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A Decision Support System for End-of-Life Products

In one volume

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Declaration

I hereby declare that the work presented in this thesis is my own and that it has not been used to obtain a degree in this university or elsewhere.

Laurentiu Dimache

To my wife Aurora
and my family

Abstract

In recent years public awareness of environmental issues has increased dramatically. This awareness has resulted in increased governmental control of related matters, for example, of waste and of industrial emissions. Consumer and legislative pressures are forcing manufacturers to broaden the manufacturing system to include product take-back and recovery. A take-back system necessitates good logistics and information systems.

This thesis proposes a decision support system that assists in decision-making in relation to end-of-life (EOL) products. There are several options at the end-of-life of a product: reuse/part reclamation, remanufacturing, recycling, incineration (with or without energy recovery) or discard to landfill. Each option has an economic and an environmental impact. The impacts are described by indicators that have specific values for each option. Decision-makers – who may be recycling companies, original equipment manufacturers or local authorities – need to determine which option, or combination of options, is best in a given situation. A mathematical model to assist in this decision is proposed. The model is based on vectors that contain indicators' values for each EOL option. A generic EOL scenario, which may comprise a combination of EOL options is expressed as a linear combination of options. This modelling approach permits the use of linear algebra tools in expressing and solving problems related to EOL scenario of products such as: calculate the best scenario structure given the targets set by the EU WEEE Directive and the EOL options vectors; solve 'What If' situations; when used in combination with a multi-criteria analysis method (such as AHP), identify the best EOL option from an environmental and economic point of view. Based on the mathematical model and the Business Process Reengineering methodology, the decision support system for end-of-life products is developed.

Published Work Associated with This Thesis

Dimache, Laurentiu; Dimache, Aurora & Goggin, Kate – *Products End-of-Life Scenario Modelling Using Linear Algebra*, Proceedings of the 13^{th} SETAC (Society of Environmental Toxicology and Chemistry) Conference, April 2003;

Dimache, Aurora; Dimache, Laurentiu & Goggin, Kate – *Analytical Hierarchy Process (AHP) in Decision-Making for End-of-Life of Products*, Proceedings of the 2^{nd} Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems, June 2003.

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Chapter 1. Introduction

1.1. Introduction

Resource recovery, the recovery of functional or material value from products at end-of-life, is an area currently receiving considerable attention from policy makers, from product manufacturers, from engineering researchers and from the general public [Gog98]. At all levels, national and international, sustainable development, polluter pays principle and extended producer responsibility are being taken into account in setting strategies and plans for further change and development.

Sustainable development, polluter pays and extended producer responsibility are basic fundamentals that govern all the phases in a product life cycle. As the end-of-life is the last phase in the cycle, it makes sense discussing end of life of a product bearing in mind the mentioned principles.

Environmental laws that put pressure on firms to take back their products and take care of further treatment are becoming a reality. An example of this is the Draft Directive of the European Parliament and of the Council on waste electrical and electronic equipment (WEEE) which sets recovery targets and assigns responsibilities for the "collection, treatment and environmentally sound disposal" of WEEE [WEEE02].

1.2. Thesis Motivation

As the result of legislative and consumer pressures, manufacturing can no longer be considered a simple open system into which flow various resources for conversion, and out of which flow products, wastes and pollution. A much more extensive view of manufacturing should be taken.

If we consider the systems view of manufacturing, and track the consequences of manufacturing and design decisions throughout the entire product development cycle, this would take us through (1) raw materials production, (2) manufacturing, (3) the use phase, and finally to (4) the end of life phase. This is far broader view of manufacturing than the one that simply looks at the consumption, wastes and pollutants occurring at the factory. These two different views of manufacturing can be seen in figure 1.1.

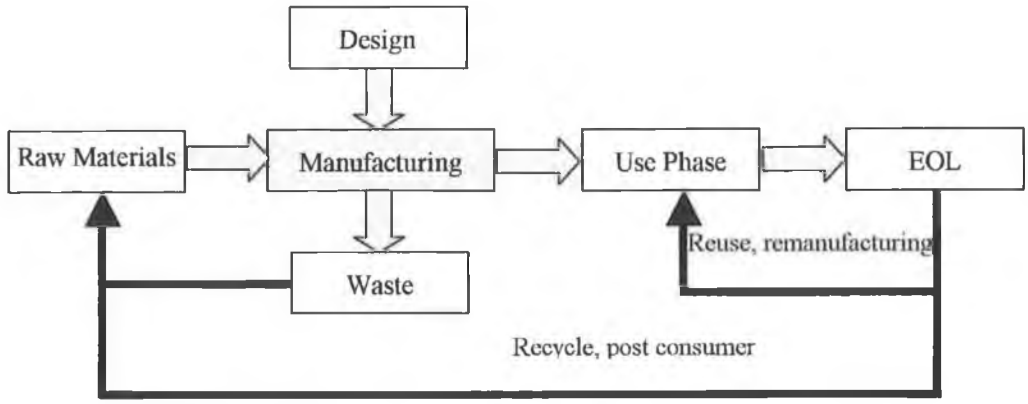


Figure 1.1. Two different views of manufacturing: open system and closed-loop system [Gut01]

It has become clear that integrating manufacturing into a sustainable society requires the broader systems view which includes resource recovery through reuse, remanufacturing (product recovery) and recycling (materials recovery).

Product take-back for recovery activities are currently being actively promoted as a means for reducing the effects of manufacturing on the environment. But this initiative is not backed up with models to support recovery organisation and activity. The main deficits that exist in relation to recovery are decision support which is required in all areas of recovery, producers having no historical experience to assist them, and business models that are needed to provide a basis for recovery.

1.3. Thesis Structure

This thesis presents a model of decision support system applicable to waste electrical and electronic equipment. The model is developed to facilitate compliance with the EU Draft Directive on waste electrical and electronic equipment (WEEE Directive) and aims to offer support in decision-making for recovery of electrical and electronic products.

Chapter 2 highlights the impacts of manufacturing on the environment, causes of concern for both authorities and the public. The consequences of this concern are: new environmental legislation to force product take-back for recovery; eco-labelling programs to facilitate the choice of consumers; international and regional standards to support producers in their attempt to include environment in their business decisions. Special attention is given to product take-back legislation in the area of electrical and electronic equipment. Design to support recovery is also addressed in this chapter.

Chapter 3 is a review of logistics related to take-back. It presents product take-back policies as a consequence of the extended producer responsibility principle together with some examples in the electronics industry. The complex area of reverse logistics as required for product take-back is investigated and the deficit related to information systems to support reverse logistics highlighted.

In chapter 4 the area of information systems, especially decision support systems as a particular type of information systems, is addressed. This chapter reveals the necessity of development of a business area model before attempting to develop a decision support system, therefore some methodologies (such as CIMOSA and BPR) and methods (SADT, IDEF family) are investigated for potential application to the model.

In chapter 5 the decision support software system for end-of-life products is developed. The model is based on the EU WEEE Directive and can be applied to end-of-life electrical and electronic goods. It proposes BPR as the methodology to be used in the development of the decision support system and IDEF methods to model functionality and processes. The model can support decisions regarding the best end-of-life options from an environmental and economic point of view, allow 'What If' situations to be modelled and perform goal seeking analysis in terms of minimising cost of recovery or maximising recovery percentage. A software application that supports the decision model is presented in this chapter as well. The software application is structured into two main components: a database and a front-end application. The front-end application includes a graphic user interface that guides the user in the process of introducing data and retrieving information. The software structure is detailed with examples in chapter 5 and a CD containing the prototype software enclosed at the back of the thesis.

Finally, chapter 6 concludes the thesis. In this chapter the thesis is summarised and conclusions drawn while developing the thesis are noted. Recommendations are made for further work.

1.4. Conclusions

Recovery of end-of-life products is increasingly being promoted as a means of reducing the environmental burden manufacturing places on the environment. Manufacturing faces increasing pressures that mandate product take-back for recovery. The difficulties producers envisage are deficits in the area of information system and decision support for reverse logistics. This thesis tries to address these problems.

Chapter 2. Product Recovery – A Necessity

2.1. Introduction

Manufacturing is one of the oldest economic activities of humanity and is full of tradition and craft. Like all important human enterprises, manufacturing is subject to constant consideration and to constant technological change. Technological development has evolved from craft through small batch production to mass production to automated and integrated production.

As production increased, the amount of waste increased and so did the impact on the environment. All manufacturing processes interact with the environment. Every industry is different, so each has a specific impact. That is the reason why manufacturers are increasingly called on to widen their range of vision to include environmental issues.

Traditionally, manufacturers did not feel responsible for their products after consumer use. The bulk of used products were dumped or incinerated with considerable damage to the environment. Today, consumers and authorities expect manufacturers to reduce the impact on environment generated by their end-of-life products.

2.2. Impacts of Manufacturing on Environment

Manufacturing is one of the few ways that wealth is created. It can be defined as *"the transformation of material into something useful and portable"* [EM565].

Among industrial activities manufacturing's impact on the environment is enormous. Manufacturing industries are dominant in their environmental impact in such areas as toxic chemicals, waste, energy and carbon emissions. It is also a heavy user of water, and there have been many cases of air, water and soil contamination.

Figure 2.1 shows an EPA (USA) survey on toxic releases from different industrial activities. Among the industries selected by EPA for toxic materials monitoring, manufacturing releases are larger than all other activities, with the one exception of metal mining, which is closely related to manufacturing.

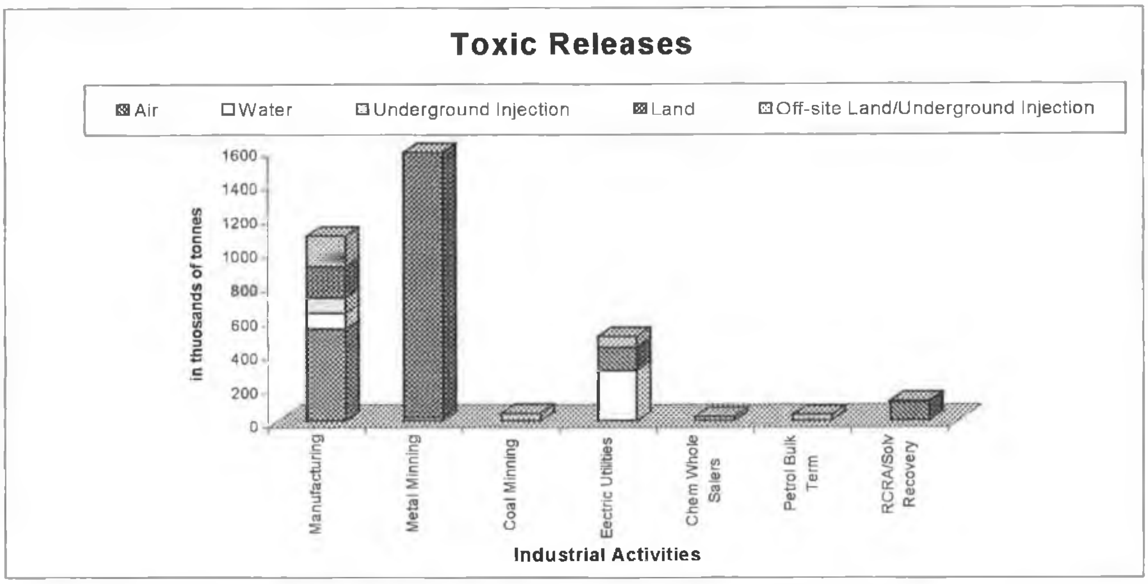


Figure 2.1. Toxic releases in USA by category in 1998 [Gut01]

In Figure 2.2 the total waste generation by sector in the EU is presented. It is illustrated that manufacturing is one of the most waste generating industrial activities.

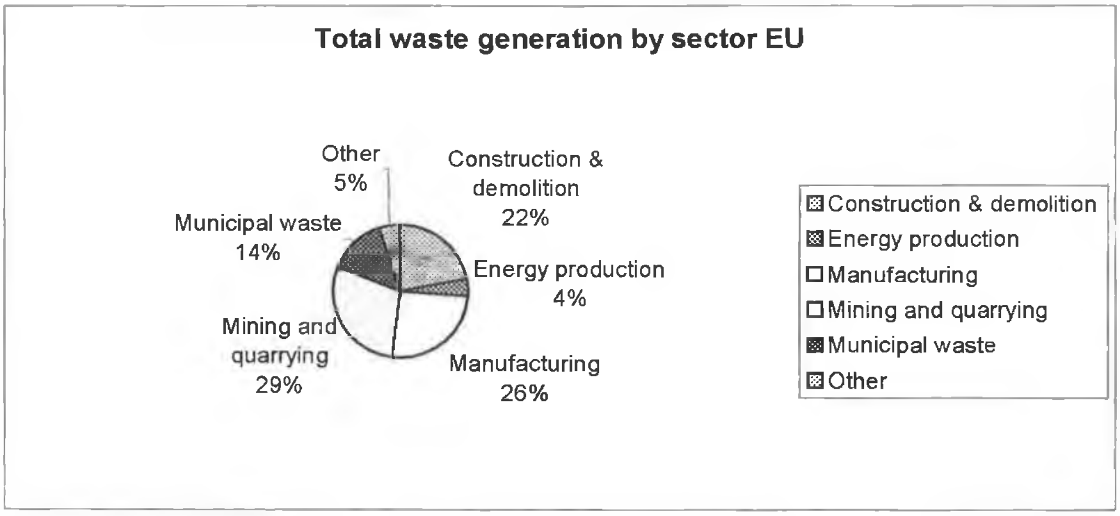


Figure 2.2. Total waste generation by sector in EU countries 1992-1997 [EEA01]

In terms of energy usage, manufacturing dominates all other industrial activities, taking up to 80% of the total [Gut01]. And because most of energy consumption is from carbon-based fuels – oil, natural gas and coal – manufacturing's contribution to carbon emissions is again dominating all industrial activities.

The nature and extent of the environmental impact varies by manufacturing sector. The environmental impacts are often quite large for industries such as the metals or plastics (often categorised as chemicals). For example, in terms of toxic releases, plastics, chemicals, primary metals and fabricated metals collectively account for 63% of all manufacturing releases (see figure 2.1) [Gut01]. Similarly, chemicals and primary metals play a primary role in carbon emission and energy usage.

In conclusion, when all the factors presented above are considered, we can say that manufacturing is perhaps the most significant industrial activity in terms of environmental impacts.

2.2.1. Impacts of Metal Manufacturing on Environment

Traditional metal manufacturing involves mining, casting, machining, forging and surface protection (painting and coating). There have been substantial improvements made to these processes to ameliorate their impact on the environment, and research is continuing to decrease their environmental load. These efforts are driven by a variety of pressures, but all are focused on more efficient use of metals, alloys, and energy, as well as the total costs of production.

The major contributors to environmental problems from metal manufacturing are [Gut01]:

- *Casting* – When molten metal is poured into the mould, the thermal decomposition products from the coal and resins are released into the atmosphere. These decomposition products include greenhouse gases and other gases that are listed in the list of hazardous air pollutants.
- *Machining* – The coolants and lubricants used in machining generate water pollution and air quality problems, and can contaminate scrap used in remelting.

- *Metal forming and forging* – The impacts on environment are related mainly to energy and materials usage.
- *Joining* - If products are joined too well (as in welding) they cannot be disassembled for repair, or reuse. Adhesives may be used, but they do not degrade in the environment.
- *Coating* - The primary problem in painting has been the use of organic solvents as the vehicle for pigments. These solvents require extensive treatment of the exhaust air from the painting operations before the air can be released to the atmosphere.

Regarding the aluminium industry, it can be said that the main problems related to the environment are: energy consumption, perfluorocarbon emission and greenhouse gases generation. But remelting of aluminium to secondary ingot or aluminium products saves 90-95% of the energy required for primary ingot production [Rhy95].

2.2.2. Impacts of Plastics Manufacturing on Environment

Plastics have a poor environmental image in large due to their contribution to litter and landfills. But major environmental impacts occur early in their life cycle in the petroleum and chemical industries during processing, where they contribute to volatile organic compounds, hazardous air pollutants, waste, wastewater, and energy related impacts.

Table 2.1. Some potential environmental problems with plastics [Gut01]

Phase	Problem
Petroleum extraction, refining	Leaks, spills, releases, solvents, energy, hazardous air pollutants, VOCs, waste and wastewater, use of non-renewable, limited resources
Primary conversion	Toxic materials, energy usage, hazardous air pollutants, VOCs, waste and wastewater
Processing	Hazardous air pollutants, VOCs, hazardous materials, waste and wastewater
Use	Out-gassing, unreacted monomer, release of residual solvents, degradation and failure of the product, interaction with environmental liquids, acids, foods, etc.
End of life	Solid hazard, litter, leaching, hazardous release during incineration, unsustainable

The potential environmental impacts associated with different life-cycle phases of plastic products are listed in table 2.1.

2.2.3. Impacts of Electronics Manufacturing on Environment

Electronics manufacturing can be divided into several sub-industries. These are wafer fabrication and chip-level packaging, printed wiring board manufacture and board-level assembly, display manufacturing and final assembly (see figure 2.3).

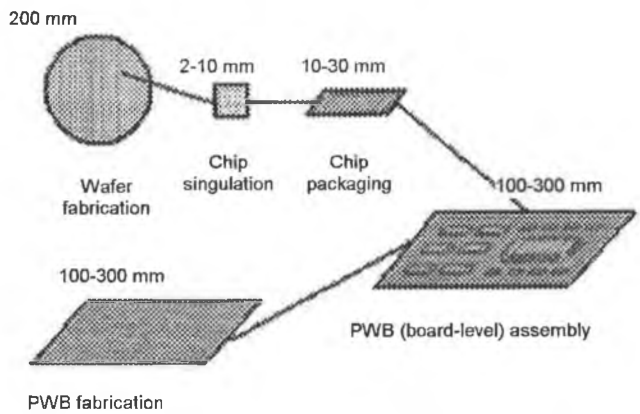


Figure 2.3. Integrated circuits fabrication steps [Gut01]

While the electronics industry is not a highly toxic one – with only 1.6% of total toxic release emissions [Gut01] – the processes used to manufacture the components can be extremely materials and water consuming. An important area of concern is the use of hazardous materials that have a huge environmental impact if the electronic products are discarded to landfill at the end of their useful life.

Displays

Computer displays are predominately cathode ray tubes (CRT's); an increasing number of displays are flat panel displays (FPDs) that are used either in laptop or as stand-alone desktop units. During the manufacture of CRT's, the environmental issue is energy consumption due to the extreme temperatures used to form the glass. The biggest concern surrounding CRT's is the lead that is contained in the funnel glass and in some panel glass and its potential effect on ground water supplies if placed in landfill.

Other components

Nickel/cadmium batteries are a problem due to the cadmium. However, with the shift to lithium batteries, this will be a problem only with older products at the end of life.

Storage media, specifically hard drives, have been manufactured using process similar to wafer and printed wiring boards fabrication and have similar problems with water consumption and plating bath solutions.

2.3. Drivers of Product Recovery

The impact of manufacturing on the environment cannot be neglected. As shown in the previous section, it appears during the actual manufacturing process as emissions to air, water and soil, energy and materials consumption, as well as after, during the consumer phase of the products life cycle and especially at the end of their useful life. Waste is a difficult problem society faces today. Governments, industries and the public have been receptive and responsive to the waste problem. Therefore, manufacturers have started to show more interest in producing products that are environmentally friendly and which will be taken back at the end of their useful lives for recovery (reuse, remanufacturing, recycling).

Thus, the system producer/consumer changes from an open system as in figure 2.4 to a closed-loop system as shown in figure 2.5. In the first case all materials included in the product will be disposed of when the product reaches its end of life. When a take-back for recovery system is implemented, the loop is closed and product or material reuse becomes possible; energy and materials consumption during manufacturing reduces and what reaches landfill is less and is controlled in terms of hazardous waste.

Increasing responsibility is being placed on firms to take back used products and packaging materials for recovery. The main pressures put on producers to become active in recovery activities are [RL03], [Gog98]:

- The growing environmental consciousness of consumers;
- Competitive pressures from companies in the same industry;
- Eco-labels;
- Industry standards on environmental protection at international and regional level;
- Environmental laws that force firms to take back their products and take care of further treatment.

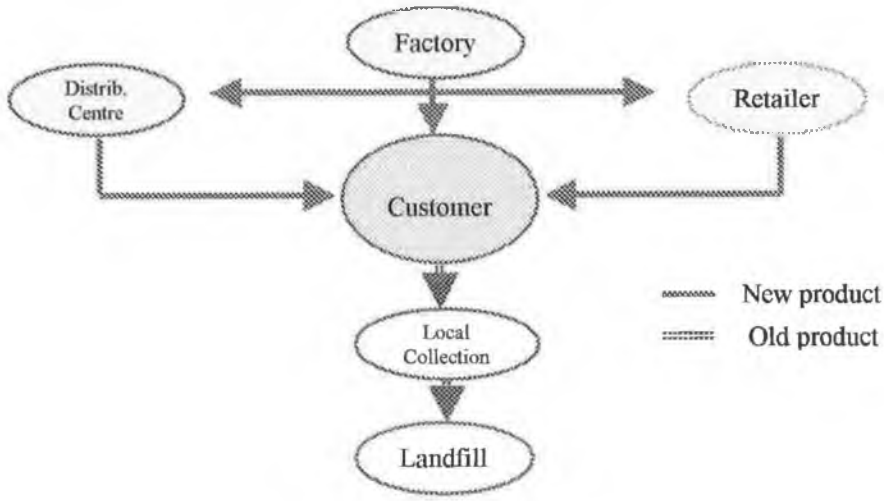


Figure 2.4. Open loop system [modified from R&L98]

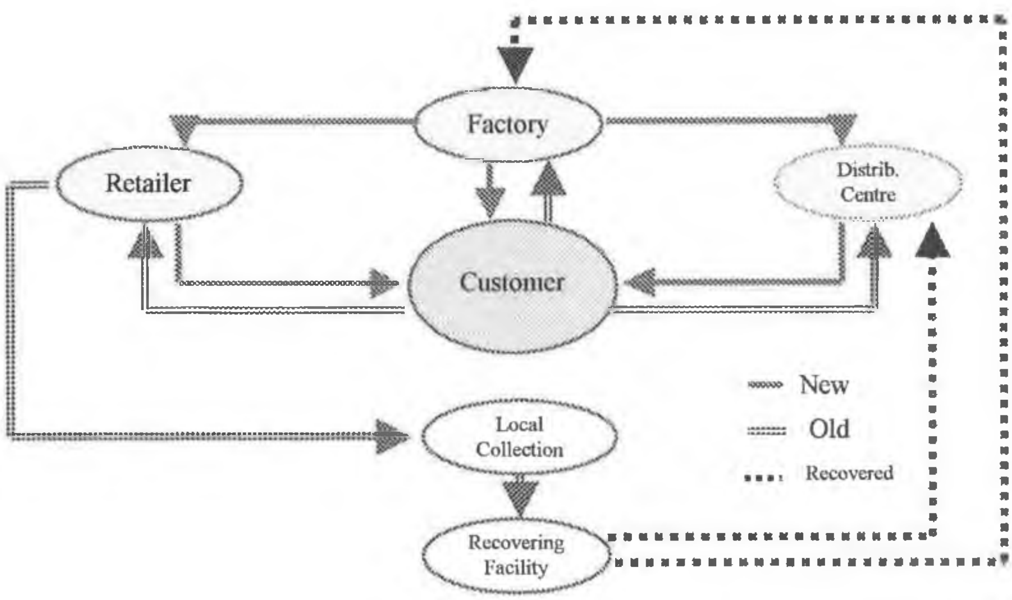


Figure 2.5. Closed loop system [modified from R&L98]

2.3.1. Environmental Consciousness of Consumers

Customers have certain "rights" which historically have guided governments in the development and implementation of various legislation including environmental protection laws, hazardous materials regulations and other consumer protection initiatives. These rights are considered to be [RL03]:

- the right of safety
- the right to be informed
- the right to choose
- the right to be heard.

Many aspects of business interface with these customer rights, including recycling, waste disposal, remanufacturing, source reduction, product returns and product repairs, refurbishing and warranties. Most often, firms try to be socially responsible, though they do not want to spend too much doing so. However, there is a trend in companies behaviour towards production of products containing less hazardous materials, products containing recycled materials, longer-life products, repairable products [Cog01] as a consequence of the 'voice of community'. Research in the UK has shown that environmental considerations considerably impact consumer choice, with approximately 40% of a survey respondents claiming that they would be willing to pay more for environmentally sound goods over products that are not seen to be as 'green' [END98].

2.3.2. Competitive Pressures

Product recovery is also seen as conferring competitive advantage. Many companies such as Dell, Hewlett Packard [HP02], Xerox [XX02] or British Telecom are already taking back products for reuse/remanufacturing/recycling. This gives them competitive advantage over those firms who are not doing it yet and who intend only to do so when forced by legislation. Pressure is on those companies not currently involved in recovery.

2.3.3. Eco-labels

Eco-labels are instruments which guarantee the public that products conform to minimum environmental standards [IISD01]. The eco-labelled goods still possess environmental impacts. However, they are considered to be superior relative to other products that fulfil a similar role.

Environmental labelling or *eco-labelling* is a guide for consumers to choose products and services that cause less damage to the environment [GEP01]. Environmental labelling makes a positive statement that identifies products and services as less harmful to the environment than similar products or services used for a specific function.

Participation on eco-labelling programs is *voluntary*. If a firm decides not to participate, it will not be able to display an eco-label on its product, but it will still enjoy the same access to the market as those companies which do participate in the program and do meet the standards necessary to display the eco-label.

The need for rules about environmental labelling or eco-labelling has led to concerted efforts to develop eco-labelling protocols or standards worthy of public trust.

Eco-labelling has a number of major *benefits*. It influences consumer choice, improves economic efficiency, and can enhance market development. It also promotes continual improvement, certification systems, and monitoring [EL03].

Owing to increasing public demand for environmentally friendly products, both governments and the private sector have become involved in eco-labelling programs. Currently, there are 28 eco-labelling programs in existence worldwide. Some of them are exemplified in figure 2.6.

Figure 2.6. Examples of eco-labelling programs logos [EL03], [EPG99], [ES03], [BA03]

2.3.4. Industry Standards on Environment Protection

Many international organisations have already developed tools to help companies examine, monitor and improve the environmental aspect of their activity. Such tools are:

- ***The ISO 14000 Series*** developed by the International Organisation for Standardisation (ISO) has been designed to help enterprises meet their environmental management system needs. An overview of environmental management is given in figure 2.7.

  The ISO 14000 Series covers two main areas [IISD96]:

  - *Organisation Evaluation*
    -Environmental Management Systems (ISO 14001, ISO 14004)
    -Environmental Performance Evaluation (14031)
    -Environmental Auditing (ISO 14010, 14011)
  - *Products, Services and Processes*
    -Life Cycle Assessment (ISO 14040, 14041, 14042, 14043)
    -Environmental Labelling (ISO 14020, 14021, 14022, 14023, 14024, 14025)
    -Environmental Aspects in Product Standards (ISO 14060)

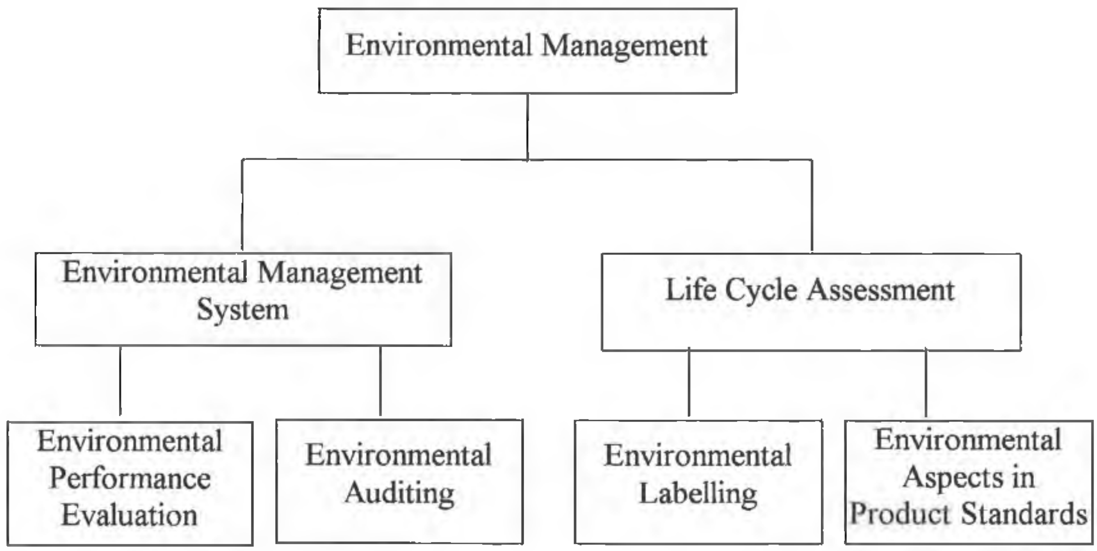


Figure 2.7. Environmental Management [Stu98]

These standards do *not* tell organisations what environmental performance they must achieve (besides compliance with environmental regulations). Instead, the standards describe a system that will help an organisation to achieve its own objectives and targets. The assumption is that better environmental management will lead indirectly to a better environmental performance.

