	17	Un-known	SWAP 1998 (a)

†Assuming 9.25 kg electronics waste per person per year. Assuming 0.75 million tonnes total waste per year, 70% from domestic sector - 48% domestic appliances & assumed 50% data / office products arising in the home (ICER 1998). Total population of Great Britain 56.75 million (Regional Trends 1996).

For both domestic and commercial sectors, very little information is available on end-of-life equipment in terms of the quantities or distribution, existing end-of-life pathways, current trends, or on social or market acceptance of proposed product take back arrangements. Across Europe, various organisations have recognised the need to increase their understanding of these social and market factors, and have completed related research projects. These studies have revealed that people typically “dispose” of their end-of-life products in a variety of different ways (as shown in Table 3).

Table 3: End-of-life pathways of electronic products in households and businesses

Household end-of-life options	Business end-of-life options
(a) Sell privately second-hand (b) Give to family and friends (c) Store within the home (d) Return to retailers and manufacturers (e) Take to local authority civic amenity sites as "scrap" for recycling (f) Dispose of as waste	(g) Transfer or sell to employees (h) Dispose of as waste (i) Donate to public institutions, charities, and schools (j) Sell to second-hand brokers (k) Return to manufacturers or distributors (l) Dispose of as waste (m) Store in offices or warehouse
Sources: ECTEL 1997, VROM Miniserie 1993 in Voute 1994. Information on commercial research also provided by Domestic and General, Comet, and ICER 1998[6]	Sources: The Corporation of London 1996. SWAP 1998 (b). Information on commercial research also provided by Hewlett-Packard GmbH 1997[7]

It appears that although these research projects are useful, they are clearly limited for the purposes of establishing product-take-back operations in the UK. They are either conducted overseas (where only limited inferences should be made in absence of well-qualified data for the UK), or restricted to particular product categories, sectors of society, or product-take-back operations.

There is very little other research on electronic waste disposal in the academic literature. Market and social research has focussed on attitudinal, motivational, and behavioural aspects of public involvement in general domestic recycling schemes. This has been largely to understand how recycling schemes can be designed and developed to encourage greater participation (Schultz *et al* 1995, Thørgesen 1996). In comparison there is very little research on arisings of waste and recycling in the commercial sector all together.

> *"...Although there are many anecdotal reports about recycling efforts in the commercial sector, no systematic empirical studies have described and evaluated this important domain of recycling activity."*
>
> Oskamp et al 1994: 478-479

A study of the patterns of use and disposal of Information Technology (IT) equipment by UK companies (employing 500 or more people) has already been completed as part of this research project. 132 responses were received (a response rate of 26%) covering an estimated 3% of "business to business" IT markets, and a broad range of industry sectors. 86% of respondents claimed to have responsibility for redundant IT equipment within their companies, the remainder being the people most "knowledgeable" on the subject available.

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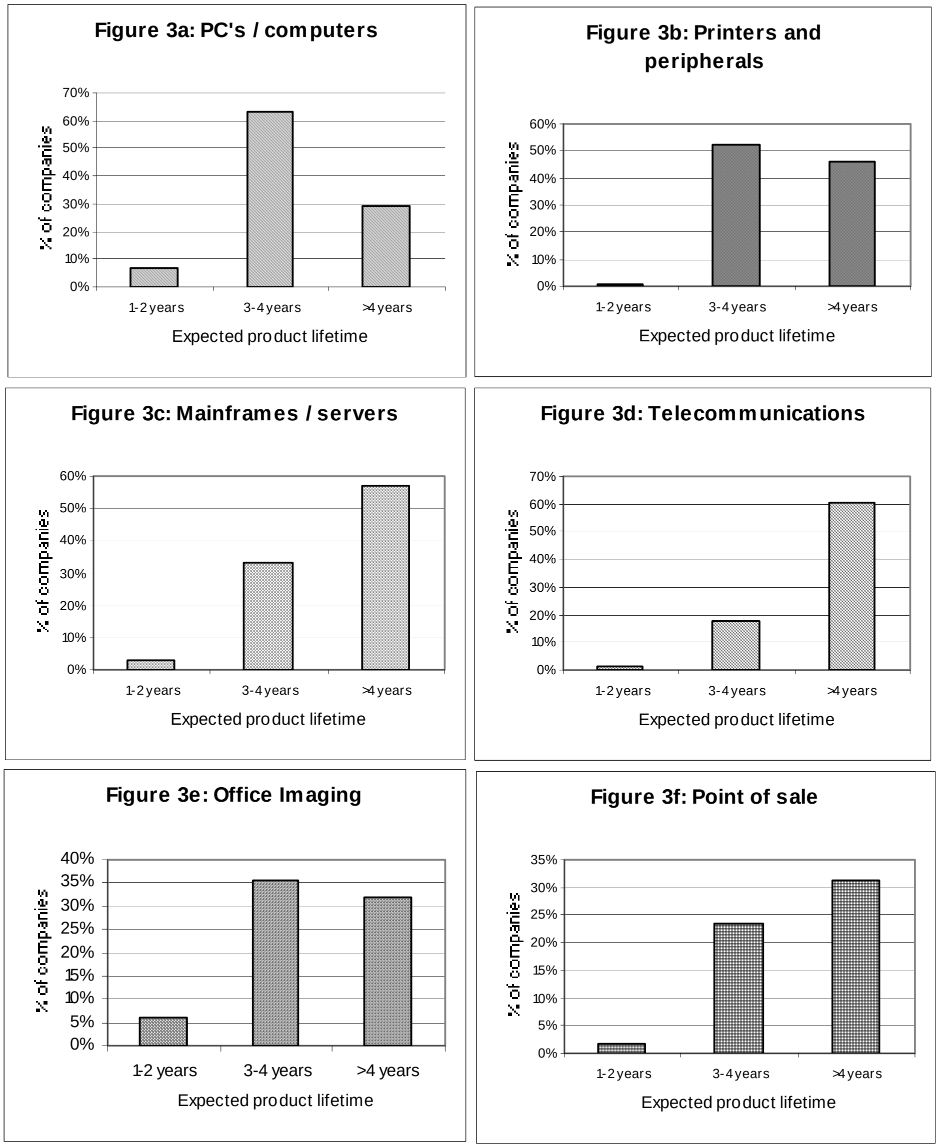
[6] Source, commercial research completed by Domestic and General Group PLC, Comet Group PLC, and ICER, 1998

[7] Source, commercial research completed by Hewlett-Packard Limited GmbH, 1996 (Confidential).

Figures 3a to 3f: Product life time of IT equipment in UK companies



Results revealed that despite continuing trends to shorter product technology development and obsolescence cycles an average of 97% of companies used their IT equipment[8] for more than two years (see Figs 3a to 3f). Depending on product type, 20% to 40% of companies were not loyal to any particular brand. With regards to product end-of-life it was found that technology, software, and system upgrades were the main causes of product obsolescence, rather than problems supporting or maintaining existing products (see Fig. 4). Further insights into the disposal of equipment by companies were gained. While 72% of companies disposed of their redundant IT equipment as ‘waste’ i.e. with no economic recovery, 84% also transferred equipment to staff, 71% donated equipment to charity, and 68% sold equipment through brokers (see Fig. 5). Therefore much of

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[8] Including PCs and computers, printers and peripherals, mainframes and servers, telecommunications, point-of-sale, and office imaging equipment.

the redundant IT equipment arising from the commercial sector is passed on for subsequent use in homes, companies, schools, and public institutions via employees, charities, and brokers.

Figure 4: Reasons for "end-of-life"

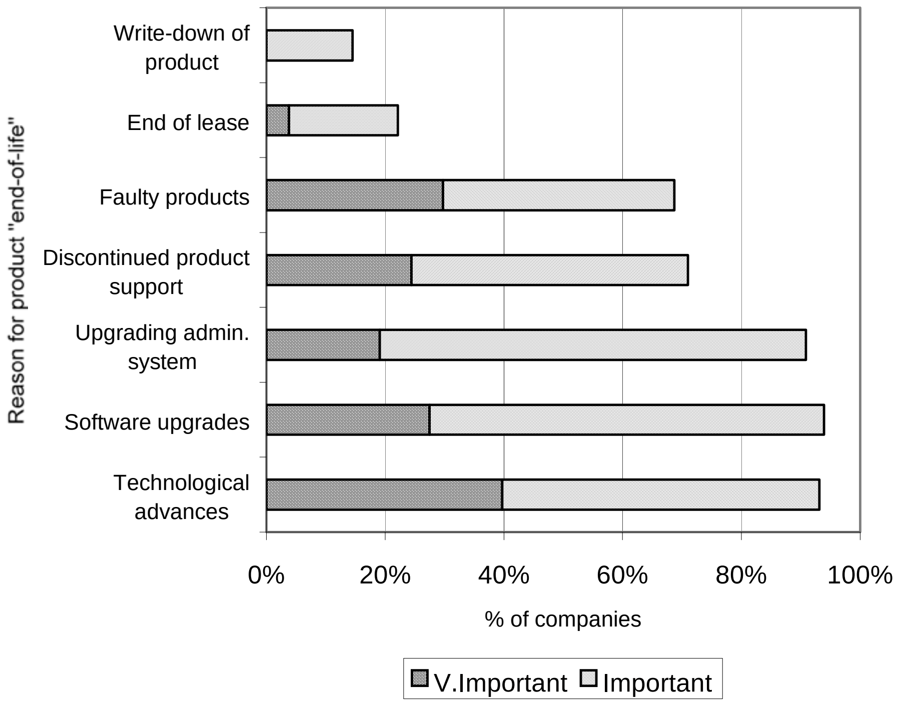
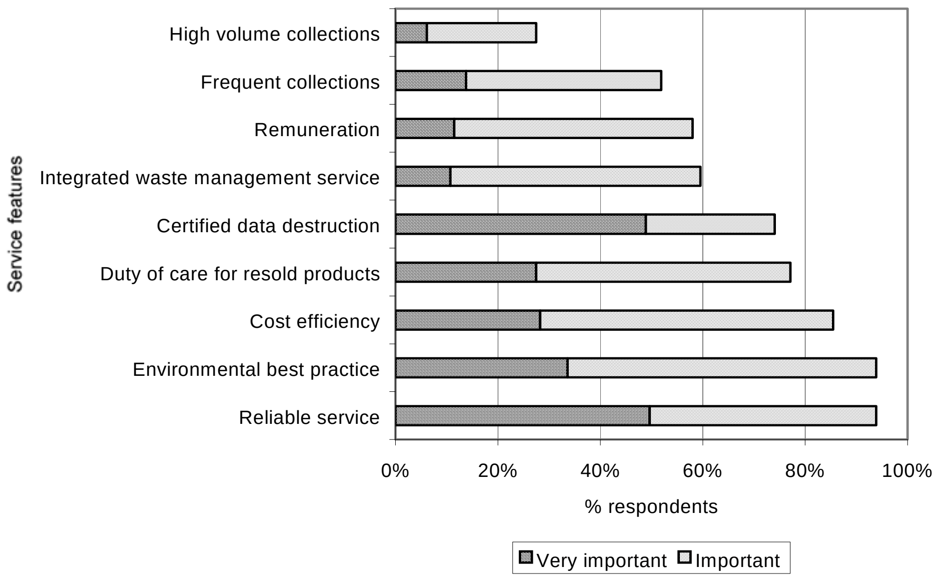


Figure 5: Services used for the disposal of redundant IT products

77% of respondents saw a need for better developed services to manage their redundant IT equipment. Results showed that the important features of future end-of-life services included reliability, cost efficiency, and duty of care for resold products (see Fig. 6). Although 93% of respondents stated that environmental best practice was an important service element, this should be interpreted with caution as results also showed that 80% of companies were potentially breaching UK waste management legislation, and that only 8% had environmental policies on the management of redundant IT equipment. Other success factors that could be used as service differentiators included certified data destruction (used only by 23% of companies, but perceived as an important by 73% of respondents); brand name support for second hand sale of products; acceptance of all brands of returned products (due to the extent of brand mixing within companies); and provision of national collection services.

Figure 6: Perceived important features of a recycling / resuse service



More details of the results of this research are presented in a paper submitted to the 1998 EngD Conference (Mayers *et al* 1998 [b]). Based on these findings this paper argued that the term ‘end-of-life’ is an inappropriate description for redundant IT equipment from the commercial sector. Most of this equipment retains considerable utility that is passed on to subsequent users. It concluded that IT producers may miss significant business opportunities if they exclude the management of redundant equipment from their overall service offerings. Such services could meet the requirements of European legislation (as reuse is considered a legitimate form of recycling), capitalise on growing second-user markets, and add value to existing products and product-related services. Examples of these services include product trade-in, leasing, and take-back. More fundamentally, it was suggested that a shift away from understanding commercial customers as purely consumers of product technology could aid the development of more enduring service-oriented relationships.

A larger project known officially as the E-SCOPE (Electronics Industry - Social Considerations of Product End-of-life) survey was also started as part of this research in January 1998. This will involve a survey of 500 to 750 homes in selected areas of the UK using in-home interviews, and up to 7 follow-up focus groups. Progress to date is described further in Section 7.2.2.

Section 3 conclusions

Various social and market researches have demonstrated how the disposal of electronics appliances can be complicated by “behavioural” factors such as storage, second-hand sale, repair and upgrade, and recovery for scrap metal recycling. In addition the recycling schemes proposed under Producer Responsibility differ substantially from conventionally run municipal recycling schemes. For example they may involve collection of products by retailers, through second-hand stores, or even train stations as in Switzerland (Wäger *et al* 1997). Therefore, the use and disposal of electronic products in commercial and domestic sectors has been and is currently being investigated through market and social research studies as part of this project. In the next section an outline of existing electronics end-of-life processing methods and technologies is given.

4. Electronics End-of-Life Management processes

The collection, treatment, recycling, and disposal of electronic products (which contain a wide variety of subassemblies, components, and materials) is a labour intensive and complex process. From a pilot recycling study conducted in the UK, it can be estimated that collection costs range from around 50% to 75% of total recycling costs (LEEP 1996). In addition materials recycling technologies often require significant investment in process development and acquisition of capital resources. These processes must be understood if end-of-life electronics products are to be managed effectively by producers. Within the UK there are around 30 end-of-life "processors" who claim to accept electronics wastes for reuse or recycling, treatment, and disposal (ICER 1998 [c]). An outline of these recycling and disposal processes is given below. This is based on a basic review of particular examples of different End-of-Life Management operations in the UK, Europe, and the USA[9].

Plate 1: "Stillages" used for transporting end-of-life computer monitors

C.K.Mayers: Hewlett-Packard Recycling Centre, Sindelfingen (Germany)

4.1 Sorting of inbound goods

Inbound equipment is typically bought into a warehousing area or holding yard on wooden pallets or reusable steel or wooden "stillages" (see Plate 1). Equipment is then logged onto inventory (sometimes onto computer and using bar code or

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[9] Through basic telephone survey (see example in Appendix 1), review of company brochures, 13 site visits, and Internet based information.

microdot tracking systems), or weighed depending on whether it will be recycled or resold. This is then sorted and passed on either directly for refurbishment and resale, manual disassembly, or for bulk materials recovery.

4.2 Refurbishment

Old equipment and parts may be tested and repaired for reuse (see Plate 2). Before resale products may be upgraded, cosmetically enhanced (by cleaning and even re-casing), and even re-branded. Data and operating systems are erased where necessary, sometimes to certified standards. Finally products may be sold to brokers or specialist distributors, who sell refurbished products and parts into second-hand markets.

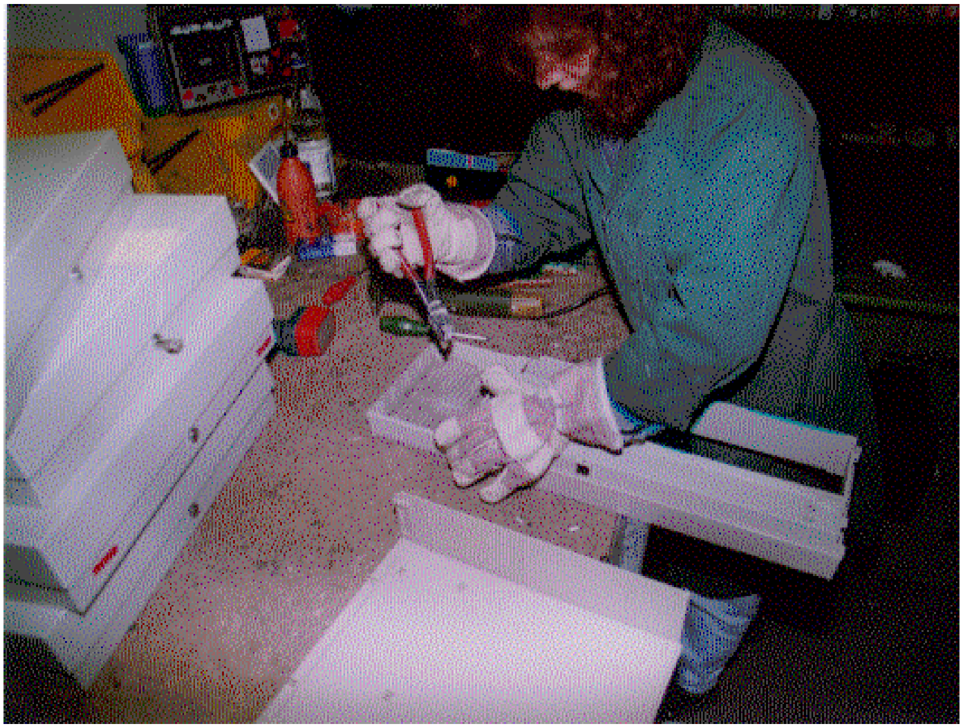
Plate 2: Typical used-product testing area

C.K.Mayers: Siemens Nixdorf Recycling Centre, Paderbourne (Germany)

4.3 Dismantling

Once sorted, electronic equipment may be dismantled to recover working components for resale, material fractions for recycling (mainly metals and plastics), and parts containing hazardous materials for treatment (such as batteries, cathode ray tubes, mercury switches, and capacitors). Dismantling can be completed rapidly by experienced operators using common tools such as drills, manual and automatic screwdrivers, hammers, and pliers (see Plate 3).

Plate 3: Worker at manual disassembly station.



C.K.Mayers: Siemens Nixdorf Recycling Centre, Paderbourne (Germany)

4.4 Bulk processing of materials for recycling and disposal

4.4.1 Pre-processing and materials production

The reclamation of materials from electronic products involves two main stages, pre-processing, and materials production. During pre-processing materials are identified, sorted, and refined to appropriate standards in preparation for the materials production stage. For example:

- Mixed plastics are often incompatible in recycling operations due to their different chemical and physical properties. Plastics identification and separation is therefore key to the success of recycling. Although some new products contain labelled plastic components to aid identification, these will not enter the waste stream for some years, and recyclers complain that in many cases the labels are incorrect. Near and Mid-range Infra-Red (NIR and MIR) spectroscopic techniques have been developed that are capable of rapidly identifying mixed plastics from specific waste streams (Scott and Waterland 1995, van der Broek *et al* 1996, Graham, Hendra, & Mucci 1995, Intex Logistics & Nicolet Instruments 1996, Graham, Hendra, & Mucci 1995).

- Various metals in electronic products (including precious and semi-precious metals such as copper, silver, and gold from printed circuit boards) may be refined through shredding, granulation, and density classification by air or water (over a vibrating table). It has been estimated that 310,000 tonnes of large household equipment (such as refrigerators and washing machines) were shredded in the UK in 1997, 50% originating from civic amenity sites (ICER 1998 [b]).

At the materials production stage, pre-processed recyclate is further processed to produce various grades of recycled materials to be resold in place of raw materials, or to be mixed with virgin resources in the production of raw materials. The materials recycling stage may be further classified as:

1. Closed loop: where materials are recycled with the same or similar products
2. Open loop: where materials are recycled as a substitute for virgin materials
3. Low-grade recovery: where materials are used in bulk for their chemical or physical properties in low value applications.

In descending order these recycling routes have decreasing material quality specifications, which affects the type of pre-processing required. For example:

- Once identified and separated, plastics recycling occurs through relatively straightforward processes including (Wogrolly 1994):

  (1) Cleaning and decontamination: De-labeling, separation of materials, and cleaning
  (2) Re-granulation: Processing into fine plastic granules
  (3) Extrusion: Reformation of heated plastic granules into plastic pellets with consistent size and shape[10]

  Alternatively mixed plastics can be recovered by a variety of methods to create low specification materials e.g. wood replacements, noise resistant materials, and wall cladding (Hauss 1994). “Feedstock” recycling technologies have also been developed that can reform mixed polymers to monomers for re-refining as a raw material[11]. However, these processes are highly energy intensive and expensive. Unfortunately due to the limitations imposed by technology and markets, plastics recyclers usually require clean, guaranteed, and high volume supplies of known polymer composition with an assured end-market. At present the recycling of plastics from electronic wastes is restricted to specific closed loop operations, and low-grade recovery routes.

- Metals can be recovered from circuit boards through thermal treatment in a furnace. Circuit board scrap is mixed with a flux of quartz and limestone, and with coke, and is smelted in a shaft furnace with oxygen. Various precious, noble, and base metals may be recovered through this process e.g. “black copper” which can be up to 80% pure. Zinc and lead from may also be reclaimed from metal rich dusts arising within the furnace (Legarth et al 1995). Metal refining companies also use chemical processes to dissolve metals out of printed circuit board wastes.

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[10] Stage added by author from review of recycling processes
[11] Information provided by BP (1997)

New technologies for printed circuit board recycling are still under development and commercialisation. For example, NEC have developed a process to reclaim circuit board components for reuse and recycling, and also for separating solder, glass resin, and copper from the depopulated boards for recycling (Waste and Environment Today 1995).

- Recycling and treatment options for waste Cathode Ray Tubes (CRTs) are very limited (Smith et al 1996). It appears that most electronics recyclers in the UK deal with CRTs by either:

  - Disposing of them as hazardous waste
  - Storing them until legitimate recycling routes are made available
  - Recycling them elsewhere in Europe e.g. in lead smelting processes
  - Treating and “recovering” the pulverised glass as a vitreous lining in hazardous waste incinerator furnaces

  Recycling CRT glass is difficult because it consists of three glass types that require separation, funnel glass containing around 8% lead, screen glass containing barium, and a glass paste or frit (ZWEI 1996). Various technologies are presently under development or are in use within Europe.

  A CRT treatment process has been developed in the UK using micro-bacteria to actively remove and absorb metal and phosphorous coatings (Watson & Ellwood 1993). Lead contained in CRT glass can be recovered outside of the UK by use as a flux within lead smelting processes. Unfortunately closed loop recycling of CRT glass into new products is limited by the strict specifications over the composition of reclaimed glass (ZWEI 1996).

Plate 4: Precious metals smelter

E.Bettac: Union Miniere, Hoboeken (Belgium)

4.4.2 Scale of operations

Materials or even whole products set aside for recycling could be treated, pre-processed, or even made into raw materials onsite in small-scale processes. Where internal facilities do not exist, materials can be stored in skips (hazardous wastes in sealed drums or designated storage areas) for periodic collection by specialist material recyclers and waste management companies. For example, precious metals may be initially refined from printed circuit boards in a small-scale smelting furnace onsite, or may be transported unprocessed for smelting at large metal refineries (see Plate 4).

Section 4 conclusions

It appears that there are three different recycling and recovery routes for materials reclaimed from electronics wastes. The use of any particular route will depend on available technology, materials specifications, and market demand:

- Closed loop recycling: Materials returned to manufacturers for use in new products
- Open loop recycling: Recycling by material producers
- Low value recovery: Use of physical and chemical properties of reclaimed materials e.g. as structural materials, or for energy recovery

The extent to which producers can control the costs and environmental impacts of electronics recycling will be partially dependent on their ability to exploit recycling markets and influence the development and deployment of recycling technologies. Although there is much research on electronics recycling processes and technology, there appears to be comparatively little research on how producers can best manage their End-of-Life Management processes under future producer responsibility legislation.

5. Producer responsibility in practice

Many major producers of electronic goods have initiated their own processes to manage their waste electronic products. Many of these industry schemes have developed from commercial asset management processes set up for equipment returned from business operations, such as:

- Ex-lease equipment
- Surplus production and obsolete stock
- End of line product
- Returns for repair
- Customer returns
- Ex-internal assets
- Product recalls

These processes are now under development:

- Due to increased customer pressure for asset management services and environmentally responsible disposal routes.
- To enhance companies perceived environmental performance.
- To exert control over second hand product markets.
- In preparation for Producer Responsibility legislation.