- ***The European Union's Eco-Management and Audit Scheme***, known as ***EMAS***, is a regional standard. Actually, both ISO 14001 and EMAS are based on ***BS 7750***, the first standard for environmental management system (EMS) published by the British Standards Institution. EMAS requires for the implementation of an EMS the following steps [EMAS01]:

  - conduct an *environmental review* considering all environmental aspects of the organisation's activities, products and services, methods to assess these, its legal and regulatory framework and existing environmental management practices and procedures
  - in the light of the results of the review, establish an effective *environmental management system* aimed at achieving the organisation's environmental policy defined by the top management. The management system needs to set responsibilities, objectives, means, operational procedures, training needs, monitoring and communication systems
  - carry out an *environmental audit* assessing in particular the management system in place and conformity with the organisation's policy and programme as well as compliance with relevant environmental regulatory requirements
  - provide a *statement* of its environmental performance which lays down the results achieved against the environmental objectives and the future steps to be undertaken in order to continuously improve the organisation's environmental performance.

- Another organisation, at a regional level, is ***CENELEC (European Committee for Electrotechnical Standardisation)***. CENELEC role is to deal with the development and adaptation of its standards to meet the requirements of European environmental legislation and initiatives, and market demands.

The prime role of CENELEC is the harmonisation of all standards in relation to electrotechnology. The main CENELEC's environmental interests are [CEN97]:

- targets for pollution reduction (reduction of emission, material conservation, water and waste, product disposal, substitution or reduction of hazardous substances);
- materials using aspects (minimum material content of product, decreasing the number of different materials, reuse/refurbishing of sub-assemblies or components, easy disassembly and recyclability, efficient use of energy and resources);
- measures (detect in the standard points related to environmental aspects, identify parameters related to environmental aspects, include in the standards measuring methods);
- certification (environmental audits and conformity assessments, LCA, eco-labelling).

2.3.5. Environmental Law

Environmental concern is the reason why many governments have adopted new legislation concerning the integration of the environmental dimension in company policy. The threat of legislative pressure is actually the dominant force that has determined producers to consider product take-back.

The environmental policies of different governments and organisations are governed by a series of principles that will be presented in the following sections.

2.3.5.1. Sustainable Development Principle

The *principle of sustainable development* is central to the environmental policies of governments world-wide as well as being the essence of international agreements. *Sustainable development* is defined by the Rio Declaration on Environment and

Development as *"development which meets the needs of the present generation without compromising the capacity to meet the needs of future generations"* [UN92].

Starting from this definition, the EU even proposes a strategy for sustainable development that sets the strategic goal *"to become the most resource efficient economy in the world, combining high standards of living, good public health, strong social inclusion and cohesion and a high quality environment with the long term objective of reaching levels of resource use and environmental impact that are in line with the carrying capacity of the European and global environment"* [EU01].

While there are numerous interpretations of sustainable development, common to these are *three core concepts* that serve as important guides for public policy [GrL02]:

- Sustainable development recognises that it is not only the traditional measures of economic welfare that matter. *Quality of life and well-being are determined by many factors* – income, the state of people's health, their level of education, cultural diversity, environmental quality – that are all part of the sustainable development equation.
- *An integrated approach to planning and decision-making* is therefore needed to take into account these many dimensions – social, economic and environmental – of sustainable development.
- This integrated approach must embody *commitment to equity*. Sustainable development carries with it the need not only to create wealth and conserve the environment, but also to ensure their fair distribution.

2.3.5.2. Extended Producer Responsibility Principle

A second principle, that of *extended producer responsibility (EPR)*, represents another of the foundations of environmental policy of many countries in the developed world. The Organisation for Economic Cooperation and Development (OECD) defines EPR as "*an environmental policy approach in which a producer's responsibility, physical and/or financial, for a product is extended to the post-consumer stage of a product's life cycle*" [OECD01].

Therefore there are two key features of extended producer responsibility policy [GrL02]: (1) the shifting of responsibility (physically and/or economically, fully or partially) upstream to the producer and away from municipalities, and (2) to provide incentives to producers to take environmental considerations into the design of the product.

EPR presents a policy approach that can stimulate cleaner product design and production by the producer that helps promote common environmental goals – waste prevention and reduction, increased use of recycled materials in production, increased recycling and the internalisation of environmental costs (externalities) into the price of the product [Lin92].

2.3.5.3. The Polluter Pays Principle

The principle to be used for allocating costs of pollution prevention and control measures to encourage rational use of scarce environmental resources and to avoid distortions in international trade is the so called "*polluter pays principle*" (PPP) [Dog1].

The "polluter pays principle" implies that those who pollute the environment and destroy biodiversity should carry the costs of the negative effects pollution and loss of biodiversity create in society [OECD74]. The rationale behind PPP is that polluters, who usually do not suffer from their activities, will try to reduce their emissions if they have to pay for them.

There are several ways that polluter can be made pay. The main approaches are listed below [Dog1]:

- Regulations and standards resulting in emission control costs for the polluter;
- Taxes or charges on polluting production inputs or products, or on emissions;
- Tradable pollution permits;
- Compensation or liability charges.

There are important differences between these options. Economists will often favour economic instruments, such as charge schemes, or tradable pollution permits (pollution rights which can be traded in the market) over regulations and standards, since they tend to be more cost-efficient.

2.3.5.4. Shared Responsibility Principle

Shared responsibility is a key principle for environmental protection. It is a pluralist approach which involves both the public and private sectors in achieving the aims of sustainable development [EC95].

The shared responsibility principle calls on those in the product life cycle – manufacturers, retailers, users and disposers – to share responsibility for reducing the environmental impacts of products [EPA01]:

- *manufacturers* have the greatest ability, and therefore the greatest responsibility, to reduce the environmental impacts of their products by reducing use of toxic substances, designing for reuse and recyclability, and creating take back programs
- as the sector with the closest ties to consumers, *retailers* are one of the gateways to shared responsibility. From preferring product providers who offer greater environmental performance, to enabling consumer return of products for recycling, retailers are an integral part of the product stewardship.
- all products are designed with a *consumer* in mind. Ultimately, it is the consumer who makes the choice between competing products and who must use and dispose of products responsibly. They must take the extra steps to present products that they no longer need for recycling or other end-of-life treatment.
- *governments* and *local authorities* are essential to fostering shared responsibility. They must incorporate such objectives into their solid waste master plans and encourage recycling of products, incentivise the development of products with stronger environmental attributes.

2.3.5.5. Environmental Legislation

Laws, regulations, directives, etc. pertaining to resource recovery are likely to increase in number in the future. The majority of laws are being developed in Europe but countries in North America and Asia will likely contribute to the worldwide growth in legislation.

Germany's legislation regarding take back of packaging obliges manufacturers and distributors to accept the return of all used transport packaging and to reuse or recycle it independently of the public waste disposal system [Gog98]. The proposed German "Take-Back Law" requires all automobile manufacturers to take back all vehicles which were ever sold in that country [ELV03]. This program started in 1995. In addition, proposed German law requires automobile manufacturers to meet recycling targets with components and materials from the dismantled vehicles.

The Netherlands has imposed a landfill ban on electronic products and the government has warned that compulsory take-back will be imposed on manufacturers and importers if industry does not offer counter proposals to achieve take-back and recovery [Gog98].

The Pollution Prevention Act in the US, 1990 [EPA03], focuses industry, government, and public attention on reducing the amount of pollution through cost-effective changes in production, operation, and raw materials use. Pollution prevention includes practices that protect resource base through conservation. Such practices include recycling, source reduction, and sustainable agriculture.

EU Legislation on Environment

The EU legislation regarding the environment is based on Council Directives and Recommendations.

The European Union has selected waste prevention and recycling as major policy goals and began adopting legislation regarding waste management as early as 1975 [Lis96]. EU Directives on waste have for the large part been determined by the various

Environmental Action Programmes. In 1989 the EU drew up a policy document entitled Waste Management Strategy which set long-term aspirations with regard to the EU waste management legislation and activities. In 1997, the Council adopted a Resolution on a Community strategy for waste management which is a review of the 1989 strategy [EU03]. Then several Directives on waste appeared such as Council Directive 75/442/EC (waste framework) [EU03].

The Council adopted many other Directives that cover many areas such as hazardous waste, pollution, packaging, take-back of end-of-life vehicles or waste electrical and electronic equipment (WEEE) (see Appendix A for more details on EU environmental legislation).

Legislation for Electrical and Electronic Products Take-Back

Legislation governing take-back of electrical and electronic goods is being developed in many countries all over the world. It aims to address a perceived crisis related to the growing amount and toxicity of waste electrical and electronic equipment (WEEE).

Electronics take-back in the US has focused almost entirely on voluntary business initiatives [SLW98]. Legislation pertaining to electronics take-back has been proposed but not mandated in some states.

Asian legislative activities for take-back of electrical and electronic goods include the Japanese law on the recycling of end-of-life electric home appliances (EL-EHA) which was put into effect in April 2001 [N&K01]. Taiwan is another country to mandate take-back for computers, televisions, refrigerators, air conditioners and washing machines beginning in 1998 [SLW98].

In Europe legislation for electronic product take-back is increasing rapidly. An overview of electrical and electronic equipment take-back policies in five European countries is provided in Table 2.2 (see Appendix C for more details).

Table 2.2. WEEE take-back policies matrix [D&N01]

Measurement Criteria	Denmark	Germany	The Netherlands	Norway	Switzerland
Regulation Name (effective date)	Order #1067 on Mgt. Of Waste from Electrical and Electronic Products (1997)	Draft Ordinance Concerning the Disposal of Information Technology Equipment	The Disposal of Brown and White Goods Decree (1998)	Regulations Regarding Scrapped Electrical and Electronics Products (1999)	Ordinance on the Return, Taking Back and the Disposal of Electrical and Electronic Appliances (1998)
Authority	Ministry of Environment and Energy	Federal Minister for the Environment, Nature and Nuclear Safety	Ministry of Housing, Spatial Planning and Environment	Ministry of the Environment	Swiss Agency for the Environment, Forests and Landscape
Products Covered	All products dependent on internal or external power supply	All IT equipment	Household appliances, IT, stereos, hot water and heating equipment telecom equipment	All products reliant on electrical current for function	Entertainment, IT, telecom equipment, household appliances
Products Excluded	Batteries, refrigeration products (covered separately)	Toner and print cartridges, CDs	N/A	Batteries, refrigeration products (covered separately)	N/A
Financial Responsibility	Municipalities/ taxpayers	Manufacturers, importers and distributors	Manufacturers, importers	Manufacturers, importers	Manufacturers, importers, distributors
Recovery Responsibility	Municipalities	Municipalities	Producers and municipalities	Producers and municipalities	Producers and municipalities
Recycling Targets	Not specified	Not specified	45-75% depending on product type	100%	100%

At the EU level, the electrical and electronic products take-back policies are governed by the *EU Draft Directive on Waste from Electrical and Electronic Equipment* (*WEEE Directive*) [WEEE02]. The WEEE Directive is due to be enforced in 2004 in all member states. To resolve the environmental problems associated with WEEE, the EU WEEE Directive seeks to promote changes in the design of electrical products so that they are composed of less toxic materials and can be more easily repaired, upgraded and reused, or at least disassembled and recycled in a safer manner [D&N01]. The Directive establishes compulsory targets for collection by 2006. Between 70% and 95% (by weight) of all collected equipment is to be recycled or reused [WEEE02]. The initial draft directive prohibited the use of mercury, cadmium, hexavalent chromium and brominates flame retardants in all electrical goods by the year 2004 [WEEE02]. Producers must label equipment to identify plastic types and the location of all hazardous substances in order to enhance recycling and consumer awareness. The producer have to supply the recoverer with the necessary data about the product in order to facilitate the recovery process. The Directive places the full financial responsibility on producers to set up and operate collection systems. EU member states must collect information from producers on an annual basis about the quantity of equipment placed on the market (by numbers and weight) and the quantities of products recovered. This data will be reported to the EU Commission on a regular basis [WEEE02].

In addition to legislative mandates, voluntary corporate stewardship activities are increasing as well. For example, in the UK the Lothian and Edinburgh Environmental Partnership (LEEP), Electronic Equipment Manufacturers Recycling Group (EMERG), and the Industry Council for Electronic Equipment Recycling (ICER) have piloted projects that have collected over 100 million tonnes of electronic equipment in order to analyse the profitability of recovery [SLW98].

2.4. Design to Support Product Recovery

A general concept that has arisen in recent years as part of the search for more sustainable ways to provide for human needs is Clean Technology. A *"Clean Technology"* is a mean of preventing environmental damage at sources by producing lower quantities of waste and less harmful residuals than alternative means with which it is economically competitive, and to use less energy and resources during the industrial throughput processes [Ulh97].

Therefore, waste minimisation and pollution prevention are components of Clean Technology. The most effective way to reduce waste and environmental impacts is to *design out* the problems before they occur. Design for Environment (DfE) comprises techniques and logistics to improve the design of the product from an environmental perspective.

2.4.1. Design for Environment

Design for Environment (DfE) can be defined as *"the systematic consideration, during new production and process development, of design issues associated with environmental safety and health over the full product life cycle"* [F&W94].

Products designed with environmental considerations in mind may result in products which are more costly to purchase but which are less costly to own and operate and less damaging to the environment. Because it offers new perspectives with a product and business focus, DfE can be a powerful tool to make a company more competitive and more innovative, as well as more environmentally responsible.

DfE provides an organised structure into which companies can integrate most features of sustainable development (eco-efficiency, pollution prevention and clean production etc.). DfE strategies can play a significant *role in product innovation* by [DEG03]:

- Providing new criteria for evaluating design such as choices for materials, production techniques, finishing technologies, and packaging methods. The new criteria can often lead to innovative product or service solutions.
- Considering the entire product life cycle a process which can stimulate partnerships with suppliers/distributors/recyclers, open up new market areas, and increase product quality.

2.4.1.1. DfE Strategies

The DfE Strategy Wheel (see figure 2.8) provides a basic framework that can be used systematically to review the entire life cycle of a product. It is a tool that can: stimulate the creative design process, assist in visualising current environmental performance and highlight opportunities for improvement [DEG03].

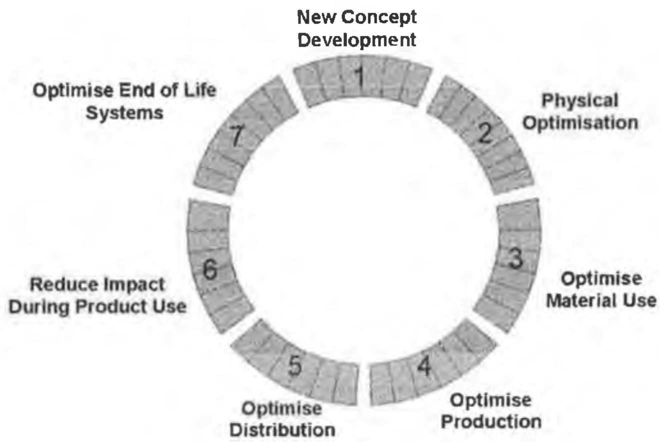


Figure 2.8. DfE Strategy wheel [DEG03]

The most important DfE strategy from a recovery perspective is *Optimise End of Life Systems*. This strategy focuses on:

- Reuse
- Disassembly
- Remanufacturing
- Recycling
- Safer incineration

Optimise End-of-Life Systems [DEG03], [Kuo01]

This strategy is aimed at reusing valuable product parts/components and ensuring proper waste management at the end of a product's useful life. Optimised end-of-life systems can reduce environmental impacts through reinvestment of the original materials and energy used in manufacturing.

Companies should consider various end-of-life scenarios (re-use, remanufacturing, recycling, incineration, landfill). At the same time, different environmental, disassembly, remanufacturing and recycling issues should be considered during the design stages.

Design for Reuse of Product

Design for Reuse of Product focuses on reuse of the whole product, either for the same application or a new one. The more the product retains its original form, the more environmental merit is achieved, provided that take-back programs and reccovery systems are developed simultaneously.

The *benefits* of Design for Reuse of Product include:

- Greater environmental appeal for end-users.
- Increase in sales.
- Cost-savings.

When applying Design for Reuse of Product, products should be designed:

- With appropriate technical and aesthetic life spans in mind.
- To be pleasing/useful for successive users in order to maximise life spans.
- To use quality components and reliable technology that will not become prematurely obsolete and will, therefore, contribute to maintaining value.
- To contribute to ease of cleaning, maintenance and upgrading.

Design for Disassembly

To optimise a product's end-of-life system, design for disassembly should be considered. Designing for disassembly can have the following *benefits*:

- Facilitate maintenance and repair, thereby reducing costs.
- Facilitate part/component reuse, thereby recovering materials and reducing costs.
- Assist material recycling, thereby avoiding disposal and handling of waste.
- Assist product testing and failure-mode/end-of-life analysis.
- Facilitate product take-back and extended producer responsibility, thereby reducing liability and assisting in regulatory compliance.

In general, in designing for disassembly designers should attempt to:

- Use detachable joints such as snap, screw or bayonet instead of welded, glued or soldered connections.
- Use standardised joints so that the product can be dismantled with a few universal tools, e.g. one type and size of screw.
- Position joints so that the product does not need to be turned or moved for dismantling.
- Indicate on the product how it should be opened non-destructively, e.g. where and how to apply leverage with a screwdriver to open snap connections.
- Put parts that are likely to wear out at the same time in close proximity so they can be easily replaced simultaneously.
- Indicate on the product which parts must be cleaned or maintained in a specific way, e.g. colour-coded lubricating points.

Design for Remanufacturing

Design for Remanufacturing focuses on remanufacturing/refurbishing in the context of restoring and repairing sub-assemblies. Re-manufacturing/refurbishing is related to designing for disassembly and modular product structure.

Remanufacturing can *benefit* a company by:

- Recovering materials and the costs embodied in products.
- Providing a reliable, cost-effective supply of parts/components for inclusion into new product production or service operations.
- Saving the costs of new manufacturing/purchasing.

Remanufacturing/refurbishing considerations:

- Design for disassembly, i.e. from product to sub-assemblies, to ensure easy accessibility for inspection, cleaning, repair and replacement of vulnerable/sensitive sub-assemblies or parts
- Design a modular product structure so that each module can be detached and remanufactured in the most suitable way

- Design parts/components to facilitate ease of cleaning/repair and retrofitting prior to reuse
- Indicate parts/components that must be lubricated or maintained in a specific way through colour coding or integral labels
- Consider the tooling requirements for remanufacturing in the physical design of parts/components
- Consider transportation and packaging requirements for remanufactured parts/components.

Design for Recycling

Design for Recycling focuses on making products that can be easily disassembled and using materials suitable for recycling. The levels of recycling, in order of the greatest environmental benefit to the least, are:

- Primary recycling – back to the original application.
- Secondary recycling – to a lower-grade application.
- Tertiary recycling – decomposition into raw materials.

This strategy is related to Design for disassembly which helps facilitate material recycling. To facilitate recycling:

- Try to recover and use recyclable materials for which a market already exists
- If toxic materials have to be used in the product, they should be concentrated in adjacent areas so that they can be easily detached
- If non-destructive disassembly is not possible, ensure that the different materials can be easily separated into groups of mutually compatible materials.

In the design of the product, factors to be also considered are:

- Integrating as many functions in one part as possible
- Minimising the types of materials used in the whole product
- If this is not possible, consider the compatibility of materials, e.g.,

glass/ceramics, plastics, various metals

- Using recyclable materials such as thermoplastics rather than composite materials such as laminates, fillers, fire retardants and fibreglass reinforcements
- Avoiding use of polluting elements such as stickers that interfere with the recycling process
- Marking any parts made of synthetic materials with a standardised material code.

Design for Safer Incineration

When product, component or material reuse and recycling are not possible, incineration – preferably with energy recovery – is an end-of-life option.

It is possible to design for safer incineration by avoiding the use of materials that can lead to toxic emissions if the product were to be incinerated without adequate environmental controls. When the use of heavy metals or other potentially toxic materials is unavoidable, the product should be designed for easy disassembly and promote programs to recover the hazardous materials separately.

2.5. Conclusions

The area of "environmental manufacturing" addresses the central long-term dilemma for manufacturing: how to achieve economic growth while protecting the environment. The conflict is fundamental, rooted in part in the material conversion process, which takes from the earth and gives to the customer, and in part in consumerism which focuses on current needs often disregarding the future. The resolution of this conflict is a serious issue for society as in the future it may threaten our well-being.

In order to motivate producers to address environmental issues, governments and international industrial organisation have developed a set of tools to assist companies in examining the environmental aspects of their products. Governments in many developed countries have adopted new legislation concerning the integration of the environmental dimension into company policy.

Once a firm is motivated to address environmental issues, there are lots of things to do. There are many aspects to the problem, including: toxic materials, waste and wastewater, emissions and greenhouse gases, energy usage, and material and product recovery. Therefore significant changes in the manufacturing process are necessary.

Closed-loop manufacturing deals with recovery of products (reuse/part reclamation, remanufacturing) and recovery of materials (recycling), avoiding – as much as possible – disposal at the end of the useful life of products. Reverse manufacturing has environmental benefits as well as its own environmental costs that require attention.

In order to close the manufacturing loop through product and material recovery, a strong take-back policy must be in place and best logistics engineering methodologies be applied. The next chapter will have an in-depth look at take-back and reverse logistics.

Chapter 3. Logistics Related to Products Take-Back

3.1. Introduction

Conventionally it is considered that the flow of goods in a supply chain ends with the consumer. In reality, however, there is an additional goods flow from the consumers back to producers that occurs *after* the final distribution of the product to the consumer (as suggested by the simplified supply chain schematic in Figure 3.1).

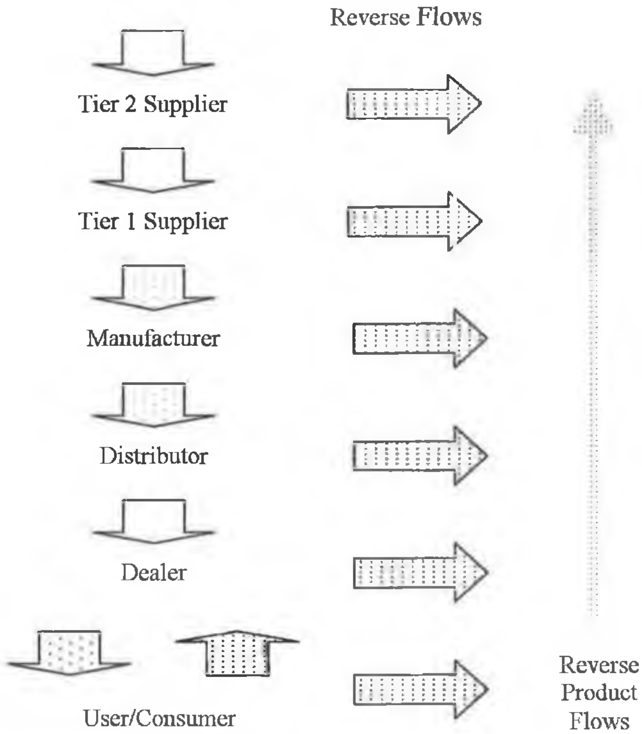


Figure 3.1. Simplified supply chain flow [Mar98]

Increasingly, manufacturers and suppliers in industry are being held responsible for their products that reach the end of the useful life. In an effort to deal with this responsibility and the related supply chain complexity, many industries are beginning to implement take-back policies for their end-of-life (EOL) products. And this, in turn, necessitates developing an infrastructure to handle post-distribution and post-consumption activities. The management of this reverse product flow is the concern of the recently evolved field of *Reverse Logistics* [Fle00].

3.2. Extended Producer Responsibility and Product Take-Back

3.2.1. Principles of EPR – Basis of Product Take-Back Policies

The concept of extended producer responsibility (EPR) and product take-back is not new. It has actually been around for hundreds of years, for example the milk distributors who sold their products in glass jars and then collected the jars from the consumers for refilling – practice now called ***product take-back***. Those take-back programs were driven by need (limited resources and money); nowadays they are driven by the phenomenon of massive amounts of waste generated at world scale.

This phenomenon has led to one of the fundamental principles of EPR: *producers have a responsibility for the waste and environmental impacts generated by their products* [D&N01]. EPR shifts responsibility for waste from government to private industry, forcing producers to internalise waste management costs in their product prices [Inf98].

Another key principle of EPR is that the most effective way to reduce waste and environmental impacts is to *design out the problems before they occur*, rather than attempting to manage waste and control environmental impacts after they are generated. Thus, EPR places the intervention focus on changes within product design, development, delivery and collection systems, rather than on manufacturing facilities and waste disposal methods. This encourages firms to design their products for easy disassembly, to use fewer, lighter, more durable and less toxic materials, and to restructure product delivery and collection systems to more easily recapture end-of-life goods for reuse, remanufacturing and recycling [D&N01], [Fis98].

The principles of EPR have helped a growing number of firms adopt successful take-back programs. For example, some electronic equipment manufacturers today have discovered that if they design their products for easy disassembly and remanufacturing, large cost savings or revenues can be generated by collecting end-of-life products from customers and refurbishing them for resale, or by reusing parts in new products. Cost savings and increased revenues can be found through the reuse of components, casings and subassemblies because it is often cheaper to reuse than to produce from virgin materials. These firms have found that as more of a product is reused or recycled, less bulk and toxic materials enter the waste stream.

3.2.2. Approaches to EPR Policy

EPR has already had major impacts on take-back. Many companies implemented such policies voluntarily for marketing purposes, but most take-back programs in Europe and other countries have been stimulated by legislation. The four policy approaches that have been used to promote EPR are [D&N01]:

- The first is *physical management*, where the producer bears the responsibility for physically caring for his/her products, or used products, or the impacts of the products at the end of their life cycles. This can be mandated by government, or adopted voluntarily by producers;
- The second is *economic responsibility*, where the producer covers all or part of the costs for managing waste at the end of his/her product's life;
- The third is *liability*, where the producer is held legally liable for environmental damages caused by his/her product in the production, use or disposal stages;
- Finally, *information liability tools* have been used, where the producer provides information to the public on the effects on the environment or public health that his/her product may have during various stages of its life cycle.

Figure 3.2 presents different policy instruments that have been used to implement the EPR policy approaches.

The choice of policy approach or instruments depends on the product of concern, its environmental impacts, and the practicality of applying such an approach to each product category.

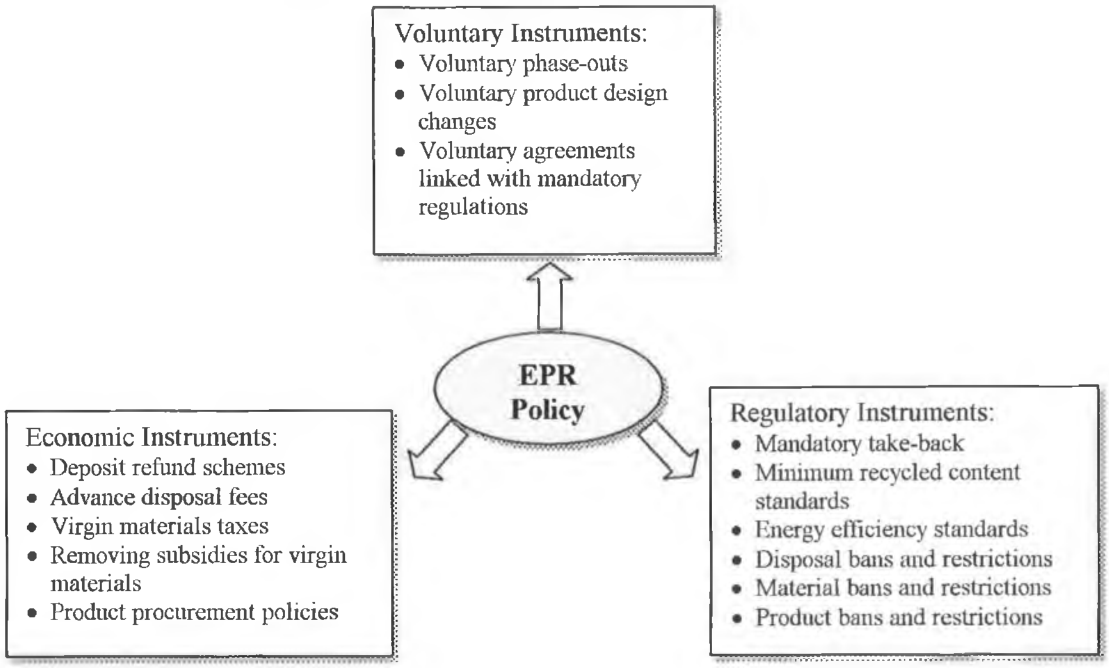


Figure 3.2. EPR policy instruments [adapted from D&N01]

3.2.3. Models of Take-Back [S&J03]

Increasingly, produces are being encouraged to take on more responsibility for stewardship of their products. Take-back programs are already being planned and implemented in conjunction with the legislative directives that support the EPR. Some potential modes of take-back are:

1. *OEM (original equipment manufacturers) take-back* – are EPR systems in which OEMs themselves take physical and economic responsibility for the products that they have manufactured. Each company manages their own processing facilities in which their products are remanufactured or recycled. Manufacturers pay the costs of recovery and any other costs that may arise from these activities. The OEM take-back mode of organising end-of-life management seems to be strong in terms of economic and information feedback, operational efficiencies, and potential for closed-loop recycling. But it is not without disadvantages. Some logistical complications appear as OEM-managed recovery is a highly specialised mode. Therefore, a few recovery centres are within a given area and products have to travel

a long distance to be recovered. Another drawback is the complicated way of getting the end-of-life products from the consumers to the processing facilities.

2. *Pooled take-back* – refer to EPR approaches in which physical and economic responsibility of products is assumed by consortia of manufacturers grouped by product category. The most important advantage of this model is well-developed reverse logistics. The consortium has more processing facilities in a given area, and, as a result, products have shorter distances to travel at their end of life. As there is only one place for products of each category to go, it is simpler to develop a system for collecting end-of-life products. Furthermore, as the consortium deals with a broader variety of products than single OEMs, they benefit from better specialisation and expertise in recovery. Of course, there are disadvantages of this model as well. One is the economic cost. An OEM has to pay a certain amount, based on a calculated estimate of the costs which might be or might not be very accurate. Another area of concern is the feedback information to product designers.

3. *Third-party take-back* – are EPR systems in which private companies assume end-of-life responsibility for products on behalf of OEMs. The OEM pays a fee to a third-party that promises to ensure that the manufacturer's products are retired in a way that is environmentally responsible and compliant with EPR legislation. Manufacturers benefit from a system of this type because they can meet their product end-of-life responsibilities while simultaneously eliminating the financial risk associated with end-of-life uncertainties and they can focus on what they do best and leave recovery to specialised companies. Some disadvantages of the third-party model are: the difficulty in identification of end-of-life products when a consumer no longer has any use for a product; the problem of dismantling and identifying materials – processors would require an effective transfer of knowledge related to the design of product; difficulties in finding suitable markets for the reusable/recyclable parts and materials removed from the products.

All of the three take-back models presented have advantages and disadvantages; however, the third-party take-back mode appears to be the most advantageous from the OEM's point of view. It looks like a promising approach of EPR providing that an information system is in place, information system capable of offering the processor the information he/she needs about the products.

3.2.4. Electrical and Electronic Equipment Take-Back Policies [Ste99], [D&N01], [HP02], [XX02], [Ayr97]

Driven by the limitations of landfill space as well as the social and political climate to promote sustainability, take-back activities and legislation for electrical and electronic products are increasing in various countries. Disposal of such products in landfills is discouraged due to the presence of hazardous substances such as lead contained in televisions and computer monitors which form approximately 60% of the weight of the total waste stream of consumer electronic products.

However, due to various reasons, many companies have already implemented take-back systems. Some examples are given below.

Dell Computers

Dell offers computers on a lease so that customers do not have to worry about disposal regulations. At the end of the lease, the equipment is returned to Dell to be refurbished or utilised using other asset recovery techniques. In addition, Dell operates a value recovery service that repatriates functional equipment and pays a fair market value to the customer. Dell also offers a PC recycling service intended to pick up non-functional equipment.

Dell collects these products from locations that can meet targets for minimum numbers of units and transports them to a disposition centre. Units that have economic value are sold to vendors; units with no residual value are recycled by other vendors according to strict statements-of-work. Less than 1% of the non-functional products that Dell receives end up in landfills [D&N01].

A. Factors Encouraging Adoption of EPR

Dell began the asset recovery service in 1991 long before recycling was fashionable. It did so as a sales tool that enabled Dell to sell to large customers who needed older machines removed after upgrading to Dell machines.

B. Economic Assessment

Dell will not release information regarding the costs associated with its asset recovery service. Dell views the service as an important part of its marketing strategy and its activities are financed by sales of new units.

C. Assessment of Effectiveness

Dell is only concerned that customers are not fully utilising their service and are storing or disposing of equipment in a non-environmentally sound manner.

D. Barriers to Success

Dell's asset recovery service does not receive any revenue in recovered assets from non-functional equipment. Rather this potential revenue is credited to Dell from the vendor to subsidise future disposal of machines.

Hewlett-Packard (HP)

Hewlett-Packard Company is a market leader in information technology equipment and has been a pioneer in environmental stewardship since the early 1990s. HP has utilised Design-for-Environment practices since 1995 and institutionalised strict green procurement criteria as well.

HP does not have a formal domestic take-back program for its retail customers. HP recovers equipment through its trade-in and trade-up programs and through its Unix leasing business segment. In addition, HP has an extensive take-back program for its printer toner cartridges.

HP states that they have recycled over 25 million LaserJet cartridges worldwide since the program began, avoiding 31,000 tons of landfilled materials [HP02].

A. Factors Encouraging Adoption of EPR

HP initiated its existing take-back program for three primary reasons. First, customers were demanding value for computers and peripherals that they wanted to replace with new units. The HP trade-in program provided customer satisfaction for this marketing segment. Customers who required environmentally sound disposal of their equipment could be assured that their needs would be met by HP's stringent environmental disposal techniques. Second, the trade-in program was a necessary component in HP's business development plan. Finally, HP was able to realise cost savings from the retrieved materials. Valuable or scarce components could be retrieved from old equipment and remanufactured for sale in new units.

B. Economic Assessment

HP expressed the belief that environmentally sound treatment of end-of-life equipment is expensive. These products have very little market value with which to offset disposal costs. At HP's Roseville, California remanufacturing site the costs associated with processing end-of-life goods are offset by revenues received from the higher value commercial take-backs from trade-ins and trade-ups to yield a break-even for the facility as a whole. HP's ability to operate at a break-even is, in part, due to its investment in some of the largest and most sophisticated shredding and separation equipment available. With approximately six million dollars invested in this remanufacturing equipment, it is a cornerstone of HP's commitment to environmental goals and achievements.

C. Assessment of Effectiveness

HP's program is very effective according to Renee St. Denis, Environmental Business Unit Manager at HP. The company processes approximately 3.5 million pounds of products a month with none of the recovered materials going to landfills [HP02].

D. Barriers to Success

Due to ill-defined burden sharing arrangements between distributors, resellers and manufacturers, HP is not ready for full scale consumer take-backs. The company believes that the responsibility for the costs incurred for product returning, remanufacturing and disposal have not been specified at the point of sale. Placing the burden solely on the HP would not be equitable since value is extracted all along the supply chain.

E. Future Improvements

In addition to clarification of burden sharing for a retail take-back program, HP feels that its program could be improved through regulatory reform that would declassify broken monitors as hazardous materials. Reverse logistics problems also need to be addressed as well as work on effective plastics recycling to reduce costs and to meet new product quality requirements.

Xerox Corporation

Beginning in 1993, Xerox was undoubtedly the first U.S. corporation to begin an aggressive product take-back program. Xerox achieves this by leasing products to customers rather than selling them. This enables Xerox to recover the product through what it calls Asset Recycling Management (ARM). The returned products are sent to a dedicated recovery centre to be remanufactured or disassembled for material reclamation.

A. Factors Encouraging Adoption of EPR

Xerox is committed to a strategy of environmental stewardship through the reduction of waste and promoting the use of recycled materials.

B. Economic Assessment:

The financial benefits of equipment remanufacture and parts reuse amount to several hundred million dollars a year [XX02].

C. Assessment of Effectiveness

Xerox uses a design for the environment (DFE) strategy with the goal of producing waste-free products. Through the use of sophisticated signature testing, life-cycle analysis, design for analysis software and product-coding Xerox has re-engineered its manufacturing process.

D. Barriers to Success

Misperception among some customers that products with some recycled part content are inferior to those built from all-new parts.

IBM

As part of its Product End-of-Life Management (PELM) activities, IBM began offering product take-back programs in Europe in 1989 and continues to enhance and expand these offerings.

There are currently 14 such programs in the U.S., Europe, and Asia. There are 9 major Materials Recovery Centres around the world, and additional locations support parts return and regional collection. In 1999 more than 59,000 metric tons of manufacturing scrap, IBM-owned end-of-life machines and customer-returned equipment were processed through these operations [D&N01]. IBM sent only 3.7% of this amount to landfills [D&N01].

Recycling and dismantling expertise is shared among the Materials Recovery Centres in order to increase recycling efficiencies and reduce the amount of waste sent to landfills. In addition, the centres share their experiences, concerns and recommendations with IBM product development teams in order to ensure that issues affecting the end-of-life management of products are addressed early in the design phase of new products.

3.2.5. Economic and Environmental Costs and Benefits of Take-Back Policies

Because of their relative newness, it is difficult to assess the economic costs and benefits of take-back policies. It appears as though policies that establish a financial incentive for product design changes generate the greatest benefits [D&N01]. The more the economic incentives are built into mandated take-back programs, the more likely they are to succeed [Mar98].

In terms of the overall costs or benefits to society, studies with different methodologies and assumptions end up with widely divergent conclusions. An example is the discrepancy in estimated costs between the German and Swedish consumer packaging programs. A study in Sweden claims that the total cost to society for the recycling of packaging waste amounts to 3,900 USD/tonne [D&N01]. A study of the German Green Dot system calculated that recycling packaging costs are around 403 USD/tonne [D&N01]. This huge discrepancy indicates the difficulties in comparing studies conducted with disparate methodologies.

Nevertheless, the environmental data suggests that while there were start-up problems, many of the take-back policies today are producing environmental benefits. For example, the application of the Japanese law on the recycling of end-of-life electric home appliances (EL-EHA) had a positive effect on the recovery of such products (from 200,000 to 1,200,000 products in four months [GoJ01]) thus reducing the environmental load.

A number of organisations (such as Hewlett-Packard, Dell, IBM) are capitalising on take-back for recovery opportunities. They have implemented successful reuse and recycling programs. These initiatives not only have reduced the amount of waste fed into the supply chain and the landfills, but also have lowered operating costs for these companies. All of these organisations have begun to think of the reverse manufacturing process as “investment recovery” as opposed to simply minimising the cost of waste management. They have been able to recover their cost investments from one or more of the following areas: raw material and packaging procurement, manufacturing, waste disposal, and current and future regulatory compliance. Furthermore, many of the programs implemented by these leaders bring the added benefits of improved employee morale and public image. For these companies, the benefits outweighed the costs of their reverse logistics and source-reduction programs.

Yet cost *is* a real issue. At multiple points in the typical supply chain, materials and supplies flow back up the chain or to waste sites. All of the "REs" (reuse, remanufacturing, recycling) associated with these reverse flows bring cost implications.

3.3. Reverse Logistics

In order to take back their products, producers need a good logistics system in place. Nowadays it is recognised that *reverse logistics* is a component of the total logistics management process that is growing in importance. Companies that develop an expertise in reverse logistics activities realised that it can be used to gain competitive advantage in their markets.

3.3.1. What is Reverse Logistics?

Starting from the definition of logistics, the Council of Logistics Management defines the ***reverse logistics*** as "*the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal*" [CLM03].

From a *business logistics perspective*, the term ***reverse logistics*** refers to the role of logistics in product returns, source reduction, recycling, materials substitution, reuse of materials, waste disposal, and refurbishing, repair and remanufacturing [Sto98].

From an *engineering logistics perspective*, it is referred to as ***reverse logistics management*** [Sto98] and is a systematic business model that applies best logistics engineering and management methodologies across the enterprise in order to profitably close the loop on the supply channel.

Recycling, reuse and *remanufacturing* programs are encompassed within the concept of ***reverse logistics***, as reverse logistics encompasses the logistics management skills and activities involved in reducing, managing and disposing of wastes. It also includes *reverse distribution* [D&M93], which is the process by which a company collects its used, damaged or outdated products or packaging from end-users.

Reverse logistics deals with the following *questions* [RL03]:

- What alternatives are available to recover products, product parts, and materials
- Who should perform the various recovery activities
- How should the various activities be performed
- If it is possible to integrate the activities that are typical for reverse logistics with classical production and distribution systems
- What are the costs and benefits of reverse logistics, both from an economical and an environmental point of view.

3.3.2. Reverse Logistics Activities

Reverse logistics can include a wide variety of activities. These activities can be related to [R&L98]:

- Goods in reverse flow that are coming from:
  - the end user;
  - a member of the distribution channel such as a retailer or distribution centre.

- Materials in the reverse flow:
  - product materials;
  - packaging materials.

A number of sources for products entering the reverse flow are shown in Table 3.1.

Table 3.1. Sources of reverse flow [R&L98]

	Supply chain partners	End users
Product	• stock balancing returns • marketing returns • end of life/season • transit damage	• defective/unwanted products • warranty returns • recalls • environmental disposal issues
Packaging	• reusable totes • multi-trip packaging • disposal requirements	• reuse • recycling • disposal restrictions

This work focuses on products that reach the end-of-life stage of their life cycle when end users do not want them anymore, therefore they will represent the reverse flow in the reverse logistics systems considered further on.

Typical reverse logistics activities would be the processes a company uses to collect used, damaged, unwanted or outdated products, and to recover them. Some of such activities are presented in Table 3.2.

Table 3.2. Common reverse logistics activities [R&L98]

Subject	Reverse Logistics Activities
Product	Products Return to Supplier Resell Sell via Outlet Recondition Refurbish Remanufacture Reclaim parts Reclaim Materials Recycle Landfill
Packaging	Packaging Reuse Refurbish Reclaim Materials Recycle Landfill

Figure 3.3 presents in detail different activities in reverse logistics that end-of-life products may be subject to in opposition to the direct flow of activities in the manufacturing process.

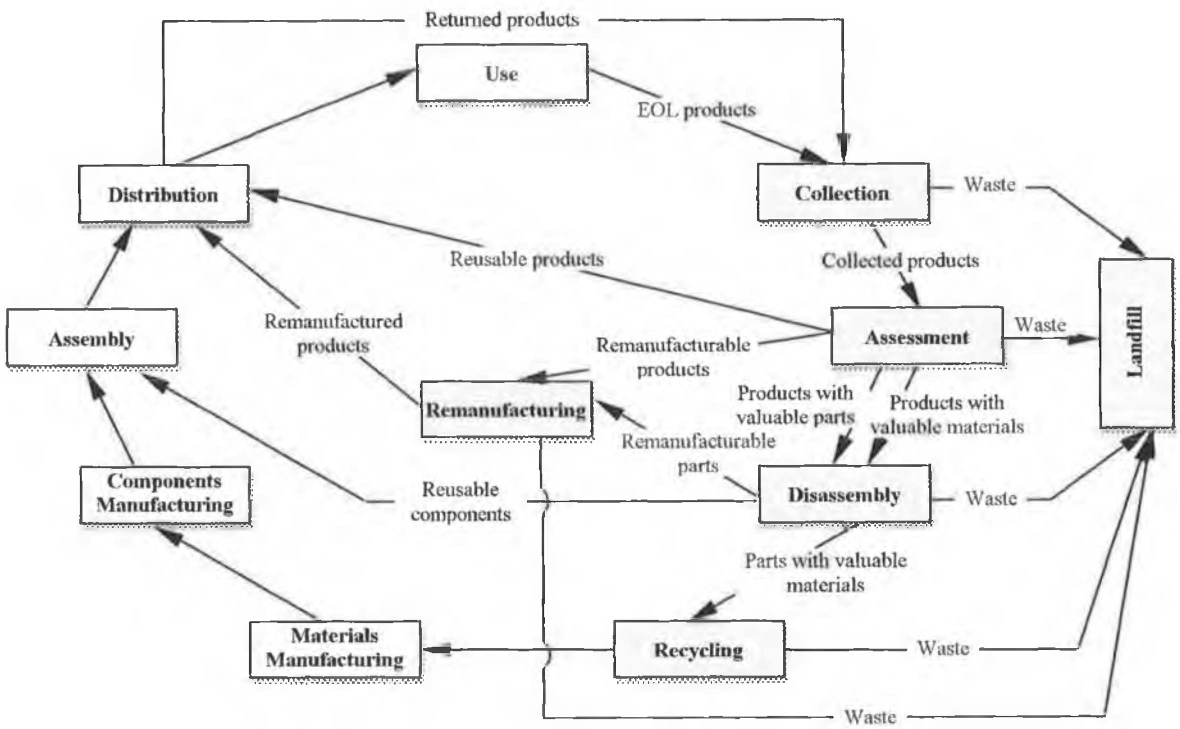


Figure 3.3. Reverse logistics activities and manufacturing [Whi03]

Once end-of-life products are collected, the first and most cost effective option is resell for reuse. If the product cannot be sold "as is", it can be subject to some operations such as reconditioning, refurbishing or remanufacturing before being resold. If the firm does not perform these activities in-house, a third party firm may be contracted, or the product can be sold outright to a reconditioning/ remanufacturing/refurbishing firm. After performing these activities, the product may be sold as a reconditioned or remanufactured product, but not as new. If the product cannot be reconditioned in any way, because of its poor condition, legal implications, or environmental restrictions, the firm will try to dispose of the product for the least cost. Any valuable parts and/or materials that can be reclaimed will be reclaimed, and any other recyclable materials will be removed before the remainder is finally sent to a landfill.

Therefore, the main end-of-life options are [G&B98], [Gog98], [Gui00], [Fle97]:

- ***Reuse/part reclamation*** – the use of a product or component part in its same form for the same use without remanufacturing. It may be the reuse of the entire product or the reuse of components of a product.
- ***Remanufacturing*** – conserves the product identity and seeks to bring the product back into an 'as new' condition by carrying out the necessary disassembly, cleaning, refurbishment and replacement operations. Remanufacturing focuses on value-added recovery rather than just materials recovery.
- ***Recycling*** – the process by which products are processed to recover base materials without conserving any product structures. It is mainly driven by economic and regulatory factors.
- ***Landfill*** – disposal without any material or energy recovery. It is to be regarded as a matter of last resort.

The management of products and materials in the reverse flow is the concern of reverse logistics which encompasses the logistics activities all the way from used products no longer required by the user to products or materials again usable in a market. The logistics of product and materials recovery, in relation to conventional forward manufacturing and logistics, is not 'the same, but reversed' [G&B98]. It raises many issues that have to be considered when designing reverse logistics networks for products and materials recovery.

3.3.3. Reverse Logistics Network Design [Fle01], [Gog98], [Fle00]

The design of a reverse logistics network is critical as economic viability of recovery can depend heavily on logistics costs, to the extent that they may negate the financial and environmental benefits of recovery. The decision as to the optimal design of the reverse logistics network is dependent on different factors [Gog98], [Fle01]:

- The form of reprocessing (remanufacturing, recycling and reuse)
- The owner of the recovery process (original equipment manufacturers – OEM – versus third party)
- The level of recovery which influences the frequency of collection.

Design for Reverse Logistics Networks for Mandated Product Take-Back

An important group of reverse logistics networks concerns supply chains established in response to environmental product take-back legislation. A typical example is the national electronics recycling network in the Netherlands [RL03].

In such cases OEMs are held responsible for keeping their products out of the waste stream at the end of life. While OEMs are legally and financially responsible for product take-back and recovery, the execution is typically outsourced to logistics service providers and specialised recycling companies.

The corresponding reverse logistics network design very much focuses on low-cost collection. Typically, the solutions found are those involving drop-locations, possibly in co-operation with municipal waste collection, where customers can hand in their products, which are then stored and shipped for further processing once a certain volume has accumulated. The test and grade operation does not appear to play a prominent role in these systems. Products may be roughly sorted by product category at the collection side, partly for administrative reasons. Further separation of material fractions occurs during the recycling process.

Design for Reverse Logistics Networks for Remanufacturing

Another important class of reverse logistics networks concerns remanufacturing, with the goal of recapturing value added from used products. Two cases can be identified here: closed-loop supply chains managed by OEMs and specialised remanufacturers.

OEMs managed systems

One typical example is IBM [IBM01]. The focus in such cases tends to be on the business market, due to higher product values and closer customer relations, which facilitate product monitoring during the entire life cycle.

Typically, OEM-managed closed-loop chains encompass multiple sorts of used product flows, from different sources and with different motivations, such as end-of-lease returns, 'old-for-new' buy-backs, and take-back as an element of customer service. In view of these heterogeneous product flows the testing and sorting operations play an important role, in order to maximise the value recovered. Coordination issues are also important in the OEM-managed networks. Not only inbound and outbound flows of used products need to be coordinated but also recovery and original manufacturing, which may partly substitute each other. Hence, reverse logistics networks typically need to be embedded in a larger overall solution and this adds to the complexity of logistics decision-making.

Specialised remanufacturers

Automotive remanufacturers, industrial equipment remanufacturers, and tyre retreaders are some of the numerous examples of specialised remanufacturers [Ayr97]. The main characteristic of such systems is a prominent trading and brokerage function. The business is strongly opportunity driven, seeking an optimal match of supply and demand. Furthermore, it is worth emphasising that profit maximisation rather than cost minimisation is the dominant decision criterion.

The brokerage character of dedicated remanufacturing chains is also reflected in the corresponding logistics networks. Rather than adding some collection infrastructure to an existing logistics network, remanufacturing companies need to design an integral network panning all the way from supply to demand. In particular, the location of the actual manufacturing site naturally relies on both the supply sources and customer locations.

Careful management of the supply side is vital to ensure availability of the right recoverable products. In order to optimally support this task, the corresponding inbound network requires a high degree of flexibility and responsiveness. The testing and sorting operation plays an important role. As remanufacturers, in general, have little means to monitor products during the initial part of the life cycle the state of an incoming product is only known after visual inspection. Consequently, location of this operation is an important element of the logistics network design.

Design for Reverse Logistics Networks for Recycling

Systems driven by the recovery of material value through recycling form another class of closed-loop supply chains with distinctive characteristics. Above all, material recycling chains are characterised by fairly low profit margins and the need for high investments for specialised recycling installations and equipment. The combination of high investment costs and low margins obviously calls for high processing volumes.

This reasoning is directly reflected in the structure of the corresponding logistics networks. Typically, one observes a highly centralised network relying on one, large scale recycling facility. Testing and sorting in a strict sense appear not to be very relevant for material recycling. Instead, often some pre-processing operation to enhance transportation efficiency will be found. Shredding and combustion may substantially reduce transportation costs for the bulk of collected EOL products.

Design for Reverse Logistics Networks for Reuse

Another type of network can be found in systems of directly reusable products. In this case timing of returns is reported to be an important element of uncertainty.

Reusable items requiring only minor processing steps such as cleaning and visual inspection can be expected to lead to a rather flat network structure comprising all the processes in one location. Moreover, a fairly large number of reuse cycles and absence of other processing steps makes transportation a major cost component. This may be a reason for a decentralised network with depots close to customers locations. Availability and service aspects point to the same direction.

3.3.4. Issues in Reverse Logistics

The logistics of product and material recovery bears little resemblance to that of conventional manufacturing [G&B98]. It raises a number of issues that have to be considered when designing reverse logistics networks such as collection, reverse distribution, production planning and inventory control, and information system.

Collection

In a reverse logistics structure, one of the major issues is the *collection* of the retired items and/or their package. In order to perform recovery profitably and according to applicable laws and regulations, collection of retired products must be planned.

Collection decisions involve selection of *location* of collection centres, where retired products are collected and stored prior to distribution to recycling or remanufacturing facilities (at central collection points, households, retail outlets or at distributors facilities), *collection method* (third party, in-house or specialist contractors), *collection frequency* (daily, weekly, monthly or on request) and *layout design* of collection centres (including material handling and storage) [G&G99], [G&B98].

Reverse Distribution

Reverse distribution is the transportation of end-of-life products to the recoverer or producer. Reverse distribution can take place through [Fle97]:

- the original forward channel
- a separate reverse channel
- combinations of the forward and reverse channel.

In a conventional manufacturing environment, newly manufactured products from a single source are delivered to multiple destinations, thus having a diverging effect. This is referred to as *forward distribution* [G&G99]. On the other hand, used products originate from multiple sources and are brought to a single product recovery facility, resulting in a converging process. Flow of used products back into the production environment is known as *reverse distribution* [G&G99] – see figure 3.4.

Reverse distribution is not necessarily a symmetric picture of forward distribution [Fle97]. Therefore, modifications and extensions of traditional network design models are required.

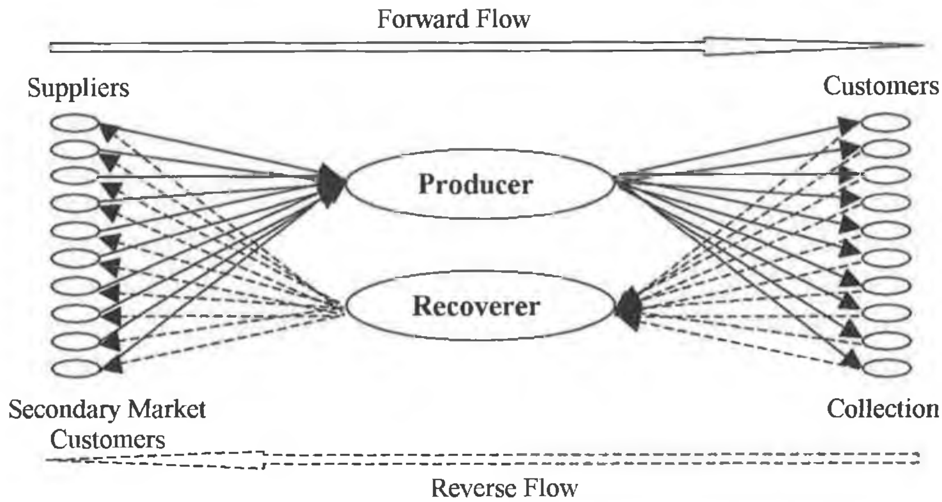


Figure 3.4. Forward and reverse distribution [Gog98]

Production Planning and Inventory Control [Qin00], [G&G99], [Fle97], [L&S97], [Gui00]

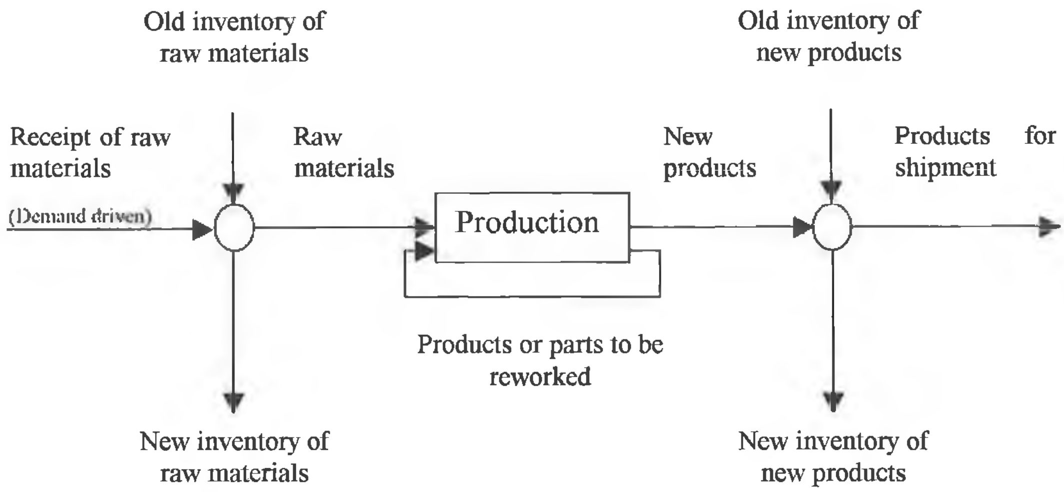
Applicability of traditional *production planning* and scheduling methods to product recovery systems is limited. Thus, either new methodologies have to be developed or modifications have to be made to the traditional methods to handle the complications due to the recovery systems.

The structure of a production planning in a reverse system at a macro level is quite similar to that of a traditional production planning system (see figure 3.5) as the production planning in a reverse system also has production capacity, demand, space and inventory balance restrictions. Nonetheless, notable differences exist between the two systems because of the characteristics of the recovery activities:

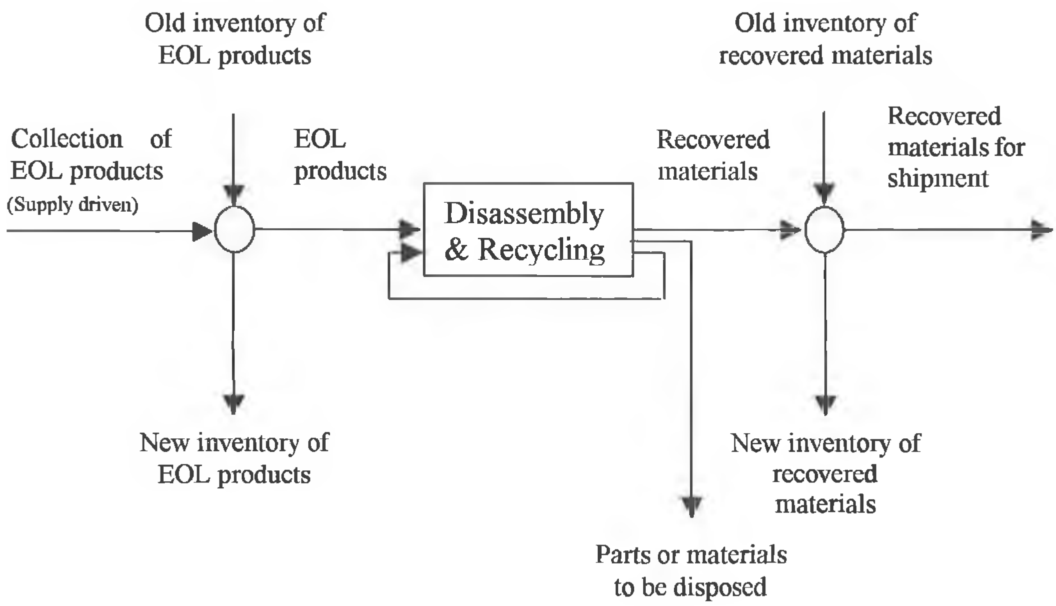
- uncertain timing and quantity of returns
- the need to balance returns with demands
- the disassembly of returned products
- the uncertainty in materials recovered from returned items
- the requirement for a reverse logistics network
- the complication of material matching requirements

- routing uncertainty and processing time uncertainty.