Of the 75-90% by weight of larger “white goods” already recovered for recycling, half is from customers returning their end-of-life products to distributors upon delivery of new products (ICER 1998 [b]). Producers of “brown” and “grey goods” appear to have far less well-established product-recycling processes. Most producers have international recycling centres within Europe and the US, and work in partnership with third party end-of-life processors outside of major company locations. For example Hewlett-Packard has recycling centres at Böblingen in Germany, Grenoble in France, and Roseville in California. The Digital Equipment Corporation (now owned by Compaq) also has international facilities in Contocock in New Hampshire, and Njimegen in the Netherlands (Merlot 1996). Some companies have sold their international recycling operations and now subcontract these services. For example, Philips has recently sold their recycling plant at Eindhoven in the Netherlands to an international waste management company.

Although perhaps a lower cost option, subcontracting of national or even international End-of-Life Management processes can result in a loss of control over returned products by electronics producers. Alternatively, the consolidation of products through international centres owned by producers may have high impact on the environment due to increased transport requirements. Certain products, components, and materials need to be processed internationally due to the global nature of supply chains i.e. centralised manufacturing and materials production. The degree of international consolidation must be balanced against opportunities for decentralised services at a national level, close to the point of source where possible, and also against the ability of the producer to control the costs and environmental impacts of subcontracted processes.

The most successful producer-led End-of-Life Management schemes have been developed for commercial or business users of office-based equipment. The office imaging industry (manufacturing photocopiers and printing equipment) have developed sophisticated asset management processes for customers returning "end-of-lease" products. Xerox reclaimed 30% of their products by weight in 1993 (representing 7200 tonnes of waste avoided), and 50% by weight in 1995 through their recycling plants in the UK, France, and the Netherlands (Maslenikova 1996, ENDS 1996). In the information technology industry some companies have established asset-management and product return services. Siemens Nixdorf have established a network of 42 collection points in Germany for end-of-life equipment returned from customers. In 1995 a total of 5,400 tonnes of equipment was returned to their recycling plant in Paderbourne. This represented around 30% of products sold by weight based on 1990 sales figures (Business and the Environment 1995). However only in best cases have producers been able to match collection targets proposed by the European Union, which can be calculated as approximately 25%-35% by weight of the electronics waste arising each year in the UK (WEEE – 27/7/98).

As discussed in section 3, apart from for larger "white goods" and leased telephone returns, attempts at collecting end-of-life products from domestic sources have been less successful and recycling rates remain low.

Many companies have successfully established closed-loop recycling programmes for various products. For example IBM recycles PVC from end-of-life keyboards into the casing of computers at their Greenock manufacturing plant in Scotland, and Siemens Nixdorf recovers plastics from the end-of-life equipment in Germany for use in new products. While these processes may appear to be the recycling ideal (maintaining maximum utility of materials), they require a clean and consistent supply of materials, which may limit their development for end-of-life products with return rates and materials quality that cannot be guaranteed.

Section 5 conclusions

Ultimately the future of these producer-led initiatives will be determined by the development of European legislation, and national producer responsibility schemes (see section 2). Although many producers already manage their end-of-life electronic products, there is no information available on how these programmes could be developed within the framework of Producer Responsibility. Research on the "End-of-Life Management" of products could help producers develop the expertise needed to ensure that the costs and environmental impacts of these processes can be reduced and controlled under Producer Responsibility legislation. The next section outlines the focus of this research project, research questions, and proposes a research thesis based on the concepts of End-of-Life Management and "reverse logistics".

6. End-of-Life Management and reverse logistics

In the preceding chapters five key areas were investigated:

- The environmental problems of end-of-life electronics recycling and disposal
- The international development of Producer Responsibility for electronics waste
- Current patterns of use and disposal of electronic equipment
- End-of-life processing operations
- Producer related End-of-Life Management initiatives

This section presents the focus and aim of the research. Ultimately this research will address the question:

How can producers develop environmentally legitimate and commercially viable End-of-Life Management processes for electronics products?

The following research questions have been developed from the research opportunities identified in previous sections. They cover broadly the contributions to knowledge that this project will make:

Environmental management

Deployment of environmentally sound practice in industry.

(1) How can producers accurately assess the overall environment impacts of their End-of-Life Management processes?
(2) How can producers ensure environmental standards are met through their End-of-Life Management processes?

Government policy

Reconciliation of government and industry perspectives.

(1) How can government and industry perspectives be reconciled in the development of environmentally legitimate and commercially viable Producer Responsibility legislation for electronics goods?

Society and markets

Investigation of social and market factors of use, recycling, and disposal of electronic goods.

(1) What are the existing patterns of use and disposal of electronic products?
(2) What is the capability of the market for end-of-life services?
(3) How do markets for recyclates and second-hand products affect the commercial viability of End-of-Life Management processes?

End-of-life management

Development of commercially viable and environmentally legitimate recycling processes.

(1) What is "best-practice" in the management of end-of-life electronic goods?
(2) In what way could government policy, markets, and society influence the environmental success or failure of electronics End-of-Life Management processes?
(3) How can electronics producers improve the management of end-of-life electronic goods to minimise cost whilst best reducing negative environmental impacts?

Various researchers are developing the concept of "reverse logistics" to improve the planning and organisation of recovery and waste management operations. It has been argued that existing materials recycling channels are poorly developed in comparison to conventional logistics operations used to distribute products to markets (Pohlen and Farris 1992). Even seemingly simple reverse logistics operations, such as the collection of used chemical drums from customers for reuse by suppliers, requires *"vastly expanded infrastructure and new management systems"* (Guitini 1997: 81).

Similarly, the current infrastructure and markets for recycling end-of-life electronic products in the UK are not sufficient to meet the anticipated future demands of Producer Responsibility. In section 3 it was described how recycling rates for brown and grey goods are very low, and in section 1 that there are significant environmental concerns over existing recycling systems e.g. such as the release of CFCs during the shredding of refrigerators. The problem of poorly developed infrastructure for recycling "durable goods" (which includes electronics products) has been also noted in the US, where it has been estimated that recycling rates are as low as 2.7% by weight (Polymer News 1993).

Existing research into reverse logistics appears to have focused on three main areas:

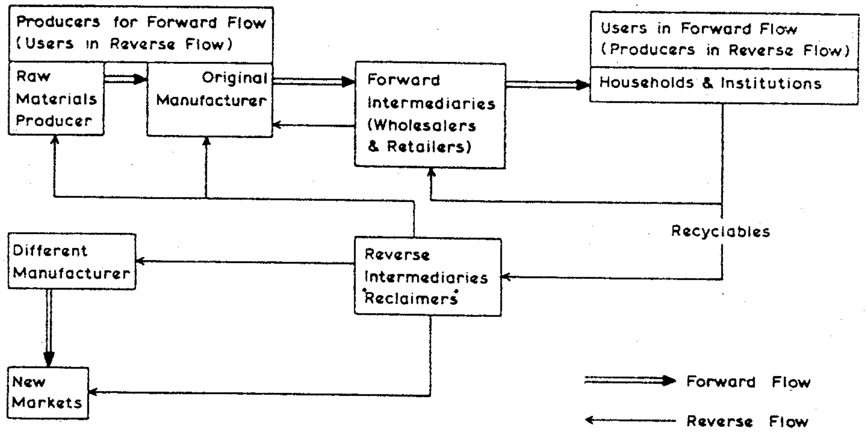
> Supply chain issues: Reverse logistics research on supply chain issues has typically focused on the management of returned products, packaging, and waste in distribution chains. For example, this has been discussed through case studies on waste minimisation (Guitini & Andel 1995, Melbin 1995), for the management of returnable chemical drums (Guitini 1997), and for waste management more generally in distribution (Stock 1992, Kopicki *et al* 1993).
>
> Operational research: Various mathematical operational research methods have been developed to help solve and find optimal cost solutions for specific reverse logistics problems. For example, algorithms have been developed for the optimisation of recycling facility location and product recycling (Krikke 1998), the management of returnable packaging (Kroon & Vjrigens 1994), and for planning component recovery systems (Veerakamolmal and Gupta 1998).
>
> Waste management: Some researchers have proposed and investigated strategies and theoretical frameworks to improve the level of logistical sophistication in recycling and the management of wastes. Generic "channel"

> structures[12] have been proposed for the "embryonic" recycling industry (Guiltnan & Nwokoye 1974), and for plastics recycling (Pohlen and Farris 1992). Another example of such research is the planning of sustainable transport systems for product take-back and recycling (Hieber 1994).

There can be overlap between most of these areas, especially in the application of operational research methods to both supply chain and waste management problems. This research is chiefly concerned with the use of logistics expertise in waste management and recycling.

As discussed in section 4, the processing of end-of-life electronics wastes proceeds via a complex arrangement of processes through which many products, components, and materials may be separated for reuse, recycling, and treatment and disposal as waste. A diverse number of players may be involved in similarly diverse number of functions within these End-of-Life Management chains.

Figure 7: Forward and reverse distribution, the Guiltnan and Nwokoye model



Source: Guiltnan and Nwokoye 1974: 29

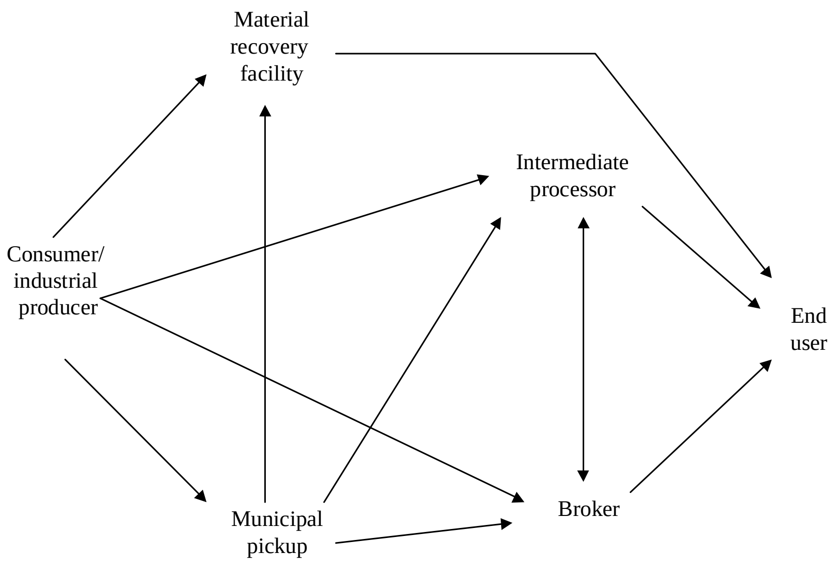
It is important to understand the general structure of recycling and waste management chains if product end-of-life is to be managed effectively. Two "channel" models have been proposed in the literature[12]. The first, the Guiltinan and Nwokoye model, gives a basic outline of closed and open loop recycling processes in relation to distribution (see Fig. 7). In this model open loop recycling proceeds through 3 intermediaries; "reverse intermediaries" which could include collectors and pre-processors of recyclate, "different manufacturers" such as material producers, and the "new markets" which are supplied with recycled materials. Closed loop recycling proceeds through members of the original product supply chain such as "original manufacturers" and "raw material producers", either via "forward" or "reverse" intermediaries (distributors or specialised collectors). The second, the

---

[12] The term "channel" is used to describe a distribution system or supply chain, and can include all stages necessary to produce, sell, and supply products and services to customers. Therefore reverse distribution channels can include all stages necessary to provide end-of-life management services to product end-users.

Pohlen and Farris model (see Fig. 8) describes the relationships between five crucial players in plastics recycling in the US based upon empirical research. Unfortunately these “channel” models are not sufficient for the development of End-of-Life Management processes for electronics goods. The Guiltnan and Nwokoye model lacks sufficient detail, and the Pohlen and Farris model is too focussed plastics recycling, and on the roles of key players rather than the relationshops between common recycling functions.

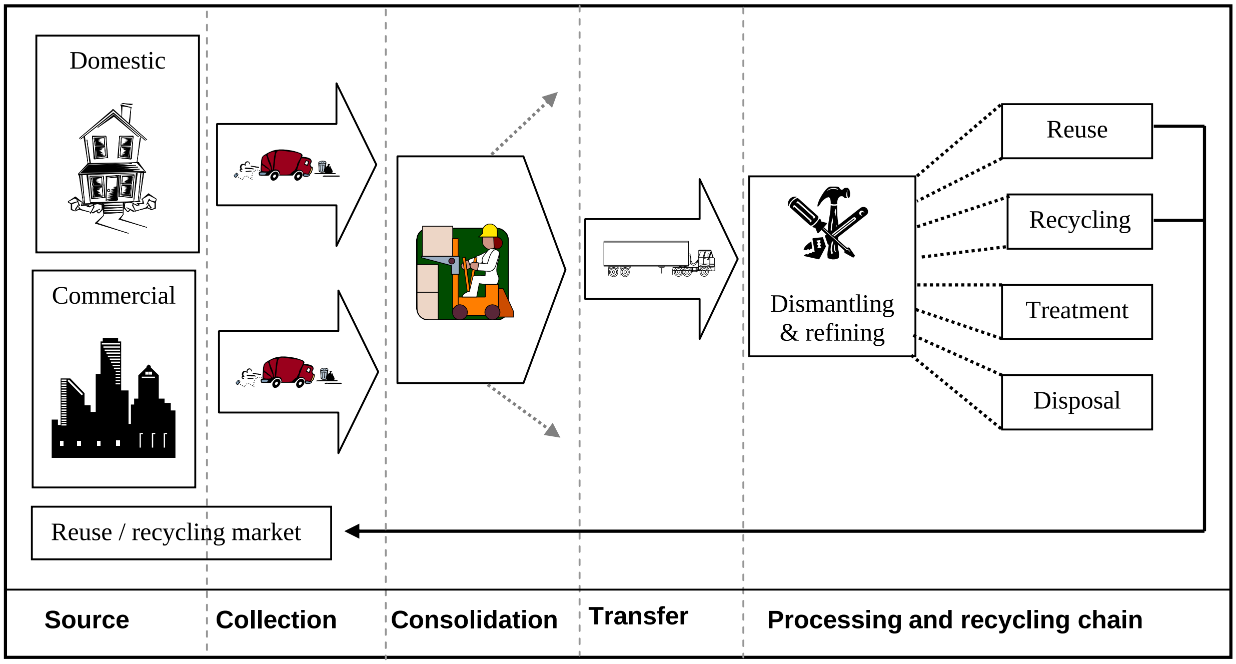
Figure 8: Combinations of reverse channels, the Pohlen and Farris model



Source: Pohlen and Farris 1992: 36

A basic outline structure for end-of-life electronics management channel is proposed in Fig. 9. This includes product collection from end-users, consolidation at collection points, transfer, and processing for resale, reuse, and treatment and disposal. Other players may also play a role e.g. overall process integrators or managers. This concept of channel structure is important because it includes all stages of the End-of-Life Management process. The channel structure is therefore a key determinant of cost and environmental impact. A channel is also a mechanism through which end-user and recycling markets may be exploited. Therefore a producers’ influence over an end-of-life channel will determine their ability to manage the costs and environmental impacts of their end-of-life products.

Figure 9: The Product Recycling Chain



Zikmund and Stanton (1971) were amongst the first to recognise recycling as a "channels of reverse distribution" problem by identifying various early recycling channels under development in the US. Although their perspective was highly insightful into the future development of recycling programmes, their main focus was on market development rather than aspects of logistical process development and integration.

In distributive logistics, a channel is described as a vertical marketing or distribution system (Gill & Allerheiligen 1981). A distribution channel is a specific sequence or collection of parties involved in the production and supply of a particular product or service to the market. Therefore channel members within a supply chain should have similar objectives and can benefit through greater co-operation and integration of activities, especially in the area of physical distribution (Christopher 1992). Three types of channel system have been identified (*op cit* 1981)

(1) Loosely organised: processing goods routinely e.g. convenience goods channels
(2) Consensus systems: organised through partnerships and co-operation.
(3) Highly organised: vertically integrated through contractual agreement (contractual systems) or direct ownership (corporate systems).

The channel concept could also be useful for the development and application of life cycle approaches to environmental management, which also takes a broader view of the overall chain of activities in product manufacture, distribution, use, and disposal in the determination of environmental impacts.

Section 6 conclusions

The management of end-of-life products centres on the selection of optimal channels (with respect to environment and cost) of reverse distribution. In section 5 various existing producer-led end-of-life returns processes were discussed, and the future uncertainty over the development of these channels was highlighted with respect to the development of Producer Responsibility legislation (as discussed in section 2). Together with the preceding discussion on reverse logistics and end-of-life management, the overall aim of this research project is that:

> *End-of-life electronic goods may be treated, recycled, and disposed of through a variety of different channels. As producers of electronic goods are to be made responsible for managing their waste products at end-of-life through Producer Responsibility legislation, they must ensure that they develop End-of-Life Management (EOLM) processes that are both environmentally legitimate and commercially viable. This research will develop a system by which producers of electronics equipment can identify, compare, and control the environmental impacts and costs of their End-of-Life Management processes based on a unique combination of Life-Cycle Assessment and logistics management methods.*
>
> *More specifically this End-of-Life Management System will be developed to help producers evaluate and compare national and international EOLM processes, different industry options under Producer Responsibility legislation, and possible customer focussed end-of-life services for commercial and domestic sectors.*

Further support for this approach can be found from Krikke (1998) and Pohlen and Farris (1992):

> *"Future study must overcome channel inefficiencies, identify opportunities for increased industry / government co-operation, and provide direction as the channels evolve and mature".*
>
> Pohlen and Farris 1992: 45

The research methodology, future plan, and progress to date are outlined in the following section.

7. Research methodology, progress, and plan

7.1 Research methodology

7.1.1 Alternative methodologies

Several methodologies could be used to investigate the development of End-of-Life Management processes. Given the research focus and questions outlined in the previous section a list of methodologies considered is given in Table 4 (overleaf).

7.1.2 Investigation of End-of-Life Management opportunities and constraints

End-of-life channel management strategies should be based on product end-user requirements (customers of EOLM processes), best practice, and expected future legislative requirements. Existing patterns of use and disposal of electronic products are currently being investigated through empirical market and social research studies (discussed in Section 3). Market based approaches (particularly looking at end-user market segmentation) have an important role to play developing both logistics service (Christopher 1992, Murphy & Daley 1994) and recycling programme (Howenstine 1993, Zikmund and Stanton 1971) strategies:

> *"Talking to customers is the pre-requisite of developing successful service strategies. It is always a mistake to think that because someone has a long experience of a particular industry that they automatically know what customers want. In the same way we should never contemplate introducing a new product to the market without first researching customer requirements and preferences, so too we should not develop service delivery systems without a clear indication of customer needs"*
>
> Christopher 1992: 86

A number of selected European case studies will be used to investigate best practice in end-of-life management. The constraints and developments of UK and European Union Producer Responsibility legislation will be investigated through literature review.

Table 4: Research methodologies considered

Research method	*Description*
Main research methods	
Life-Cycle Assessment	Systematic review of overall environmental impacts of alternative End-of-Life Management channels (taking into consideration cradle-to-grave impacts).
Logistical costing methods	The application of logistics mission based costing methods to determine critical costs within End-of-Life Management channels.
Background research methods	
Applied research and analysis of existing data	Use of industrial sponsor (Hewlett-Packard Limited) as a test case, and of information made available from other sources e.g. literature review and other organisations.
Analysis of legislative developments	Analysis of legislative developments in the UK and Europe through literature review, to investigate constraints and opportunities for End-of-Life Management.
Best practice logistics case studies	Case study surveys of industry best practice in End-of-Life Management in Europe for testing and further development.
Market and social research	Surveys of patterns of use and disposal of electronic products in commercial and domestic sectors to investigate sources of end-of-life electronics and the market scope for End-of-Life Management services.
Other methods considered but not used	
Operational research models	The development of algorithms and other mathematical approaches to calculate optimal solutions to specific End-of-Life Management problems. Cannot be adapted to fundamental changes in the structure of recycling channels without expert knowledge.
Environmental management and auditing	The incorporation of End-of-Life Management into existing industrial environmental management systems such as ISO 14000. Does not explicitly include assessment of costs or life-cycle impacts.
Dynamic or static system modeling	Development of a systems model to simulate the effects of different End-of-Life Management strategies and scenarios in the planning of End-of-Life Management channels. Not flexible enough to be adapted to fundamental changes in the structure of recycling channels or suitable for tactical and operational logistics support.

7.1.3 Logistics costing and environmental assessment

The key drivers of critical environmental impacts and costs of End-of-Life Management processes will be determined by developing a model combining environmental Life-Cycle Assessment and logistics cost management methods. Three methods of logistics cost accounting have been identified:

1. Short-run costing: Analysis of the variable costs of logistics processes linked to operational activity, and return on short-term investments. Appropriate for short-term "tactical" management decisions (Shillinglaw 1960).

2. Mission based costing: Analysis of the "attributable costs"[13] of individual market focussed "missions" [14]. Suitable for longer-term "strategic" policy decisions (Christopher 1971, Barret 1982, Christopher 1992).

3. Total cost method: Analysis of the total costs of logistics systems (including non-divisible, non-attributable costs). Suitable for long-term planning and investment type decisions (Christopher 1971).

The *"mission costing"* method was selected for further research due to its potential usefulness in strategic logistics decision making, and in integrating the total attributable costs[13] of channels of distribution (or reverse distribution) to market focussed product or service "missions"[14]. As argued in the previous section, consideration of end-user markets and market segmentation is important in the development of channels of reverse distribution.

As a holistic supply chain management approach, mission based costing is also potentially useful due to its similarity to Life-Cycle Assessment. Both approaches could be used to evaluate chains of industrial activity by cross-tabulating inventories of costs or environmental impacts across functional boundaries (throughout a companies' distribution channel or from "cradle-to-grave") to evaluate a defined service mission in terms of cost and profitability, or unit of functionality (service) in terms of environmental impact. Fig. 10 shows a mission costing matrix adapted from work by Christopher (1971) to include life-cycle environmental impact data. This approach would allow key drivers of environmental impacts and costs to be identified and analysed, and would provide clear analysis of the costs and environmental impacts related to the management of end-of-life processes. In addition it would highlight potential conflicts between environmental impacts and costs, and allow causal relationships identified. The disadvantages of this approach are that:

---

[13] An attributable cost is defined as *"the cost per unit that could be avoided on average if a product or function were discontinued entirely without changing the supporting organisational structure"* (Shillinglaw 1963: 80)

[14] A logistics "mission" could be described as the provision of a particular service level to particular customers through a particular (reverse) distribution channel. It is therefore defined and differentiated by a combination of the specific product provided, market serviced, service level provided, and cost (Barret 1983).

- The “mission identification” stage of mission costing, and the “scoping” stage of Life-Cycle Assessment involves a degree of subjectivity which may result in errors.
- It does not indicate how environmental impacts and costs may be optimised
- Different environmental impacts may not be directly comparable
- It is limited by the quality and availability of necessary data
- It is limited by the time-frames in which necessary data must be collected

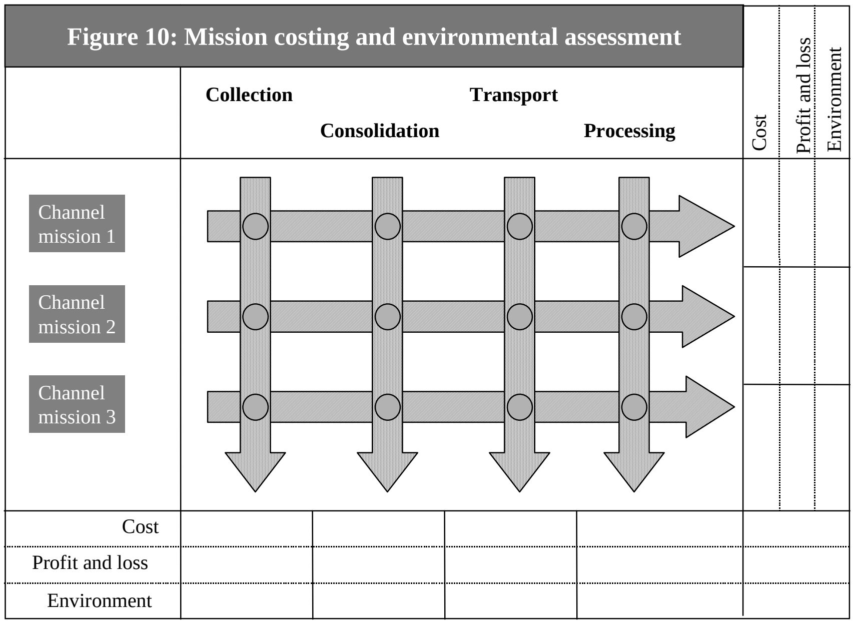


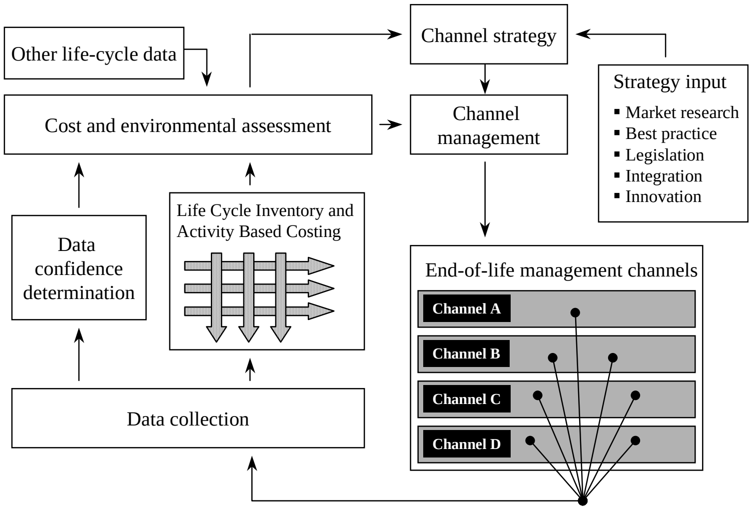
Figure 10: Mission costing and environmental assessment

These potential limitations will be addressed within “cost and environmental assessment” and “channel strategy” stages in the proposed End-of-Life Management system described in the next section.

7.1.4 End-of-Life Management system outline

Information gained from empirical and background research discussed in Section 7.1.2 will be used in the development of an End-of-Life Management system incorporating the mission costing and Life-Cycle Assessment method discussed in Section 7.1.3. The proposed system is shown in Fig. 11. The scope of activities, channel missions, and goals and targets of various EOLM approaches will first be defined at a strategic and policy making level, based on best practice, end-user market requirements, and future government legislation. EOLM channel strategies will then be implemented at a tactical or operational management level, where EOLM channels will be established, monitored, and controlled. At an operational level data will then be collected by various “operators” over a period of time so that the success of different channel missions can be analysed. The combined Life-Cycle Assessment and mission costing method will then be used to evaluate key drivers of environmental impact and cost. Progress towards strategic environmental and economic targets will then be assessed, including information on data coverage and quality, and other external or background information as necessary. The results of this assessment will then be fed back at tactical and strategic management levels, and the management cycle will begin again.

Figure 11: Proposed End-of-Life Management system



The proposed system will be tested through application to Hewlett-Packard Limited existing electronics End-of-Life Management processes in the UK and Europe (see Appendix 2 for a brief description of these activities). Three main experimental stages will be used to focus the development of the system:

(1) Testing and development of system on existing End-of-Life Management processes for later comparison as an experimental “control”.
(2) Incorporation and testing of best practices.
(3) Development and testing of market focused service strategies.

In each case the ability of the management system to assess both environmental impacts and costs will be tested. Full consideration will be given of the scope of expected legislation so that the research is applicable to future End-of-Life Management programmes.

7.2 Progress to date

7.2.1 Progress since project start

Progress over the first 18 months is detailed in previous 6 months progress reports (Mayers 1997 [a], Mayers 1997 [b], Mayers 1998 [a]). The research focus, method, and plan has been refined over previous reports, but there have been no major departures from the central theme of the research. This can be seen through the different research titles that have been proposed (see Table 5 below).

Table 5: Project titles proposed to date

"Managing End-of-Life Electronic Equipment - achieving logistical and environmental optimisation in closed economic cycles."

Six month report project title (Mayers 1997 [a])

“Managing waste electronic products. Improving the logistical efficiency and environmental evaluation of electronics recycling systems.”

Twelve month report project title (Mayers 1997 [b])

“Managing end-of-life electronics for cost effective and environmentally responsible waste reduction.”

Eighteen month report project title (Mayers 1998 [a])

“The development of environmentally legitimate and commercially viable end-of-life management processes for electronic products.”

Agreed research title (at 24 month stage)

7.2.2 Research progress

Progress is reviewed with respect to objectives and deliverables set in the previous six-month report in Table 6 below. Although various projects are reported as off-track, appropriate remedial action has been taken and current progress is deemed satisfactory.

Table 6: Six-month progress summary

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(1) Literature review: The literature review has been updated as part of the 2 year dissertation. It has been refined and condensed with respect to the research focus (*completed*).

---

(2) Time management: Time management skills have been improved, and deadlines for reports and assessments have been met. The target set to complete assessments within four weeks of completing a module is ideal, but has not always been an appropriate or necessary (*on-track*).

---

(3) Publications: A paper covering the rationale of Producer Responsibility is ready for publication given minor changes. It will be submitted to an appropriate journal before 31/10/98. Other papers will be prepared within 4 months of completion of specific research studies (*on-track*).

---

(4) Research focus: the research focus has been defined, and thesis stated within this 2-year dissertation (*completed*).

---

(5) E-SCOPE project: The E-SCOPE project has been delayed by 12 weeks due to difficulties accessing additional funding obtained through landfill tax, and the request for additional project meetings by project partners. This project is now scheduled to be completed by 31/01/99. Fortunately, the planned release of the European Union proposed Directive (which the project end was to coincide with) has also slipped by this margin (*off-track*).

---

(6) Redundant IT survey: Although minor tasks of the redundant IT survey (described in Section 3) have slipped, it should still be finished to plan (by mid-August). A report and analysis of results to date (Mayers *et al* 1998 [b]) has already been conducted (*on-track*).

---

(7) Best practice study: As anticipated time frames set by the University of Stuttgart for the best practice study were too ambitious (for a finish in June). The project will now finish by the end of December (*on-track*).

7.3 Research plan: objectives and deliverables

The proposed overall long-term objectives of this project are detailed in Table 7 (for more details see the breakdown of specific deliverables given in Appendix 3):

Table 7: Long term project objectives

1. To complete an extensive literature review covering End-of-Life Management of electronic products under producer responsibility.
2. To evaluate constraints and opportunities from the development of UK and European Producer Responsibility legislation for end-of-life electronics products.
3. To verify patterns of use and disposal of end-of-life electronics products in commercial and domestic sectors, and to identify the scope for end-of-life product management services.
4. To explore issues in reverse logistics “chain management” by identifying strategies, structures and methods to give an overview of best practice and effective performance measurement.
5. To develop, implement, and test an End-of-Life Management system through applied research.
6. To investigate data quality and improve data confidence for product end-of-life costs and environmental impacts.
7. To propose an effective End-of-Life Management system to evaluate critical drivers of cost and environmental impact in the development of effective End-of-Life Management processes.
8. Publish papers relevant to research focus in peer reviewed journals within four months of completed research.

Conclusion

This dissertation has discussed the development of Producer Responsibility for electronics waste in the UK. This included the environmental concerns over electronics waste, the development of Producer Responsibility, patterns of use and disposal of electronic appliances, existing end-of-life electronics management processes, and the current status of producer led initiatives. The focus of this research was given as:

The development of environmentally legitimate and commercially viable End-of-Life Management processes for electronics products.

An outline EOLM system, research methodology, and long term objectives have been described, and progress over the previous six months reviewed. The main arguments developed through the dissertation were that:

- Producers must be able to manage the environmental impacts (as well as costs) of their EOLM operations. Life-Cycle Assessment can be used effectively to assess different end-of-life treatment, recycling, and disposal options. Legislation should support this approach by advocating a “case-by-case” approach to regulating EOLM systems.

- Given the opportunity for the formation of voluntary solutions in the UK, the need to reconcile government and industry perspectives and agree areas of responsibility is fundamentally important to the success of future electronics recycling programmes. An evaluation of the development of this legislation has been already completed as part of this research project (Mayers *et al* 1997 [c], Mayers and France 1998).

- The disposal of electronics appliances can be complicated by “behavioural” factors such as storage, second-hand sale, repair and upgrade, and recovery for scrap metal recycling. Therefore the use and disposal of electronic products in commercial and domestic sectors has been and is currently being investigated through market and social studies as part of this research.

- End-of-life processing of electronic wastes includes four main stages:

    - Sorting of inbound goods
    - Refurbishment
    - Dismantling
    - Bulk processing of materials for recycling and disposal

  In addition there are two main stages to product recycling, pre-processing and material processing, and three alternative recycling and recovery routes, closed loop recycling, open loop recycling, and low value recovery. Although there is much research on electronics recycling processes and technology, there appears to be comparatively little research on how producers can best manage their EOLM processes under future producer responsibility legislation.

- Although many producers already manage their end-of-life electronic products, there is no information available on how these programmes could be developed within the framework of Producer Responsibility. Research on the End-of-Life Management (EOLM) of products could help producers develop the expertise needed to ensure that the costs and environmental impacts of these processes can be reduced and controlled under Producer Responsibility legislation.

In conclusion it was argued that product End-of-Life Management centres on the selection of optimal channels (with respect to environment and cost) of reverse distribution, and so therefore could be enhanced by the adaptation of existing logistics management approaches. The aim of this research was summarised:

> *End-of-life electronic goods may be treated, recycled, and disposed of through a variety of different channels. As producers of electronic goods are to be made responsible for managing their waste products at end-of-life through Producer Responsibility legislation, they must ensure that they develop End-of-Life Management (EOLM) processes that are both environmentally legitimate and commercially viable. This research will develop a system by which producers of electronics equipment can identify, compare, and control the environmental impacts and costs of their End-of-Life Management processes based on a unique combination of Life-Cycle Assessment and logistics management methods.*
>
> *More specifically this End-of-Life Management system will be developed to help producers evaluate and compare national and international EOLM processes, different industry options under Producer Responsibility legislation, and possible customer focused end-of-life services for commercial and domestic sectors.*

A method capable of analysing the environmental impacts and costs of alternative EOLM processes was outlined. This incorporated aspects of environmental Life-Cycle Assessment methodology, and a similar logistics technique called *mission based costing*. An EOLM system was then proposed incorporating this methodology, empirical and background research, and steps necessary for the application and use of such a methodology in industry e.g. data collection, channel strategy, and environmental impact and cost assessment. Finally, seven long-term objectives were proposed for the completion of this work over the next two years.

Glossary

ABS:	Acrylonitrile-butadiene-styrene
Brown goods:	General term for entertainment electronics e.g. HI-FI, televisions, & video**.**
CFCs:	Chloro flouro carbons- responsible for the depletion of the ozone layer.
Closed loop recycling:	Recycling of waste materials for same product applications
Dioxins:	A group of phenolic carbon based compounds, some of which are disputed to be highly carcinogenic.
Durable goods:	Hard wearing products. Includes automobiles, furniture, electronics etc.
EEE:	EU definition "*…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 …and designed for use with a voltage rating not exceeding 1000 Volt for alternating current and 1500 Volt for direct current."* (WEEE-27/7/98).
Electrical products:	Products relying on the supply of electricity e.g. vacuum cleaners.
Electronic products:	(1) Products containing integrated circuitry e.g. computers. (2) Used more generally in this dissertation to include electrical and electronic products
Electronic wastes:	Abbreviated and convenient term for WEEE used in this dissertation.
End-of-Life (EOL):	The period in which a product becomes waste as defined by the EU. Not a clear cut stage.
End-users:	Users of a product at end-of-life.
Grey goods:	General term for IT electronics e.g. computers, photocopiers, & phones.
PCBs:	Poly-chlorinated bi-phenyls

Producer:	A manufacturer or importer of a product or service within a country.
PVC:	Poly-vinyl chloride
Supply chain:	The process of raw material production, manufacturing, and distribution
Recovery:	To reclaim something of potential value from a waste stream
Recyclate:	Feedstock for a recycling process (as opposed to waste for disposal)
Recycling:	The reuse of materials or even products (when used more ambiguously) reclaimed at end-of-life or from waste.
Reverse logistics:	The collection products, packaging, or wastes counter to conventional logistics processes or for recycling.
Reuse:	The effective re-deployment of functional components and products reclaimed from waste or at end-of-life e.g. second-hand parts, sub-assemblies, and components.
Waste stream	A category or flow of one specific type of waste.
Take-back:	Used to describe the process of collecting and transporting products from end-users.
Value chain:	See supply chain above
White goods:	General term for convenience electronics e.g. refrigerators & kettles.
WEEE:	The EU legal definition of waste that *"waste shall mean any substance or object…which the holder discards, intend to discard, or is required to discard"* (75/442/EEC) applied to the proposed definition of EEE (Electrical and Electronic Equipment.

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Appendix 1: Example telephone survey

H Company Confidential

Example of telephone survey conducted on UK electronics end-of-life processors.

Recycler	*[RECYCLER]*
Services	Brokerage, dismantling, & recycling
No. sites	3.00
Locations	Altringham (CHESHIRE), Byley (CHESHIRE), Trafford Park (MANCHESTER)
Appropriate wastes	IT and Telecommunications
Materials processed on-site	Glass and screen phosphors from CRTs
Materials handled	Ferrous / Non-ferrous metals, Aluminum, Printed circuit boards, plastics, batteries, cathode-ray-tubes.
Reuse	Limited IC recovery, low spec PCs and telecoms equipment
Logistics capacity	Warehousing, 9 vans / 7.5 ton trucks. Also use 3rd party companies.
Technology used	CRT glass recycling process (to make new glass products)
Other vendors used / partners	5 different recycling vendors
Turnover	£2.3 million
Capacity	8000-10000 PCs and about 4000-5000 other. 8-12 tonnes / month recycled.
Employees	49
Existing customers	[Banks, Government Departments, Energy sector, major supermarket chains]
Environmental concerns	Registering for ISO 140001 – documented system, policy, and auditing.
HSE concerns	Quality manager responsible for Health and Safety.
Security	Building alarmed by Red Care, manned security for mornings and weekends.
Inventory control	Software for inventory management using barcode system (record products to component level). Batches weighed pallets.
Future developments	Going for 14001, developing an in-house printed circuit board process (granulation and water separation for precious metals recovery). Full members of ICER. ISO 9002 accredited.
Contact	[CONTACT DETAILS]
Years of operation	2 years
Overall	CRT recycling process appears relatively innovative. Look like a promising company for future development and almost have ISO 14001.
HP involvement	None

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Appendix 2: Hewlett-Packard Ltd product take-back position

Hewlett-Packard Ltd's position on "Product Take-Back".

The Hewlett-Packard Company is committed to conducting operations world-wide in an environmentally responsible manner and as such recognises the importance of the recovery and recycling of "End of Life" electronic equipment

In the UK, Hewlett-Packard receives few requests for end-of-life (EOL) product take back (PTB).

In the expectation that this need will grow, and in view of future proposed legislation, Hewlett-Packard Ltd has taken several firm initiatives in the management of EOL electronic equipment.

Recycling Technology

Hewlett-Packard Ltd has established working relationships and research partnerships with a number of UK recyclers, and are collaborating with them in advancing the technology and supply line for recycled materials.

Industry Groups

HP is dedicated to the development of effective solutions to product take back and recycling. The company is an active member of a number of industry associations and in particular is a director of ICER (the Industry Council for Electronic Recycling).

End-of-Life Management Research

It has been estimated that product-take-back could cost the UK electronics industry over £100 million yearly. HP has set up two research projects jointly with the European Union and Brunel and Surrey Universities respectively, through which state-of-the art approaches to product end-of-life management, take-back logistics, and environmentally responsible disposal are under development.

Electronics Recycling

Hewlett-Packard Limited are at present renegotiating their electronics recycling processes with new service providers. For further information please call 0118 927 4445.

This statement is valid 18th September 1998.

For more information please contact:
Hewlett-Packard:-UK EHS (Product Take-Back)

Tel 0118 927 444

Appendix 3: Research objectives and deliverables

Objective	*Deliverable*	*Due*
1. **To complete an extensive literature review covering End-of-Life Management of electronic products under producer responsibility.**		
	(1) Initial literature review	**Completed 01/04/96**
	(2) Literature review updated	**Completed 17/07/98** & every 6 months (until project end)
2. **To evaluate constraints and opportunities from the development of UK and European Producer Responsibility legislation for end-of-life electronics products.**		
	(1) Critical review of legislative developments	**Completed 31/08/98**
	(2) Legislative matrix updated:	**31/11/98 & 31/01/98** & every 3 months (until 31/04/00)
3. **To verify patterns of use and disposal of end-of-life electronics products in commercial and domestic sectors, and to identify the scope for end-of-life product management services.**		
	(1) Commercial sector study (redundant IT survey)	**Completed 15/08/98**
	(2) Domestic sector study (the E-SCOPE project)	To be completed **31/01/99**
	(3) Market analysis completed	To be completed **31/04/98**
4. **To explore issues in reverse logistics "chain management" by identifying strategies, structures and methods to give an overview of best practice and effective performance measurement.**		
	(1) Minimum of ten case studies completed	To be completed **31/10/98**
	(2) Best practice study report	To be completed **31/12/98**

5. **To develop, implement, and test an End-of-Life Management model through applied research.**

(1)	Initial End-of-Life Management model defined	**21/03/99**
(2)	End-of-Life Management model refined	**21/07/99**

6. **To investigate data quality and improve data confidence for product end-of-life costs and environmental impacts.**

(1)	Data collection requirements defined.	**01/04/99**
(2)	Data availability limitations evaluated	**05/12/99**

7. **To propose an effective End-of-Life Management model based on critical drivers of cost and environmental impact, and to evaluate effective End-of-Life Management strategies using both cost and environmental parameters.**

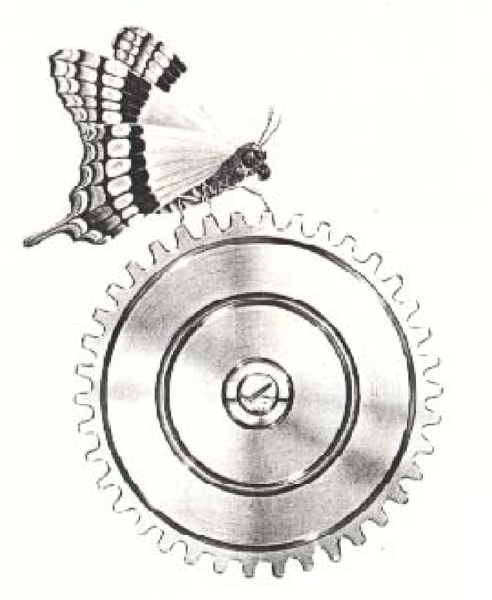
(1)	Industry best-practices evaluated	**31/11/99**
(2)	Optimum service strategies evaluated	**31/04/00**
(3)	Project report(s) completed	**02/07/00**

8. **Publish papers relevant to research focus in academically vetted journals within four months of completed research.**

(1)	Producer responsibility paper submitted	Submitted by **31/10/98**
(2)	Paper on redundant IT study	Submitted by **31/12/99**
(3)	Paper on best practice case studies	Submitted by **31/04/99**

Chapter 5, Vol. 2

An Investigation of the Implications and Effectiveness of Producer Responsibility for the Disposal of WEEE.



30 month report

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Abstract

This report is the 30-month report submitted as a requirement of the Engineering Doctorate programme in Environmental Technology. This research concerns the development of environmentally legitimate and commercially viable End-of-Life Management processes for electronic products. The report is split into three sections. In the introduction the research focus is summarised. In the second section progress compared to research plan is reviewed. In the third and ultimate section, a detailed review of progress is given on the development and implementation of a proposed End-of-Life Management system.

The report concludes that satisfactory progress has been made over the last six-months, and that significant industrial and academic contributions have already been made in the areas of Producer Responsibility policy formulation, and reverse logistics in End-of-Life management.

Contents

1. Introduction

This 30-month research report is the fifth of a series of 6-monthly progress reports required as part of the Engineering Doctorate programme. The 24-month report preceding this was the two-year project dissertation and literature review.

Based upon a review of this dissertation, a two-year *viva-voce* was held with the author in October. This review was undertaken by Professor Roland Clift (Centre for Environmental Strategy, University of Surrey) and external examiner Professor Ray Allen (Department of Civil Engineering, University of Sheffield). It was attended by all supervisors, and was ultimately a success. In summary the feedback from the examiners was that:

- Based on progress to date, the research should result in a body of knowledge sufficient for a doctorate at the end of the four-year project.
- That the research was of sufficient interest to be presented at a Centre of Environmental Strategy seminar at the University of Surrey (which is also useful for peer review).
- That a "conceptual" paper should be produced from the research to capitalise on and develop some of the unique ideas and broader aspects that may be of benefit the wider environmental community.

The first point reinforces the need to continually monitor and review project progress and to ensure all deliverables are "on-track" or otherwise under control. The second point will be followed-up within this academic year (before October 1999). Finally, a conceptual paper will be written between the author and Dr. Chris France (academic supervisor to the project) by December 1999.

In the following sub-sections the research focus is described and structure of this report summarised.

1.1 Research focus

In the two-year research dissertation and literature review, five key areas were discussed:

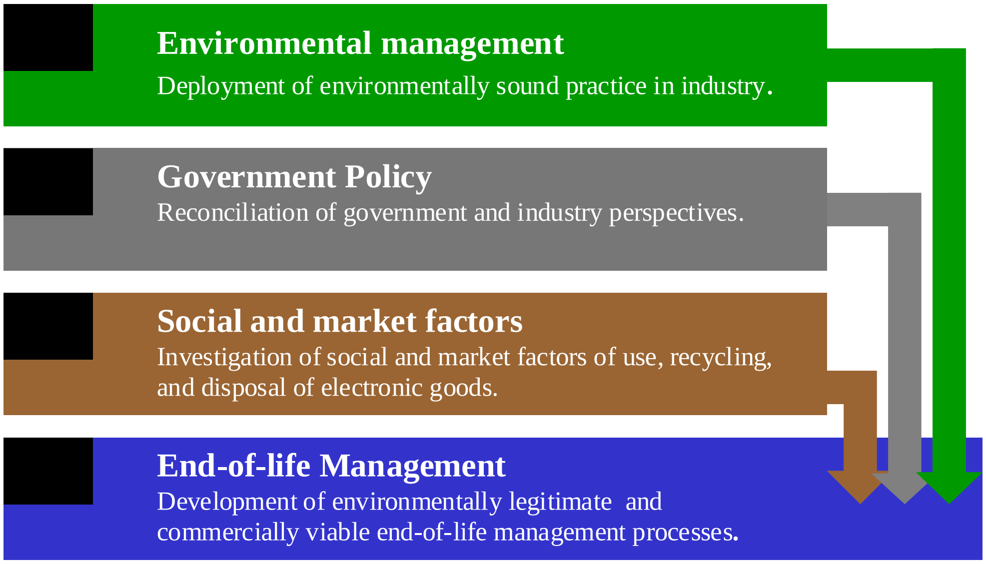
- The environmental problems of end-of-life electronics recycling and disposal
- The international development of Producer Responsibility for electronics waste
- Current patterns of use and disposal for electronic equipment
- End-of-life processing operations
- Producer related End-of-Life Management initiatives

In Section 6 the research focus was presented as:

The development of environmentally legitimate and commercially viable End-of-Life Management processes for electronic products.

Several related research questions were also developed from the research opportunities identified in the literature review (see Appendix 1). Together with the stated research focus, these cover broadly the contributions to knowledge that this project will make (as shown in Fig. 1.1).

Figure 1.1: End-of-Life Management research summary



1.2 Report summary

In this 30-month report, an overview of research progress compared to plan is given in Section 2. In Section 3 a more detailed review of progress is given on the development of the End-of-Life Management system proposed initially in Section 7 of the 24-month report. In the concluding section (Section 4) an overall summary of progress is given and academic achievements to date are summarised.

2. Progress overview

In Appendix 3 of the previous 24-month report, a detailed project plan including objectives and deliverables was presented. This section reviews the progress to date compared to this plan.

Table 2.1: Research progress overview

	1998-1999				1999-2000				
Task	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Deliverable / output
Producer Responsibility research	■	■							☑ Proposal presented to the DTI (05/02/99)
	▨	▨							
Market and social research	■	■							☐ Market research report completed (30/05/99)
	▨				Now for completion May 99				
Best practice study	■								☑ Study report completed (31/12/98)
	▨				Originally due Jun 98				
EOLM system development (stage 1)	■	■							☐ Internal processes evaluated (31/09/99)
	▨	▨	▨	▨	▨				
EOLM system development (stage 2)		■							☐ Optimum services evaluated (31/04/00)
		▨	▨	▨	▨	▨	▨		
EOLM data requirements specification	■	■							☑ Requirements specified (01/03/99)
	▨	▨	▨						
EOLM report development									☐ EOLM report completed (28/04/00)
						▨	▨		
EngD portfolio development	■	■							☐ EngD portfolio completed (28/04/00)
	▨	▨	▨	▨	▨	▨	▨		
Academic papers	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Submission date
Producer Responsibility paper	■	■							☑ 31/01/99
	▨								
Use and disposal of IT equipment in companies	■	■							☐ 30/04/99
	▨								
Disposal of household appliances									☐ 30/06/99
			▨	▨					
Consumption of household appliance									☐ TBA
Reverse logistics structures and methods									☐ TBA
EOLM system development									☐ 31/03/00
				▨	▨	▨			
EOLM overall conceptual paper									☐ 31/05/00
					▨	▨	▨		

■ Actual progress to date

▨ Project plan

A general overview of the research plan and deliverables is given in Table 2.1 above. A comprehensive overview of progress compared to plan is presented in Appendix 2. Deliverables completed since the previous 24-month report include:

- Legislative tracking: With involvement in a new industry body called PRIMER (the Producer's Institute for the Management of Electronics Recycling, originally proposed by the author), the author has helped to develop an industry proposal for product-take-back in the UK in place of planned legislative tracking work. This proposal was developed using a systematic approach developed by the author known as the "elements based approach" (Mayers and France, 1998).