Some researchers have analysed the recovery options of the product by carrying out the part level cost and benefit analysis considering the cost of activities required during the recovery process and the physical properties of the product. Others have studied scheduling activities in a product recovery system. Some techniques utilise Material Requirements Planning (MRP) using reverse bill of materials (BOM).



Traditional production planning for new products



Production planning in a reverse system for EOL products

Figure 3.5. Comparison of traditional production planning and reverse systems production planning [Qui00]

Another key area in reverse logistics is *inventory management*. Appropriate control mechanisms are required to integrate the return flow of used products into the producer's materials planning.

Figure 3.6 presents the situation when EOL products are returned to the original producer.

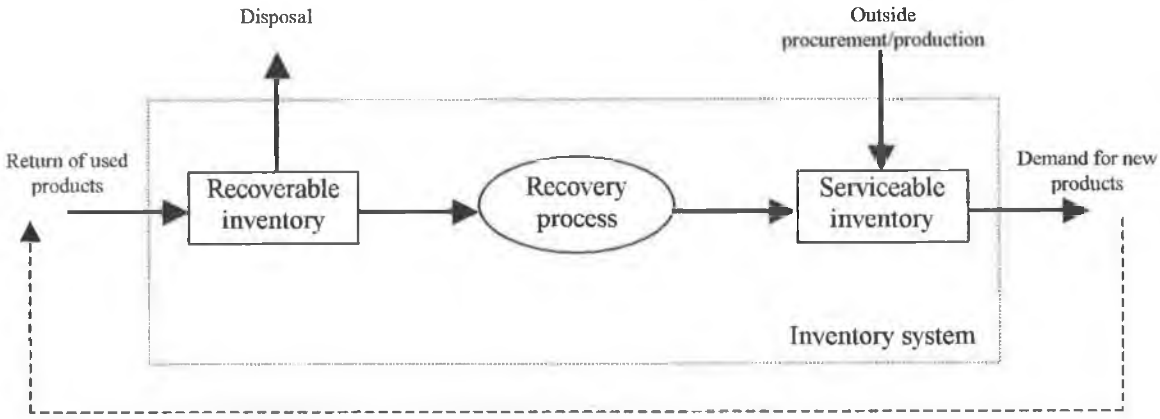


Figure 3.6. Inventory control with returned products [Fle97]

The producer meets demands for new products and receives used products returned from the market. He/she has two alternatives for fulfilling the demand:

- order the required raw materials externally and fabricate new products
- recover old products and bring them back to 'as new' condition.

The objective of inventory control is to control external component orders and the internal component recovery process to guarantee a required service level and to minimise costs.

The producer has little control on the return flow because of the characteristics of recovery activities enumerated before.

Information System

In reverse logistics the complex information flow must be considered. In this case information – as well as product – does not flow in a single direction as in a traditional manufacturing system. A model of information flow in reverse logistics is presented in figure 3.7.

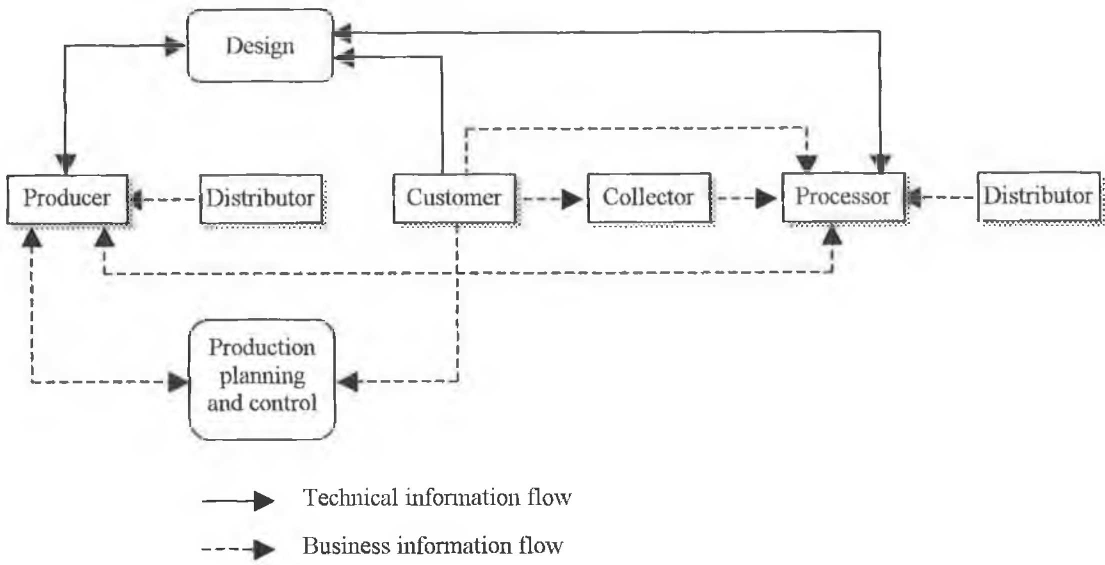


Figure 3.7. Information flow in reverse logistics [Gog98, modified]

A supporting information system regarding reverse flow is very important in designing the reverse logistics structure. What the information system should offer is a tool that support the end-of-life products recovery by providing easy access to data regarding opportunities to introduce a product to the reverse flow, and provide feedback from recoverers to the original manufacturer on design for sustainable production.

3.4. Conclusions

In response to concerns about an apparent landfill capacity crisis and growing public support for environmental initiatives, governments have enacted many take-back laws. Governments have increasingly looked to manufacturers to show more responsibility for reducing their own wastes and facilitating the recovery of their products.

The success of waste reduction programs often depends on their logistics. Three of the most common activities associated with more advanced programs all involve managing flows of recycled and/or reused materials [D&M93]:

- Purchasing recycled material as a manufacturing input;

- Reducing, reusing and recycling wastes from distribution and manufacturing;
- Taking back products and packaging from customers for reuse and recycling.

A proactive approach to reverse logistics is good from every perspective: market, regulatory, and environmental.

One key issue in reverse logistics is a supporting information system. A reverse business system is not a traditional system simply reversed. It is a real challenge to handle all the problems reverse logistics pose. It is a complex system where none of the usual business instruments work, new information flow occurs and a new tool to support it is necessary.

With robust reverse business systems in place, organisations can take full advantage of the recovery of their products while aggressively conserving resources.

Chapter 4. Decision Support Systems and Data Modelling

4.1. Introduction

Reverse logistics and end-of-life processing can be seen as a new kind of business. As "every business is an information business" and "information is the glue that holds together the structure of all business" [Boc99], the need for an information system related to reverse activities is obvious.

As the previous chapter showed, reverse logistics is a complex business that cannot be successful without a solid information system in place. Reengineering of the old system or a new system is needed.

The WEEE Directive [WEEE02] recognised the need of an information system in reverse logistics. A huge amount of information must flow between producers and all the other players in the reverse channel. Information on component and material identification must be provided by producers in order to facilitate the management and recovery/recycling of WEEE. On the other hand, information about the weight or the numbers of items of electrical and electronic equipment put on the market in the EU and the rates of collection, recovery/recycling of WEEE is necessary to monitor the achievement of the objectives of the Directive. Therefore an information system capable of recording data and supporting decisions for EOL products is becoming a necessity.

General features, principles and methods related to business information systems are applicable for any kind of business, including reverse activities. An overview of information business systems and decision support systems will be presented in this chapter.

4.2. Information Systems

Information systems are the organisation's instrumentation. They inform decision makers at all levels about those variables which represent the state of the organisation (e.g. cash held at bank, inventory holdings) and about those which represent changes, or rate of change, in variables affecting the organisation (e.g. production rates, cash flow, profit and loss, employees' weekly pay) [Bro82].

An information system is an organised combination of people, hardware, software, communications networks, and data resources that collects, transforms, and disseminates information in an organisation [Bri98] – see figure 4.1.

Nowadays information systems are mainly computer-based but components which are not computer-based still exist. Computer based or not, design principles hold for all types of information systems.

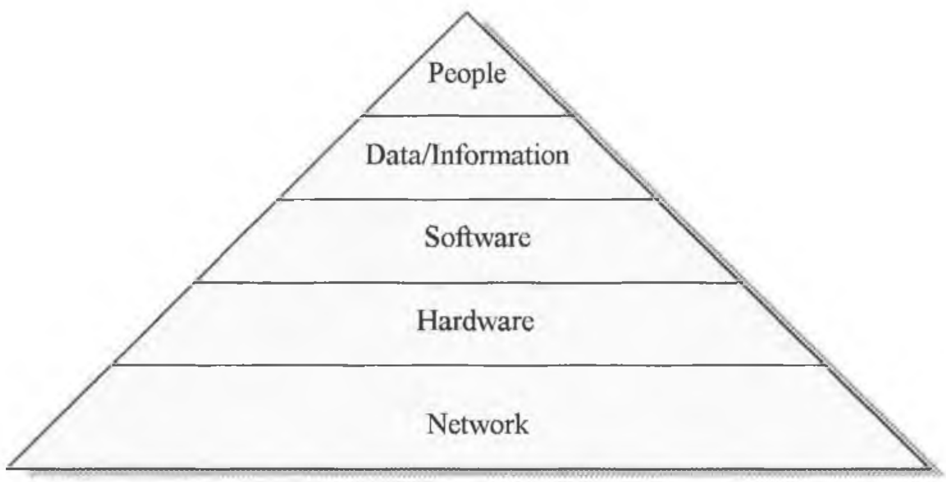


Figure 4.1. Information systems [Bri98]

4.2.1. Data and Information

Very often people use terms data and information interchangeably. But they have different meanings especially when they are used in relation to information systems.

Data are collections of raw facts or observations that are considered to have little or no value until they have been processed and transformed into information. There are several definitions for data in common use [Boc99]:

- A series of non-random symbols, numbers, values or words
- A series of facts obtained by observation or research
- A collection of non-random facts
- The record of an event or fact.

An example of data is the record of the sale of a product to a customer by the business. This is not information until it undergoes some sort of processing and the results of the processing are communicated for a particular purpose.

Several definitions for information in common use are [Boc99], [Cur95]:

- Data that have been processed so that they are meaningful
- Data that have been processed for a purpose
- Data that have been interpreted and understood
- Information acts to reduce uncertainty about a situation or event.

The data in the previous example can become information if the amount of sale is aggregated with other sales amounts and result is transferred to a debtors' control account.

Therefore, data need to be processed in order to obtain information – see figure 4.2.

Figure 4.2. Data versus information [Bri98]

Examples of data processing include [Boc99], [Cur95]:

- *Classification of data* – placing data into categories

- *Rearranging/sorting data* – organising data so that items are grouped together or placed into a particular order
- *Aggregating/summarising data* (calculating averages, totals, subtotals etc)
- *Performing calculations on data*
- *Selection of data* – choosing or discarding items of data based on a selection criteria.

Information Quality

The key attributes or characteristics of information quality that make the information valuable and useful can be grouped in three categories: content, time and form. Table 4.1 presents these attributes.

Table 4.1. Attributes of information quality [Bri98], [B&G89], [Cur95]

Time Dimension	
Timeliness	Information provided when it is needed
Currency	Information up-to-date when provided
Frequency	Information provided as often as needed
Time period	Information about past, present and future
Content Dimension	
Accuracy	Information free from errors
Relevance	Information related to the recipient's needs
Completeness	All information needed to be provided
Conciseness	Only information needed to be provided
Scope	Narrow scope, internal or external focus
Performance	Show performance by measuring activities, progress made
Form Dimension	
Clarity	Information in a form easy to understand
Detail	Information in detail or summary form
Order	Information in a predetermined sequence
Presentation	Information presented in narrative, numeric or graphic form
Media	Information in the form of printed documents, video displays or other media

4.2.2. Definition and Structure of a Computer-Based Information System

Generally speaking, an information system produces information that supports the activities of decision makers. A more complete definition of an information system is *a group of interrelated components that work collectively to carry out input, processing, output, storage and control actions in order to convert data into information products that can be used to support forecasting, planning, control, coordination, decision making and operational activities in an organisation* [Boc99].

Therefore, the main functions an information system must perform in any type of organisation are [Bri98]:

- Support of business operations
- Support of managerial decision-making
- Support of strategic competitive advantage.

A computer-based information system is made up of a number of components or modules that are interrelated as presented in figure 4.3 [Con85]:

- Data enter the system through the *input* section. They are converted from human to machine-readable format. These data are 'raw'.
- The raw data are checked or 'cleansed' by reference to format, range, and other criteria (*editing*), and by reference to data held in the storage device (*validation*).
- *File read* is the frequently performed task of accessing the data storage either to obtain additional data relevant to the processing function or to satisfy an inquiry and it is the first function in data processing section.
- *Process* is the section which makes calculations on the input and stored data to produce information which is to be output or returned to the data storage.
- *File update* makes the content of the data storage to agree with those results of the processing that are subsequently referenced, processed or output.
- *Output* transforms the required information to a human-readable form.
- *Balance Controls* are a series of checks on input, output and stored details that are performed, involving counts of transactions and totals of specific entities (e.g. a check that the total hours worked, as entered to the system, balances with the total hours paid)
- *Data storage* has an important role in linking the different components and the results from earlier processing with current operations. It also provides a bridge

between different categories of systems (e.g. payroll, costing and general-ledger systems use common data elements but are processed at different times).

In order to produce information having the qualities specified before, an information system needs to have the following features [Con85], [Bri98]:

- *Decision-oriented reporting* (the output from the system is designed to facilitate decision making)
- *Effective processing data* (checks and controls are appropriate, utilisation of hardware and software are efficient)
- *Effective management of data* (timing of file updates, accuracy of input data, redundancy etc.)
- *Adequate flexibility* (to meet changing needs)
- A *satisfying user environment* (appropriate machine-people interfaces).

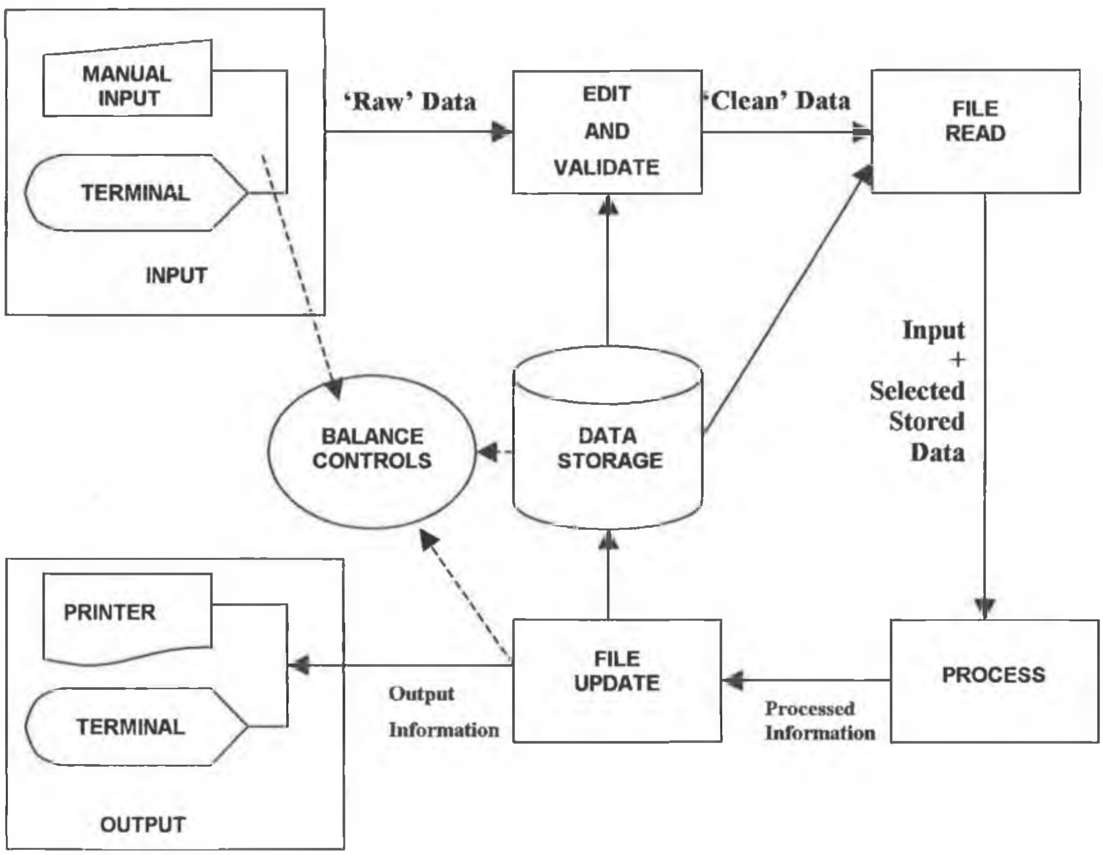


Figure 4.3. Components of an information system [Con85]

In modern organisations, most information systems are computer-based. Some of the advantages offered by a computer-based system are [Boc99]: *speed* (computers are faster then human mind in doing calculations), *accuracy* (the computers are less prone to make mistakes than humans), *reliability* (there are computers able to work 24 hours a day) and *programmability* (programs run by a computer sometimes can be changed relatively easy).

4.2.3. Categories of Computer-Based Information Systems

Information systems that can be used within the business can be divided into two categories [Boc99], [Bri98]:

1. ***Operations information systems*** – which are generally concerned with process control, transaction processing, communication and productivity
   - *Transaction processing systems* – process data resulting from business transactions, update operational databases and produce business documents
   - *Process control systems* – monitor and control industrial processes (e.g. CNC machine)
   - *Enterprise collaboration systems* – support team and workgroup communications and collaboration

2. ***Management information systems*** – provide feedback on organisational activities and help to support managerial decision-making
   - *Decision support systems* – provide interactive and ad hoc support for the decision-making process of managers
   - *Information reporting systems* – provide information in the form of prespecified reports and displays to managers
   - *Executive information systems* – provide critical information tailored to the information needs of executives.

The next section will look in more depth at decision support systems.

4.3. Decision Support Systems

There are many definitions for decision support systems (DSS) that try to cover different aspects – what they do, how they do it, how they are built and how they are used. A broad definition of DSS is "*an information system whose primary purpose is to provide knowledge workers with information on which to base informed decisions*" [Mal94].

DSS are computer-based information systems that use [Bri98]:

- Analytical models
- Specialised databases
- A decision maker's own insights and judgements
- An interactive, computer-based modelling process to support the making of semistructured and unstructured decisions by individual managers.

4.3.1. Types of Decisions

Decisions can be classified as [Boc99], [T&A01]:

- *structured (programmable) decisions* – tend to involve situations where the rules and constraints governing the decision are known. They tend to involve routine or repetitive situations where the number of possible courses of action is relatively small.
- *unstructured (unprogrammable) decisions* – tend to involve more complex situations, where the rules governing the decision are complicated or unknown. Such decisions tend to be made infrequently and are based on the experience, judgment and knowledge of the decision-maker.
- *semistructured decisions* – fall somewhere between the two extremes.

Most decisions comprise programmable and unprogrammable parts. That is why most decision support systems are information systems which provide a clear and easy-to-understand picture of structured parts of decision to a decision-maker and which try to arrange into a structured way unstructured parts of the decision.

There are three levels of managerial decision-making: strategic, tactical and operational [Cur95]. At a *strategic level* decisions tend to be unstructured and they concern with long-term company planning. Structured decisions, pertaining to medium-term planning, could be met at the *tactical level* of an organisation. At the *operational level*, it is dealt with short-term planning and day-to-day control of the organisation activities and decisions are structured with little impact on the organisation as a whole.

4.3.2. Simon's Model of Decision-Making [Boc99], [Cur95], [T&A01]

Herbert Simon provided a way to examine decision-making. According to his model, decision-making takes five stages and each stage must be completed before it is possible to move on the next one. Table 4.2 shows the stages and the activities involved in each stage in the decision-making process.

This model emphasises that the information has a critical importance in a successful decision-making. The information required to support the decision-making usually is generated by the decision itself and wrong or incomplete information can generate false solutions to the problem.

Table 4.2. Simon's model of decision-making [Boc99], [Cur95]

Stage	Activities
Intelligence	• *Awareness that the problem exists and the decision must be made*
Design	• *Identify all possible solutions (alternatives)* • *Examine possible solutions* • *Examine the implications of all possible solutions*
Choice	• *Select best solution*
Implementation	• *Implement solution*
Evaluation	• *Evaluate effectiveness or success of decision*

4.3.3. Using Decision Support Systems [Bri98], [T&A01]

Using a decision support system involves four basic types of analytical modelling activities:

- *What-if analysis* – the user makes changes to variables or relationships among variables and observes the resulting changes in the values of other variables.
- *Sensitivity analysis* – is a special case of what-if analysis. Typically, the value of only one variable is changed repeatedly and the resulting changes on other variables are observed.
- *Goal-seeking analysis* – reverses the direction of the analysis done in what-if and sensitivity analysis. Instead of observing how changes in a variable affect other variables, goal-seeking analysis sets a target value for a variable and then repeatedly changes other variables until the target value is achieved.
- *Optimisation analysis* – is a more complex extension of goal-seeking analysis. Instead of setting a specific target value for a variable, the goal is to find the optimum value for one or more target variables, given certain constraints. Then one or more other variables are changed repeatedly, subject to the specified constraints, until the best values for the target variables are discovered.

4.3.4. Facts in Decision Support Systems Design

Usually decision support systems are developed to be used for information needs which occur randomly rather than periodically and they support decision making by integrating company performance data, business rule based on decision tables and an easy-to-use graphical user interface.

As is shown in Figure 4.4, most decision support systems are based on databases established and maintained by transaction-processing systems. That is why, in designing decision support systems a complete analysis of the other existing information systems is needed.

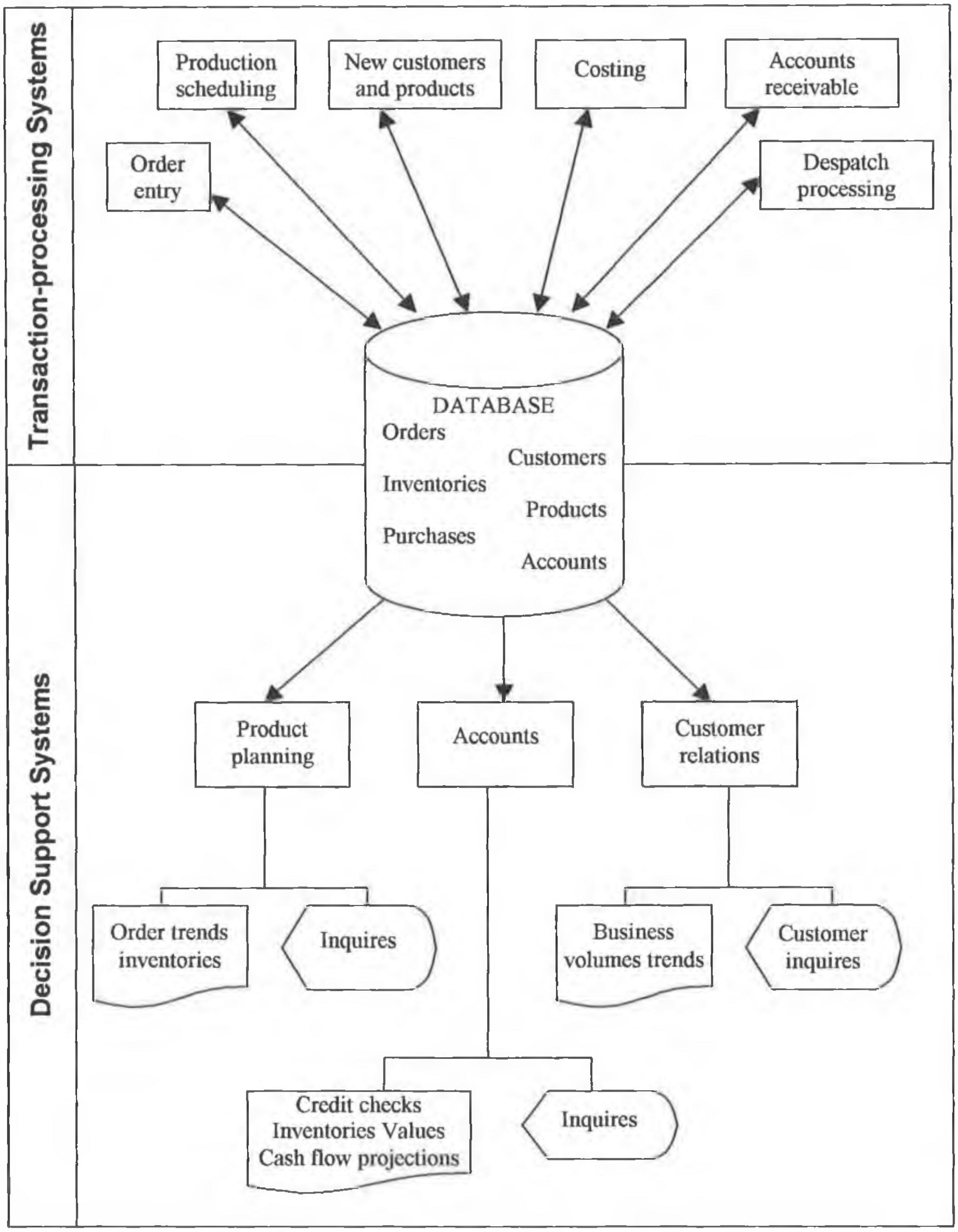


Figure 4.4. Relationship between transaction-processing systems and DSS [Bro82]

Decision-making involves selecting the correct action from a series of alternative choices. The business rules governing the correct action may be complex so diagrams and tables might be needed to help decision taking in a structured way for an easily implementing in a program code.

Before system building is started a clear image of the decision environment (business area) has to be provided to the decision support system designer. *Business area* is a logical grouping of business processes, data and locations that will be supported by designed information system. A very important stage in designing an information system is *business area analysis*. This analysis consists into a model creation of business area [Whi98]. Decision trees can be retrieved from the models structures.

A *model* is the representation of reality and usually it is a graphical representation. In a complete modelling three dimensions of the business area are important: processes, data and network [Whi98]. For each dimension a model has to be created. It is necessary to follow a *methodology* in order to create a data model, a processes model and a network model. A methodology could use one or more *methods* to create the models. The next section will present examples of methodologies and methods.

4.4. Methodologies and Methods for Business Area Modelling

A good-quality information system is one which is easy to use, provides the correct functions for end-users, is rapid in retrieving data and is reliable, secure and well integrated with other systems [Whi98]. To achieve these goals much attention needs to be paid to the analysis stage of design of information system or what was called before *business area analysis*.

An approach to business area analysis is to consider data modelling and process modelling separately. *Process modelling* is to identify the processes with clearly defined inputs, outputs and transformation processes (data flow diagrams are often used to define system processes). *Data modelling* considers how to represent data objects within the system both logically and physically (the entity relationship diagram is used to model data and a data dictionary is used to store details about the characteristics of the data – metadata) [Whi98].

The processes or program modules that will manipulate these data are designed based on the information gathered at the analysis stage in the form of functional requirements and data flow diagrams. Despite this approach of separate data and process modelling seems to be natural other techniques consider these two aspects not being separated (e.g. object oriented techniques).

The technologies that support the modelling referred before are called *methods*. The structured framework for application of these methods is the *methodology*.

4.4.1. Methodologies

Methodologies provide skeleton frameworks within which to develop a model. They present an abstract entity with various aspects described from various points of view such as functions and information [Gog98]. Some methodologies to facilitate process modelling have been developed; two of them will be presented in this section: CIMOSA and Business Process Reengineering (BPR).

4.4.1.1. CIMOSA [RGCP03], [Zwe97], [Kos99], [ATB03], [Gog98]

CIMOSA (Open Systems Architecture for Computer Integrated Manufacturing) was developed as a framework which allows modelling for Computer Integrated Manufacturing implementation and development following an Open System Architecture.

The primary objective of CIMOSA is to provide a framework for analysing the evolving requirements of an enterprise and translating these into a system which enables and integrates the functions which match the requirements. To implement a discipline in CIMOSA methodology, the *CIMOSA Reference Architecture* was developed and it contains a limited set of architectural constructs to completely describe the requirement of and the solutions for a particular enterprise.