  The PRIMER proposal was presented to the Department of Trade and Industry (DTI) on 05/02/99, and was accepted as *an option for consideration* (the first industry proposal to be acknowledged in this way). In view of this, research on Producer Responsibility policy is viewed as complete. Future updates in this area will be included as part of the literature review process (*research completed*).

- Best practice in reverse logistics case studies: 10 European "best practice" reverse logistics or End-of-Life Management case studies have been completed ahead of plan (*due 30/10/98, completed 17/10/98*).

- Best practice case studies report: A report on the Best Practice case studies has been completed. This deliverable forms part of the EU project RELOOP, and has been submitted for independent academic review (Bettac, Mayers, and Buellens, 1998). It will eventually be incorporated into the project portfolio (*completed on time 31/12/98*).

- Best practice case studies academic paper: A paper outlining the Best Practice case study research has been submitted by other authors (with appropriate acknowledgements and cross-referencing) and accepted into IEEE conference proceedings. A second more in depth paper is planned, with a submission date to be agreed (*due 31/04/99, completed 01/01/99)*

- Implementation of the proposed End-of-Life Management system: As discussed in Section 3.4, the End-of-Life Management system proposed in the two-year dissertation (Mayers, 1998), and detailed further in Section 3 of this report, has been implemented for testing within Hewlett-Packard's internal End-of-Life Management processes ahead of plan (*due 21/03/99, completed 31/01/99*).

- End-of-Life Management data requirements specification: As described in Section 3.4, End-of-Life Management data requirements have been specified as part of contractual agreements with vendors or HP process documentation (currently under development) ahead of plan (d*ue 01/04/99, completed 01/03/99).*

- Paper on Producer Responsibility policy: After a final review, an academic paper on Producer Responsibility (Mayers and France, 1998) was submitted to the journal, Greener Management International, who have targeted the paper for the July edition following academic review (*due 31/10/98, completed 15/01/99)*

Deliverables delayed, and reported as off-track include the:

- Literature review update: Due to various other commitments made in March, the update to the literature review planned will not be completed on time. This is not viewed as a critical slippage, as much of the reading and planning work for this update has already been completed (*now expected 31/04/99*, *originally due 01/04/99, off-track*).

- E-SCOPE survey: The E-SCOPE survey is not yet complete as planned. An 802 household survey was eventually conducted in December 1998 (representing one of the largest ever studies on the use and disposal of household appliances). Additional funding was secured early in December, with an increase in the size of the project, which introduced delays. As much of the work is sub-contracted and other tasks have been bought forward and redefined, this additional slippage does not present too many problems to the completion of the project within the specified time-frame (*now expected 30/05/99, originally due 31/01/99, off-track*).

- The market research report on the redundant IT study has been completed ahead of time. However, due to delays to the E-SCOPE project, this report will not be fully completed until the end of May (*task redefined and included into new task 9 – see Appendix 2*).

- Paper on the use and disposal of IT equipment in the UK commercial sector: A paper on the redundant IT study has been completed and is currently under review (Mayers, Kabouris, and Planas ,1999). Following review, the paper will be submitted to an appropriate refereed journal (*expected 31/04/99, due 31/12/98*, *off-track*).

New objectives and redefined deliverables include:

- Completion of the EngD portfolio: The addition of objective 9, "to complete all reports on all research projects necessary for the completion of the EngD portfolio".

- End-of-Life Management research: The redefinition of deliverables under objective 7, "to propose an effective End-of-Life Management system based on critical drivers of cost and environmental impact, and to evaluate effective End-of-Life Management strategies using both cost and environmental parameters." This was to match Hewlett-Packard's planned two-phase development of End-of-Life Management services (see Section 3.4).

- Completion of academic papers: Up to seven academic papers are planned on different aspects of the research, which will be submitted to appropriate independently reviewed academic journals before the end of the project (see Table 2.1).

Overall, research progress has been satisfactory, and sufficient controls put in place to deal with project slippage.

3. Product End-of-Life Management

In the 24-month dissertation, an End-of-Life Management (EOLM) system was proposed for the collection, treatment, and recycling of electronic products, incorporating novel logistics accounting and environmental assessment methodologies (Mayers, 1998, 42-44).

This system appears to be a significant contribution in the academic field of reverse logistics[1] and product End-of-Life Management, as has already been indicated by the adoption of this methodology by other researchers in the field (IAT *et al,* 1998[2]).

In this section the background of this research is summarised, the proposed End-of-Life Management system methodology outlined, and progress on its implementation and testing reviewed.

3.1 Research summary

At present there are no methods or systems available which producers of electrical and electronic goods may use to help manage the environmental legitimacy and commercial viability of their end-of-life product return channels[3]. This research aims to provide a system to fill this niche.

At present, the European Union is preparing legislation that will require Producers of electrical and electronic equipment to collect, treat, and recycle their products at end-of-life (Mayers and France, 1998). In addition there appears to be significant market demand for End-of-Life Management services (Mayers *et al*, 1999). The development of such services is therefore likely to be of key importance to the Producers of electrical and electronic products.

The two relatively new and progressive methodologies that critically underpin the End-of-Life Management system outlined in the two-year dissertation were:

<u>Environmental life-cycle assessment:</u>

> A method by which the total environmental impacts of providing and delivering a particular product or service can be determined and assessed holistically from raw

---

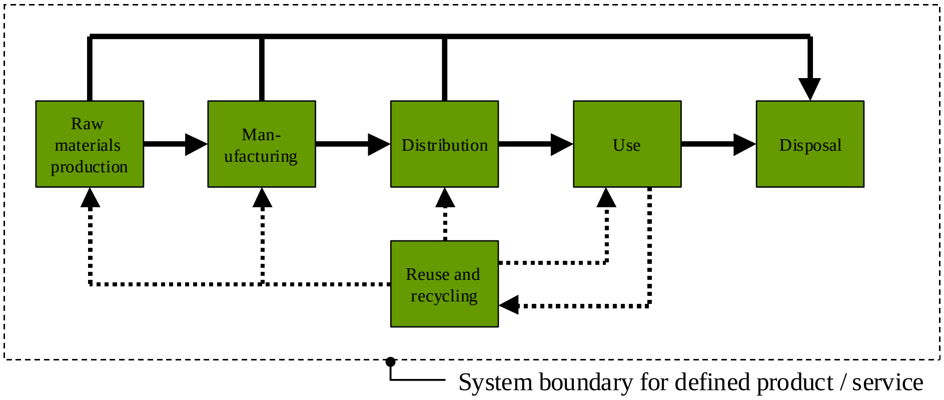
[1] "Logistics" in this case can be described as the organisation and management of material flow through processes in a supply chain (in this "reverse" case, the End-of-Life Management chain).

[2] As part of the European Union project, RELOOP, the European Commission's independent academic reviewers have reviewed this report. Their comments where that *"It seems to be a good piece of academic work, essentially a state-of-the-art survey".*

[3] In the context of a "distribution channel", a channel can be described as one possible route taken by a product in its journey through a supply chain to its first user (customer). In this case (in reverse), it is a route taken by an end-of-life product from a final end-user (customer), through collectors and end-of-life processors to final value-extraction, treatment, and disposition.

material production, through production, distribution, and use, to final disposal or recycling (cradle-to-grave, see Fig. 3.1) and compared to other products or services (ISO, 1994; OECD, 1995). To be used in the determination of the "environmental legitimacy" of End-of-Life Management processes.

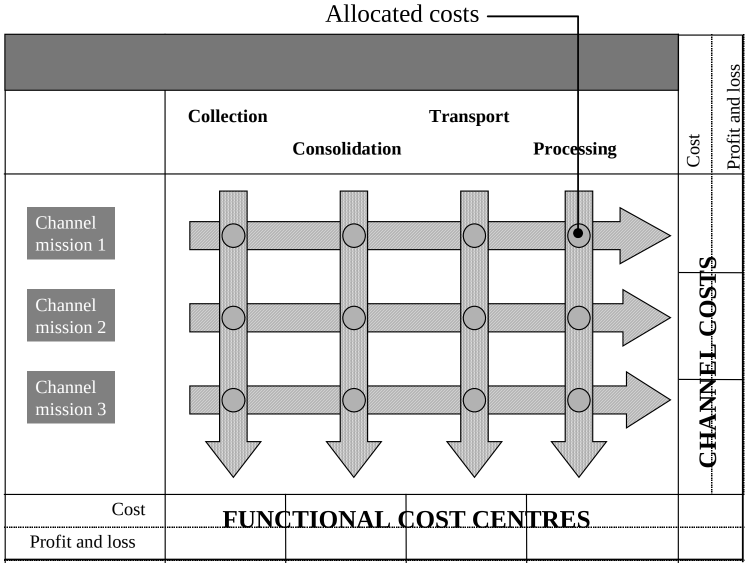
Figure 3.1: The product / service life-cycle in a life-cycle assessment



Logistical mission-based costing:

A method by which the total costs of providing and delivering a particular product or service can be determined and assessed holistically from a "supply-chain" or logistics perspective (see Fig. 3.2), and compared to other products and services (Christopher, 1992; Barret, 1982; Christopher, 1971).To be used in the determination of "commercial viability" of End-of-Life Management processes.

Figure 3.2: Mission-based costing applied to End-of-Life Management



Source: Adapted from Mayers, 1998, p43

Both methodologies are fundamentally similar, as they focus on the allocation of environmental impacts and costs throughout a defined product life-cycle or supply-chain to a specified product or service. They are discussed in more detail below.

The unique contribution to knowledge of this project is in the novel combination and application of environmental life-cycle assessment and mission-based costing methodologies to the emerging problem of product End-of-Life Management, through a defined process of continuous improvement. It is also in developing sufficient understanding of the reverse logistics of product End-of-Life Management processes, the patterns of use and disposal of end-of-life products by society, and the potential reconciliation of government and industry perspectives in the development of government policy. Such research is essential in order to:

- Develop and manage End-of-Life product return channels on a consistent and comparable basis
- Define market-focused End-of-Life Management service objectives
- Set overall programme objectives consistent with government policy

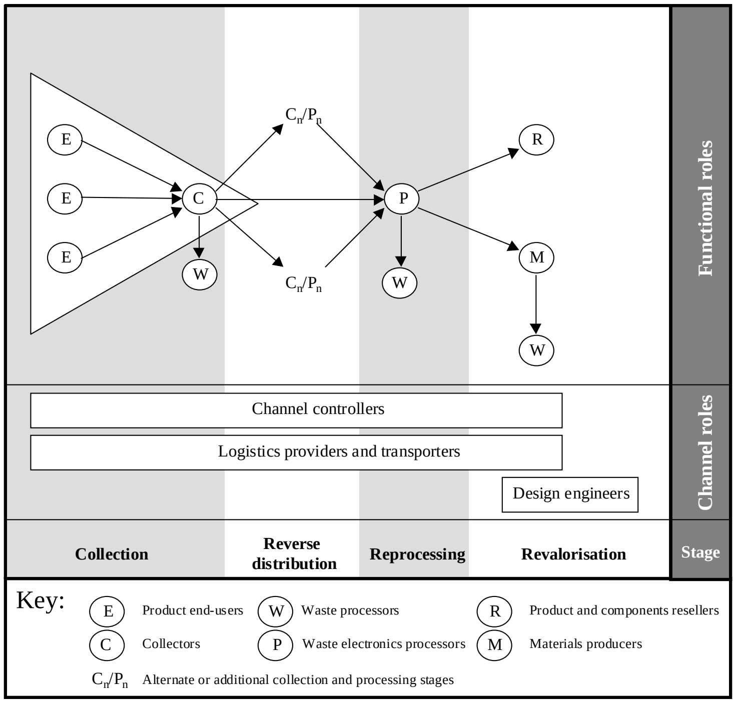
Without such additional understanding, the task of demonstrably improving product End-of-Life Management processes with respect to environment and cost would arguably not be possible. The first of these, understanding of the problem of reverse logistics, is critical in the development of the proposed End-of-Life Management system, and is detailed below.

3.2 End-of-Life Management; a channels of distribution problem

As argued in the two-year dissertation, waste management and recycling processes are best considered as logistical "channels" of reverse distribution. This is because they invariably involve the transportation of post-consumer products and materials away from end-users through processes involving various sequential stages of consolidation storage, sorting, refining, refurbishing, treatment, recycling, resale, and disposal.

Various authors have attempted to identify generic processes or theoretical reverse logistics "channel models" based on empirical research on the recycling industry in the early 70s (Guiltnan and Nwokoye, 1974), plastics recycling (Pohlen and Farris, 1992) and material reclamation in waste management (Jahre, 1995). Such theoretical research is essential in developing better understanding of the basic sequence and types of actors in reverse distribution and waste management processes, and in enabling the application of existing logistics methods and practices used in the management of conventional distribution processes.

Figure 3.3: End-of-Life Management channel model for electronic products



Source: Bettac, Mayers, and Beullens, 1998, p107

Unfortunately, existing reverse logistics channel models are limited as they either are too simplistic or too specialised for use with end-of-life electrical and electronic equipment (as detailed further in the 24-month dissertation, Mayers, 1998). Based on 10 "best practice" End-of-Life Management case studies in Europe (Bettac, Mayers, and Buellens, 1998[4]), the author has proposed an alternative channel model for these products (see Fig. 3.3 above). This model differs from those proposed in previous studies in that it contains more detail on the structure of reverse logistics processes, and focuses specifically on the management of end-of-life electronic products. Within this channel model, the roles and activities of various different types of actors[5] have been identified at different stages of the process chain:

Product end-users

> Large commercial organisations, households, producers, distributors, and retailers with end-of-life and end-of-use products for collection and disposal.

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[4] As part of the European Union project, RELOOP, the European Commission's independent academic reviewers have reviewed and accepted this report. Their comments are included in Appendix 4. In addition, a summary paper has been submitted to and accepted by the Institute of Electrical and Electronics Engineers international environmental conference (and into its proceedings).

[5] Organisations or other "entities" participating in the reverse logistics channel

1. **Collectors**

Including (but not limited to) municipalities, retailers, repair companies, brokers, recycling and waste management companies, and producers. Will either organise collection from source, or provide drop-off points for end-users.

3. **Waste electronics processors**

Includes both "front-end" processors of waste electrical and electronic equipment offering integrated resale and recycling services, and subsequent specialist recyclers in the end-of-life management chain. Processors may be engaged in repair and refurbishment, manual disassembly, pre-processing (for example granulation and shredding for precious metals recovery), and specialist processing activities (for example cathode ray tube recycling and recovery).

4. **Product and component resellers**

Traders or brokers involved in the re-marketing and resale of refurbished or remanufactured products or components.

5. **Material producers**

Companies producing finished materials using materials reclaimed from waste for use in new products. Usually operating on a global scale and at present focused mainly on the use of virgin materials.

6. **Waste processors**

Waste management companies providing waste treatment and disposal services i.e. landfill and incineration. All actors in the end-of-life chain are likely to separate waste materials from the useful materials they process, and dispose of them. Therefore waste management services may be needed at different stages throughout the end-of-life management chain. An exception to this is resellers, who are only likely to purchase or attempt to resell products with value (however processors with repair, re-manufacturing, and refurbishment processes are likely to need disposal services).

7. **Logistics providers and transporters**

Logistics providers and transporters provide vital links between all stages in the end-of-life management chain, including collection from source, and shipment to and between processors up until the final stage where products and materials are revalorised and resold. These companies may include couriers, freight hauliers, and waste management companies, and also end-users, collectors, processors, and material producers with their own transport fleets.

8. **Channel controllers**

    Actors extending their control throughout end-of-life management chains from collection through to revalorisation either through special agreement, strict sub-contractual control, or through vertical integration (acquisition) of the different stages in the chain. Channel controllers may be categorised as either commercial organisations or *reverse distributors*, and producers or producer-led consortia performing high-level integrated management functions.

9. **Design engineers**

    Of key importance to the success of Producer Responsibility legislation is the involvement of product designers, who are likely to be required to design products to reduce environmental and economic burdens at end-of-life. Design engineers may include producers, international standards bodies, and consultants who all may affect the final design and material composition of a product.

Typically, actors may play more than one role in an End-of-Life Management channel. For example product resellers may also repair and refurbish equipment, and therefore assume the additional the role of a processor. The definition of these actors and description of their sequential roles within the End-of-Life Management chain is intended to provide a useful framework or reference model for subsequent reverse logistics or End-of-Life Management research.

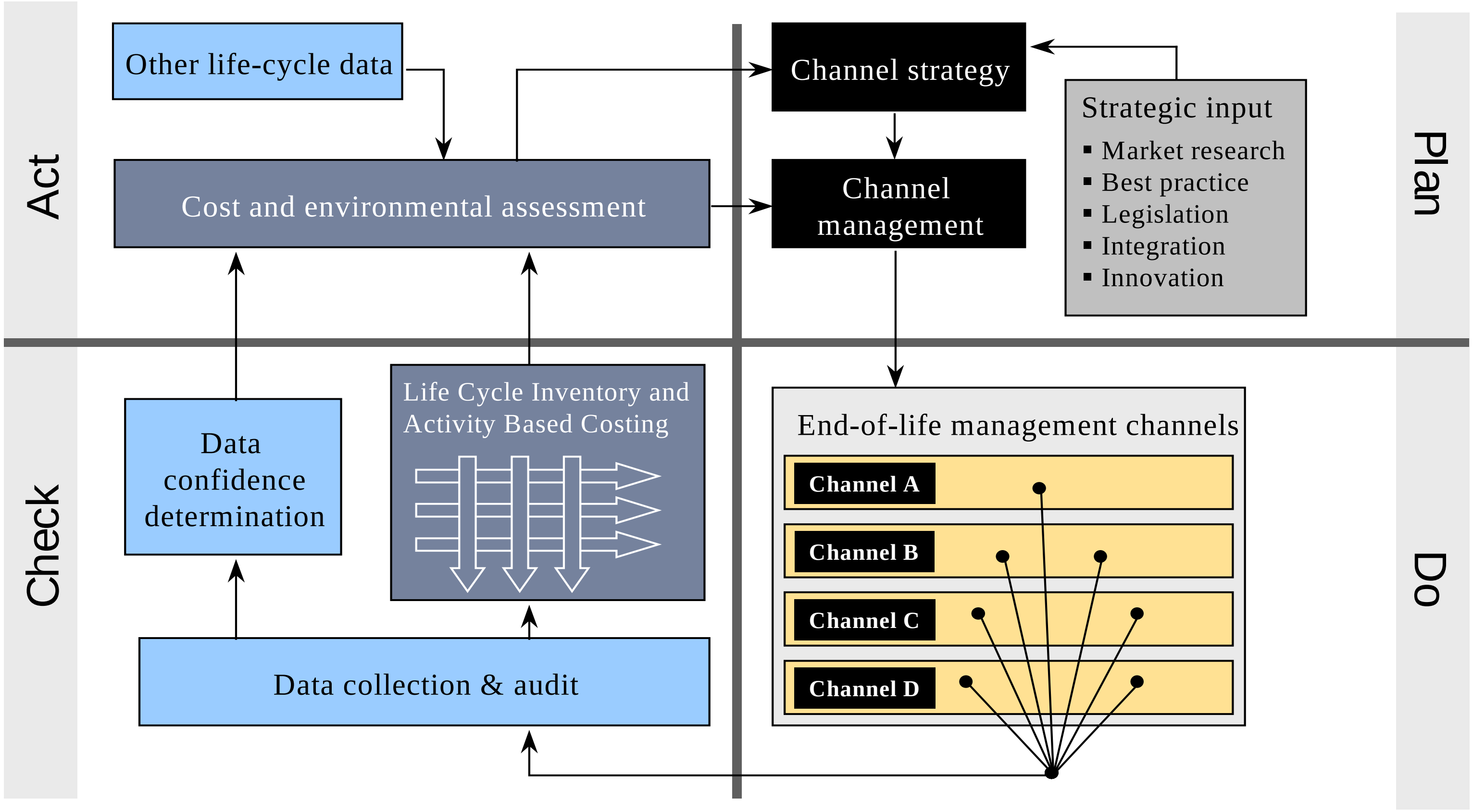
3.3 The development of an End-of-Life Management system for electronic products

The End-of-Life Management system proposed (shown in Fig. 3.4 below) is based on a process of continuous improvement. This involves the following stages:

1. Planning: The determination of End-of-Life Management strategic objectives and targets based on knowledge of government policy and identified market needs.

    The identification of specific market needs and development of End-of-Life Management channels with well-defined and market-focused service missions (viewed as the tactical objectives of the overall End-of-Life Management system).

Figure 3.4: The proposed End-of-Life Management system



Source: Mayers 1998, p44

2. Doing: The provision of defined product End-of-Life Management services through specified channels of reverse distribution.

   The continual monitoring and recording of any data from each End-of-Life Management channel required in the assessment of environmental impacts and financial costs.

3. Checking: The production of inventories of environmental impacts and costs for each End-of-Life Management channel based on life-cycle assessment and mission based costing methodologies.

   The determination of the accuracy and sufficiency of data collected in determining the environmental legitimacy and commercial viability of each End-of-Life Management channel.

4. Acting: The review of collected data on environmental impact and cost in comparison to original service missions (tactical objectives) and overall End-of-Life Management programme strategic objectives and targets. May draw on external or "background" data (such as energy used in production of raw materials from virgin resources compared to resources recovered from waste) in addition to data collected directly from End-of-Life Management channels.

   The feedback of recommendations from cost and environmental assessments to determine appropriate improvements in channel strategy and management (including strategic and tactical objectives). This stage then completes a loop back to the planning stage.

The process of continuous improvement described above (known as a "PDCA" cycle) incorporates both life-cycle assessment and mission-based costing methodologies well, because broadly they involve similar stages (as shown in Table 3.1 below). It will be developed and tested using Hewlett-Packard's existing End-of-Life Management processes (as described in the following section).

To ensure methodologies are effectively combined, the mission identification stage of mission-based costing is to be used to define the life-cycle of the End-of-Life Management channel under study. Therefore the "unit of functionality" (measurable unit of a product or service) needed within life-cycle assessment is to be defined by the market-focused "service mission" of the End-of-Life Management channel under study, and the system boundary of life-cycle assessment as the End-of-Life Management channel itself. This does not exclude the use of data from "outside" the defined End-of-Life Management channel i.e. from background systems as described above.

In the next section, progress on the development and testing of this End-of-Life Management system on Hewlett-Packard's End-of-Life Management processes to date is described.

Table 3.1: The combination of life-cycle assessment and mission-based costing methodologies in End-of-Life Management.

End-of-Life Management stage	Methodology	Equivalent stages	Description
1. Planning: Channel strategy & channel management.	Life-cycle assessment	Goal definition & scoping	Definition of functional unit & setting of system boundaries
	Mission costing	Mission identification	Identification of service missions, & development & identification of channel processes
2. Doing Operational stage & data collection.	Life-cycle assessment	Inventory analysis	Data collection
	Mission costing	Mission costing	Data collection
3. Checking Data inventory & data quality assessment.	Life-cycle assessment	Inventory analysis	Calculation of direct environmental impacts
	Mission costing	Mission costing	Calculation of channel costs
4. Acting Environmental and cost assessment compared to strategic and tactical objectives.	Life-cycle assessment	Valuation and improvement assessment	Prioritisation of environmental impacts and recommendations for environmental policy
	Mission costing	Assessment of channel costs	Channel cost assessment and policy recommendations

3.4 End-of-Life Management within Hewlett-Packard

Background

Hewlett-Packard Limited (HP) develop, manufacture, and supply globally a wide range of test and measurement, chemical analysis, healthcare, and information technology products. World wide HP had a net revenue of $46 billion in 1998, and employed over 124,000 people. This project is based within the sales region of Hewlett-Packard Limited, which imports, distributes, and supplies products to market within the UK.

Since 1994, HP has established working relationships with a number of UK electronics recyclers (processors) in the recycling of their End-of-Life equipment, including:

- R.Frazier Limited; in Dumfries, Cumbernauld
- The Intex Group; in Horndean, Hampshire

- MANN UK Limited; in Ross-on-Wye, Herefordshire

These processes are discussed in more detail below.

The development of HP's EOLM programme

Each year HP recycles around 120 tonnes (almost 50 lorry loads) of electronics related scrap in the UK. After a change in suppliers in August 1997, the proposed End-of-Life Management system has been under development, and has been incorporated into HP's management practices and vendor contracts and agreements.

Prior to August 1997, all HP electronic equipment recycling activities were physically consolidated and organised through an "Asset Recycling Centre" at a HP warehouse in Winnersh Triangle, Berkshire. Within the last 18 months much of this product flow has been moved offsite, and is now organised by a management team known as EOLM. This team consists of focused specialists in reverse logistics and End-of-Life management (principally the author), marketing and commercial development, logistics process management, and accounting.

Today EOLM is recognised officially as one of two European centres of competence in electronic product recycling within HP (the other being in Böblingen, Germany). This is based on various unique programme successes resulting from the implementation of basic elements of the proposed End-of-Life Management methodology:

- Reduction of electronics recycling and disposal costs by 90% through opening up product and component resale channels (a strategic decision based upon the evidence from market research demonstrating various competitive advantages), rationalisation of collection logistics, and full competitive tendering of reprocessing contracts. Recycling costs have been reduced to the equivalent cost of waste disposal.

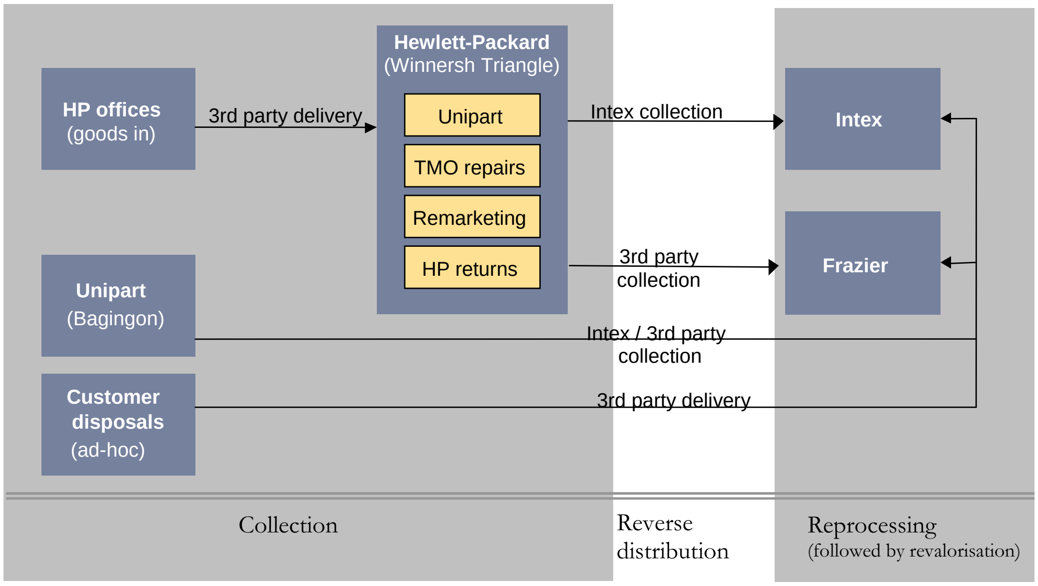
- The development of basic standards and processes governing vendor review, request for quotation, vendor selection, contract development, and ongoing supplier management (incorporating and specifying requirements of the End-of-Life Management system).

These developments have been part of a first phase of development of HP's EOLM processes, focussing on the provision of internal End-of-Life Management services. The second phase of development is the expansion of these existing services to external customers. Various processes are presently being negotiated for piloting, including:

- A printer trade-in with high street retailers Dixons and PC World.
- A redundant IT equipment management service to educational authorities in the South West of England, as part of a £70 million tender for new products by a national education authority.
- The management of HP printer consumables take-back for the UK.
- Customer returns processes for HP's operations in the UK

The implementation of product End-of-Life Management

Figure 3.5: Hewlett-Packard's phase 1 End-of-Life Management processes



An overview of HP's existing EOLM "phase 1" processes (supporting internal equipment disposal needs) is given in Fig. 3.5. Three main product return streams have been identified:

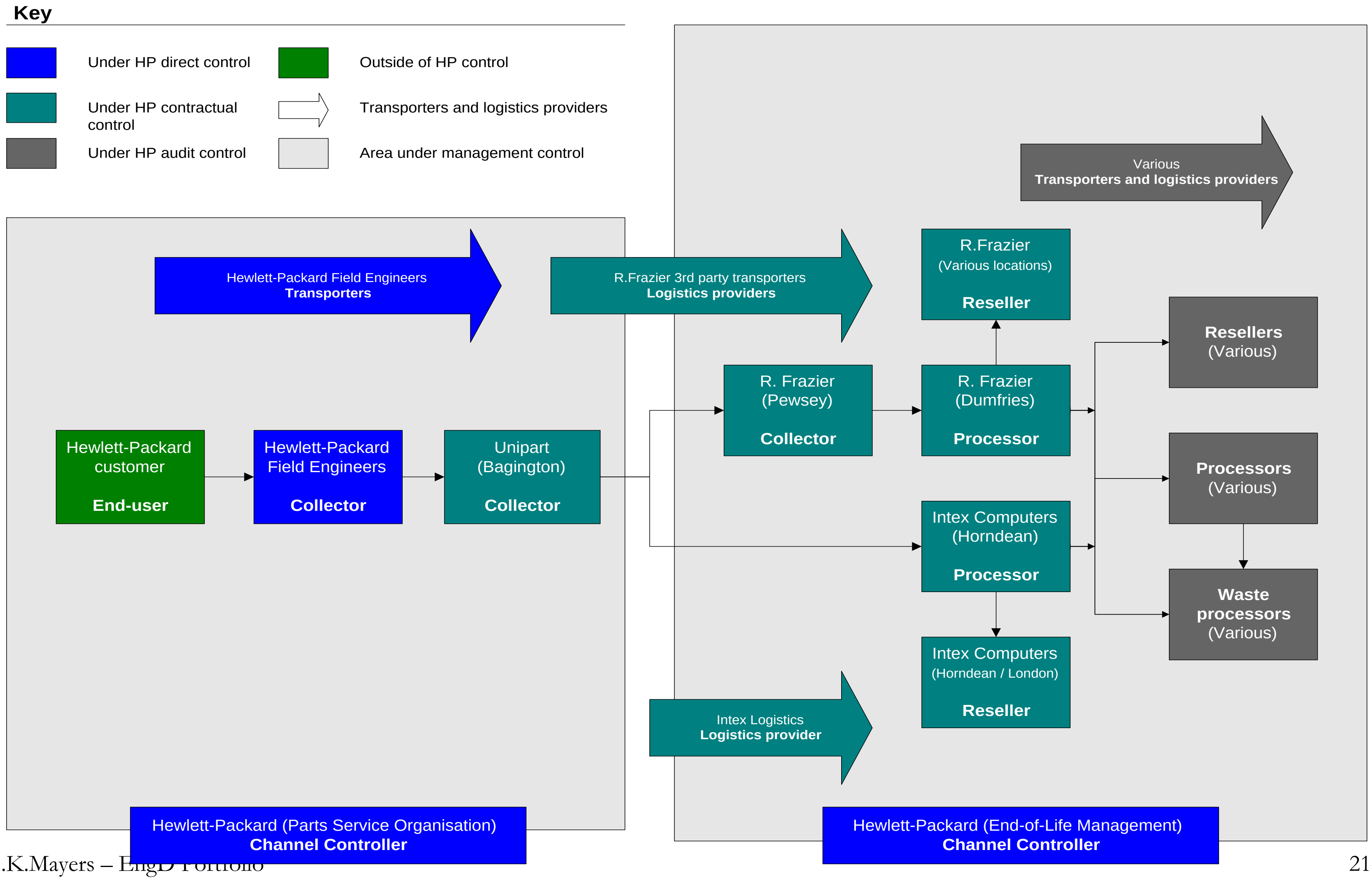
1. Redundant IT equipment returned from major HP offices via the internal logistics network for disposal at the HP Winnersh Triangle warehouse. Includes infrequent ad-hoc disposal of redundant IT equipment returned from customers (either directly or through the HP Winnersh Triangle warehouse).

2. Irreparable faulty parts and test and measurement products returned to the Test and Measurement repair centre at the HP Winnersh Triangle warehouse from HP customers and disposed of as scrap.

3. Faulty spare parts from customer products returned by HP field repair engineers to the Unipart parts distribution hub at Bagington, and rejected as scrap for disposal.

Applying the proposed End-of-Life Management methodology, each of these "product return streams" are serviced by an individually defined End-of-Life Management channel, documented from collection to revalorisation (based on the theoretical channel model presented in Section 3.2). The End-of-Life Management channel for the third product returns stream described above (faulty spare parts) is shown as an example in Fig. 3.6 below.

Figure 3.6: An example of an End-of-Life Management channel: spare parts return



A market focused service mission has been defined for each product return stream described above:

Channel 1:	To provide a self-financing asset management process for End-of-Life redundant IT equipment arising from HP office facilities, ensuring satisfactory data destruction, electrical safety testing, legislative compliance and providing value-added employee resale, equipment donation, and product recycling and disposal services.
Channel 2:	To provide a disposal route for the resale, recycling, and controlled disposal of repairs scrap and faulty End-of-Life products from the TMO repair area
Channel 3:	To ensure the frequent removal of high volumes of low-grade spare parts returned from Unipart hubs for resale, recycling, and controlled disposal

During the next 6 months data on material flows, cost, and environmental impacts will be collated from these processes. Reporting and data requirements have been specified in detail (see Appendix 3) within new recycling contracts agreed with HP's 3rd party EOLM service providers and HP process documentation currently under development.

Environmental impact data will be collated from a variety of primary and secondary sources including:

- HP / vendor reports
- Published data
- Available HP product information
- Existing and new LCA databases and tools
- Monitoring and auditing

The environmental impacts that appear to be of greatest concern in the collection, treatment, recycling, and disposal of electronic products are (Mayers, 1998, 7-10):

- Contamination by poly-chlorinated bi-phenyls
- Metals dispersion
- Energy consumption
- Carbon dioxide emissions / atmospheric emissions
- Creation and dispersion of dioxins
- Quantity of waste disposed
- Quantity virgin materials conserved

The results of this environmental assessment will be included in more detail within the next 6-month report.

4. Conclusions

In this 30-month report a summary of the research focus, an overview of research progress, and a detailed account of the development and implementation of a proposed End-of-Life Management system has been given.

Research summary

In the previous 24-month report (the two-year dissertation and literature review), the research focus and title was described as:

> *The development of environmentally legitimate and commercially viable End-of-Life Management processes for electronic products.*

Following feedback from the two-year *viva-voce*, it appears that this research (based on progress to date) should result in a sufficient body of knowledge to satisfy the requirements of the Engineering Doctorate programme by the end of the project in September 1999.

Progress overview.

Although some deliverables are off-track compared to plan, these are not seen as critical as various other deliverables have been completed ahead of plan, and much of the work on delayed deliverables has already been completed. Progress over the last six months appears therefore satisfactory.

Product End-of-Life Management

The End-of-Life Management system proposed in Section 7 of the two-year dissertation was described in more detail in Section 3. Two similar methodologies were discussed that critically underpin the proposed system methodology. These were environmental life-cycle assessment and logistical mission-based costing, which will allow the key drivers of environmental impact and cost to be identified within product End-of-Life Management processes. The contributions to knowledge from the development of this system and completion of related research are:

- The combination and application of novel life-cycle assessment and mission based costing methodologies to the problem of reverse logistics and End-of-Life Management, using a basic system of continuous improvement.

- Related research into reverse logistics processes, social and market factors of product use and disposal, and government policy.

The different stages of the proposed End-of-Life Management system methodology include:

Planning:	Determination of channel strategy and channel management
Doing:	Service provision (operational stage), and data collection
Checking:	Completion of inventories of environmental impact and cost data, and determination of data quality
Acting:	Environmental and cost assessment compared to strategic and tactical objectives

Using a reverse logistics channel model proposed by the author (from an investigation of 10 “best-practice” case studies) to outline the structure of Hewlett-Packard Limited’s End-of-Life Management processes (to be used as a test study), the implementation of this methodology was described. Over the next six months, key drivers of environmental impact and financial costs will be investigated for selected Hewlett-Packard End-of-Life Management services.

The main contributions to knowledge that have been made from progress to date include:

- The “reconciliation of government and industry perspectives” through the acceptance of an industry–led proposal to managing Waste from Electrical and Electronic Equipment by the DTI of the UK government, developed using an approach proposed by the author of this report and their academic supervisor (Mayers and France, 1998).

- The development of a theoretical reverse logistics model from empirical research on 10 “best practice” case studies, which has been reviewed and accepted by the European Commission’s independent academic reviewers as part of the European Union project, RELOOP.

- The proposed End-of-Life Management system methodology, which has been incorporated into an academic report (IAT *et al*, 1998) as part of the European Union project, RELOOP.

Overall, project progress has been satisfactory over the last six-month period. If the project is to continue to remain on-track over the next six months, significant progress must be made in the implementation and testing of the proposed End-of-Life Management system, especially with respect to environmental assessment.

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Appendix 1: Research questions

Environmental management

Deployment of environmentally sound practice in industry.

(1) How can producers accurately assess the overall environment impacts of their End-of-Life Management processes?
(2) How can producers ensure environmental standards are met through their End-of-Life Management processes?

Government policy

Reconciliation of government and industry perspectives.

(1) How can government and industry perspectives be reconciled in the development of environmentally legitimate and commercially viable Producer Responsibility legislation for electronic goods?

Society and markets

Investigation of social and market factors of use, recycling, and disposal of electronic goods.

(1) What are the existing patterns of use and disposal of electronic products?
(2) What is the capability of the market for end-of-life services?
(3) How do markets for recyclates and second-hand products affect the commercial viability of End-of-Life Management processes?

End-of-life management

Development of commercially viable and environmentally legitimate recycling processes.

(1) What is "best-practice" in the management of end-of-life electronic goods?
(2) In what way could government policy, markets, and society influence the environmental success or failure of electronics End-of-Life Management processes?
(3) How can electronics producers improve the management of end-of-life electronic goods to minimise cost whilst best reducing negative environmental impacts?

Appendix 2: Research progress overview

Research objectives and deliverables:

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1. **To complete an extensive literature review covering End-of-Life Management of electronic products under Producer Responsibility**

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(1)	Initial literature review:	**Completed 01/04/96**
(2)	Literature review updated:	**Every 6 months until project end** **Completed 17/07/98** Due 01/04/99, to be completed 31/04/99, **off-track.**

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2. **To evaluate constraints and opportunities from the development of UK and European Producer Responsibility legislation for end-of-life electronic products.**

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(1)	Critical review of legislative developments:	**Completed 31/08/98**
(2)	Legislative matrix updated:	**Completed 31/01/98** **Completed 31/11/98** No further updates required, incorporated into literature review

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3. **To verify patterns of use and disposal of end-of-life electronic products in the commercial and domestic sectors, and to identify the scope for end-of-life product management services**.

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(1)	Commercial sector IT study (the redundant IT survey):	**Completed 15/08/98**
(2)	Domestic sector study (the E-SCOPE project):	**Off-track, due 31/01/98** Main survey completed, focus groups to be completed 14/04/99. Task 5 & 6 bought forward to compensate.

(3) Market research report completed: Changed to task 9

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4. **To explore issues in reverse logistics "chain management" by identifying strategies, structures, and methods to give an overview of current practice and establish a basis of comparison between systems.**

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(1) Minimum of ten case studies completed: **Due 31/10/98, completed 17/10/98**

(2) Best practice study report: **Due 31/12/98, completed 31/12/98**, see new task 9

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5. **To develop, implement, and test an End-of-Life Management model through applied research.**

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(1) Initial End-of-Life Management system defined and implemented: **Due 21/03/99, completed 01/03/99**

(2) End-of-Life Management system refined: **Due 21/07/99**

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6. **To investigate data quality and improve data confidence for product end-of-life costs and environmental impacts**

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(1) Data collection requirements defined: **Due 01/04/99, completed 01/03/99**

(2) Data availability and quality limitations evaluated: **Due 05/12/99**

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7. **To propose an effective End-of-Life Management system based on critical drivers of cost and environmental impact, and to evaluate effective End-of-Life Management strategies using both cost and environmental parameters.**

---

(1) Industry best-practices evaluated: **Requirement removed**

(2) HP internal EOLM processes evaluated:
(phase 1 EOLM plan completed): **New task, due 31/09/99**

(3) Optimum service strategies evaluated
(phase 2 EOLM plan completed): **Due 31/04/00**

(4) Project report(s) completed: Replaced with task 9.

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8. Publish papers relevant to research focus in academically vetted journals within four months of completed research.

---

(1) Producer responsibility paper submitted: **Due 31/10/98, completed 15/01/99**

(2) Paper on redundant IT study: **Due 31/12/98**, paper under review to be submitted 31/04/99, **offtrack**.

(3) Paper on Best Practice Study: **Due 31/04/99**, first paper by other authors submitted and accepted into IEEE conference proceedings. Second in depth paper planned, submission date to be agreed.

(4) 1st paper on E-SCOPE study
(disposal behaviour): **New task, paper due 30/06/99**, abstract submitted to Greening of Industry Network conference.

(5) 2nd paper on E-SCOPE study
(consumer behaviour): **New task, date to be agreed.**

(6) Paper on EOLM system method: **New task, due 31/03/00.**

(7) Conceptual paper on EOLM, Industrial
Ecology, and Producer Responsibility: **New task, due 30/12/99.**

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9. To complete all reports on all research projects necessary for the completion of the EngD portfolio

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(1) Market research report on
redundant IT and E-SCOPE studies: **Due 31/05/99**, redundant IT study report completed -

On-track. E-SCOPE report **Off-track**

(2) Best Practice study improved and edited: **Date to be agreed.**

(3) Project report on EOLM study: **Due 02/05/00**

(4) Project portfolio completed including necessary covering documents: **Due 02/07/00**

Appendix 3: Contractual data requirements specification

Monthly reporting format

Report to include following statements where applicable, for defined streams of products and materials.
Reports may be required in hardcopy and spreadsheet format

Cost and revenue statement:	**Units**	**Brief summary required?**
Transport	£	N
Storage	£	N
Sorting	£	N
Materials processing	£	N
Product refurbishment	£	N
Administration	£	N
Waste disposal (non-hazardous)	£	N
Waste disposal (hazardous, inc. CRTs)	£	N
Revenue on sales	£	N
Revenue on material recycling	£	N
Commissions (25%)	£	N
Net profit:	£	N
Current account balance:	£	N
Invoice amount:	£	N

Materials recycling statement	**Units**	**Brief summary required?**
Paper and cardboard packaging recycled	kg: £/kg or £	N
Plastics recycled	kg: £/kg or £	Y - summary of polymer types
Cable recycled	kg: £/kg or £	N
CRTs recycled	kg and units:£/kg or £	N
Printed Circuit Boards recycled	kg: £/kg or £	N
Ferrous metals recycled	kg: £/kg or £	N

Waste disposal statement	Units	Brief summary required?
Hazardous wastes disposed (by category)	kg: £/kg or £	N
CRTs disposed	kg and units:£/kg or £	N
Non-hazardous waste disposed	kg:£/kg or £	Y - summary of materials

Product resale inventory

Rolling inventory required (including products received in previous months and not yet resold or disposed)

For each product "in process":	Units	Brief summary required?
Collection date	Date	N
Source	Location	N
Inventory ID	Number	N
Product description	-	Y
Make	-	Y
Model	-	Y
Quality	Reconditioning / repair required (REC / REP)	
Quantity	Number	N
Status	Received, Tested, Sold, Scrapped	
Price	£	N

Appendix 4: Comments of EC independent academic reviewers on the RELOOP reverse logistics best practice study

The comments below relate to a study conducted by the author as part of the European Union project, RELOOP, referred to in this report (Bettac, Mayers, and Buellens, 1998):

D3 – Current practices and management of take-back logistics and electronics recycling in Europe.

In the comments made last October on the final draft of D3, the review team was concerned with the shallowness of the data collected through the interviews, and with the lack of homogeneity in the data collected across the companies[6]. The present version of D3 is greatly improved and provides considerable insight into the TBL (Take Back Logistics) processes and the overall business models of the companies studied. The performance metrics presented are meaningful and appropriate. The cost management models presented are sufficiently detailed to allow the reader to understand the issues underlying TBL economics. Chapter 12 in particular [*conclusions*] should be looked at for possible publication.

Independent reviewers:

Prof. Leo Alting (Engineering – academic reviewer)
Prof. Jim Browne (Logistics – academic reviewer)
Mr. Marco Guida (IT systems – industrial reviewer)

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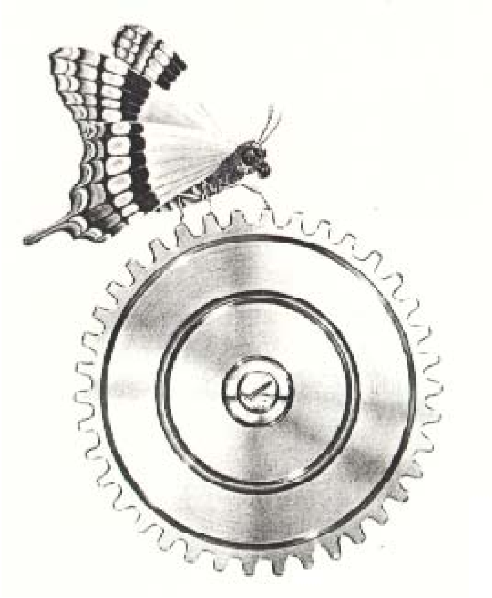
[6] Comments based on a substantially incomplete, unedited, and preliminary overview of results without detailed analysis and conclusions

Brunel and Surrey Engineering Doctorate Programme in Environmental Technology

Chapter 6, Vol. 2

An Investigation of the Implications and Effectiveness of Producer Responsibility for the Disposal of WEEE.



36 month report

Kieren Mayers

Environmental Research Engineer
Department of Manufacturing and Engineering Systems
Brunel University

Academic supervisor:	**Industrial supervisor:**
Dr. Chris France Senior Lecturer and EngD Programme Director Centre for Environmental Strategy University of Surrey	Dr. Zoe Jackson Tom Davis NickGunn Hewlett-Packard Limited

Abstract

This report is the 36-month report submitted as a requirement of the Engineering Doctorate programme in Environmental Technology. This research concerns the improvement of the environmental legitimacy and commercial viability of End-of-Life Management processes for electronic products.

The report is split into four sections. In the introduction the research focus is updated and summarised. In the second section research progress compared to plan is reviewed. In the third section, work necessary to complete and conclude remaining research is detailed, and the research plan revised accordingly. The fourth and ultimate section presents a summary overview of the research project and expected form of the final project portfolio.

The report concludes that satisfactory progress has been made over the last six months, but that significant effort is now necessary to ensure timely completion of the project. This will require that projects with continually slipping time scales now be completed according to plan.

Contents

1. Introduction

This 36-month research report is the sixth of a series of 6-monthly progress reports required as part of the Engineering Doctorate programme. The development of the research focus and aim is summarised as a brief introduction below. This is followed in the following three sections by a review of project progress compared to plan, a discussion of future work required for project completion, and finally an outline project overview.

1.1 Research development to date

In conjunction with the two-year dissertation submitted as the 24-month report in September 1998, a *viva-voce* was held with the author in October. This review was undertaken by Professor Roland Clift (Centre for Environmental Strategy, University of Surrey) and external examiner Professor Ray Allen (Department of Chemical Engineering, University of Sheffield). It was attended by all supervisors, and was ultimately a success. In summary the feedback from the examiners was that:

- Based on progress to date, the research should result in a body of knowledge sufficient for a doctorate at the end of the four-year project.
- That the research was of sufficient interest to be presented at a Centre of Environmental Strategy seminar at the University of Surrey (which is also useful for peer review).
- That a "conceptual" paper should be produced from the research to capitalise on and develop some of the unique ideas and broader aspects that may be of benefit the wider environmental community.

The first point reinforces the need to continually monitor and review project progress and to ensure all deliverables are "on-track" or otherwise under control. The second point has been followed-up by a presentation at the 1999 EngD Conference. A presentation will be made to the Centre of Environmental Strategy on completion of research on environmental (life-cycle) assessment. Finally, a conceptual paper will be written between the author and Dr. Chris France (academic supervisor to the project) before the completion of the project in October 2000.