CIMOSA Modelling Framework

CIMOSA offers a three-dimensional framework that has a dimension of genericity, a dimension of enterprise models and a dimension of views as shown in Figure 4.5.

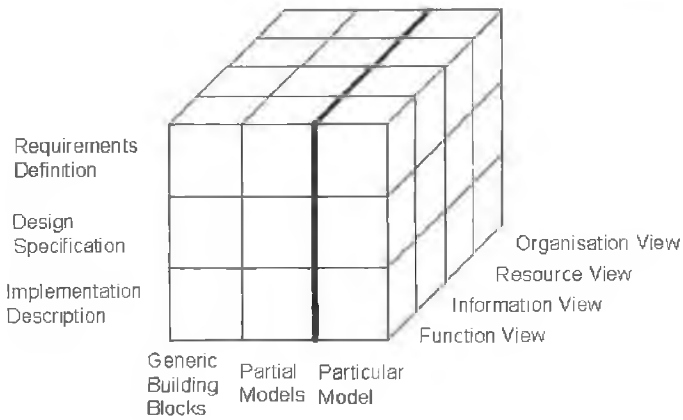


Figure 4.5. CIMOSA modelling framework [Zwe97]

The *genericity dimension* is concerned with the degree of particularisation. It goes from generic building blocks (for functions, objectives, services, etc.) through partial models (applicable to a wide range of industrial sectors, companies, etc.) to their aggregation into a model of a specific enterprise domain. The particular model embodies all necessary knowledge of the enterprise in a form that can be used directly for the specification of an integrated set of manufacturing technology and information technology components.

The *dimension of enterprise modelling* consists of three modelling levels:

- The *requirements definition level* uses a simple language to identify the business requirements of the enterprise, reflecting the objectives of that enterprise.
- The *design specification level* uses a computer processable language to identify and quantify, in an implementation independent format, the technology required to perform the identified processes. It structures and optimises the processes according to the overall enterprise constraints and the selected technology.
- The *implementation description level* defines in a computer executable form the means of process execution by selecting actual vendor products to provide the information technology and manufacturing technology components.

The *dimension of views* is composed of four views (function, information, resource and organisation) which are windows through which selective aspects of an enterprise can be observed and manipulated. Depending on the view some details are emphasised while others are suppressed for an easy identification of the aspects subjected by the view.

Modelling with CIMOSA

CIMOSA models the relations to the internal and external environments. It provides a process-oriented modelling concept that captures both the process functionality and the process behaviour. It supports the modelling of individual *enterprise domains (DM)* which may contain one or several individual *processes (P-1, P-2...)*. Domains and processes are defined by the user according to his/her needs for controlling the business operations.

Large processes are broken down into smaller ones ending in network enterprise activities which are connected by *behavioural rule sets (BRS)*. Processes are triggered by events and completed by producing their end-results. Producing the end-result may start another process or be used to synchronise other processes. Processes can start one another demanding sub-results be produced, which are used in the course of their own processing.

Steps that should be taken in a CIMOSA modelling process can be identified in figure 4.6.

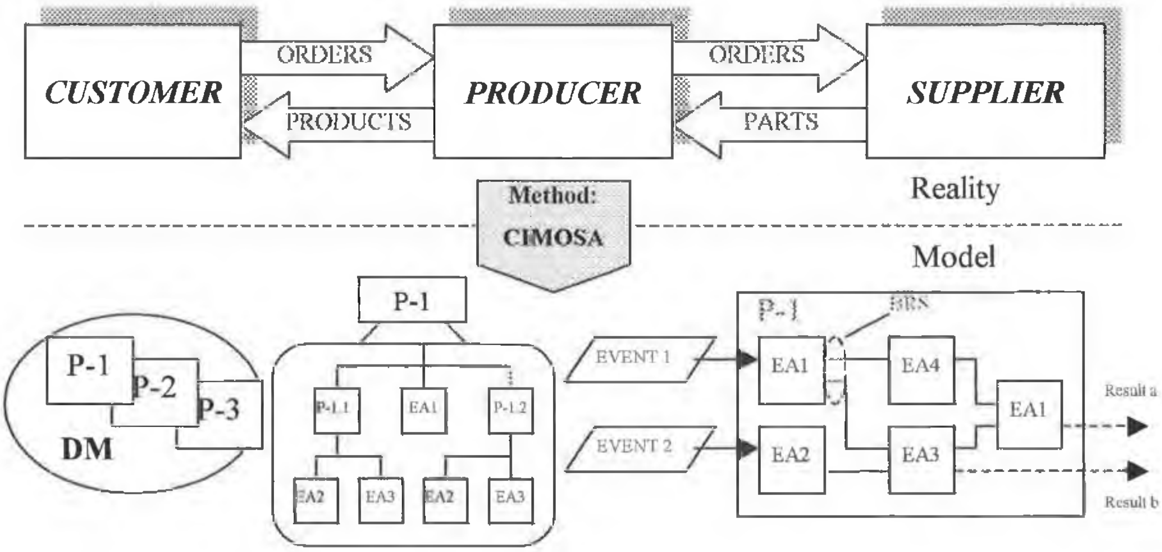


Figure 4.6. Modelling with CIMOSA [Kos99]

Having determined the business domain to be modelled and its relationships with its environment, the business processes and their activities are identified. The information items used in the model are identified as inputs and outputs of the enterprise activities. The *inputs* define the things to be processed (materials/parts, information) and the resources needed for processing and control the information for the processing by the particular activity. *Outputs* will be the results and the ending statuses of both the activity and the resources. The information attached to the ending status may be used in monitoring processes for administrative purposes. Inputs and outputs are aspects of enterprise objects that are represented in the information part of the enterprise model.

The behavioural rule sets (BRS) identify the conditions under which the different activities will be started. Business processes are started by events and the actual start activity may be different for different events. Process results may also be produced by different activities and at different times.

4.4.1.2. Business Process Reengineering

Business process reengineering, process improvement, business transformation, process innovation and business process redesign [G&M97] are terms frequently used interchangeably. The essence of *business process reengineering (BPR)* is a radical change in the way in which organisations perform business activities and is defined as "*the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed*" [A&F02], [C&C97], [Mac97].

The four keywords in the definition of BPR are *fundamental*, *radical*, *dramatic* and *process* [C&C97], [G&N97]. That means the business process has to undergo fundamental changes to improve productivity and quality. Reengineering determines what an organisation must do, how to do it. It is a radical approach and entails "business reinvention – not business improvement, business enhancement or business modification" [A&F02]. The essence of BPR is not about incremental improvement but about major step level improvement [Kha00] that focus on the business process – a collection of activities or tasks that create outputs of value to customers.

BPR Tools and Techniques

The radical improvement of processes is the goal of BPR, as the definition suggests. There are different tools and techniques that can be used to achieve this goals including [ON&S99]:

- process visualisation
- process mapping/operational method study
- change management
- benchmarking
- process and customer focus.

Usually when discussing BPR a mixture of these tools and techniques is considered. Therefore, as a strategic, cross-functional activity, BPR must be integrated with other aspects of management if it is to succeed.

BPR Framework

Successful BPR initiatives recognise that the methods, tools and methodologies they choose must fit together into a cohesive framework to be productive. The components of a BPR framework are [May98] – see figure 4.7:

- A set of guiding principles for BPR;
- The BPR process consisting of a set of phases and time-phased activities, clear milestones and phase products;
- A set of methods, strategies and tools for BPR, and understanding of the role of these methods, strategies and tools supporting the BPR process.

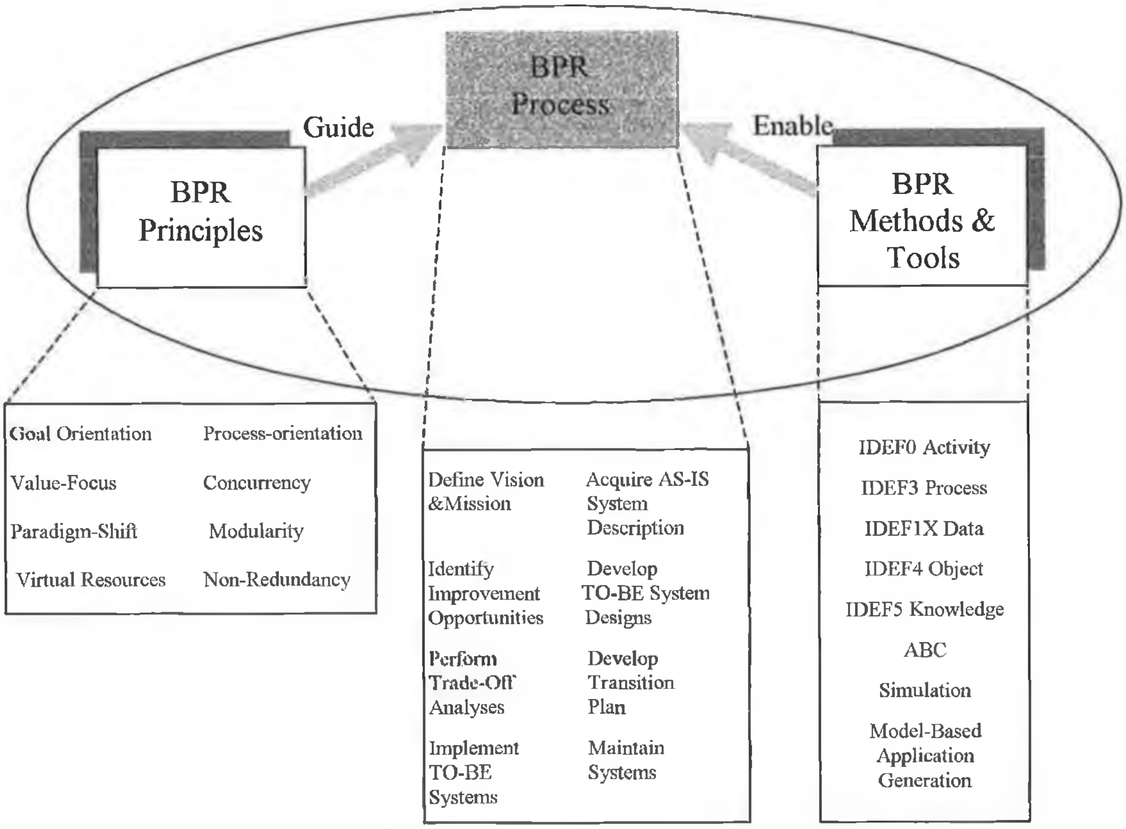


Figure 4.7. BPR Principles, methods and tools [May98]

A generic BPR methodology proceeds through a series of stages [G&M97]:

- *Preparation* – development of executive consensus on the importance of reengineering. The reengineering team is established along with a reengineering plan.
- *Process-think* – definitions of customers and processes, analysis of value-adding activities, process mapping.
- *Creation* – identify current process elements (organisation, systems, information flows, etc.) and a new process vision on what changes are required in order to achieve the desired changes in performance.
- *Technical design* – description of hardware, software, procedures, systems and controls employed by the reengineering process.
- *Social design* – staffing, jobs, career paths and incentives are considered in conjunction with technical design.

- *Implementation* – produces pilot and full production versions of the reengineered process and continual change mechanisms.

Information Technology and BPR [Mar97], [G&N97]

Reengineered or not, business processes do not work in isolation from each other. Ideally, they slot perfectly together, using common information avoiding duplication or departmental versions of data. The main goal is that information flows efficiently around the business, moving through and between processes which are each tuned to deliver maximum value to the end customer.

Information Technology (IT) provides powerful new tools to help implement reengineered business processes. BPR and IT form an integral system in improving the performance of manufacturing companies. IT can save time and improve accuracy in exchanging information about company goals and strategies. It removes much of the human error inherent in repetitive tasks. IT saves money because it reduces errors, and the time it takes to accomplish tasks.

4.4.2. Methods

A method can be thought as a procedure for doing something plus a representational notation. A method may also be described as consisting of three components: a definition, a discipline and many uses [May95a]. The method *definition* is established by characterising the method's basic motivations, concepts and theoretical foundations. The *discipline* component includes the syntax of the method and the procedure by which the method is applied and represents the user interface for the method. The *use* component characterises how to apply the method in different situations, such as when the method is applied together with other methods versus in a stand-alone fashion. This section will present two methods: Structured Analysis and Design Technique (SADT) and IDEF.

4.4.2.1. Structured Analysis and Design Technique (SADT)

The purpose of SADT is to organise, display and provide a straightforward technique for identifying all information necessary for publication of acceptable requirements and design specification and allows the engineers a better understanding of the problem that is to be solved [M&K03]. SADT is used to structure more efficiently the general analysis and design phases of an information system life cycle. The method originates in the field of software and knowledge engineering, but has been used widely to model decision-making activities [Hal97].

The SADT model is based on a hierarchical and modular description of the system in terms of functions. A SADT model is composed of boxes linked together by arrows showing transformation of inputs and outputs by means of mechanisms or support data and this under the supervisory of control activities (see figures 4.8 and 4.9).

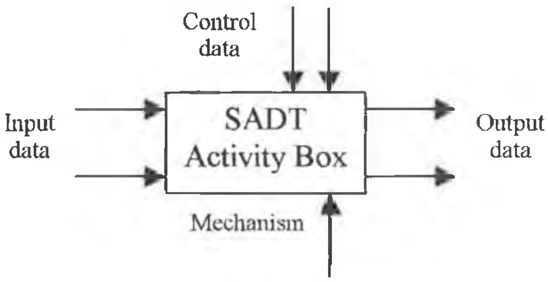


Figure 4.8. SADT Activity Box [M&K03], [Lam99], [Z&V97], [S&B98]

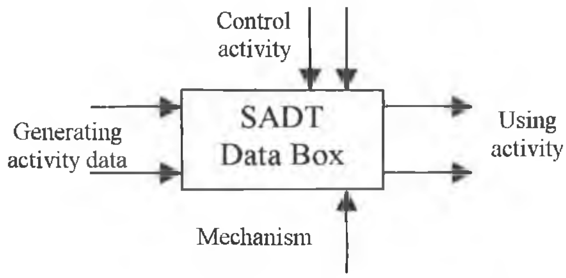


Figure 4.9. SADT Data Box [M&K03], [Lam99], [Z&V97], [S&B98]

SADT was developed by examining the problems associated with defining systems requirements and makes use of two types of models: activity model and data model. An SADT *activity model (actigram)* describes the decomposition of activities (see figure 4.9) and a SADT *data model (datagram)* describes the decomposition of data (see figure 4.10) [Lam99]. Each type of model contains both activities and data; the difference lies in the primary focus on the decomposition (activities or data).

The activity or transformation which is modelled in an SADT box (called ICOM – input-control-output-mechanism [S&B98]) can be defined as broadly or as specifically as desired. It can be decomposed into a number of sub-activities which are themselves further decomposed until the leaf activities, representing sufficient detail to serve the purpose of the model builder, are reached – see figure 4.10.

Chronological numbers or "C-numbers" are used to identify unique versions of a diagram, and they are also used to link together diagrams in the model hierarchy.

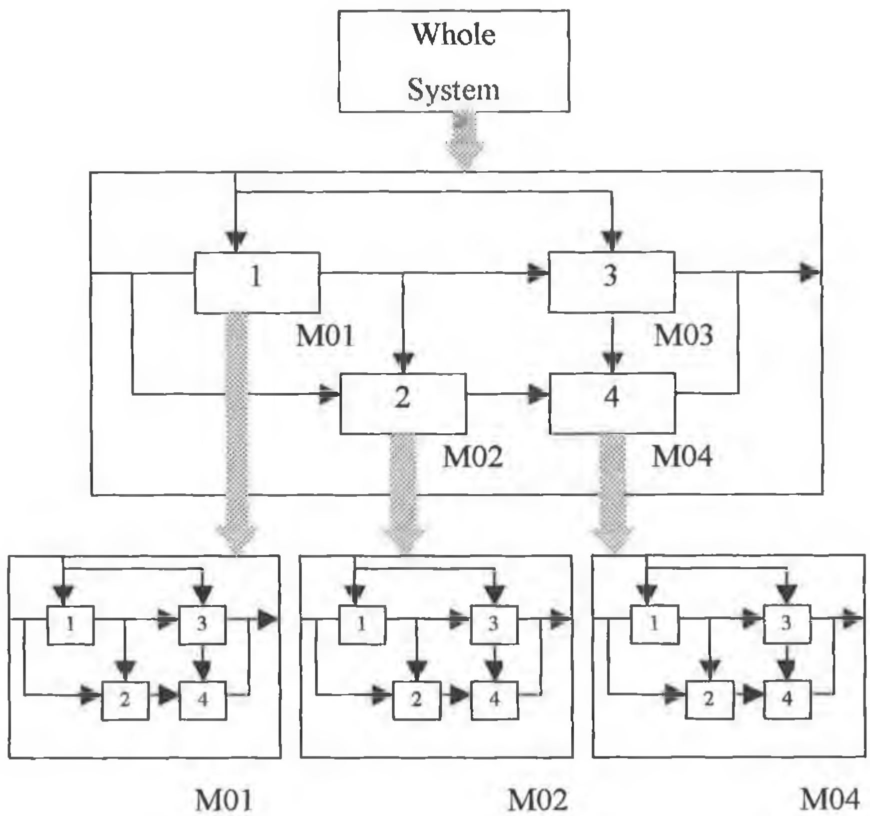


Figure 4.10. Hierarchical decomposition of SADT diagram [M&K03]

SADT Modelling Procedure

In building a SADT diagram it is really important to follow a certain procedure. The SADT procedure can be divided into *four stages* [M&K03] – see figure 4.11:

- The start of the modelling procedure
- Continuing the modelling process
- Self-Review by the author
- Review by others.

SADT was developed as a structured analysis methodology, it laid down the basis for a new method called IDEF0. Evolving from SADT and IDEF0, IDEF family methods has been developing as a powerful set of methods used in system analysis stage.

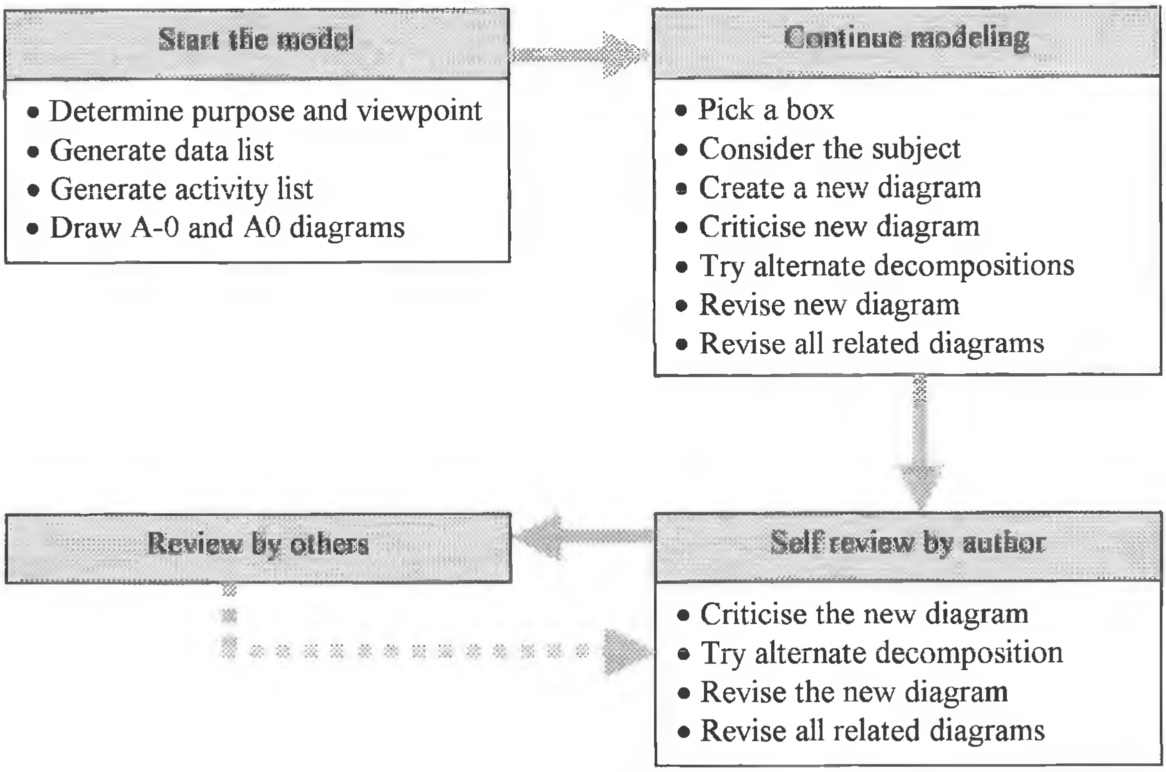


Figure 4.11. SADT Procedure [M&K03]

4.4.2.2. IDEF Methods

The name IDEF originates from the US Air Force program for Integrated Computer-Aided Manufacturing (ICAM) which developed the first ICAM Definition or *IDEF* methods. Recently, with the expanded focus and use of IDEF methods as part of Concurrent Engineering, Total Quality Management and business re-engineering initiatives, the IDEF acronym has been recast as an integrated family of *Integration Definition methods* – a family of mutually-supportive methods for enterprise integration. Figure 4.12 presents a list of IDEF methods.

The first generation of IDEF methods emerged from the Air Force's ICAM program which developed the *IDEF0 Function Modelling Method* [IDEF0], the *IDEF1*

Information Modelling Method [May92] and the *IDEF2 Simulation Modelling Method* [May95a].

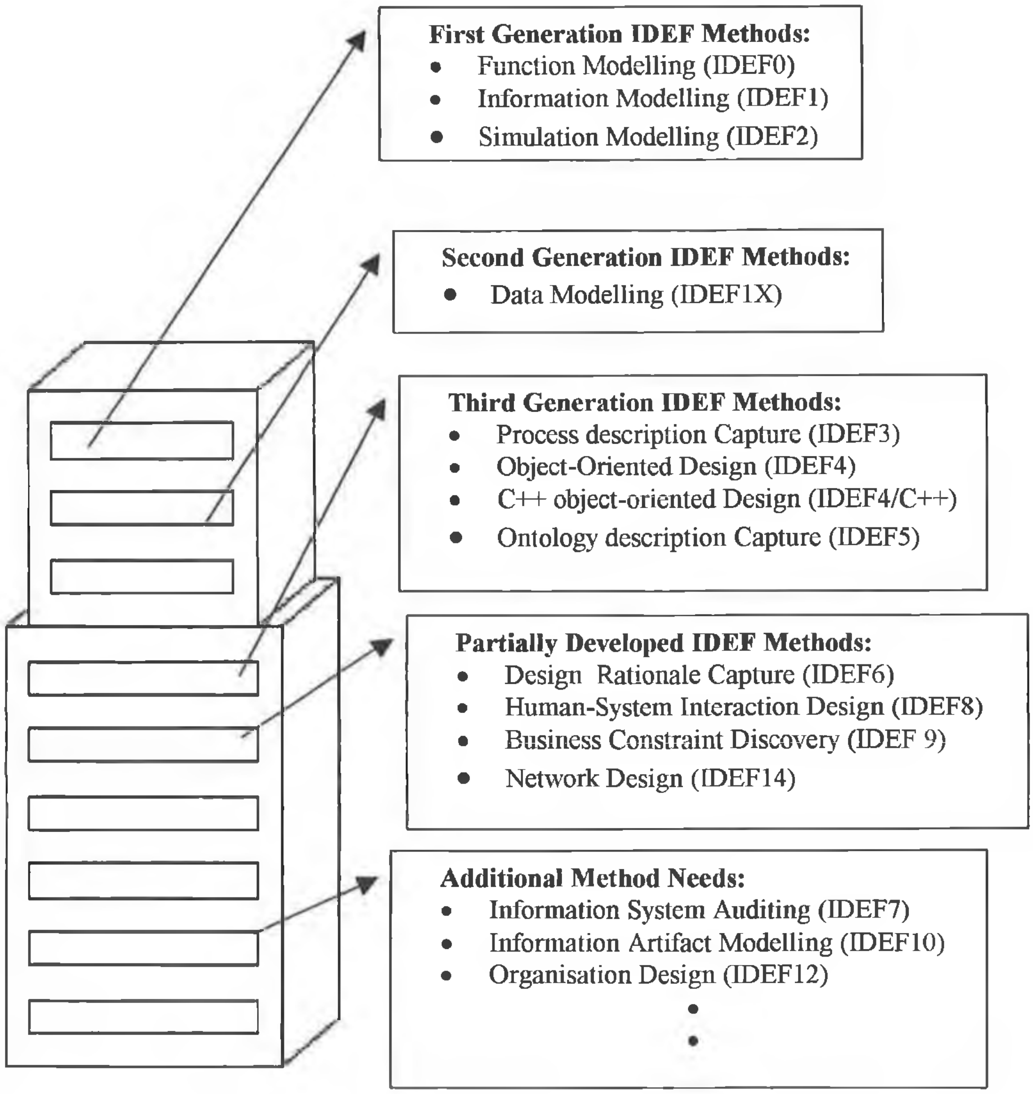


Figure 4.12. IDEF methods case [May95a]

A second ICAM project later developed the *IDEF1X Data Modelling Method* [IDEF1X]. IDEF1X facilitates the movement of information requirements, the product of IDEF1 analysis, toward actual systems implementation by establishing a discipline for logical database design.

A third generation of IDEF methods emerged from the need for method technology supporting the development of evolving, information-integrated systems supporting Concurrent Engineering. Thus *Process Description Capture Method (IDEF3)*

[May95b], *Object-Oriented Design Method (IDEF4 and IDEF4 C++)* [IICE95], and *Ontology Description Capture Method (IDEF5)* [IICE94] were developed.

In the same program framework which facilitated third generation of methods to come up, preliminary developments were also accomplished for *Business Constraint Discovery Method (IDEF9)* [May95c], *Design Rationale Capture Method (IDEF6)* [May95a], *Human-System Interaction Design (IDEF8)* [May95a] and network design *(IDEF14)* [May95a]. These methods are considered still partially developed.

Even if the list of IDEF methods presented so far should seem impressively long, still there are aspects of a business which are not fully captured through these methods, therefore additional methods are needed. Some of these methods are being developed (*Information System Auditing Method – IDEF7, Information Artefact Modelling Method – IDEF10, Organisation Design Method – IDEF12*) [May95a] or are to be invented.

IDEF0 Method [IDEF0]

IDEF0 (Integration DEFinition language 0) is based on SADT and includes both a definition of graphical modelling language (syntax and semantics) and a description of a comprehensive methodology for developing models.

IDEF0 may be used to model a variety of automated and non-automated systems. For new systems, IDEF0 may be used first to define the requirements and specify the functions, and then to design an implementation that meets the requirements and performs the function. For existing systems, IDEF0 can be used to analyse the functions the system performs and to record the mechanisms (means) by which these are performed.

The result of applying IDEF0 to a system is a model that consists of a hierarchical series of diagrams, text and glossary cross-referenced to each other. The two primary modelling components are functions (represented on a diagram by boxes) and the data and objects that inter-relate those functions (represented by arrows).

As a function modelling language, IDEF0 is comprehensive and expressive, capable of graphically representing a wide variety of business, manufacturing and other types of enterprise operations to any level of detail. It can be generated by a variety of computer graphics tools; numerous commercial products specifically support development and analysis of IDEF0 diagrams and models.

In addition to definition of the IDEF0 language, IDEF0 method also prescribes procedures and techniques for developing and interpreting models, such as data gathering, diagram construction, review cycles and documentation.

IDEF1X Method [IDEF1X]

IDEF1X method which is IDEF1 extended is a modelling language for developing a logical model of data.

Use of this method permits the construction of semantic data models which may serve to support the management of data as resource, the integration of information systems, and the building of computer databases.

IDEF1X method has the following primary objectives:

- To provide a means for completely understanding and analysing an organisation's data resources;
- To provide a common means of representing and communicating the complexity of data;
- To provide a method for presenting an overall view of the data required to run an enterprise;
- To provide means for defining an application-independent view of data which can be validated by users and transformed into a physical database design;
- To provide a method for deriving an integrated data definition from existing data resources.

4.5. Modelling in Reverse Logistics

As emphasised earlier, before developing a decision support system, a business area analysis is necessary – data and process modelling. Two methodologies as frameworks for the models have been presented (CIMOSA and BPR) and two methods than can support modelling – SADT and IDEF family.

Either of the two methodologies is a good approach for reverse logistics modelling. CIMOSA offers the three dimension-cube that permits the consideration of all aspects involved in modelling, including the genericity dimension which makes possible modelling a reverse chain at a high level from which a particular model (such as the application of the model to a certain company) can be obtained. BPR offers a set of principles, methods and tools that can also be used to model the reverse chain at any level. Both methodologies involve the identification of the main players ('actors') in the reverse chain, the processes and the flow of information between processes/activities. Both can use one or a combination of methods in order to structure the analysis and design of the decision support system.

The decision support system developed for end-of-life products and described in this thesis, is modelled with the BPR methodology and uses two of the methods in the IDEF family: IDEF0 for function modelling and IDEF1X for information and data modelling. The BPR methodology can be easily followed when modelling processes and activities in reverse logistics and, what is also important, "uses information technology as a central lever" [G&M97].