In the previous 30-month report it was concluded that overall, project progress had been satisfactory. It was also noted that significant contributions to knowledge had already been made in the areas of the development of Producer Responsibility policy, and reverse logistics (product end-of-life management). Finally, it was agreed that if the project was to remain on-track, significant progress must be made in the implementation and testing of the proposed End-of-Life Management system, especially with respect to environmental assessment.

1.2 Research focus

In the two-year research dissertation and literature review, five key areas were discussed:

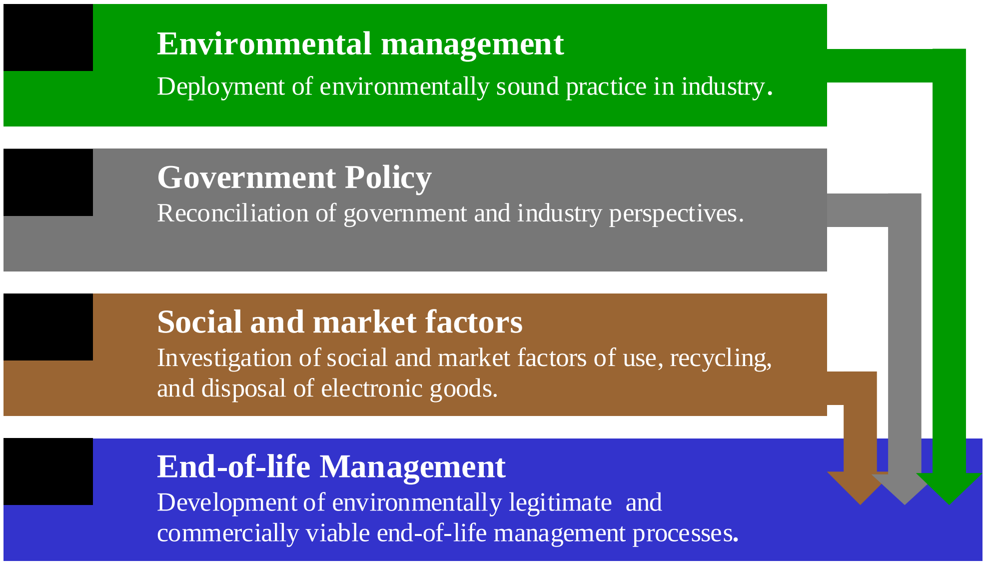
- Environmental problems of waste electronics product recycling and disposal
- International development of Producer Responsibility policies for electronics waste
- Current patterns of use and disposal of electronic equipment
- End-of-life processing operations
- Producer related End-of-Life Management initiatives
- Theoretical reverse logistics framework models

This review justified the basis of the research focus and title, which was presented as:

The development of environmentally legitimate and commercially viable End-of-Life Management processes for electronic products.

Several related research questions were also developed from the research opportunities identified in the literature review (see Appendix 1 for more detail). Together with the stated research focus, these cover broadly the contributions to knowledge that this project will make (as shown in Fig. 1.1).

Figure 1.1: End-of-Life Management research summary



Within the last six months, important changes in the project definition and research plan (described in detail in Section 3) have been incorporated into the research aim and objectives. Originally in the project definition, it was planned to develop a system which could "assure" the environmental legitimacy and commercial viability of end-of-life management processes for electronic products. Given the current poor state of knowledge on the environmental impacts of the collection, treatment, and recycling of waste from electrical and electronic equipment, it is clear that such an "ideal" system will not be achievable. To describe better the research project, the focus and aim have been revised thus:

Research focus:	**Improving the environmentally legitimacy and commercially viability End-of-Life Management processes for electronic products.**
Research aim:	The aim of this research is to develop a system of continuous improvement capable of evaluating the environmental impacts and costs of different End-of-Life Management processes for electronic products, such that they can be better managed and improved. A multi-disciplinary approach has been adopted in achieving this aim, including environmental impact assessment, financial accounting, social and market research, theoretical reverse logistics research, and an analysis of government polices.

1.2 Report summary

In this 36-month report, an overview of research progress compared to plan is given in Section 2. In Section 3, changes to the project programme concerning research on the proposed End-of-Life Management system is given, and the project plan revised accordingly. Section 4 draws together all the areas of research undertaken and presents a brief overview of key project components, contributions to knowledge, and expected contents of the project portfolio. In the concluding section (Section 5) an overall summary of progress is given and the revised research plan is outlined.

2. Progress overview

In Section 2 of the previous 30-month report, a detailed project plan including objectives and deliverables was presented and reviewed. A review of project progress to date compared to this plan is presented below (and is summarised in the "tracking" Gannt chart in Fig. 2.1). The review covers three specific areas:

- Deliverables completed to plan
- Deliverables delayed and "off-track"
- Changes to the project programme

This does not include discussion of deliverables currently in progress and "on-track". A copy of the full project plan has been included in Appendix 2 for further information.

2.1 Progress summary

Deliverables completed to plan since the 30-month report include:

- Literature review update: An update to the literature review was completed during April (see task 1 in Fig. 2.1). The review was re-written in areas to include new literature reviewed since the previous update as part of the 24-month report and dissertation (*originally due 01/04/99, completed 31/04/99*).

- E-SCOPE survey: An analysis of the results of the E-SCOPE study has been completed in relation to product disposal (as described in task 3, Fig. 2.1). However, the completion of the project report is likely to be delayed as other participants are late on their agreed inputs, particularly on the analysis of results on issues of product consumption and lifetime. Despite the expected late delivery of the project report, the E-SCOPE project has been completed (*originally due 31/12/98, project complete, final report expected 31/12/99*).

Deliverables delayed over the last six-months, and consequently reported as "***off-track***" are:

- Paper on the use and disposal of IT equipment in the UK commercial sector: The paper completed for publication on the redundant IT study (Mayers, France, Kabouris, and Planas, 1999, see task 6[2] in Fig 2.1) is at present under informal peer review. This is at the suggestion of the project academic supervisor, and is to be sure of the methodology used before being submitted to an appropriate refereed journal (*expected 31/04/99, due 31/12/98*, *off-track*).

Table 2.1: Research progress overview

	1998-1999				1999-2000				
Task	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Deliverable / output
1. Literature review & 6 monthly updates	■	■	■	■	■				☐ Literature review completed (31/12/99)
	▨	▨	▨	▨					
2. Producer Responsibility research	■	■							☑ Proposal presented to the DTI (05/02/99)
	▨	▨							
3. Market and social research	■	■	■	■	■				☑ Market research completed (31/05/99)
	▨				Report delivery late: exp. Dec 99				
4. Best practice study	■								☑ Study report completed (31/12/98)
	▨				Originally due Jun 98				
5.2 EOLM data requirements specification	■	■							☑ Requirements specified (01/03/99)
	▨	▨	▨						
5.3 EOLM system development	■	■	■	■		Project plan revised			☐ Internal processes evaluated (31/09/99)
	▨	▨	▨	▨	▨				
5.4 EOLM system development		■				Project plan revised			☐ Optimum services evaluated (28/04/00)
		▨	▨	▨	▨	▨	▨		
6. Academic papers	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Submission date
(1) Producer responsibility paper	■	■							☑ 31/01/99, published Greener Management International
	▨								
(2) Use and disposal of IT equipment in companies	■	■							☐ 30/04/99, informal peer review underway
	▨								
(3) Reverse logistics structures and methods									☐ TBA
(4) Disposal of household appliances			■	■					☐ 30/06/99
			▨	▨	Now for completion Dec 99				
(5) Consumption of household appliance									Requirement removed
(6) EOLM conceptual paper									☐ 31/09/00
7. Portfolio reports	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Submission date
(1) Reverse logistics "best practice study	■								☑ Completed 31/12/98, possibly to be improved
	▨								
(2) Social and market research report	■	■	■						☐ 31/05/99, now for completion 31/12/99
	▨	▨	▨	▨	▨				
(3) EOLM report development			■	■					☐ 28/04/00
						▨	▨		
(4) Portfolio completed including bridging document									☐ 31/04/00
					▨	▨	▨		

■ Actual progress to date

▨ Project plan

New objectives and redefined deliverables include:

- Final literature review: The literature review (task 1) will be mostly complete and ready for initial informal review by December 1999. This will include extended reviews of the mission costing approach, general life-cycle costing approaches, and other general updates. It is expected that this will require at least one week of additional effort. A full reference list will be drawn up from all reports in the project portfolio (as described in Section 4), as the literature review extends into each of the studies undertaken.

- Paper on the consumption of household appliances: Although two papers were planned on the E-SCOPE study (tasks 6[4] and 6[5]), only one of these, the overview paper on the use and disposal of household appliances was seen as relevant to this research. Therefore the requirement for a paper on the consumption and lifetime of household appliances has been removed. The completion of the remaining paper has been delayed with the completion of the related project report (task 6[2]).

- End-of-Life Management system development: Work has continued on the application and evaluation of the proposed end-of-life management system methodology on Hewlett-Packard's product end-of-life management processes (task 5). This investigation has centered on a printer “trade-in” conducted between the Dixons Stores Group and Hewlett-Packard Limited in April 1999 (Mayers *et al* 1999). This project is two months behind schedule. This was due to a delay to the completion of the printer trade-in programme outside of the author’s control.

  As described in more detail in Section 3, research on the proposed End-of-Life Management system has now been re-organised substantially to cover four areas (*research plan re-organised, originally due 31/09/99, to date on-track).* These are:

  - The development and refinement of the proposed system methodology
  - The completion of a mission costing exercise
  - The completion of an environmental life-cycle inventory exercise
  - An investigation of appropriate decision-making frameworks.

- Environmental assessment: Progress on the completion of the environmental life-cycle assessment (and mission costing) exercises has been reported in a paper to the 1999 EngD conference (Mayers *et al* 1999), which has been included in Appendix 3 for reference.

3. Twelve-month research plan

This section presents a revised plan detailing work necessary for completion of the project over the next twelve-month period. As described below, this work includes completion of research on the proposed End-of-Life Management system, and the completion of the project portfolio and remaining six-month reports.

Completion of project reports and the project portfolio

At present, the sponsoring company is undergoing major re-organisational changes that will result in significant changes to the project's industrial supervision. Following these changes a portfolio completion plan (including a supervisor review schedule) will be agreed at the earliest opportunity. This portfolio completion plan will be included in the April progress report. An outline plan for the final structure of the project portfolio has been included in the following section.

In addition to the project portfolio, two six-month project reports also remain to be completed. The next project report for submission in April 2000 will contain a key progress review on portfolio completion. The final report for submission in October is likely to contain nominal details on revisions to be made following *viva*, and a nominal review of project completion.

Completion of research on the proposed End-of-Life Management system

Although most research tasks have been completed or are near completion, remaining tasks relate to the development and implementation of the proposed End-of-Life Management system within the test company, Hewlett-Packard Limited. In the 30-month report, End-of-Life Management research was focussed on the particular development of internal product asset management processes, and their extension in the provision of services to distributors and customers uniquely within Hewlett-Packard Limited.

Subsequently, research on the development, implementation, and testing of the proposed End-of-Life Management system was planned in four stages:

1. Data requirements specification (completed 01/03/99)
2. Methodology refinement (final refinement due 28/04/00)
3. Application of methodology to internal service development (due 31/09/99)
4. Application of methodology external service development (due 28/04/99)

Based on results to date, it now appears possible to use the results of this focussed study more generally to comment on and compare the differences between "typical" asset management approaches within companies to the proposed End-of-Life Management system. This comparison reflects the difference between common "functional" and "facility" based asset management approaches used by companies, to the more holistic and customer-focussed integrated "reverse" supply-chain management approach proposed. The research plan has been re-organised, into the three key activities described below to accommodate for this broader perspective.

1. **Continual methodological development and refinement (overall End-of-Life Management system).**

   As each stage of the End-of-Life Management system is implemented and tested, the research methodology is further developed and refined. For example, within the last six months it has been recognised that an initial review of End-of-Life Management processes is required at the "Policy development and planning" or "Planning" stage. In addition it has been recognised that input of external environmental data is needed at the "Data collection and inventory" or "Checking" as opposed to the "Cost and environmental assessment" or "Acting" stage. The paper included in Appendix 3 gives an updated and detailed overview of the proposed system methodology for further information.

2. **Completion of environmental assessment and mission costing of the selected End-of-Life Management channel (Data collection and inventory or "Checking" stage).**

   It must be recognised that at the "Checking" stage of the proposed system methodology, mission costing and environmental assessment become separate but related activities involving different exercises and levels of expertise. The results of the mission costing and life-cycle assessment approaches will be compared to more common facility and asset management approaches used within companies. Depending on the success of the End-of-Life Management system under development, it may be possible to fully implement and test the system on a number or processes before the completion of the project.

   Work on the development and implementation of the mission costing approach has been fully completed (task 5.3). Two investigations will be included in the final project report. The first investigation is a detailed comparison of the mission costing approach to traditional facility or asset management approaches using the results of the printer trade-in. The second investigation is a less detailed but complete mission costing of all of Hewlett-Packard's product end-of-life management processes in the UK. The results of the full mission costing will be used to show the broad applicability and usefulness of the approach on a range of different end-of-life management process.

3. **Evaluation of decision making frameworks (assessment stage).**

   Finally, alternative decision-making approaches must be evaluated in terms of their effectiveness in performing cost / benefit analyses and deciding upon appropriate courses of action given different conflicting cost and environmental factors. This will include consideration of data quality and limitations. Examples of decision making "frameworks" include stakeholder models, valuation techniques, and basic criteria-based approaches.

These changes have been incorporated into a revised research plan presented in Table 3.1 (see Appendix 2 for more detail). A project completion date is proposed for the end of April. This will allow a 3-4 month contingency should any problems occur.

Table 3.1: New research plan and progress overview

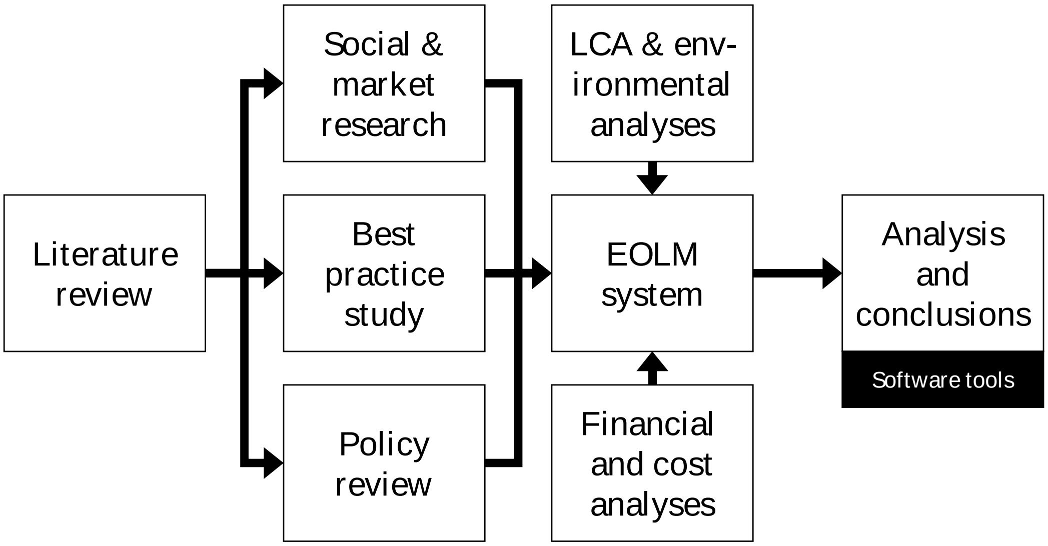
Task	1998-1999				1999-2000				
	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Deliverable / output
1. Literature review & 6 monthly updates	■	■	■	■	■				☐ Literature review completed (31/12/99)
	▨	▨	▨	▨					
2. Producer Responsibility research	■	■							☑ Proposal presented to the DTI (05/02/99)
	▨	▨							
3. Market and social research	■	■	■	■	■				☑ Market research completed (31/12/99)
	▨				Report delivery late: exp. Dec 99				
4. Best practice study	■								☑ Study report completed (31/12/98)
	▨				Originally due Jun 98				
5.1 EOLM system methodology development	■	■	■	■					☐ System methodology completed (28/02/00)
	▨	▨	▨	▨	▨	▨			
5.2 EOLM data requirements specification	■	■							☑ Requirements specified (01/03/99)
	▨	▨	▨						
5.3 Implementation and testing of mission costing method			■	■					☑ Mission costing completed (31/10/99)
			▨	▨	▨				
5.4 Implementation and testing of life-cycle assessment method				■					☐ Life-cycle inventory completed (31/12/99)
				▨	▨				
5.5 Evaluation of decision-making frameworks									☐ Decision framework adopted (28/02/00)
					▨	▨			
6. Academic papers	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Submission date
(1) Producer responsibility paper	■	■							☑ 31/01/99, published Greener Management International
	▨								
(2) Use and disposal of IT equipment in companies	■	■							☐ 30/04/99, informal peer review underway
	▨								
(3) Reverse logistics structures and methods									☐ TBA
(4) Disposal of household appliances			■	■					☐ 30/06/99
			▨	▨	Now for completion Dec 99				
(5) Consumption of household appliance									Requirement removed
(6) EOLM conceptual paper									☐ 31/09/00
7. Portfolio reports	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Submission date
(1) Reverse logistics "best practice study	■								☑ Completed 31/12/98, possibly to be improved
	▨								
(2) Social and market research report	■	■	■						☐ 31/05/99, now for completion 31/12/99
	▨	▨	▨	▨	▨				
(3) EOLM report development			■	■					☐ 28/04/00
						▨	▨		
(4) Portfolio completed including bridging document									☐ 31/04/00
					▨	▨	▨		

■ Actual progress to date ▨ Project plan

4. Research overview

Following the summary of the project focus and aim, review of progress to date compared to plan, and future plan of research presented in the preceding three sections, this section completes the progress report with a summary overview of research. A brief description of each area of research undertaken is given below, including a summary of current status and the expected form of the completed project portfolio. A diagrammatic overview showing the linkages between the different areas of research is shown in Fig. 4.1 below.

Figure 4.1: Research overview



1. **Literature review**

   Covering environmental impacts of electronic product recycling and disposal, the development of Producer Responsibility legislation, patterns of product use and disposal, and the development of new approaches to waste management and the management of Waste Electrical and Electronic Equipment.

   Proposed completion date, end December 1999.
   Main report completed & periodic updates *on-track*.

2. **Social and market research**

   Commercial and domestic research examining the use and disposal of electrical and electronic products. This research is critical in determining the service levels required by product end-users, and in providing previously unknown information on the quantities and sources of different categories of waste equipment arising in the UK necessary for the development of effective product end-of-life management processes.

Original completion date proposed end of May 1999
Report already completed covering commercial markets.
Report on domestic markets (the E-SCOPE project) in progress, expected completion now end of December 1999, *off-track*.

3. **Best practice study**

Review of existing practices and processes employed in the collection, treatment, and recycling of end-of-life electronic products. Essential in developing a theoretical "reverse logistics" framework as a basis of understanding or foundation for the advancement and development of product end-of-life management methodologies.

Report completed December 1998, theoretical logistics model proposed.
Report already reviewed as part of European Union project, RELOOP[1].

4. **Policy review**

Investigation of the scope and possible future directions of future Producer Responsibility policy for waste electronic products. Fundamental in the development of product End-of-Life Management systems, as future legislation will influence materials recycling targets, environmental standards, and determine various operating requirements for product treatment, recycling, and disposal operations.

Review of legislation and "elements based approach" completed through academic paper accepted by the journal, Greener Management International (Mayers and France 1999).
In addition, the "elements based approach" proposed within this paper has been adopted in the formation of the UK industry group, PRIMER.

5. **End-of-Life Management research**

The development and testing of the proposed End-of-Life Management system methodology, based on the novel combination of life-cycle assessment and logistics management approaches in a system of continuous improvement. This system is to be evaluated in respect of its ability to improve the environmental legitimacy and commercial viability of product End-of-Life Management processes. Key stages of research include the development and refinement of the proposed system methodology, the completion a "test-run" environmental assessment and costing in a

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[1] As part of the European Union project, RELOOP, the European Commission's independent academic reviewers have reviewed and accepted this report. In addition, a summary paper has been submitted to and accepted by the Institute of Electrical and Electronics Engineers international environmental conference (and into its proceedings).

real "case study", and an evaluation of possible decision frameworks (an important part of the development of the overall system methodology).

Implementation and testing in progress
Methodology report currently in progress.
***On-track* for completion by April 2000.**

6. Analysis and conclusions

Finally, the various key findings of research will be discussed in the context of the End-of-Life Management system under development. This will include a brief discussion on generic lessons for different industry sectors, the cost of implementing the system methodology, and the role of Information Technology in implementing the proposed End-of-Life Management system

Report due 28/04/99.
To form part of an extended study "bridging document".

Figure 4.2: Proposed structure of the final project portfolio

Volume 1: Main project results

- Introduction
- Bridging document (key findings)
- Literature review
- EOLM system and example
- Main reference list
- Appendices

Volume 2: Project reports

- Introduction
- Project reports (best practice study / social and market research / government policy)
- Papers
- Main reference list
- Appendices

Volume 3: Background information

- Six month project reports
- Meeting minutes
- Main reference list
- Appendices

7. The project portfolio

The proposed structure of the final project portfolio is described in Fig. 4.2 above. It is expected the final portfolio will consist of three volumes. The first volume will contain key sections including:

- The literature review.
- The "bridging document" linking together all areas of research and stating contributions to knowledge as described above.

- A report on the proposed End-of-Life Management system.

The second volume will contain specific project reports on social and market research and the best practice study. It will also contain copies of relevant published papers, for example in the area of policy development (Mayers and France 1999). The third and final section will contain all the six-monthly project progress reports and supervisor meeting minutes for reference.

Each volume will contain a full and combined reference list, with Appendices for each report appended to the back within each volume. Once the portfolio has been completed and approved with the appropriate supervisors, it will be submitted ready for *viva*. It is expected that this will be between April and July. Decisions will be made on the final portfolio submission date pending major re-organisation activities within the sponsoring company Hewlett-Packard Limited.

Portfolio submission date to be agreed 31/11/99.

5. Conclusions

In this 36-month project report for the Engineering Doctorate programme, progress has been reviewed with respect to the research plan, and the project aims and objectives updated.

Deliverables completed in the last six-month period include:

- The E-SCOPE project, investigating the use and disposal of household appliances.
- An update to the literature review.

The only deliverable reported as "off-track" was a paper on the use and disposal of IT products in the commercial sector. Various changes were made to the project programme, including:

- A new completion date for the literature review.
- The removal of the requirement for a paper on the consumption and lifetime of household appliances based on the E-SCOPE study
- Changes to research on the proposed End-of-Life Management system.

The most significant changes made to the project in the last six months were:

- A project redefinition - updated to emphasise the continuous improvement approach.

- A revised and updated research plan on the proposed End-of-Life Management system. Three main activities now remain to be completed in relation to this research. These are continued methodological development and refinement, the completion of a test life-cycle assessment and mission costing exercise, and a review of available decision-making frameworks.

Overall the project is still considered to be on-track for completion in April. Current research is on the critical path for the completion of the project. Therefore, it is increasingly important that project slippages are better managed than they have been previously.

References

Mayers, C.K. (1998). *The development of environmentally legitimate and commercially viable End-of-Life Management processes for electronic products.* 31/09/99, two-year Engineering Doctorate dissertation held at the Department of Manufacturing and Engineering Systems, Brunel University, United Kingdom.

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Mayers, C.K. and France, C. (1999). Meeting the "Producer Responsibility" challenge: the future for the electronics and electrical goods industry in the UK Accepted by *Greener Management International*, for July 1999 edition.

Mayers, C.K, France. C, Kabouris, E., and S. Planas (1999). The use and disposal of IT products within commercial markets. *Working paper*.

Appendix 1: Research questions

Environmental management

Deployment of environmentally sound practice in industry.

(1) How can producers accurately assess the overall environment impacts of their End-of-Life Management processes?
(2) How can producers ensure environmental standards are met through their End-of-Life Management processes?

Government policy

Reconciliation of government and industry perspectives.

(1) How can government and industry perspectives be reconciled in the development of environmentally legitimate and commercially viable Producer Responsibility legislation for electronic goods?

Society and markets

Investigation of social and market factors of use, recycling, and disposal of electronic goods.

(1) What are the existing patterns of use and disposal of electronic products?
(2) What is the capability of the market for end-of-life services?
(3) How do markets for recyclates and second-hand products affect the commercial viability of End-of-Life Management processes?