The theory presented in this chapter has been of use in developing the system presented in the next chapter.

4.6. Conclusions

What happens to the product after the end of its useful life is crucial. The need for a decision support system regarding the end-of-life products, especially in the electrical and electronics industry, has become a reality mainly as the result of legislative and customer pressures.

In order to design a decision support system linked to the reverse flow of products some issues must be kept in mind:

- A clear image of the decision environment (business area) is needed before starting the design of the decision support system
- A model of the business area regarding data, processes and network is necessary when designing the decision support system
- The decision support system is based on databases established and maintained by a transaction-processing system.

Chapter 5. Decision Support System for End-of-Life Products

5.1. Introduction

Product recovery is a fact today. OEMs may assume responsibility for take-back themselves or delegate it to a third-party. Whether the recovery is performed in house by producers or by third parties, a clear and extended evaluation of the activity is absolutely needed by producers, processors and policy makers.

To assess all the dimensions of the recovery activity (environmental and economic), data is needed, then, based on these raw data, indicators can be calculated. Once the indicators are obtained, decision-making becomes possible. The inconsistent time and spatial location of the data collection points, along with the fact that the volume of data regarding waste recovery is enormous, use of information technology for collection, storage and manipulation of data is a must.

This chapter presents a decision support system applied to electrical and electronic equipment. Following the BPR methodology and principles (see chapter 4) and the IDEF family methods (see chapter 4), the DSS model together with a supporting software prototype are developed.

The DSS developed in this thesis is founded on the work on EEDSS (Environmental and Economic Decision Support System) project sponsored by Enterprise Ireland and based on the WEEE Directive. A methodology, a Decision Support System (DSS) mathematical model, and a software tool have been developed within the EEDSS project to support assessment and decision-making in terms of end-of-life (EOL) option for electrical and electronic equipment. The methodology supplies product modelling and mathematical formulae to calculate the environmental indicators and costs that will be addressed in the DSS model in this thesis and it also describes the usage of

Analytical Hierarchy Process (AHP) method in choosing the most appropriate EOL option for a certain product [EEDSS02a].

This chapter presents in detail the DSS mathematical model and the BPR methodology for DSS, and the software application.

5.2. DSS for EOL Products Model

Principles like sustainable development, extended producer responsibility or polluter pays are included in environmental laws that put pressure on firms to take back their products and give them the proper EOL treatment. Both the legislation already in place and the pending legislation are unambiguous as to considering recovery a must but they are not that precise in pointing which EOL scenario would be the best. Rather the legislation offers a list of EOL options from which to choose. Therefore models and tools to support decision-making regarding the EOL scenario are welcome.

5.2.1. Product EOL Options

The treatment options a product may undergo at its end-of-life stage are: re-use/ part reclamation, remanufacturing, recycling, incineration with or without energy recovery and disposal to landfill. As incineration is not a viable option for Ireland, it will not be considered in the model.

According to the Draft WEEE Directive, *reuse* means any operation by which a whole product or its components, having reached their end-of-life, are used for the same purpose for which they were conceived [WEEE02]. The reuse of a product may be the reuse of the entire product, for example the selling of second hand cars or computers, or it may be the reuse of components of a product, for spares for example. The most effective solution to the sustainment of the resources that comprise a product is to reuse it at end of life [Gog98]. Through extension of the product life cycle in this way all the material, human, energy and process resources are sustained through continued use of the full product functionality.

Remanufacturing is an environmentally and economically sound way to achieve many of the goals of sustainable development. Remanufacturing focuses on value-added recovery, rather than just materials recovery (recycling) [Dan00]. The United States Environmental Protection Agency considers remanufacturing as an “integral foundation of reuse activities” and reports that “less energy is used and less waste is produced with this type of activities” [EPA97]. Lund defines *remanufacturing* as “an industrial process in which worn-out products are restored to like-new condition. Through a series of industrial processes in a factory environment, a discarded product is completely disassembled. Useable parts are cleaned, refurbished, and put into inventory. Then the new product is reassembled from the old one and, where necessary, new parts to produce a fully equivalent – and sometimes superior – in performance and expected lifetime to the original product” [Lun83].

Recycling is defined by the WEEE Directive as the reprocessing in a production process of the waste materials for the original purpose or for other purposes, but excluding energy recovery [WEEE02]. Recycling is performed to retrieve the material content of the used and non-functioning products. Recycling represents a process by which products otherwise destined for disposal are processed to recover base materials [Gog98]. The recovered material represents little of the human, energy and process resource inputs, but allows the material properties to be sustained [Gog98].

The ultimate end-of-life options are *incineration with energy recovery* or simply *discard to landfill*. *Incineration with energy recovery* is the controlled burning of wastes at high temperatures in a facility designed for efficient and complete combustion [R&K95] . Landfilling is a long-used practice of depositing waste in a dump site at the outskirts of a community. Disposal without any material or energy recovery is to be regarded as a matter of last resort. As mentioned before incineration is not considered in this model.

Each of the end-of-life options presented has an impact on environment, an impact on community and economic implications. In the model developed only environmental and economic impacts are considered.

5.2.2. Environmental and Economic Vectors Associated to EOL Options

One of the key goals of sustainability is that companies should provide more value for their products and services while seeking to transform less materials and energy and to reduce the influences on environment.

In order to measure progress towards sustainable goals of a company, a set of indicators is calculated. They must include information on the firm's economic performance, as well as its environmental performance.

The Environmental Vector

The impact of any company activity on environment is vast but it can be classified into three main categories: damage to resources, damage to ecosystem and damage to human health [Goe97], [Goe00]. There is a great variety of environmental indicators in use that show these impacts. The main categories of indicators that show environmental performance are: (1) materials use – indicator that tracks resource inputs; (2) energy consumption – quantity of energy used; (3) non-product output – quantities of waste generated before recycling, treatment or disposal; (4) pollutant releases – quantities of pollutants released to air, water and land [Ran98] .

For the model the following environmental indicators have been chosen [EEDSS02a]:

- *Environmental indicators that show damage to resources*:
    - Non-renewable primary energy input
    - Materials consumption
    - Water consumption
- *Environmental indicators that show damage to ecosystem*:
    - Greenhouse effect
    - Ozone layer depletion
    - Acidification
    - Water nutrient pollution
- *Environmental indicators that show damage to human health*:

- Hazardous substances emitted into air
- Hazardous substances emitted into water
- Emission of carcinogenic substances

As the WEEE Directive will force producers to consider different targets for the rate of recovery of their products, another set of indicators has been considered:

- *Environmental indicators that show compliance with regulation*:
  - Percentage of waste that is reused/reman/rec/incinerated/landfilled
  - Average percentage of product that is reused/reman/rec/incinerated/ landfilled

Given a product and considering that the whole product (100%) is subject to one EOL treatment option, for each EOL option the values of these indicators will be calculated. For a certain EOL option these values represent the coordinates of the environmental vector for that particular EOL option.

Therefore, there will be four environmental vectors, one for each EOL option. If we use column matrix notation for the vectors, for reuse/part reclamation we'll have the following vector:

$\mathbf{v}_{reuse} = \begin{bmatrix} v_{reuse_1} \\ v_{reuse_2} \\ \vdots \\ v_{reuse_n} \end{bmatrix}$ where $v_{reuse_1}, \ldots, v_{reuse_n}$ are the values of the environmental indicators

n = number of environmental indicators considered.

The maximum number of environmental indicators in this model is 12:

- 3 indicators pertaining to damage to resources
- 4 indicators pertaining to damage to ecosystem
- 3 indicators pertaining to damage to human health
- 2 indicators pertaining to compliance with regulation.

Similarly $\mathbf{v}_{remanufacturing}$, $\mathbf{v}_{recycling}$, $\mathbf{v}_{landfill}$ can be obtained.

The Economic Vector

Economic indicators give a very good image of the business and all decision-makers are familiar with their meaning. Indicators like net sales, profit, costs, cash flow, gross profit margin, return on investment or debt ratio are relevant for any business.

For the companies involved in activities at the end-of-life of products cost is an important issue. Although producers will be obliged by law to recover their products, processing cost will be a prime issue when choosing the end-of-life option for their products. That is the reason why the costing elements were chosen as economic indicators for the model.

As it is very important to know the structure of the cost, the following components of the processing cost are included in the model:

- Direct material costs
- Direct labour costs
- Production overheads

Given a product and considering that the whole product (100%) is subject to one EOL treatment option, for each EOL option the values of these indicators will be calculated. In the model, for a certain EOL option these values represent the coordinates of the economic vector for that particular EOL option.

Therefore, there will be four economic vectors, one for each EOL option. If we use column matrix notation for the vectors, for reuse/part reclamation we'll have the following vector:

$\mathbf{w}_{reuse} = \begin{bmatrix} w_{reuse_1} \\ w_{reuse_2} \\ \vdots \\ w_{reuse_m} \end{bmatrix}$ where $w_{reuse_1}, \ldots, w_{reuse_m}$ are the values of the economic indicators

m = number of economic indicators considered.

The number of environmental indicators in this model is 3 – the components of the cost.

Similarly $\mathbf{w}_{remanufacturing}$, $\mathbf{w}_{recycling}$, $\mathbf{w}_{landfill}$ can be obtained.

5.2.3. EOL Scenario Modelling

So far it has been considered that a waste product reaching its end-of-life stage will be 100% reused or remanufactured or recycled or incinerated or landfilled. But the EOL scenario may be a combination of all of these or just of some of them. Maybe only a component of the product can be reused and another recycled and the rest of it landfilled.

Due to legislation such as the WEEE Directive, producers are becoming interested in the environmental impact of their EOL products, as well as the economic implications, whatever the combination of EOL treatment they may be subject to. The model presented here calculates the environmental and economic impacts of a product subject to a generic EOL scenario treatment that can be any combination of the four options (reuse/part reclamation, remanufacturing, recycling and landfill).

Let us consider an EOL scenario for a product as follows:

p_1 - % of the product's weight that is reused
p_2 - % of the product's weight that is remanufactured
p_3 - % of the product's weight that is recycled
p_4 - % of the product's weight that is landfilled

The environmental impact of this product is given by a vector, denoted as $\mathbf{v}_{EOL}$, which is a linear combination of the environmental vectors of the four EOL options ($\mathbf{v}_{reuse}$, $\mathbf{v}_{remanufacturing}$, $\mathbf{v}_{recycling}$, $\mathbf{v}_{landfill}$) with weights p_1, p_2, p_3, p_4.

$$v_{EOL} = p_1 v_{reuse} + p_2 v_{remanufacturing} + p_3 v_{recycling} + p_4 v_{landfill}$$

Or, if matrices are used, the same result will be obtained with the equation:

$$\mathbf{V} \times \mathbf{p} = \mathbf{v}_{EOL}$$

where $\mathbf{V} = [\mathbf{v}_{reuse}\ \mathbf{v}_{remanufacturing}\ \mathbf{v}_{recycling}\ \mathbf{v}_{landfill}]$ = environmental matrix of product

$$p = \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \end{bmatrix} = \text{Structural vector of EOL scenario}$$

Or

$$\begin{bmatrix} v_{reuse_1} & v_{remanufacturing_1} & v_{recycling_1} & v_{landfill_1} \\ v_{reuse_2} & v_{remanufacturing_2} & v_{recycling_2} & v_{landfill_2} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ v_{reuse_n} & v_{remanufacturing_n} & v_{recycling_n} & v_{landfill_n} \end{bmatrix} \times \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \end{bmatrix} = \begin{bmatrix} v_{EOL_1} \\ v_{EOL_2} \\ \vdots \\ \vdots \\ v_{EOL_n} \end{bmatrix}$$

Similarly, the economic vector associated to the EOL scenario could be laid down. The economic vector:

$$w_{EOL} = p_1 w_{reuse} + p_2 w_{remanufacturing} + p_3 w_{recycling} + p_4 w_{landfill}$$

Or, using matrices:

$$\mathbf{W} \times \mathbf{p} = \mathbf{w}_{EOL}$$

where $\mathbf{W} = [\mathbf{w}_{reuse}\ \mathbf{w}_{remanufacturing}\ \mathbf{w}_{recycling}\ \mathbf{w}_{landfill}]$ = economic matrix of product.

It could be said that two matrices (environmental and economic) and the structural vector enable a mathematical description of the EOL scenario. In addition to the model methodologies must be developed in order to calculate the elements of all the matrices and vectors. Such a methodology is the one developed within the EEDSS project [EEDSS02a].

5.2.4. The DSS Model and Decision-Making

This section presents the implications of the approach to EOL scenario on some of the decision-support analytical activities.

What-If Analysis

The model can be used for solving a 'what if' situation. For instance, if the decision-maker (producer, processor) considers product design changes (producer), technology changes (processor) or any other change in activity, he/she might be interested in finding the total environmental or economic impact of the product in a given EOL scenario. Such changes might alter entries in the environmental or the economic matrix of the model and, consequently, the total impact of the product subject to the given EOL scenario.

Aiming to identify the key indicators/options/processes, *sensitivity analysis* could be also performed by changing repeatedly a certain variable and looking at the values of the impact. Of course important changes in the total impact point out a key indicator hence the key option/process that the focus should be directed to.

Goal-Seeking Analysis

Another possible application of the model is the calculation of the best EOL scenario from an environmental and/or economic point of view, given some environmental and/or economic constraints.

Different laws and regulations set maximum or minimum values for different environmental indicators (maximum emissions of CO_2, minimum quantity of products recycled). At the same time, companies involved in treatment of EOL products could afford up to a maximum amount of money (economic constraint). These facts are also referred to as constraints and they are given as maximum or minimum values for different indicators denoted $c_{env_1}, c_{env_2}, \dots, c_{env_n}$ (for the environmental indicators) and $c_{ec_1}, c_{ec_2}, \dots, c_{ec_m}$ (for the economic indicators).

Given an EOL scenario for a product depicted by the environmental and economic indicators and considering the constraints on those indicators, the following (in)equations may be written:

$$v_{EOL\,1}(\leq)(=)(\geq)\,c_{env1},\, v_{EOL\,2}(\leq)(=)(\geq)\,c_{env2},\dots,\, v_{EOL\,n}(\leq)(=)(\geq)\,c_{env\,n}$$
$$w_{EOL\,1}(\leq)(=)(\geq)\,c_{ec1},\, w_{EOL\,2}(\leq)(=)(\geq)\,c_{ec2},\dots,\, w_{EOL\,m}(\leq)(=)(\geq)\,c_{ec\,m}$$

Considering the formulae given by the model the following system of (in)equations will be obtained:

$$\begin{cases}
v_{reuse_1} \cdot p_1 + v_{remanufacturing_1} \cdot p_2 + v_{recycling_1} \cdot p_3 + v_{landfill_1} \cdot p_4 (\leq)(=)(\geq) c_{env_1} \\
v_{reuse_2} \cdot p_1 + v_{remanufacturing_2} \cdot p_2 + v_{recycling_2} \cdot p_3 + v_{landfill_2} \cdot p_4 (\leq)(=)(\geq) c_{env_2} \\
\vdots \\
v_{reuse_n} \cdot p_1 + v_{remanufacturing_n} \cdot p_2 + v_{recycling_n} \cdot p_3 + v_{landfill_n} \cdot p_4 (\leq)(=)(\geq) c_{env_n} \\
\\
w_{reuse_1} \cdot p_1 + w_{remanufacturing_1} \cdot p_2 + w_{recycling_1} \cdot p_3 + w_{landfill_1} \cdot p_4 (\leq)(=)(\geq) c_{ec1} \\
w_{reuse_2} \cdot p_1 + w_{remanufacturing_2} \cdot p_2 + w_{recycling_2} \cdot p_3 + w_{landfill_2} \cdot p_4 (\leq)(=)(\geq) c_{ec_2} \\
\vdots \\
w_{reuse_m} \cdot p_1 + w_{remanufacturing_m} \cdot p_2 + w_{recycling_m} \cdot p_3 + w_{landfill_m} \cdot p_4 (\leq)(=)(\geq) c_{ec_m}
\end{cases}$$

By solving the system of (in)equations above a feasible value or a feasible region could be determined as solution for the goal-seeking activity.

Going further and trying to find the optimum value from the feasible region based on a certain objective function, we get into the *optimisation analysis* area.

For instance WEEE Directive aims at maximisation of recovery which is the maximisation of reuse, remanufacturing and recycling of products, or the objective is:

$$z = p_1 + p_2 + p_3 = \max$$

From a producer point of view, the objective will most likely be minimum cost. In this case the objective function expression looks like:

$$z = \sum_{i=1}^{m} w_{EOL_i} = min$$

The Model and Multi-Criteria Analysis

The model offers the evaluation of the EOL scenario by providing values on various environmental indicators and costs. While the costs can be expressed in a single unit (money) the environmental indicators are expressed in unrelated measure units. This situation can be overcome by using the model in conjunction with a multi-criteria method. So the outputs of the model could serve as inputs in the multi-criteria method.

As the model is based on linear algebra it can be relatively easily implemented in a software tool. The software application presented later in this chapter will make use of the model and a multi-criteria method (Analytical Hierarchical Process).

5.3. BPR and DSS for EOL Products

Business Process Reengineering (BPR) has been chosen as the framework to develop the DSS model. Therefore tools and principles mentioned in Chapter 4 are used to model business area (players, activities, processes related to product recovery) and develop the software. The BPR methodology permits radical changes including engineering of new processes, which is absolutely necessary when it comes to modelling processes and infrastructure to accommodate new business constraints (in this case – new legislation).

5.3.1. Analysis of Needs

In order to determine the necessity of a DSS for end-of-life electrical and electronic products, those involved in various stages of the product life cycle have been interviewed to find the extent of their implication in the recovery activity and their need for the DSS [EEDSS02b]. The results are presented below:

1. **Producers**
   - Aware of the legislative requirements, therefore trying already to implement a product take-back scheme and organise recovery of their products
   - An imperative need of a good information system that permit collection of information from all players involved in the chain, traceability of their products, calculation of indicators that show compliance/non-compliance with regulation and decision support

2. **Local authorities**
   - The main role in the recovery chain is gathering reports that show producers' compliance/non-compliance with regulation; they also organise collection systems
   - An information system to permit gathering information – very useful and welcome

3. **EPA**
   - Huge implication in making law recommendations and coordination of the law application based on reports from producers; gathering reports is another role of EPA
   - A reporting tool necessary to have a complete image of the producers and their products and the compliance to legislation; both dimensions – environmental and economic of the recovery activities as well as a decision support tool are of interest

4. **Recyclers**
   - Very important role in recovery as they actually perform the processes involved in recycling
   - A strong need for an information system to permit transfer of information between producers and recyclers and for a decision support tool

5. **Remanufacturers**
   - Very important role in recovery as they actually perform the processes involved in remanufacturing and reuse/part reclamation
   - A strong need for an information system to permit transfer of information between producers and recyclers and for a decision support tool

6. **Retailers**
   - Role only in collection of products as part of a take-back policy initiated by producers and in providing business information to producers
   - no interest in WEEE Directive; driven by producers' initiatives.

5.3.2. Players and Processes in Electrical and Electronic Equipment Recovery

5.3.2.1. Players

The main players in the recovery activity are: producers, retailers, collectors, and processors (remanufacturers and recyclers). Definitions for these players are provided below:

- *Producer* is a facility which [WEEE02]
  - manufactures and sells electrical and electronic equipment under his own brand
  - resells under his own brand equipment produced by other suppliers
  - imports or exports electrical and electronic equipment on a professional basis into an EU Member State

- *Retailer (distributor)* is a facility which provides electrical and electronic equipment on a commercial basis to the party who is going to use it [WEEE02]. It is important that distributors (retailers) are integrated into the whole recovery business as not only are they responsible for the delivery of product to customer but they provide the link between the recovery operations and the customer.

- *Collector* is a facility which provides reverse distribution for electrical and electronic equipment. Collectors may be local authorities, retailers or the processors themselves. The collector is a crucial link in the recovery chain. The recovery business as a whole is based on collection. The efficiency and effectiveness of recovery is dependent on collection.

- *Processor (recoverer)* is a facility which provides treatment to EOL electrical and electronic products in order to be recovered and/or discarded to landfill in an environmental sound way. Recovery includes product, material or energy recovery. Processors represent the core of recovery. They carry out significant value-adding activities, converting discarded EOL products into output via reprocessing activities.

5.3.2.2. Activities and Processes

Once the product reaches the processing stage the algorithm described by the decision tree in figure 5.1 will be followed.

In Appendix D, IDEF0 method was used to model processes and activities in WEEE processing. The activities considered are the options described within the model presented earlier in this chapter: reuse, remanufacture, recycle and landfill. Possible processes associated with different EOL options are presented in Appendix D.

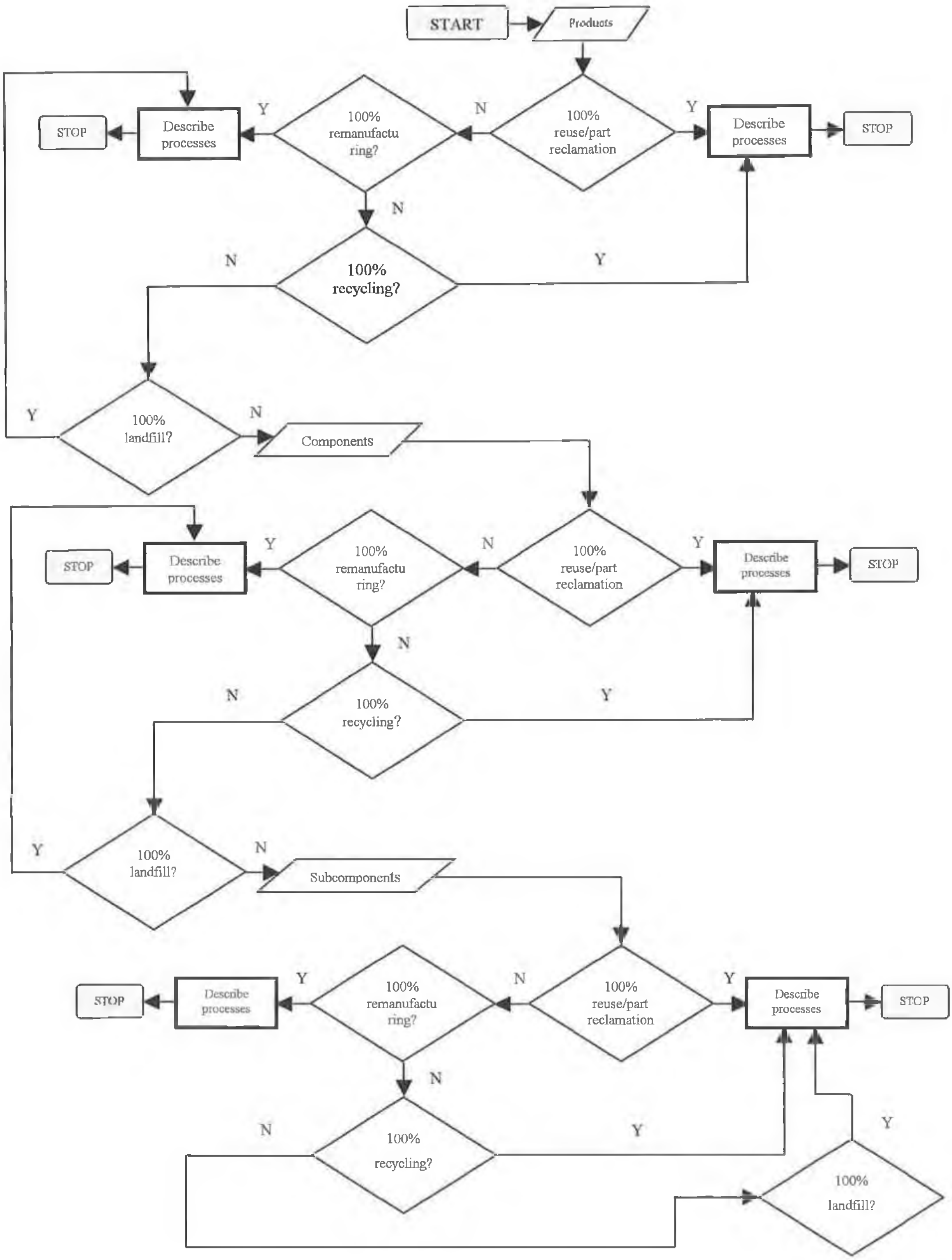


Figure 5.1. End-of-life scenario decision algorithm

5.3.3. Data Modelling

Figure 5.2 shows product flow and also the data flow that can occur and will be considered and managed by the model.

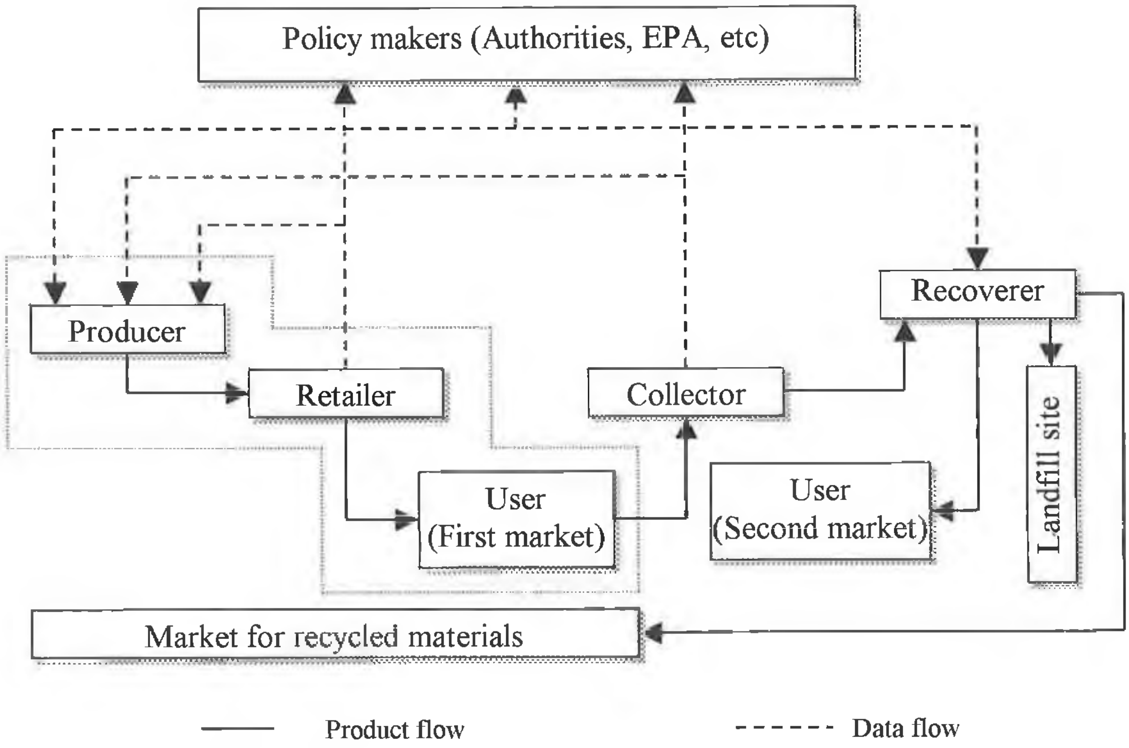


Figure 5.2. Product and data flows in recovery

The data arrows in the figure are originated and pointing at the players presented in the previous section. Policy makers are also interested in the data flow, they will benefit from the data flow by extracting information but will not input any data.

Table 5.1. Data provided by players

PLAYER	DATA PROVIDED
Producer	• Product structure and material composition
Retailer	• Quantitative data about products put on market
Collector	• Quantitative data about collected products
Processor	• Economic and environmental data regarding the EOL product processing

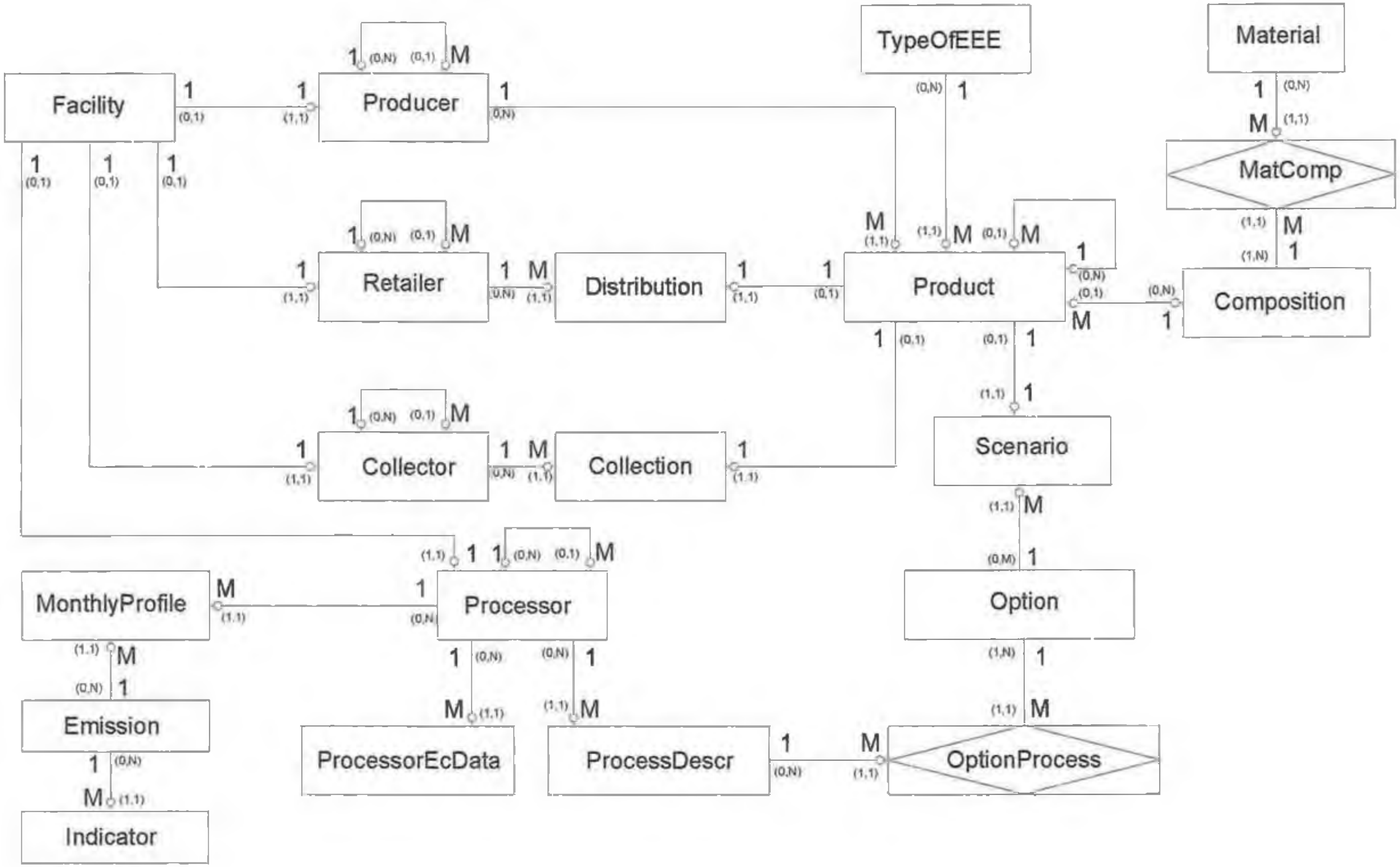


Figure 5.3. Entity relationship diagram for model

Data presented in table 5.1 are modelled by entities. Entities relationships have been identified employing the IDEF1X principles and an entity relationship diagram (ERD) has been built up. In figure 5.3 entities and their relationships are presented. The type and the cardinality of the relationship are also available.

The 'Facility' entity models general data about producing, retailing, collecting and/or processing facilities (companies). The particular data referring to the specific operation(s) of the facility are modelled by entities 'Producer', 'Retailer', 'Collector' and 'Processor'. The fact that a facility performing a certain operation could operate under another facility makes the entities to be recursive. An example in this respect would be a company which manufactures a product and the product is put on market under another company's brand name.

The 'Product' entity represents data about structure and material composition of products. As an instance of this entity can be dependent on the existence of another (a subcomponent part of a component) this entity is also recursive. 'TypeOfEEE' entity models the categories of EEE provided in Annex 1A and Annex 1B of WEEE Directive (see Appendix B). The entities 'Material', 'MatComp' and 'Composition' are data regarding material composition of the product.

'Distribution' and 'Collection' are association of 'Retailer' or 'Collector' entity instances with instances of 'Product' entity. Additional data regarding the association are also included.

Data regarding economic costs and emissions of a processing facility are modelled by the entities 'ProcessorEcData' and 'MonthlyProfile'. The environmental quantity data are provided on different emissions instances of the entity 'Emission'. Associated to the Emission instances are the environmental impacts, which are described by the 'Indicator' entity.

The entity 'Scenario' represents an association between the entities 'Product' and 'Option'. The 'Option' entity is about identifying data of an EOL option and it is in relation with 'Process' entity through the bridge entity 'OptionProcess' used to break the many-to-many relationship into two one-to-many relationships. The last entity, 'Process', represents the data regarding various processes involved by an EOL option for an EEE.

5.3.4. The Software

5.3.4.1. Functional Specifications

The software tool provides the following functions:

- Record data provided by the users (data about products, processes, costs etc.)
- Calculate environmental and economic indicators for different EOL options based on the data provided and a methodology [EEDSS02a]
- Provide reports on these indicators for the users
- Support the decision-maker choose the best end-of-life option from an environmental and economic point of view

Diagrams developed with the IDEF0 methodology that model the functionality of the tool are presented in Appendix E.

From the users' point of view, the application has the following functions, according to the type of user:

- Producers:
    - Calculate the environmental impact of their products for each end-of-life option and provide reports on environmental indicators
    - Calculate costs of processing their products for each end-of-life option and provide reports on costs
    - Calculate external indicators and provide reports on these indicators
    - Rank the possible end-of-life options based on the environmental and economic criteria (indicators)
    - Give the possibility to trace their products
- Retailers and Collectors:

- Provide data used for further calculations

- Remanufacturers, recyclers:
  - Calculate environmental impact and provide reports on environmental indicators
  - Calculate costs and other economic indicators (external indicators) and provide reports on them
  - Give the possibility to trace products

- Landfill sites:
  - Calculate environmental indicators, especially the ones that show compliance/non-compliance with legislation (percentage of waste collected that is landfilled)
  - Calculate cost indicators

- Policy makers (EPA):
  - Calculate environmental impact and provide reports on environmental indicators
  - Calculate economic indicators, especially external indicators and provide reports on such indicators
  - Offer a hierarchy of the end-of-life options based on the economic and environmental criteria provided

To support the functionalities above, a database is developed. The tool also provides front-end application which implements the calculation algorithms developed in the EEDSS methodology [EEDSS02a] and allows the user to manipulate data and retrieve the needed information.

5.3.4.2. The Structure of the Software Application

The software application provides a database to house data and a graphical user interface (GUI) to input data as well as mechanisms to retrieve information. It calculates specific indicators and generates reports according to the needs of the users and following the EEDSS methodology [EEDSS02a]. The GUI is created by developing various forms that allow the user to interact with the application.

The diagram in figure 5.4 presents schematically the components and the structure of the software.

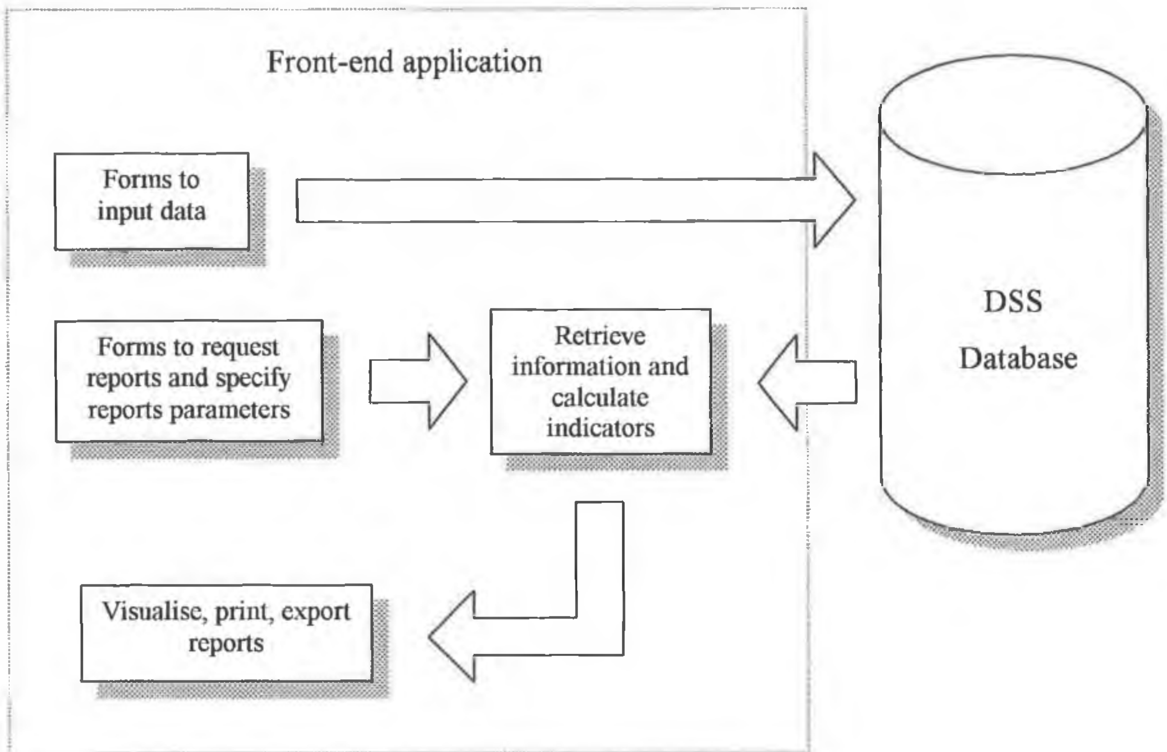


Figure 5.4. Structure of the software application

To implement the structure and manage the database, a database management system (DBMS) needs to be used. A programming language is necessary for the front-end application. The following sections present the DBMS and database as well as the programming language and the front-end application.

5.3.4.3. The DBMS and Database

The database management system (DBMS) chosen for the DSS database is Microsoft SQL Server 2000.

SQL Server 2000

The main reasons to choose this database platform were that "it is competent, comparatively cheap and wide spread" [Nil02]. Also a good reason is the availability of documentation either offered by Microsoft or by other publishers. As to the competency of MSQL Server 2000 here are its features as they were found in its specifications [HSQL01]:

- *Internet Integration*: The SQL Server 2000 database engine includes integrated XML support. It also has the scalability, availability, and security features required to operate as the data storage component of the largest Web sites
- *Scalability and Availability*: The same database engine can be used across platforms ranging from laptop computers running Microsoft Windows® 98 through large, multiprocessor servers running Microsoft Windows 2000 Data Centre Edition. SQL Server 2000 Enterprise Edition supports features such as federated servers, indexed views, and large memory support that allow it to scale to the performance levels required by the largest Web sites.
- *Enterprise-Level Database Features*: The SQL Server 2000 relational database engine supports the features required to support demanding data processing environments. The database engine protects data integrity while minimising the overhead of managing thousands of users concurrently modifying the database. SQL Server 2000 distributed queries permit to reference data from multiple sources as if it were a part of a SQL Server 2000 database, while at the same time, the distributed transaction support protects the integrity of any updates of the distributed data. Replication permit also to maintain multiple copies of data, while ensuring that the separate copies remain synchronised. One can replicate a set of data to multiple, mobile, disconnected users, have them work autonomously, and then merge their modifications back to the publisher.
- *Ease of installation, deployment, and use*: SQL Server 2000 includes a set of administrative and development tools that improve upon the process of installing, deploying, managing, and using SQL Server across several sites.

- *Data warehousing*: SQL Server 2000 includes tools for extracting and analysing summary data for online analytical processing. SQL Server also includes tools for visually designing databases and analysing data using English-based questions.

The DSS Database

Based on the entity-relationship (ER) diagram resulted from the business area analysis (see figure 5.3) the database was built in two steps:

1. Create tables (see a screenshot of SQL Server 2000 Enterprise Manager – EEDSS database in figure 5.5 which presents the list of all the tables in the database).

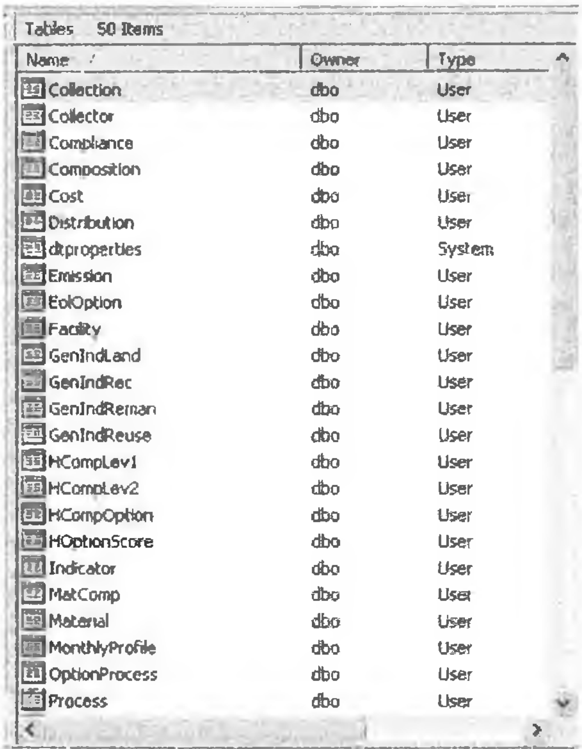


Figure 5.5. EEDSS database tables

Each table is detailed with fields and fields' description (such as type of data, length, etc.). For details about each table see Appendix F. Keys and indexes have also been set at this stage.

2. Implement relationships identified in the ER diagram (see figure 5.6).

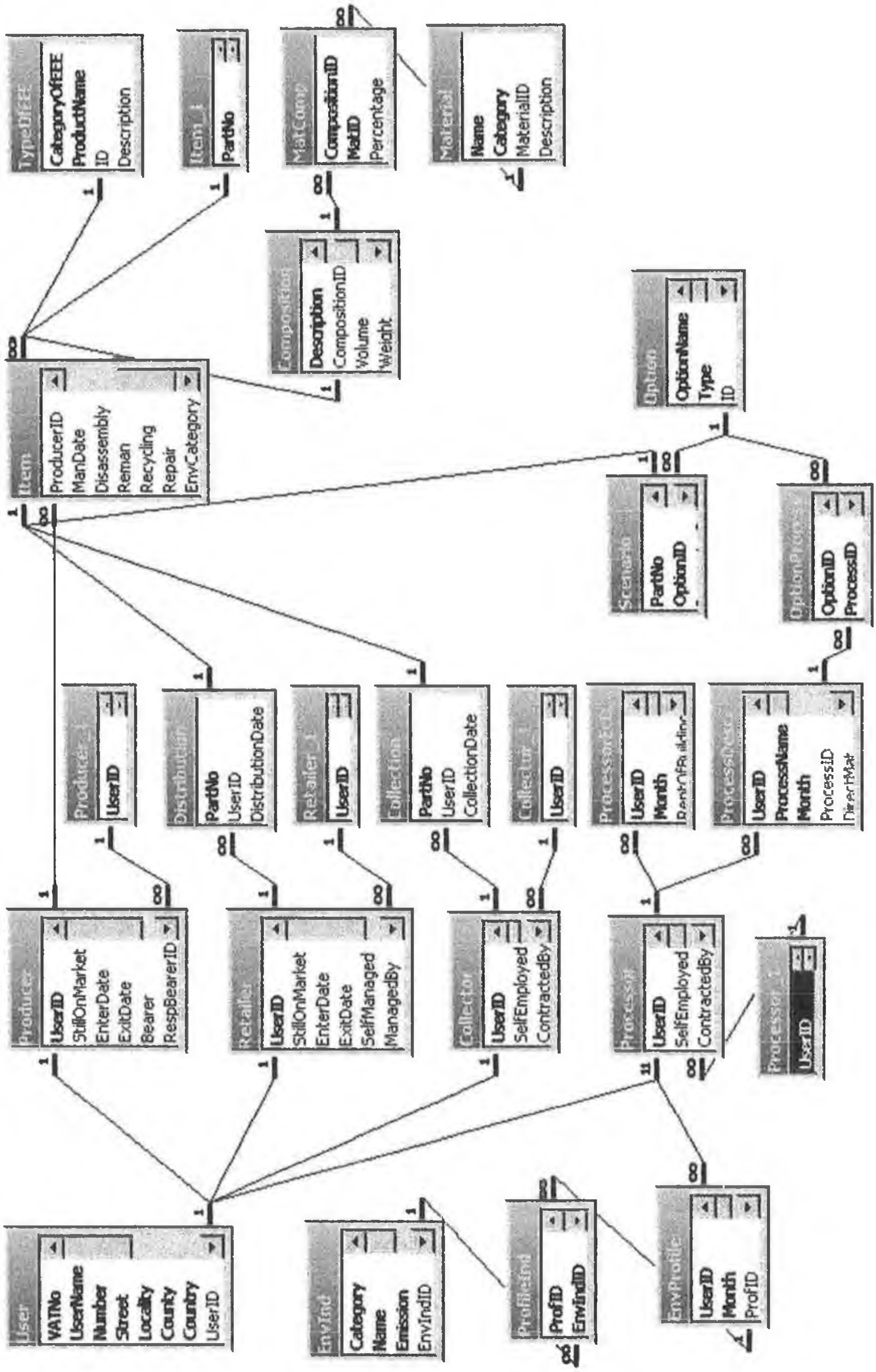


Figure 5.6. Database structure implemented with SQL Server 2000

5.3.4.4. The Front-End Application

The Programming Language

The programming language chosen to develop the front-end application is Visual Basic.NET.

Visual Basic.NET and ADO.NET [Deit02], [Mat01]

Visual Basic.NET is Microsoft's latest version of the highly popular Visual Basic. VB.NET is a pillar of the .NET Framework, and yet another step forward in the evolution of the language. It is a high-level programming language for the .NET Framework, and provides the easiest point of entry to the Microsoft.NET platform.

Visual Basic.NET has many new and improved language features compared to the old version such as inheritance, interfaces, and overloading – that makes it a powerful object-oriented programming language. It allows creating multithreaded, scalable applications using explicit multithreading. Other features in Visual Basic.NET include structured exception handling, custom attributes, and common language specification (CLS) compliance.

Visual Basic.NET supports many new or improved object-oriented language features such as inheritance, overloading, interfaces, shared members, and constructors. Also included are structured exception handling, delegates, and several new data types.
Regarding database applications, VB6 gave the new way to access databases with the integration of ActiveX Data Objects (ADO). The new VB.NET comes in with the new version of ADO.NET.

ADO.NET is designed to be a disconnected architecture which means that applications are connected to the database long enough to retrieve or to update data and are then disconnected. If data are retrieved they can be stored in ADO.Net's objects such as *DataSet* or *DataView*. The most important benefit of disconnected architecture is that it allows the application to scale up – the database will perform just as well supporting hundreds of users as it does supporting ten users.

ADO.NET is designed around System.Data namespace from which other namespaces are derived. One of the derived namespaces is System.Data.SqlClient which contains classes optimised to interact with SQL Server.

Software Solution

Classes

As mentioned before, Visual Basic.NET is totally supporting object-oriented programming; the basic building block of a software application is the *object class*. Therefore, classes were created in order to obtain forms, to implement algorithms and to input/retrieve data to/from the database. The classes are grouped in folders as seen in figure 5.7.

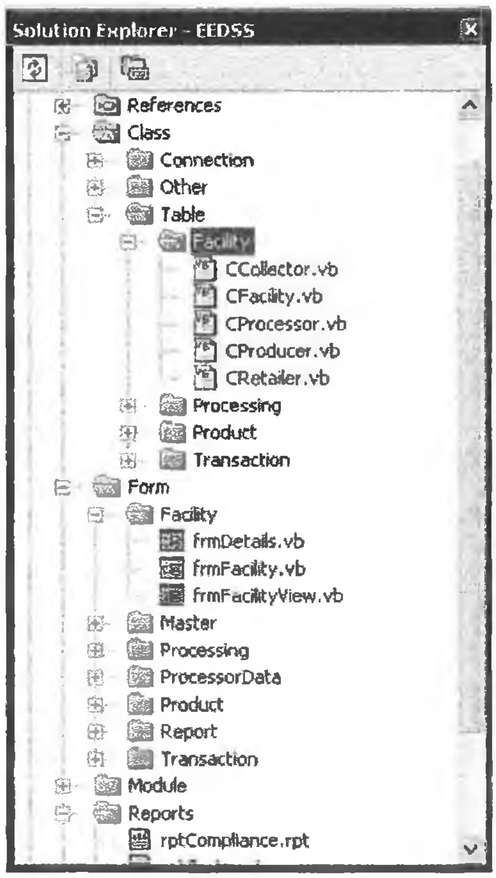


Figure 5.7. Solution structure seen with Visual Studio – Solution Explorer

The classes are grouped as follows:

- *Connection* – used to connect to the database (specifies EEDSS database on local host server)
- *Tables* – model records stored in database tables. For example, figure 5.7 shows the classes contained in "Facility" which are modelling data regarding facilities (general data regarding a facility modelled by *CFacility*, data specific to a collecting point modelled by *CCollector*, etc.). Similarly, there are classes that model data regarding products, transactions and processing.
- *Forms* – in VB.Net forms are organised as classes as well. In figure 5.7 the forms used to input, modify, delete and view data can be seen grouped in folders such as "Facility" which contains forms regarding facilities, or "Product" which contains forms regarding products. In order to access data, the forms employ objects of connection and table classes. In folder "Form" sub-folder "Report" there are other forms that contain code for retrieving data and code for the implementation of the algorithms used to calculate indicators.

Modules

The modules contain public functions to: accommodate character strings to building SQL statements, convert measure units, set the index of list/ combo boxes at a specified ID or name, convert date formats, etc.

Reports

Reports are used to visualise the results of the calculations. There are four categories of reports: reports on costs, reports on general environmental indicators, reports on compliance environmental indicators and reports on EOL options hierarchy. In this respect, Crystal Reports for Visual Studio .NET, which is the standard reporting tool for Visual Studio .NET, has been employed.

Crystal Reports for Visual Studio .NET provides the following namespaces [Deit02], [Mat01]:

- CrystalDecisions.CrystalReports.Engine Namespace - provides support for the report engine.

- CrystalDecisions.ReportSource Namespace - provides classes that comprise a layer between the Windows Forms Viewer or the Web Forms Viewer, and the CrystalReports Engine. These classes handle requests from the viewers. The classes then determine how to contact the engine and make the call on the viewer's behalf.
- CrystalDecisions.Shared Namespace - provides classes, interfaces, and enumerations that are shared by the Web Forms Viewer, Windows Forms Viewer, and Crystal Report Engine.
- CrystalDecisions.Web Namespace - provides support for the Crystal Reports Web Viewer control and its associated classes.
- CrystalDecisions.Web.Services - provides support classes for exposing Crystal Reports as Web Services.
- CrystalDecisions.Web.Services.Enterprise - provides support classes for consuming reports from Crystal Enterprise.
- CrystalDecisions.Windows.Forms - provides support for the Windows Forms Viewer control and associated classes.

The top level of the Crystal Reports object model is the *report document* object. The report document contains all the properties and methods needed to interface with and customise a report. As mentioned before there are four report documents created within the DSS application. They are linked to tables in the database which are housing calculations results.

Crystal Reports for Visual Studio .NET provides two report Viewers which can be used to view reports in applications: the Web Forms Viewer for Web applications and the Windows Forms Viewer for Windows applications. As regarding Windows Forms Viewers, they [Deit02], [Mat01]:

- host and view a Crystal Report in a Windows application.
- dynamically update the report they are hosting.
- interact with controls within a Windows application.

The Crystal Reports Windows Forms Viewer, which is available as a control in the Visual Studio Toolbox has been used in the application in connection with the four report documents.

The Graphic User Interface

Data forms were created in order to guide the user through the input data process, the indicators calculation process and the retrieving information process. Forms are graphic interfaces which contain different controls that are linked to the database so that they allow channelling the data to the appropriate location into the database. At the same time forms are used to retrieve or visualise data already stored in the database. This section provides an overview of the DSS application with examples of forms and description of the data accessed.

The graphic interface of the tool has been organised as multiple-document interface (MDI) windows. Figure 5.8 shows the parent form and the intro form on top of it.

Figure 5.8. Parent form of EEDSS tool.

By accessing the menu of this portal form, different child forms will pop up allowing the user to perform the desired operations.

Facility Data Forms

Forms to enter and access data about companies or organisations involved in the EOL treatment of EEE were created (see figure 5.9).

The form presented in figure 5.9 permits input, update, and delete data records regarding a producer, retailer, collector and/or processor facility. Company name, address, and person of contact details are needed in order to enter a new facility data into the database.

The navigation area of the form permits the user to move through the records up and down and also to sort or find according to selected criteria. In the area 'Acts as' only the roles played by the company can be clicked. Depending on the role(s) of the user (producer, retailer, collector, and processor), specific data will be manipulated. In figure 5.10 the form to access data specific to processor role is shown.

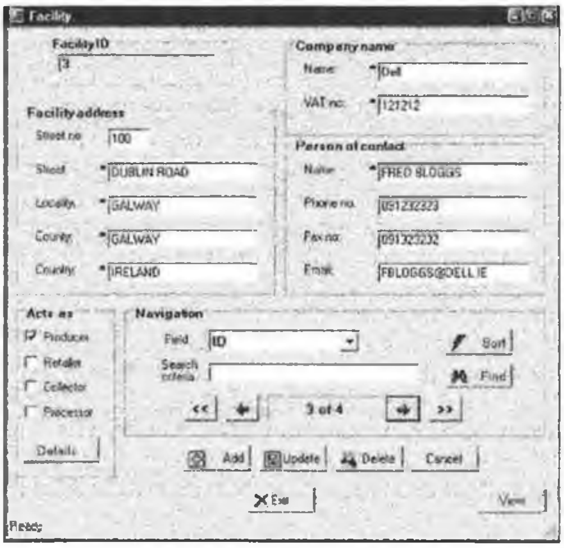


Figure 5.9. Facility data form

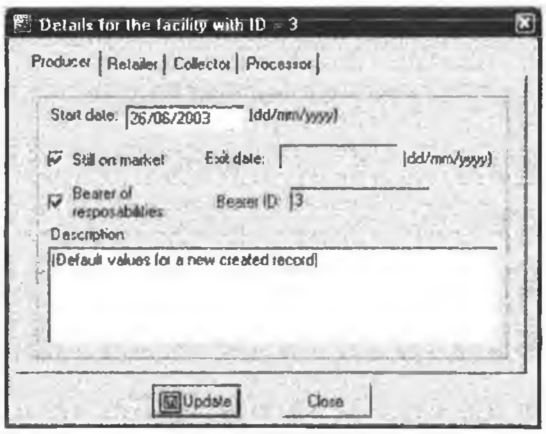


Figure 5.10. Producer details form

By clicking on a different tab data regarding other roles can be visualised and updated if necessary.

Product Data Form

Some forms are used to handle data pertaining to products such as the forms shown in figure 5.11. Usually the producer supplies the product data.

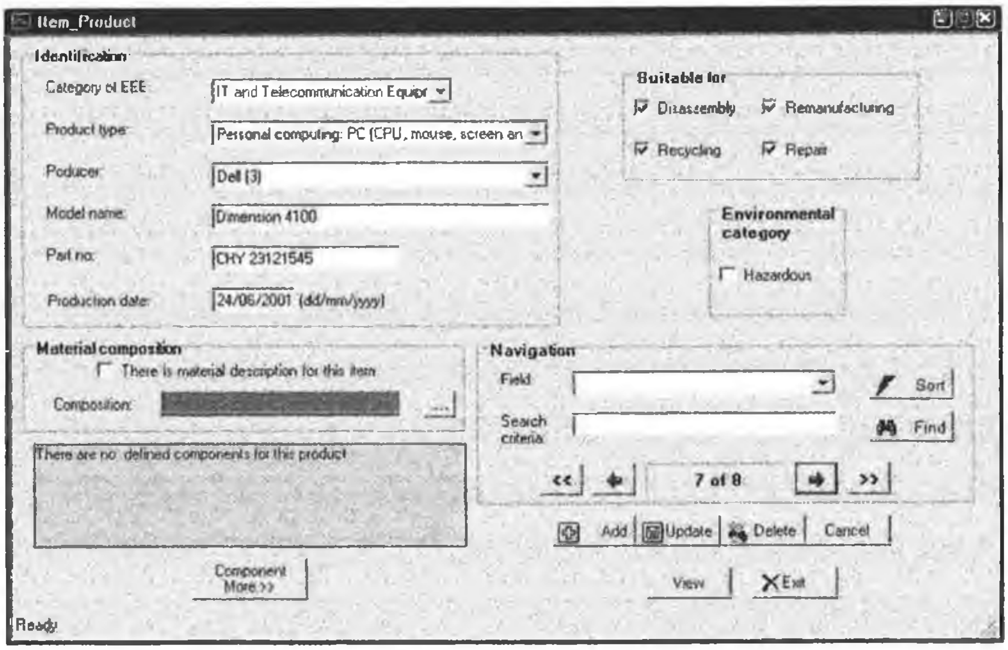
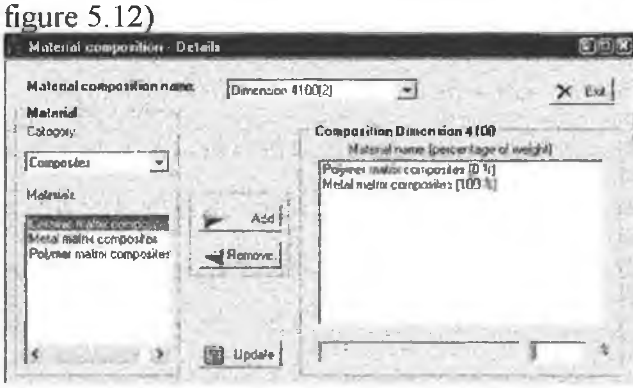


Figure 5.11. Product data form

Data regarding the product type are given by the two combo boxes. Along with the model name and part number that identify uniquely each product, the producer must be identified as well. If the product has components, a description of the components is needed; clicking 'Component' button a similar form will come up so that component details can be accessed. A full view of the products with associated components and sub-components can be accessed by selecting 'View' in the product menu. The application permits description of the product in more detail – material composition (see figure 5.12)



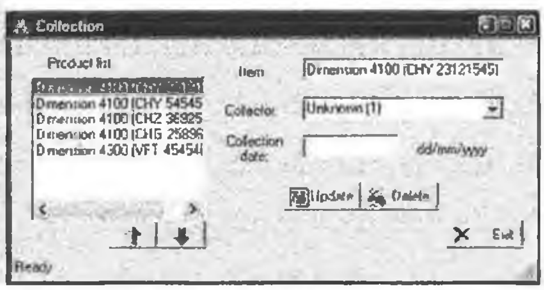


Figure 5.12. Material composition data form

Figure 5.13. Collection data form

Transaction Data Forms

These forms are for data related to the distribution, collection and EOL scenario. The retailer, the collector, respectively the processor provide these data.