End-of-life management

Development of commercially viable and environmentally legitimate recycling processes.

(1) What is "best-practice" in the management of end-of-life electronic goods?
(2) In what way could government policy, markets, and society influence the environmental success or failure of electronics End-of-Life Management processes?
(3) How can electronics producers improve the management of end-of-life electronic goods to minimise cost whilst best reducing negative environmental impacts?

Appendix 2: Research progress overview

Research objectives and deliverables:

1. **To complete an extensive literature review covering End-of-Life Management of electronic products under Producer Responsibility**

(1)	Initial literature review:	**Completed 01/04/96**
(2)	Literature review updated:	**Every 6 months until 31/12/99** **Completed 17/07/98** **Completed 31/04/99** ***On-track***

2. **To evaluate constraints and opportunities from the development of UK and European Producer Responsibility legislation for end-of-life electronic products.**

(1)	Critical review of legislative developments:	**Completed 31/08/98**
(2)	Legislative matrix updated:	**Completed 31/01/98** **Completed 31/11/98** No further updates required, incorporated into literature review

3. **To verify patterns of use and disposal of end-of-life electronic products in the commercial and domestic sectors, and to identify the scope for end-of-life product management services**.

(1)	Commercial sector IT study (the redundant IT survey):	**Completed 15/08/98**
(2)	Domestic sector study (the E-SCOPE project):	**Due 31/12/99, completed 31/09/99**

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4. **To explore issues in reverse logistics "chain management" by identifying strategies, structures, and methods to give an overview of current practice and establish a basis of comparison between systems.**

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(1) Minimum of ten case studies completed: **Due 31/10/98, completed 17/10/98**

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5. **To propose, develop, and implement an effective End-of-Life Management system based on critical drivers of cost and environmental impact, and to evaluate effective End-of-Life Management strategies using both cost and environmental parameters.**

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(1) Initial End-of-Life Management system defined and implemented: **Due 21/03/99, completed 01/03/99**

(2) Data collection requirements defined: **Due 01/04/99, completed 01/03/99**

(3) Mission costing approach completed for selected End-of-Life Management process(es): **Due 31/10/99, completed 31/09/99**

(4) Life-cycle assessment completed for selected End-of-Life Management process(es): **Due 31/12/99, *on-track***

(5) Evaluation of decision making frameworks (assessment stage): **Due 28/02/00**

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6. **Publish papers relevant to research focus in academically vetted journals within four months of completed research.**

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(1) Producer responsibility paper submitted: **Due 31/10/98, completed 15/01/99**

(2) Paper on redundant IT study: **Due 31/12/98**, ***off-track***

(3) Paper on Best Practice Study: **Due 31/04/99**, first paper by other authors submitted and accepted

		into IEEE conference proceedings. Second in depth paper planned, submission date to be agreed.
(4)	1^{st} paper on E-SCOPE study (disposal behaviour):	**Due 31/12/99**
(5)	Paper on EOLM system method:	**Due 31/03/00, *on-track***
(6)	Conceptual paper on EOLM	**Due 31/09/00**

7. To complete all reports on all research projects necessary for the completion of the EngD portfolio

(1)	Market research report on redundant IT and E-SCOPE studies:	**Due 31/05/99**, redundant IT study report completed E-SCOPE report ***off-track*, now due 31/12/99**
(2)	Best Practice study:	**Due 31/12/99, completed 31/12/99** Possibly to be edited and improved
(3)	Project report on EOLM study:	**Due 31/03/00**
(4)	Project portfolio completed for informal peer review including necessary covering documents:	**Due 31/04/00**

Appendix 3: Paper to the 1999 EngD conference

THE DEVELOPMENT OF A SYSTEM FOR IMPROVING THE ENVIRONMENTAL PERFORMANCE AND COMMERCIAL VIABILITY OF END-OF-LIFE MANAGEMENT PROCESSES FOR ELECTRONIC PRODUCTS

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Abstract

With the development of 'Producer Responsibility' policies and legislation by governments in countries throughout the developed world, the cost burdens of waste management are shifting away from society to producers, and through cost internalisation, ultimately to the individual consumer. Under this approach, producers are required to provide for the collection, treatment, and recycling of their products at "end-of-life". This major change will require producers not only to acquire new competencies, but to excel and perform beyond the current state-of-the-art in the waste management and recycling industries.

This article presents an "End-of-Life Management" system for Waste Electrical and Electronic Equipment (WEEE), a category of durable goods currently under discussion for Producer Responsibility legislation across Europe. Using a combination of life-cycle assessment, logistics management, and continuous improvement approaches, progress on the development and novel application of this methodology is described using an example of a printer trade-in between a major producer and high-street retailer in the UK. In conclusion, future research to be undertaken to further develop and evaluate the effectiveness of this system is described.

Key words: Reverse Logistics, Producer Responsibility, End-of-Life, Waste from Electrical and Electronic Equipment, Life Cycle Assessment, Quality Management, Logistics Management, Mission Costing

1. Introduction

At present, the European Commission is in the third stage of drafting a new Directive that will require Producers of Electrical and Electronic Equipment to provide for the collection, treatment, and recycling of their products at “end-of-life” (WEEE-27/7/98). The European Union has already adopted “*Producer Responsibility*” Directives for packaging (94/62 EC) and batteries (91/157 EEC), and many countries throughout the developed world have implemented similar regulations and policies (Mayers and France 1999).

Producer Responsibility is intended to be a market-based instrument of government policy, providing economic incentives for Producers to reduce the environmental impacts of their waste products (at their so-called "*end-of-life*") by redesign and / or by establishing product collection, treatment, and recycling processes. These economic incentives are likely to be significant. In 1991, it was estimated that Producer Responsibility for WEEE would cost the industry £100 million in the UK alone, which was around 0.4% of its revenue at that time (Roy 1991). In Norway, the introduction of Producer Responsibility legislation will result in price increases on new products from around £1.60 to as much as £23.80 (ENDS Daily 1999).

The introduction of Producer Responsibility demands much higher standards for waste management and recycling than are currently achieved within the waste-management industry. This includes standards for recycling and collection, and specific treatment standards, for example, governing the disposal of cathode ray tubes. In contrast with conventional logistics processes used to distribute products to market, it has been argued that "*reverse*" logistics processes used in materials recycling are poorly understood and underdeveloped in general (Pohlen and Farris 1992). There are claims that even seemingly simple reverse logistics processes, such as the collection of used chemical drums from customers for reuse by suppliers, requires *"vastly expanded infrastructure and new management systems"* (Guitini 1997: 81).

The transfer of waste management responsibilities to Producers will require them to either develop or employ considerable expertise in the fields of waste management and reverse logistics, areas not traditionally part of their core competencies. Using a novel application of environmental assessment and logistics management approaches, this paper discusses the development of a system to continuously improve the environmental performance and commercial viability of end-of-life management processes for electronic products. Firstly, a theoretical definition of the structure of reverse logistics processes for end-of-life electronic products (developed by the author and used to underpin of the proposed system) is discussed below.

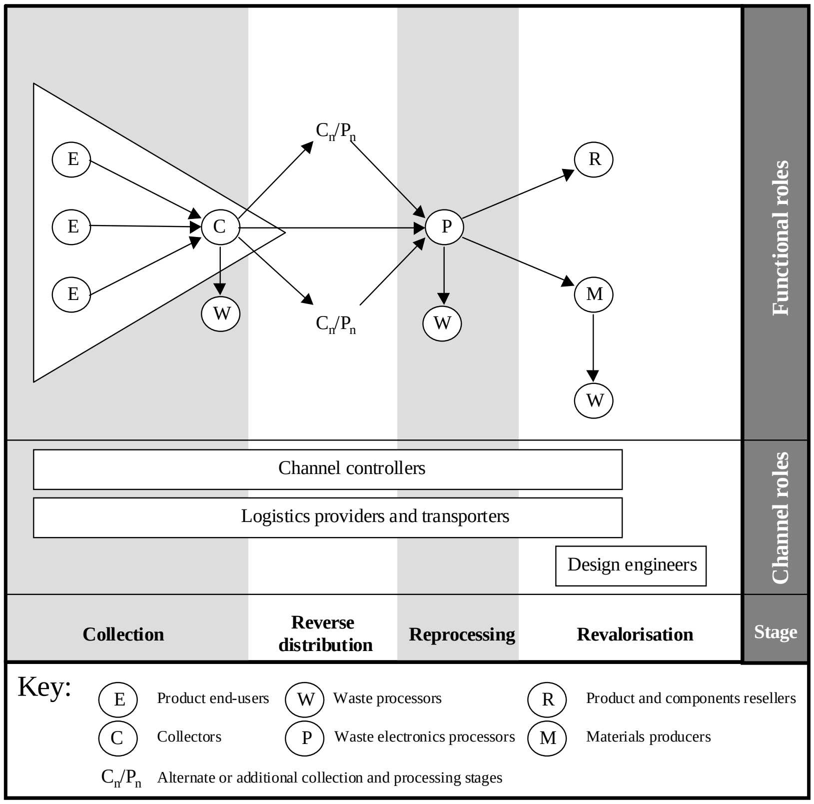
2. The logistics of product end-of-life management

In order to understand waste management and recycling processes, it has been argued that they are best considered as logistical "*channels*" of reverse distribution (Zikmund and Stanton 1971). The concept of channel structure is important because it defines the sequence of stages and players in a logistical chain of distribution (or reverse distribution). Based on 10 case studies of major End-of-Life Management processors in Europe (Bettac, Mayers, and Buellens 1998), the author has proposed a theoretical process definition or "*channel model*" for these products (see Fig. 1 below). Within this channel model, the roles and activities of various different types of organisations (or "*actors*") have been identified at different stages of the process chain. This is intended to provide a basis of comparison between End-of-Life Management processes.

3. System overview

In order to improve the environmental performance and commercial viability of product end-of-life management channels, a system has been proposed that uniquely combines environmental *lifecycle assessment* and *mission costing* (a logistics management and accounting approach) methodologies within a framework of *continuous improvement*. It is important to include continuous improvement techniques, as they are an essential feature within existing environmental management systems such as ISO 140001 and EMAS.

Figure 1: End-of-Life Management channel model for electronic products



Product end-users: Organisations & individuals disposing of end-of-life products.

Collectors: Collecting from end-users directly or through drop-off points e.g. retailers.

Waste electronics processors: Electronics recyclers & subsequent specialist materials recyclers e.g. cathode ray tube recyclers.

Product and component resellers: Traders or brokers re-marketing and reselling refurbished products or components.

Material producers: Producers of finished materials using materials reclaimed from waste for use in new products e.g. copper smelters.

Waste processors: Waste management companies providing waste treatment and disposal services.

Logistics providers and transporters: Logistics providers & transporters providing transport links between all stages in the end-of-life management chain e.g. hauliers.

Channel controllers: Performing high-level integrated management functions e.g. waste management companies and producer consortia.

Design engineers: Designing products to reduce end-of-life environmental and economic burdens.

Source: Bettac, Mayers, and Buellens, 1998

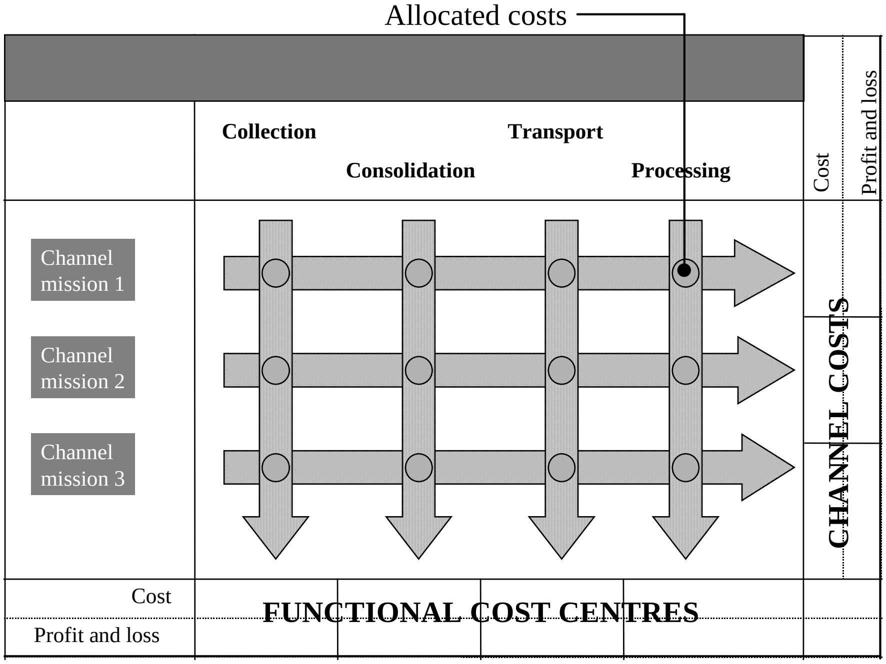
Environmental life-cycle assessment is a method by which the total environmental impacts of providing and delivering a particular product or service can be determined and assessed holistically from cradle-to-grave, and compared to other products or services (ISO 1994, OECD 1995).

Logistics mission costing is a similar method by which the total costs of providing and delivering a particular product or service can be determined and assessed holistically from a “supply-chain” or logistics perspective, and compared to other products and services (Christopher, 1992; Barret, 1982). Rather than focusing on the “functional” costs of individual stages (cost centres) in a distribution channel, as with traditional management accounting, mission costing is used to identify the overall profitability of supplying individual customer groups with agreed levels of service (defined by a series of "*channel missions*", as described in Section 4) through an *integrated* channel of distribution (as shown for end-of-life management in Fig.2).

"Each group of customers is deemed to constitute a unique physical distribution mission. If it is possible to establish the cost of supplying the various levels of service to the various market segments, i.e. to cost the physical distribution missions, the potential exists to establish the level of service which yields the highest net benefit (profit) to the company, since both the revenue and the cost implications of changes in level of service may be quantifiable." – Barret 1982: 10

For example, the mission costing method could be used to evaluate the profitability of different service delivery channels in a fast-food restaurant (such as take-away, eat-in, or home delivery), including the differential costs of ingredients and preparation in each case.

Figure 2. The mission costing method



Source: adapted from Christopher 1992.

Life-cycle assessment and missing costing methodologies are based on relatively similar procedures, whereby environmental impacts or costs are evaluated throughout a defined product supply-chain (or life cycle) and allocated to a specified product or service, and so can be used in parallel (as summarised in Table 1).

Table 1: The combined end-of-life management system methodology

End-of-Life Management stage	***Methodology***	***Equivalent stages***	***Description***
1. Policy development and planning (PLAN) *Channel strategy & channel management.*	Life-cycle assessment	Goal definition & scoping	*Definition of functional unit & setting of system boundaries*
	Mission costing	Mission identification	*Identification of service missions, & development & identification of channel processes*
2. Implementation and operation (DO) *Operational stage & data collection.*	Life-cycle assessment	Inventory analysis	*Data collection*
	Mission costing	Mission costing	*Data collection*
3. Information collection and reporting (CHECK) *Data inventory & data quality assessment.*	Life-cycle assessment	Inventory analysis	*Calculation of direct environmental impacts*
	Mission costing	Mission costing	*Calculation of channel costs*
4. Improvement assessment (ACT) *Environmental and cost assessment compared to strategic and tactical objectives.*	Life-cycle assessment	Valuation and improvement assessment	*Prioritisation of environmental impacts and recommendations for environmental policy*
	Mission costing	Assessment of channel costs	*Channel cost assessment and policy recommendations*

As an example, a printer "trade-in" conducted between a major international producer of IT products and printers and a major group of UK based high-street retailers is at present being used to evaluate the proposed system methodology. In this trade-in, various discounts were offered on the price of selected new printer products on exchange for an older model. During the month of April 1999 (the period of the trade-in), over 3,250 printers, weighing over 20 tonnes in total, were returned through retail outlets to a third party recycling organisation in the UK.

Although this trade-in was undertaken principally as a marketing promotion, to increase consumer awareness of new printing technologies and thus stimulate new product sales, it also offered useful opportunities for end-of-life management research. In terms of logistics requirements it was very similar to the take-back of products under the future proposed WEEE Directive, which is likely to require products to be returned on the sale of new through retail outlets. The proposed end-of-life management system can be divided into four key stages, which are discussed below using specific examples of the ongoing trade-in.

4. Policy development and planning (Stage 1)

Initially, strategic end-of-life management objectives must be set at an organisational level, and more specific tactical objectives decided for each individual end-of-life management channel. At this level, consideration should be given to the market for end-of-life management services, applicable legislation, industry best practice, levels of innovation, and the level process integration desired. Decisions should also be based on an initial review of the potential costs and environmental impacts of product collection, recycling, and treatment services to be used, such as through the use of 3rd party vendor assessments. The minimum decision criteria at this stage should be to ensure compliance with environmental legislation as valid basis for continuous improvement.

Objective setting

Although it may be relatively simple to set commercial and environmental objectives that *appear* tangible and achievable, it is difficult to judge the most legitimate course of action (especially regarding the environment), as all costs and impacts must be considered, some of which are likely to be in conflict:

- Conflict between environmental factors: *for example, increased rates of recycling may only be achievable with an increase in energy consumption*
- Conflict between cost factors: *for example, a reduction in the costs of reverse distribution by reducing the number of collection points in a channel may increase the direct cost of collection from end-users.*
- Conflict between cost and environmental factors: *for example, in current markets, increased plastics recycling may only be achieved at increased cost.*

An example of an environmental objective might be *"to ensure that the energy burden of individual end-of-life management channels is not above that of the equivalent alternative disposition route (unless otherwise environmentally justified)"*. Three principle objectives regarding commercial viability have been identified:

- *…to return competitive levels of net profit to internal or external customers*
- *…to operate competitively on a cost neutral basis*
- *…to be competitively priced and funded by internal or external customers*

Mission identification

At a tactical level, unique service related objectives for each end-of-life management channel must be defined by a series of individual *service missions*, in keeping with strategic end-of-life management objectives set previously. Although essentially this step is required as part of mission costing, service missions are also used to define the unit of functionality similarly required in life-cycle assessment. Service missions may be defined as a combination of statements on product (end-of-life product composition), market, service level, and cost / revenue objectives, for example *"to serve the Dutch market with product X with 95% delivery within 14 days at lowest possible cost"* (Barret 1982; 5). The identification and definition of service missions should ideally be based on detailed market investigations of (end-of-life management) service levels to be provided and the potential for revenue generation. This should be followed by market segmentation to classify separate groups of customers (end-users) on the basis of the mix of service factors to be offered.

Service-level factors or variables are critical in the identification and definition of each service mission. Factors used to describe service levels in conventional distribution, such as order fulfillment rate and order time cycle, do not necessarily have the same degree of relevance or importance to the relatively less advanced field of reverse logistics and end-of-life management. To redress this gap in knowledge, parallel research has been conducted by the author on the need for product end-of-life management services in both commercial (Mayers *et al* 1998) and domestic sectors. The results of these will be evaluated with respect to this methodology in a future paper (as described in Section 7).

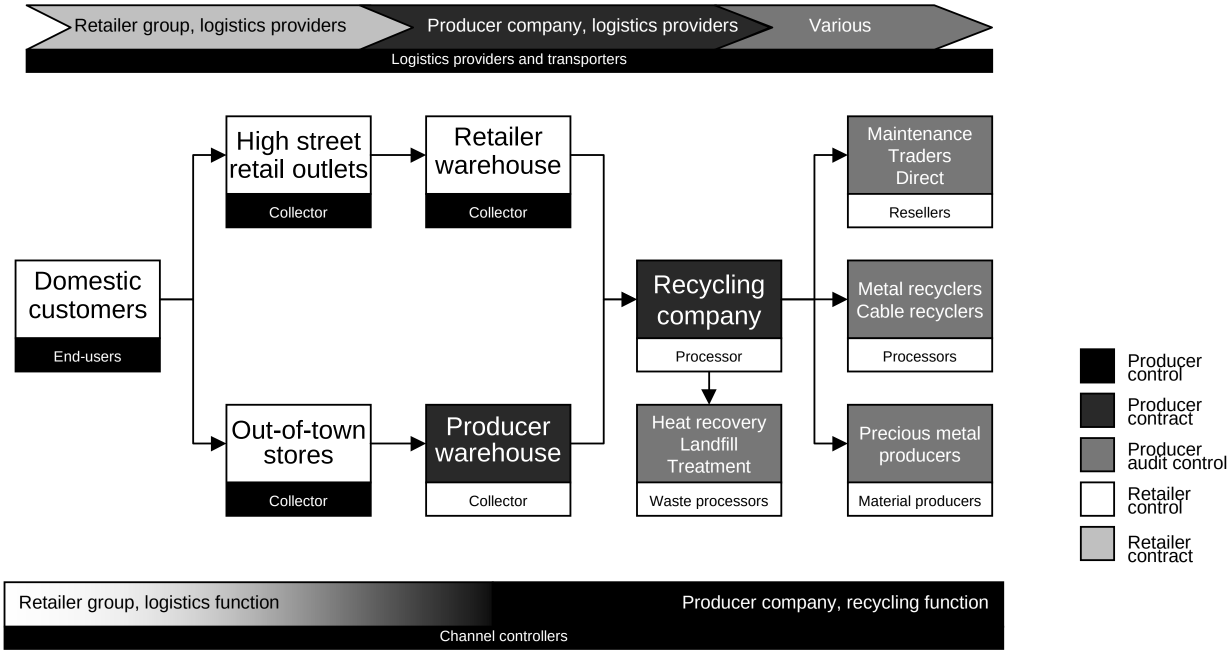
In the evaluation of the printer trade-in, the service mission was relatively simple to define given that it was a specific service offering, provided to specific customers (internal company marketing, and ultimately, the consumer): *"To provide a collection and disposal route for the resale of selected printer types, ensuring maximum material recycling and energy recovery, and controlled treatment and disposal of non-resellable printers traded-in at UK retail outlets participating in the trade-in promotion."*

Finally, dedicated end-of-life management channels must be developed as delivery mechanisms to support of each individual service mission. The "foreground" system boundary required in life-cycle assessment is determined by the equivalent structure of the end-of-life management channel under study. The end-of-life management channel set up to manage the printer trade-in is given in Fig. 3, using the process definition and terminology defined in Fig. 1.

5. Implementation and operation (Stage 2)

In the second stage of this management system, plans agreed in stage 1 are implemented and end-of-life management channels established. This requires that an appropriate network of suppliers and processes are linked together and organised to deliver agreed levels of service. Each process, or channel, must then be continually managed to ensure its integrity is maintained, its boundaries remain intact, and it is reported on separately. Good operational management is absolutely critical at this stage.

Figure 3: The printer trade-in example



6. Information collection and reporting (Stage 3)

During stage 3 (which runs parallel to stage 2), inventories of environmental impacts and costs are produced for each End-of-Life Management channel under study. The data collected at this stage must be sufficient to evaluate the environmental and financial objectives set during stage 1, and must include an identification and full reporting of all the functional "sub-systems" in the end-of-life management channel under study (Barret 1982). Records should also be made of the accuracy of data for use in data quality assessment, for example of the accuracy of weight measurements and the relevance and quality of the environmental measures used. At present, the results of the printer trade-in are awaited to begin stage 3.

To complete the mission costing of each end-of-life management channel, all costs (including divisible fixed costs that would usually be excluded from activity-based costing methods) must be attributed to relevant process variables (as shown in Table 2 for the printer trade-in) and allocated to each end-of-life management system under study. This approach is known as "attributable costing" (Shillinglaw 1963).

Towards the completion of this third stage, the environmental life-cycle assessment is undertaken incorporating additional external impact data (such as energy used in production of raw materials from virgin resources compared to resources recovered from waste) from process records, literature, and commercially available life-cycle databases. Although this assessment is principally focused on tracking the achievement of environmental objectives, the net environmental impacts of the end-of-life management channels under study should also be reviewed in order to assess the overall legitimacy of improvements made. From the literature, it appears the environmental impacts of greatest concern in the collection, treatment, recycling, and disposal of electronic products for consideration in this assessment include (Mayers and France 1999):

- Creation and dispersion of carcinogenic and bioaccumalative poly-chlorinated biphenols, dioxins, and polybrominated dibenzo-dioxins and furans
- Dispersion of metals at levels toxic to humans or eco-systems
- Energy consumption (fuel or electricity) and related environmental effects
- Carbon dioxide emissions and global warming
- Release of chloro-flouro carbons and other ozone depleting substances (from refrigerators and freezers)
- Quantity of waste disposed to landfill and related environmental effects
- Quantity virgin materials conserved and related environmental benefits

Again, specific consideration must be given in respect of the relevance of measures used and the quality of data collated if the results of the study are to be meaningful.

Table 2: The attribution of end-of-life management functional costs to process variables

	Attributable financial factors:	***Quantitative attribution factors:***
Service-level factors:	Transport	– Number of collections / pallets collected
	Sorting	– Weight / number of products received
	Storage	– Area of pallet space used
	Management and administration	– Management time
	Materials processing and dismantling	– Weight and type of materials processed
	Product refurbishment	– Number and type of products refurbished
	Treatment and disposal	– Weight / units of waste disposed
	Sales commission and profit share	– Percentage revenue / profit
Revenue factors:	Product resale	– Number and type of product resold
	Materials recycling	– Weight and type of materials recycled

Both the mission costing and life-cycle assessment exercise should include an assessment of alternative “base-line” disposal routes, for use as a basis of relative comparisons for continuous improvement. This could be a theoretical assessment of the costs and environmental impacts of disposal in landfill, and / or an actual past assessment of the previous period of operation.

7. Improvement assessment (Stage 4)

During the fourth and final stage of the end-of-life management system, data collected on the environmental impacts and costs of each individual end-of-life management channel are reviewed with respect to the original tactical service missions and overall End-of-Life Management strategic objectives and targets. Once completed, the proposed system will provide a method by which companies will be able to:

- Identify product end-users and their demands for end-of-life management services.
- Develop end-of-life management channels focused on delivering services to defined groups of end-users.
- Assess the environmental impact and cost of each end-of-life management channel.
- Identify key environmental impact and cost drivers and areas of conflict between different environmental and cost objectives.

The limitations of the proposed methodology have also been considered:

- The "mission identification" stage of mission costing, and the "scoping" stage of Life-Cycle Assessment (incorporated into stage 1 of the proposed system) involves a degree of subjectivity, which may result in errors.
- It does not indicate *how* environmental impacts and costs may be optimised.
- Different environmental impacts may not be directly comparable.
- It is limited by the quality and availability of data.
- It is limited by the time frames in which data must be collected.

As an example, based on some initial results of the printer trade-in to date, key cost drivers have been identified. The mission costing approach revealed that the cost of managing the printer trade-in (the channel control or management cost) was around 11% of total channel costs (based on an attribution of management cost by share of management time involved). The traditional management accounting approach (allocating total management cost on the basis of total weight processed for all end-of-life management channels) indicated somewhat spuriously that this management overhead constituted 60% of total costs. In addition, the latter approach does not provide the complete cost of the printer trade-in channel (it only includes the total direct "functional" processing costs of the trade-in to the producer). If in the next period of operation, a 10% cost reduction were targeted, the latter method would erroneously indicate that channel management would be a good target for cost reduction.

Finally, stage four must include a decision framework that will allow objective and defensible recommendations and decisions to be made on the objectives and targets of the next planning period, thus completing the loop back to stage 1, policy development and planning. This will be included along with an analysis of the detailed results of this study in a future paper, and is not discussed further here. Given the data gathered so far it is not possible to draw any conclusions for the improvement of the overall environmental performance and commercial viability of the printer trade-in.

8. Conclusions

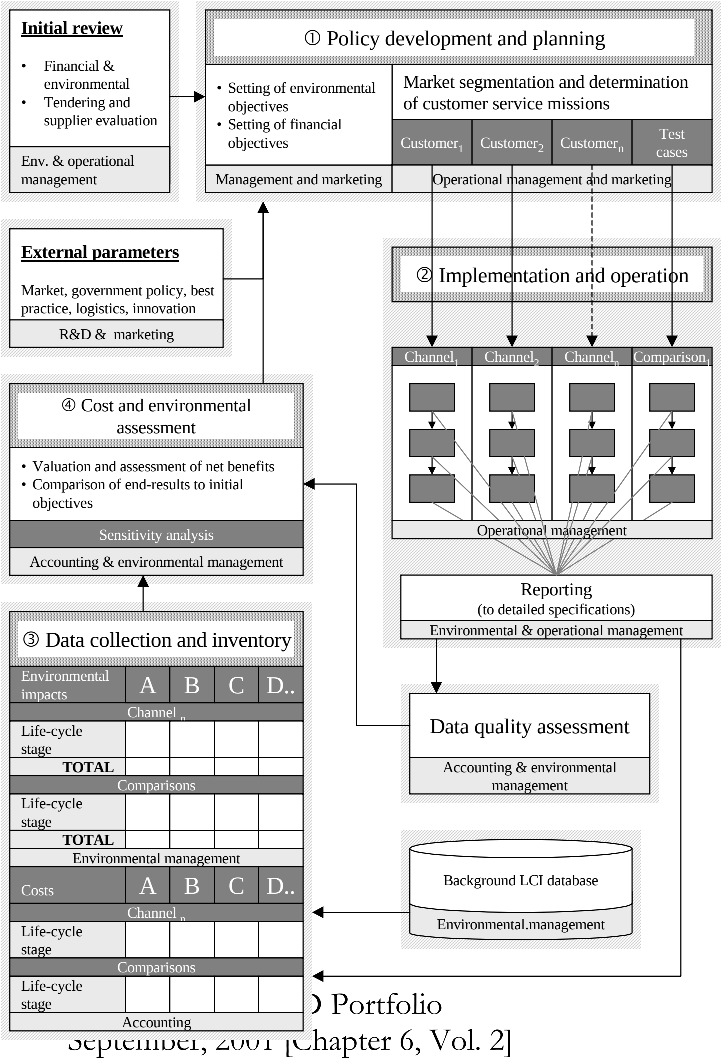
It is intended that this methodology will provide Producers of electronics equipment, and other organisations concerned with the organisation and control of end-of-life management processes for electronic products, with the means to develop competencies in waste and environmental management to meet the future needs of Producer Responsibility legislation. A complete overview of the proposed end-of-life management system has been provided in Fig. 4.

At the time of writing the methodology was still under development and testing. Areas for subsequent evaluation, development, and methodological expansion include:

- Completion of the inventory stage of the printer trade-in and subsequent analysis of mission costs and life cycle environmental impacts.

- An assessment of the additional cost overhead of operational and environmental management and reporting required in implementing this methodology.

Figure 4: The proposed end-of-life management system



- An assessment of the effectiveness of supply-chain management and life-cycle assessment software tools in reducing administrative cost overheads of the proposed methodology.

- The development of a decision framework by which decisions based on the assessment of environmental impacts and costs may be qualified using defensible and objective management criteria.

Once completed, the full results if this study will be included in a subsequent paper.

Acknowledgements

The first author would like to acknowledge all those who involved in the printer trade-in for their help in the implementation and development of the end-of-life management system.

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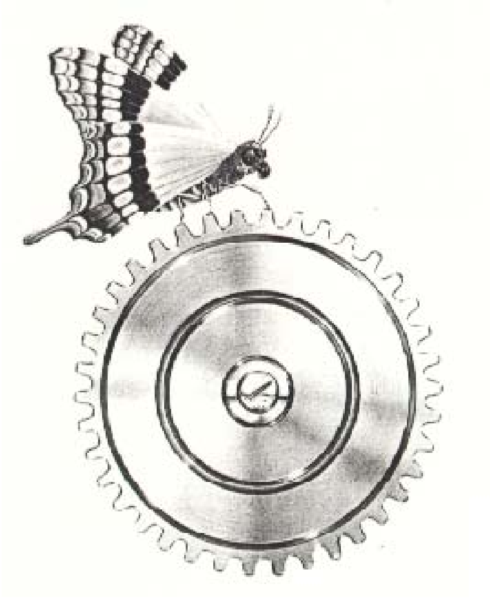
Brunel and Surrey Engineering Doctorate Programme in Environmental Technology

Chapter 7, Vol. 2

An Investigation of the Implications and Effectiveness of Producer Responsibility for the Disposal of WEEE.



42 month report

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Abstract

This report is the 42-month report submitted as a requirement of the Engineering Doctorate programme in Environmental Technology. This research concerns the improvement of the environmental performance and commercial viability of End-of-Life Management processes for electronic products.

The report is split into four sections. In the introduction the research is summarised. In the second section research progress compared to plan is reviewed. In the third section, the composition of the portfolio, and a plan for its completion are outlined. Overall conclusions are given in Section 4.

The report concludes that satisfactory progress has been made over the last six months, but that continued effort is now necessary to ensure timely completion of the project portfolio.

Contents

1. Introduction

This 42-month research report is the seventh of a series of 6-monthly progress reports required as part of the Engineering Doctorate programme. A summary of the research completed to date is provided below.

1.1 Research development to date

To date the research has proceeded without major interruption or delay, as can be seen from previous six-month reports. Following feedback from a mid-term *viva-voce* at the 24-month stage, it was determined that the research should result in a body of knowledge sufficient for a doctorate at the end of the four-year project. Certainly, significant contributions to knowledge have already been identified for this research (Mayers and France 1999).

In the previous 36-month report it was concluded that overall, the project was on-track for completion in April. However, the importance of preventing further project slippage was emphasised.

1.2 Research summary

The research programme consists of a diverse range of elements (summarised in Fig. 1.1 above, and explained further below). Consequently a wide range of literature has been consulted, covering aspects of environmental management and impact assessment, logistics[1] and waste management, financial accounting, and social and market research. Various gaps have revealed in the state of knowledge on End-of-Life Management. Consequently research studies (shown in Fig. 1.1) have been undertaken to address these gaps, including:

- The organisation of collection, treatment, and recycling processes for end-of-life electronic equipment through the development of an End-of-Life Management system.
- Financial analysis of End-of-Life Management processes for electronic equipment through Mission Costing
- The analysis of the environmental impacts of End-of-Life Management processes for electronic equipment through Life-Cycle Assessment.
- Social and market research on the use and disposal of electronic products
- Case studies on best practice in reverse logistics for waste electronic products
- Analysis of Producer Responsibility policies for WEEE

Figure 1.1: Overview of research presented in this portfolio

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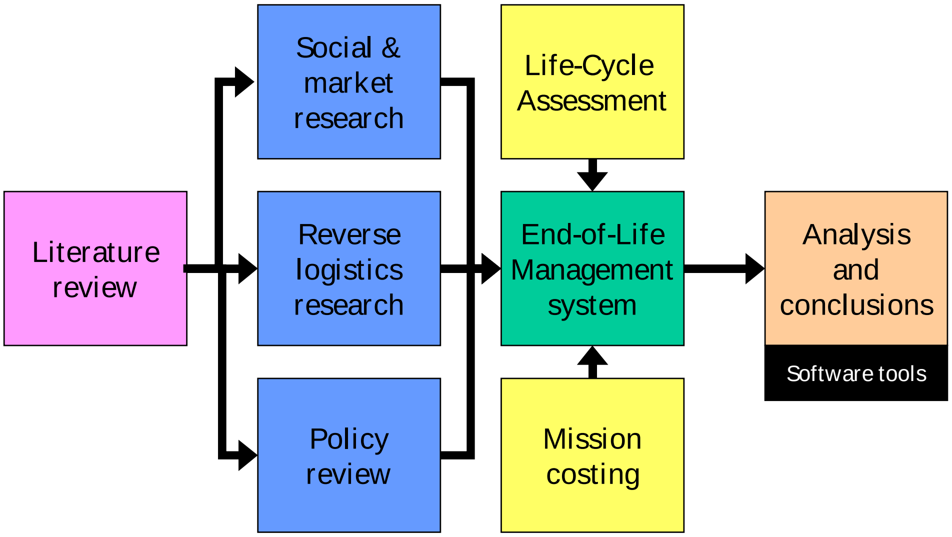
[1] "Logistics" is a term that appears not to have been defined in the literature. In the case of this work it is used to describe activities involved in physical distribution management, which includes the organisation and management of material flow through processes in a supply chain.



The main outcome of these studies has been the development of a system for managing end-of-life electronic products. This system has been tested using examples of product collection, treatment, and recycling processes from the sponsoring company, Hewlett-Packard Limited. Research tools employed in this work include environmental Life Cycle Assessment and Mission Costing. Mission Costing is a financial analysis technique developed for use in logistics, allowing the attribution of common logistics costs across different logistics channels[2].

In this study it has been shown how the combination of these methods can enable the environmental performance and commercial viability of End-of-Life Management processes to be addressed and improved simultaneously. This has been demonstrated by drawing upon practical examples of End-of-Life Management processes taken from the sponsoring company, Hewlett-Packard Limited (HP).

The implementation of the management system and the effectiveness of its results have been contextualised by extensive studies on the way in which society (including householders and commerce) use and dispose of electronic appliances. In reaching the conclusions of this research, use has been made of Life Cycle Assessment software (TEAM). In addition, the conclusions reached in this research have been used in the development of a new software tool to provide decision support in End-of-Life Management, combining both financial and environmental factors[3].

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[2] In this work a "channel" is defined as a vertical marketing or distribution system (after Gill & Allerheiligen 1981). It can be defined as the route taken by a product in its journey through a supply chain to its first user (customer). With respect to End-of-Life Management, it can be defined as the route taken by an end-of-life product from its last user through an End-of-Life Management process.

[3] This project has been sponsored by the European Commission as part of the Enterprise Logistics Cluster of the ESPRIT programme. The title of this project is RELOOP (Reverse Logistics Chain Optimisation in a Multi-User Trading Environment)

1.3 Report summary

In the following two sections of this report, a review of project progress compared to plan and a summary of the agreed final portfolio composition are provided.

2. Progress overview

In Section 2 of the previous 36-month report, a detailed project plan including objectives and deliverables was presented and reviewed. A review of project progress to date compared to this plan is presented below (and is summarised in the "tracking" Gantt chart in Fig. 2.1). The review covers three specific areas:

- Deliverables completed to plan
- Deliverables delayed and "off-track"
- Changes to the project programme

This does not include discussion of deliverables currently in progress and "on-track". A copy of the full project plan has been included in Appendix 1 for further information.

2.1 Progress summary

Deliverables completed to plan since the 36-month report include:

- Literature review update: The literature has been updated and combined with each of the individual portfolio reports (see task 1 in Table 2.1). Future updates to the literature review will occur through the completion of individual project reports. (*due 31/12/99, completed*).

- EOLM system methodology: The management system methodology has been fully developed and refined (see task 5.1 in Table 2.1). This has involved both literature review and testing within the sponsoring company, Hewlett-Packard Limited (*due 28/02/99, completed*).

- Life-cycle inventory: A life cycle inventory has now been completed on the HP printer trade-in process (as shown in task 5.4 in Table 1.1 below). The completion of this inventory had previously been delayed through problems obtaining access to the LCA software tool, TEAM (*originally due 31/12/99, completed 31/03/00*).

- Redundant IT paper: A paper reporting on the results and findings on the Redundant IT study has been submitted and accepted for review in the Journal of Industrial Marketing (see task 7 in Table 1.1 below, *completed 31/12/99*).

- Social and market research report(s): The results and findings of studies on the use and disposal of household appliances in commercial and domestic sectors have been reported in two separate volumes (see task 12 in Table 1.1 below, *due 31/12/99, completed*).

Table 2.1: Research progress overview

■ Actual progress to date ▨ Project plan

Task	1998-1999				1999-2000				
	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Deliverable / output
1. Literature review & 6 monthly updates	■ ▨	■ ▨	■ ▨	■ ▨	■ ▨				☑ Literature review completed (31/12/99)
2. Producer Responsibility research	■ ▨	■ ▨							☑ Proposal presented to the DTI (05/02/99)
3. Market and social research	■ ▨	■	■						☑ Market research completed (31/05/99)
4. Best practice study	■ ▨				Originally due Jun 98				☑ Study report completed (31/12/98)
5.1 EOLM system methodology development	■ ▨	■ ▨	■ ▨	■ ▨	■ ▨	■ ▨			☑ System methodology completed (28/02/00)
5.2 EOLM data requirements specification	■ ▨	■ ▨	▨						☑ Requirements specified (01/03/99)
5.3 Implementation and testing of mission costing method			■ ▨	■ ▨	▨				☑ Mission costing completed (30/08/99)
5.4 Implementation and testing of life-cycle assessment method				■ ▨	■ Originally due Dec 99	■			☑ Life-cycle inventory completed (31/03/00)
5.5 Evaluation of decision-making frameworks									Task redefined and combined in task 7.3
Academic papers	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Submission date
6 Producer responsibility paper	■ ▨	■							☑ 31/01/99, published Greener Management International
7 Use and disposal of IT equipment in companies	■ ▨	■	■	■	■				☑ 31/12/99, paper submitted for publication
8 Reverse logistics structures and methods									☐ TBA
9 Disposal of household appliances			■ ▨	■ ▨	■ ▨	■ ▨	▨	▨	☐ For completion 31/07/00
10 EOLM conceptual paper									☐ 31/09/00
Version 1 portfolio reports	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Submission date
11 Reverse logistics "best practice study	■ ▨								☑ Completed 31/12/98, possibly to be improved
12 Social and market research report	■ ▨	■ ▨	■ ▨	■ ▨	■ ▨				☑ 31/05/99, now for completion 31/12/99
13 EOLM report development			■	■	■	■ ▨	▨		☐ 28/04/00
14 Portfolio executive summary		Originally due Apr 00			■	■ ▨	▨		☑ 10/01/00: Executive summary completed
15 Portfolio conclusions section						■ ▨	■ ▨		☐ 24/04/00 (new task)

- Portfolio Executive Summary: The portfolio executive summary has now been completed well ahead of the project plan (see Task 14 in Table 1.1 above) to aid completion of other project reports (*due 30/04/00, completed 10/01/00*).

No deliverables are reported as "***off-track***" in this period, although two deliverables have been changed:

- The evaluation of decision frameworks: It was decided that a detailed review of decision-making frameworks was beyond the scope of this research. Alternatively, the report on the management system methodology should include a review of decision-making processes in LCA, mission costing, and continuous improvement. Therefore, this task has been included in the write-up of the management system report (see task 5.5 in Table 2.1 above).

- Portfolio conclusions: A new volume has been added to the portfolio to report on the overall conclusions to the project. This should not result in additional work as originally this section was to be included in the management system report (see task 15 in Table 2.1 above).

3. Portfolio review plan

The portfolio composition has been agreed with the project supervisors (as summarised in Sections 3.1 and 3.2). In addition, a review plan has been agreed for the preparation of each research report for final submission (as shown in Table 3.1).

Table 3.1: Supervisors review plan

Report	Version					
	1		2		3	
	Submitted	Reviewed	Submitted	Reviewed	Submitted	Reviewed
Executive summary	**10/01**	**31/01**	**01/03**	16/03 : **ZJ**	08/05	12/05
Journal papers						
Redundant IT study	**Reviewed 1998**		**03/04**	07/04		
E-SCOPE survey	**31/12**	**15/01 : ZJ**	**24/03**	31/03 : CF		
Reverse logistics study	**Reviewed 1998**		01/05	05/05		
EOLM report	**25/03**	31/03 : ZJ	10/04	14/04		
Conclusions	24/04	28/04				
Overall portfolio	29/05	02/06				

Key:

ZJ	– Zoe Jackson
CF	– Chris France
xx/xx	– On-track
xx/xx	– Off-track

3.1 Portfolio composition

The project portfolio will be divided into two main parts. Part 1, which includes this Executive Summary, contains of seven different volumes:

- Volume 1: Executive Summary
- Volume 2: Journal papers arising from this work
- Volume 3: The use and disposal of IT products by UK companies
- Volume 4: The use and disposal of household appliances in the UK
- Volume 5: European Case Studies in Best Practice in Reverse Logistics

- Volume 6: The development of a system to improve the environmental performance and commercial viability of processes for the management of end-of-life electronic products

- Volume 7: Overall conclusions (including future work and limitations)

Part 1 has been designed to cover all of the background, development, and conclusions of the work submitted for the EngD degree. Part 2 comprises of the 6 month reports, submission of which is a requirement of the EngD programme. Part 1 contains a full account of the research, in a linear and readable form, whereas Part 2 is largely redundant and the reader is advised that it need not be read to consider this thesis.

The Engineering Doctorate Programme requires that 6-monthly progress reports are submitted to the portfolio. These describe in-detail the status of the project at different stages over the four-year research period. Part 2 contains these 8 progress reports in chronological order (Vol. 1-8, Part 2).

3.2 Reader's guidelines

Readers may pursue one of three different reading options. It is recommended that the Examiners follow option 3:

1. For a research overview: Read only the Executive Summary (Vol. 1, Part 1), and use other volumes for reference as necessary.

2. For an abridged version of the research: Read the Executive Summary (Vol. 1, Part 1) followed by the management system report (Vol. 5, Part 1) and the overall research conclusions (Vol. 7, Part 1). All other reports may be used for reference where necessary.

3. For a full version of the research: Read all of volumes of Part 1 of the thesis in sequence (Vols. 1 to 7, Part 1).

4. Conclusions

In this 42-month project report for the Engineering Doctorate programme, progress has been reviewed with respect to the research plan, and the project aims and objectives updated.

Deliverables completed in the last six-month period include:

- An update to the literature review
- The finalisation of the management system methodology
- A life-cycle inventory for the printer trade-in example
- The submission of a paper on the redundant IT paper
- The completion of social and market research report(s) for the research portfolio
- The completion of an overall Executive Summary for the research

No deliverables were reported as "off-track", although some were completed ahead of plan. Various changes were made to the project programme, including:

- The removal of the requirement to evaluate decision frameworks
- The addition of a volume on research conclusions to the portfolio

Overall, the project is at present on-track for completion in April / May. However, it is essential that efforts are maintained to ensure all deliverables are completed to plan, and preferably ahead of plan.

References

Mayers, C.K. (1999). The development of environmentally legitimate and commercially viable End-of-Life Management processes for electronic products. 30/03/99, 36-month Engineering Doctorate project report, held at the Department of Manufacturing and Engineering Systems, Brunel University, United Kingdom.

Appendix 2: Research progress overview

Research objectives and deliverables:

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1. **To complete an extensive literature review covering End-of-Life Management of electronic products under Producer Responsibility**

(1)	Initial literature review:	**Completed 01/04/96**
(2)	Literature review updated:	**Every 6 months until 31/12/99** **Completed 17/07/98** **Completed 31/04/99** **Completed 31/12/99**

2. **To evaluate constraints and opportunities from the development of UK and European Producer Responsibility legislation for end-of-life electronic products.**

(1)	Critical review of legislative developments:	**Completed 31/08/98**
(2)	Legislative matrix updated:	**Completed 31/01/98** **Completed 31/11/98** No further updates required, incorporated into literature review

3. **To verify patterns of use and disposal of end-of-life electronic products in the commercial and domestic sectors, and to identify the scope for end-of-life product management services**.

(1)	Commercial sector IT study (the redundant IT survey):	**Completed 15/08/98**

(2) Domestic sector study (the E-SCOPE project): **Due 31/12/99, completed 31/09/99**

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4. **To explore issues in reverse logistics "chain management" by identifying strategies, structures, and methods to give an overview of current practice and establish a basis of comparison between systems.**

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(1) Minimum of ten case studies completed: **Due 31/10/98, completed 17/10/98**

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5. **To propose, develop, and implement an effective End-of-Life Management system based on critical drivers of cost and environmental impact, and to evaluate effective End-of-Life Management strategies using both cost and environmental parameters.**

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(1) End-of-Life Management methodology defined: **Due 28/02/00, completed**

(2) Data collection requirements defined: **Due 01/04/99, completed 01/03/99**

(3) Mission costing approach completed for selected End-of-Life Management process(es): **Due 31/10/99, completed 31/09/99**

(4) Life-cycle assessment completed for selected End-of-Life Management process(es): **Due 31/12/99, completed 31/03/00**

(5) Evaluation of decision making frameworks (assessment stage): **Requirement removed**

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6. **Publish papers relevant to research focus in academically vetted journals within four months of completed research.**

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(1)	Producer responsibility paper submitted:	**Due 31/10/98, submitted 15/01/99**
(2)	Paper on redundant IT study:	**Due 31/12/98**, **submitted *on-track*.**
(3)	Paper on Best Practice Study:	**Due 31/04/99**, first paper by other authors submitted and accepted into IEEE conference proceedings. Second in depth paper planned, submission date to be agreed.
(4)	1st paper on E-SCOPE study (disposal behaviour):	**Now expected 30/07/00**
(5)	Paper on EOLM system method:	**Due 31/09/00, *on-track***

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7. To complete all reports on all research projects necessary for the completion of the EngD portfolio

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(1)	Market research report on redundant IT and E-SCOPE studies:	Redundant IT study report: **due 31/05/99**, **completed** E-SCOPE report: **due 31/12/99, completed**
(2)	Best Practice study:	**Due 31/12/99, completed 31/12/99** Possibly to be edited and improved
(3)	Project report on EOLM study:	**Now due 10/04/00**
(4)	Project portfolio completed for informal peer review including necessary covering documents:	**Now due 02/05/00**