For a product existing already in the database the collector name and collection date can be updated (see figure 5.13). Similar to this form there are two other forms to allow enter and edit retailer name or EOL option and selling date, respectively processing date.

Processing Data Forms

The forms for processing data are used only by the processor in order to enter or edit data regarding EOL treatment of the product.

Figure 5.14 presents forms to access data regarding EOL option. A processor can define different EOL options. Each option will comprise various processes. To add or remove processes to an EOL option the second form in figure 5.14 is used.

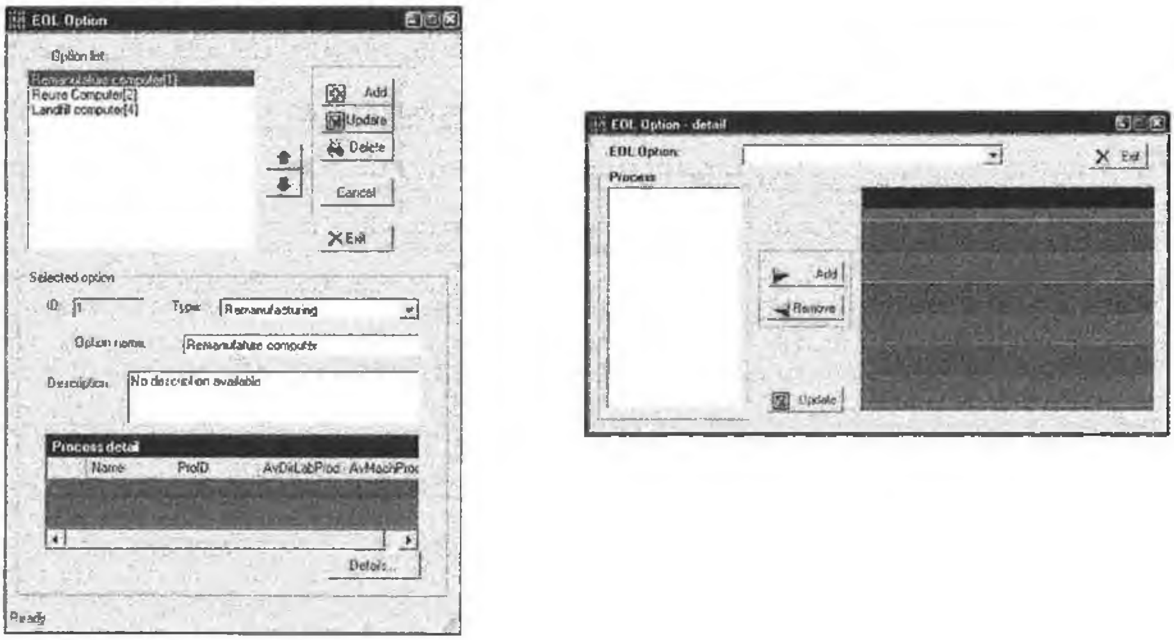


Figure 5.14. Data forms for EOL options

To manipulate general data regarding processes the first form in figure 5.15 is used. The second form is for costs data related to the processing activities.

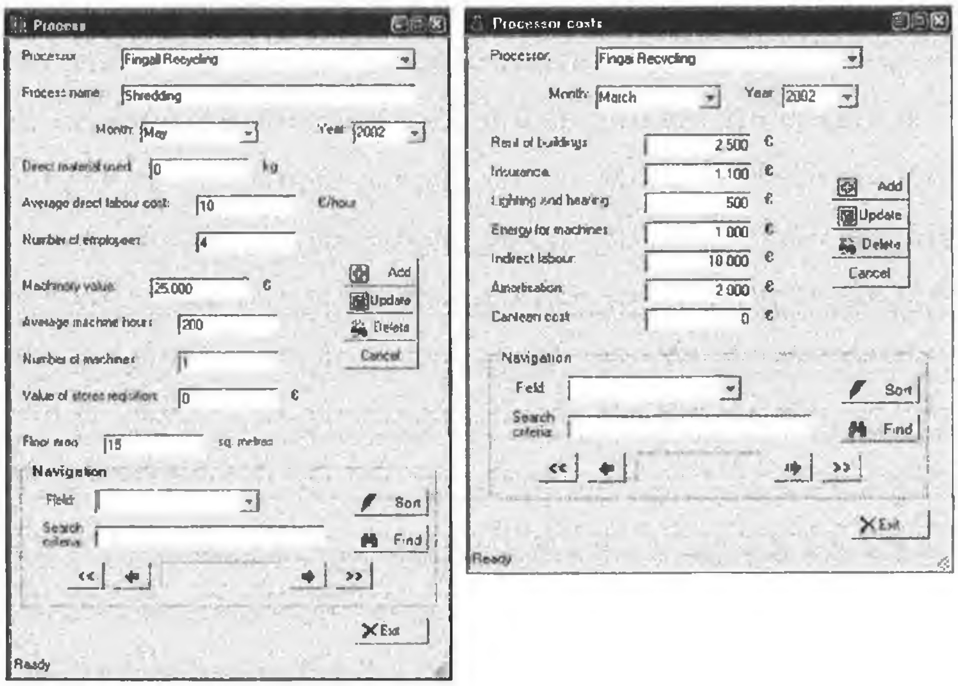


Figure 5.15. Process and processor cost forms

Another form similar to the one for the costs is used to input data regarding emissions of the processing activities.

Reports Forms

The form in figure 5.16 is used to input the parameters necessary to provide the user with the desired reports. The name of the producer along with the type of product are accessible through this form. Also a processing period has to be chosen in order to perform the calculations.

Reports on economic indicators are of interest mostly for processors and producers. The reports are available for printing or to be saved as doc, xls or pdf files.

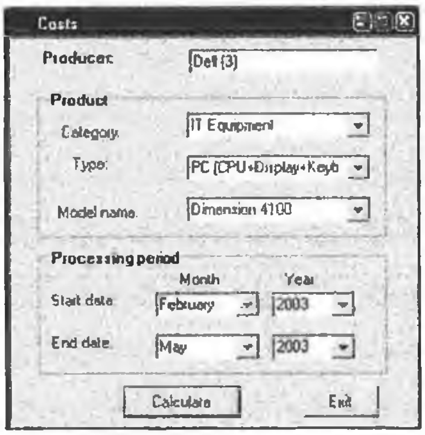


Figure 5.16. Cost report form

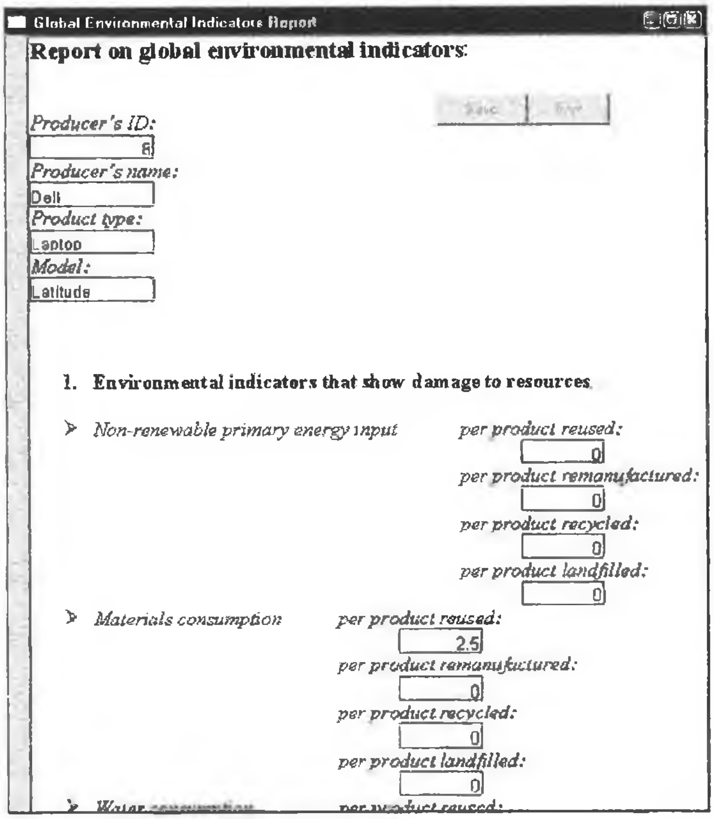


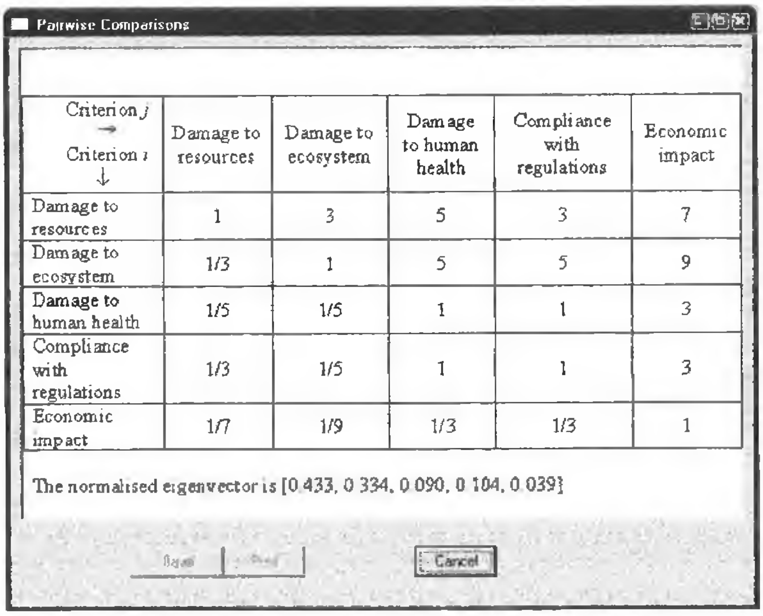
Figure 5.17. Report on global environmental indicators

Similar forms are used in specifying parameters for the reports on environmental indicators. Such a report is presented in figure 5.17.

Reports on the global environmental indicators are important especially for processors and policy makers. The reports on environmental indicators showing compliance with regulation are useful for processors, producers and policy makers.

The DSS tool helps to establish an EOL option hierarchy for a certain product. The period and the product type have to be set and, in addition, indicators taken into consideration have to be specified. The multi-criteria method employed by the DSS application is Analytical Hierarchy Process (AHP).

Comparisons are made between criteria and matrices like the one in figure 5.18 are generated.



Criterion *j* → / Criterion *i* ↓	Damage to resources	Damage to ecosystem	Damage to human health	Compliance with regulations	Economic impact
Damage to resources	1	3	5	3	7
Damage to ecosystem	1/3	1	5	5	9
Damage to human health	1/5	1/5	1	1	3
Compliance with regulations	1/3	1/5	1	1	3
Economic impact	1/7	1/9	1/3	1/3	1

The normalised eigenvector is [0.433, 0.334, 0.090, 0.104, 0.039]

Figure 5.18. Pairwise comparisons

Based on comparisons matrices and calculated values of the indicators a hierarchy of the EOL options for a certain type of product will be obtained (as in figure 5.19).

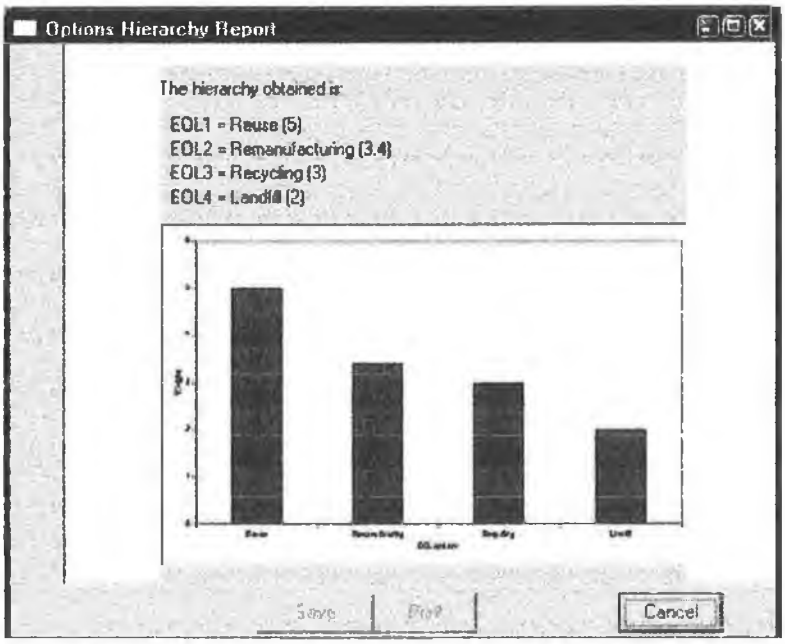


Figure 5.19. EOL option hierarchy

5.4. *Conclusions*

This chapter highlighted once more the need for an information system to handle data coming from all the parties involved in product recovery. As a consequence, a DSS for end-of-life electrical and electronic equipment was developed and presented in this chapter.

The DSS model proposed offers a mathematical model to support decision-making as well as a business area model and a software application. The model aims at solving the deficit existing at present in relation to decision support for end-of-life products.

Chapter 6. Conclusions

6.1. Thesis Summary

Manufacturing is the leading cause of detrimental impact on the environment. In waste generation, manufacturing's contribution dominates all industrial activities. In response to these problems, governments, public and industrial organisations use different instruments (such as legislation) to force manufacturers to take back their products at the end of life for recovery, thus reducing the environmental burden. The drivers of resource recovery have been investigated and presented in the thesis.

Increasingly, producers are considering take-back of their products, mostly as a result of the legislative pressure that promotes the extended producer responsibility. Three types of take-back currently practiced – OEMs take-back, pooled take-back and third-party take back – are presented in the thesis. In order to implement a product take-back scheme, whichever model chosen, a well-designed logistics take-back network must be put in place. The reverse product flow is not the forward flow simply reversed and neither is the information flow. Reverse logistics must be designed having in mind all the particularities of the reverse activities. In this context, an information system to support good organisation and management of the reverse logistics becomes a necessity.

Once end-of-life products are taken back, a fundamental decision must be made as to whether to reuse or remanufacture or recycle or simply discard them to landfill. It is not an easy decision to make as many factors must be considered, both economic and environmental. Therefore, the information system for reverse logistics should comprise a decision support system (DSS). Chapter 4 addresses the large area of information systems and reviews a set of methodologies (such as CIMOSA and BPR) and methods (such as SADT and IDEF family) that can be used in business area modelling necessary in the design of an information system.

The thesis has proposed a decision support system for end-of-life products. A mathematical model was developed to support decision-making. The model is based on linear algebra. It considers environmental and economic vectors for each end-of-life option and a given scenario vector is as a linear combination of these (e.g. a percentage of product is reuse, a percentage remanufactured, a percentage recycled and the reminder percentage landfilled). Vectors' components are values of environmental and economic indicators calculated for each end-of-life option. The model can be used in combination with Analytical Hierarchy Process (AHP) to find a hierarchy of end-of-life options as well as in solving 'What If' situations or 'goal seeking' problems. Using the BPR methodology and IDEF methods a model for reverse logistics is created and a decision support application developed. The application employs the mathematical model and a database. The DSS developed in the thesis aims at supporting compliance with the WEEE Directive.

6.2. Conclusions and Recommendations for Further Work

The practice of recovery is a relatively new activity, therefore a deficit in models and tools to support it exists. A decision support system to assist in decision-making for end-of-life products is necessary, as evidenced by a survey of needs.

The decision as to end-of-life option is fundamental in recovery. It appears at three levels: operational, tactical and strategic. The DSS developed here can be used to support decisions at the tactical and the strategic levels but it could be extended to application at all levels.

The mathematical model proposed considers only costs as economic indicators. It could be improved with the use of other economic issues such as the demand for reused/remanufactured products/components or recycled materials as well as the influence of the second market on the sales of new products on the primary market.

The software application implements only the optimisation analysis that uses AHP to obtain the best end-of-life option. It can be extended to perform more operations to support 'what if' analysis or goal seeking analysis such as 'which is the best EOL scenario for an EOL product considering various environmental and economic constraints'.

The model presented addresses recovery as a component of the reverse logistics. Another important phase in reverse logistics is collection which was regarded only as a supply for recovery in this model. The area of collection should be explored in more detail.

Business area analysis consists of a model creation for the business area that comprises processes, data and networks. The thesis offers only a data model and a process model, therefore modelling in the network area should be further developed.

As players in the reverse logistics system are spread geographically, internet technology should be used to improve the application developed in the DSS presented in this thesis.

A software application could be developed to link the application developed in the DSS to the information system already in place in companies involved in the reverse logistics chain. This would permit the transfer of information from their information systems to the application's database (for example data about products).

As most of the data used in the model are confidential, data access and security are important issues. Therefore proper security and data sharing mechanisms must be developed.

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Appendix A

European Legislation – Council Directives and Recommendations [EU03], [Lis96]

Some EU Council Directives and Recommendations on environment are:

- *Council Directive 75/442/EC (Waste Framework)* laid down the basic principles on the collection, disposal, recycling and processing of waste on a national basis. This was supplemented in 1978 by *Directive 78/319/EEC* on toxic and dangerous waste.

- *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal* (1989) gives definitions of all terms connected to waste, lists of categories of wastes and hazardous wastes, and states the conditions of transboundary movements of hazardous wastes and their disposal.

- *Council Directive 78/319/EC (Toxic And Dangerous Waste)* drew up a list of toxic and hazardous substances, providing a broad framework for the control and disposal of waste containing them and includes the "polluter pays" principle under which the holder and/or previous holder/producer of the wastes are responsible for the costs of its storage, treatment and disposal. (Radioactive wastes, certain agricultural wastes, hospital wastes, explosives and effluents discharged into water courses and sewers are not included under this directive: these are covered in part by *Directive 76/464/EEC*, a framework directive governing the discharge of dangerous substances to inland, coastal and territorial waters).

- A series of directives dealt with such issues as *Waste Oils (Council Directive 75/439/EEC*, since updated by *Council Directive 87/101/EEC*), the *Treatment and Disposal of PCBs and PCTs (76/403/EEC), Waste from the Titanium Oxide Industry (78/176/EEC)* and the *Use of Sewage Sludge in Agriculture (86/278/EEC). Council Directive 85/339/EEC* required the establishment of national programs for reduction in the volume of beverage containers disposed as waste. The programs were to begin on 1 January 1987 and updated subsequently every four years. A heavy emphasis was put on the recycling of such containers.

- However, European Union waste legislation was substantially revised by the adoption of *Directive 91/156/EEC (Waste)* and *Directive 91/689/EEC (Hazardous Waste)*. These directives provided more rigorous definitions for 'waste' and 'hazardous waste'; established broad licensing and registration conditions for those who handle, transport, dispose of or recycle waste; and required the relevant authorities to draw up waste management plans with the aim of achieving 'self-sufficiency' (i.e. disposal by Member States of their own waste), allowing the national authorities to control waste movements which do not comply with those plans.

- *Council Directives 84/631, 85/469/EEC (Transfrontier)* and *Decision 90/170/EEC* deal with the transfrontier shipment of toxic or hazardous waste as defined by *Directive 78/319/EEC* and *Directive 76/403/EEC* above. Directive 84/631/EEC requires the use of a detailed consignment note detailing the source and composition of the waste, the routes by which it will be transported, measures undertaken to ensure safe transportation and the existence of a formal agreement with the consignee of the waste. The Directive also includes conditions for packaging and labelling the waste.

- *Council Regulation 259/93/EEC (Supervision and Control of Shipments of Wastes)* has as its aim the comprehensive regulation of the movement of all waste within, into and out of the EU. The Regulation implements the *Basel Convention* and OECD Decision on the transfrontier shipment of waste. The shipment of hazardous waste destined for final disposal to non-OECD countries is prohibited. This is to prevent EU and non-OECD operators from dumping hazardous waste in developing countries. Waste for disposal within the EU requires prior authorisation. The principles of self-sufficiency (disposal by Member States of their own waste) and proximity (local waste disposal) will also apply *Regulation 259/93/EEC* was amended and extended in February 1997 in relation to waste exports out of the European Union. The amendment implemented into Community law the decision taken under the Basel Convention to immediately ban exports of hazardous waste destined for final disposal to non-OECD countries, and to ban by January 1998 all exports of hazardous waste destined for recovery in non-OECD countries.

- *Council Directive 85/337/EEC (Environmental Impact Assessment)* marked a new departure in the planning of large waste disposal facilities by requiring an environmental impact statement for new sites which will take in excess of 20,000 tonnes of waste per annum. The proposed *Directive on Landfill (OJEC C 212/93)* would introduce licence applications and technical requirements for the design, operation, monitoring, shut-down and post shut-down care for landfills. Under the proposed Directive, landfills would be classified according to the type of waste they take in (hazardous, non-hazardous and inert) and operators would be required to provide a financial guarantee to cover the costs of site operation.

- *Waste Incineration Plants: Council Directives 89/369/EEC and 89/429/EEC* regulate air emissions from new and existing municipal waste incineration plants. *Directive 94/67 on the Incineration of Hazardous* has as its goals the minimisation of emissions resulting from the incineration of hazardous waste which might be detrimental to human health and the environment.

- *Council Directive 91/271/EEC (Urban Waste Water)* aims to protect the environment from the effects of collection, treatment and discharge of urban wastewaters, discharges from certain industrial sectors and the disposal of sludge. It sets requirements regulating effluent discharges at a common fixed standard, allowing exceptions under specified conditions. It sets deadlines (ranging from 1995 to 2005) for urban areas of different population levels to provide for collection and at least secondary treatment of urban wastewaters. It establishes requirements for urban wastewater treatment plants and controls on discharges of industrial waste water into urban waste water treatment plants.

- *Decision 94/2 - the European Waste Catalogue* was adopted by the EU in 1994 with the purpose of providing a common terminology for statistical purposes. The catalogue classifies wastes by their origin and is periodically reviewed. Some difficulty in assigning hazard attribution to wastes initially slowed down the project but the Commission subsequently decided to deal with hazard attribution in a separate *Hazardous Waste List - Decision 94/904/EC* of 31 December 1994.

- *Directive 94/62/EC on Packaging & Packaging Waste* sets targets for recovery and recycling of waste from all sources, criteria which packaging must meet, and measures to encourage prevention of packaging waste. It establishes measures for the promotion of return, reuse and recovery operations. The Directive requires 60% recovery and 40% recycling of all packaging waste within five years of the Directive coming into force. Article 8 of the Directive requires that the Commission draw up a marking system to indicate the reusability or recyclability of packaging. This Directive was supplemented with *Commission Decision 99/652/EC* confirming the measures notified by Belgium pursuant to Article 6 of Directive 94/62/EC.

- *Directive 96/61/EC on Integrated Pollution Control* aims to modify and supplement existing Community legislation concerning the prevention and control of pollution from industrial plants in order to achieve an integrated approach to pollution prevention so as to preserve and improve the quality of the environment, protect human health and to ensure a rational utilisation of natural resources. It lays down the criteria by which Member States will grant operating licenses to a range of industries and processes which come within its scope. The impacts of emissions to all media (air, water and soil) have to be taken into consideration and minimised in an integrated fashion, without putting an undue pollution load on any one media.

- *Council Directive 1999/31/EC* of 26 April 1999 on the landfill of waste. The aim of this Directive is to provide for measures, procedures and guidance to prevent or reduce as far as possible negative effects on the environment, including the greenhouse effect, as well as any resulting risk to human health from landfilling of waste during the whole life cycle of the landfill. The Directive specifies that biodegradable municipal waste going to landfills must be reduced to 35% of the total amount produced in 1995 not later than 15 years after the date of issue. All the costs involved in the setting up and operation of a landfill site and the estimated costs of the closure and after-care of the site for a period of at least 30 years shall be covered by the price to be charged by the operator for the disposal of waste in that site.

- The proposed *EU Directive on End of Life Vehicles (ELV)* issued in 2000 aims firstly at ensuring a high level of environmental protection in EU and secondly at preserving the functioning of the internal market as regards end of life vehicles. It seeks to prevent the creation of waste from vehicles and to promote reuse, recycling and recovery of vehicles and their components in order to reduce the quantity of end of life vehicles waste which is landfilled or incinerated without energy recovery. It puts into practice the hierarchy of principles established by the EU waste management strategy giving priority to material recycling. It is based on the "polluter pays" principle. It also applies the principle of producer's responsibility by establishing that collection and recycling of ELVs shall not be the burden of public authorities but shall be the task of the automotive industry companies. The vehicle manufacturer plays a predominant role in the protection, preservation and improvement of the quality of environment, since he takes the key decisions concerning the waste management potential of his product, such as design, conception, use of specific materials, composition of the product and finally its marketing. In the selection of materials the designer is required to control the use of hazardous materials by reducing the amount used in the vehicle and making them easier to recycle. In the design of vehicle components and materials the designer must facilitate the dismantling, reuse, recovery and recycling of ELVs. In order to facilitate the identification of materials and components, producers must use a common component and material-coding standard. Producers are required to publish information on the rates of reuse, recycling and recovery which have been achieved in the previous year for their vehicles and components. By January 2005, the reuse and recovery shall be increased to a minimum of 85% by weight per vehicle. By January 2015, the reuse and recovery shall be increased to a minimum of 95% by weight per vehicle. The member states are required to establish a system in which a 'certificate of destruction' is a condition for deregistration of a vehicle. A licensed dismantler can only award this certificate.

- The *Draft Proposal for the EU Council Directive* examines W*aste Electrical and Electronic Equipment (WEEE)*. It lays down measures which aim, as a first priority, at the prevention of waste electrical and electronic equipment, and, in addition, at the reuse, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste. It also seeks to improve the environmental performance of all economic operators involved in the life cycle of electrical and electronic equipment and in particular operators directly involved in the treatment of WEEE. Member States must encourage research aimed at reducing the use of dangerous substances and favouring the use of less polluting substitute substances in electrical and electronic equipment. They must ensure that producers use common component and material coding standards, in particular to facilitate the identification of those components and materials which are suitable for reuse and recycling. By January 2008 the use of lead, mercury, cadmium, hexavalent chromium, PBB and PBDEs must be substituted. Member states have to take the necessary measures to ensure that systems are set up so that final holders can return WEEE from private households free of charge and that producers provide for the collection of WEEE from holders other than private households. According to this Directive, member states shall take the necessary measures to ensure that no later than 1st January 2006 the following targets are met by producers [WEEE02]:

-A minimum rate of separate collection of 4 kilograms on average per inhabitant per year of waste electrical and electronic equipment from private householders;

-For all separately collected waste electrical and electronic equipment falling under category 1 of Annex I A of the Directive (large household appliances) – see Appendix B - the rate of recovery shall be increased to a minimum of 80% by an average weight per appliance. Within the same time limit the component, material and substance reuse and recycling shall be increased to a minimum of 75% by an average weight per appliance;

-For all separately collected waste electrical and electronic equipment falling under categories 2, 4, 6 and 7 of Annex I A of the Directive (small household appliances, consumer equipment, electrical and electronic tools, and toys) – see Appendix B -, the rate of recovery shall be increased to a minimum of 60% by weight of the appliances. Within the same time limit the component, material and substance reuse and recycling shall be increased to a minimum of 50% by weight of the appliances;

-For all separately collected waste electrical and electronic equipment falling under category 3 of Annex I A of the Directive (IT and telecommunication equipment) – see Appendix B -, the rate of recovery shall be increased to a minimum of 75% by weight of the appliances. Within the same time limit the component, material and substance reuse and recycling shall be increased to a minimum of 65% by weight of the appliances;

-For all separately collected waste gas discharge lamps the rate of component, material and substance reuse and recycling shall reach a minimum of 80% by weight of the lamps;

-For all separately collected waste electrical and electronic equipment containing a Cathode Ray Tube, the rate of recovery shall be increased to a minimum of 75% by weight of the appliances. Within the same time limit the component, material and substance reuse and recycling shall be increased to a minimum of 70% by weight of the appliances.

Producers shall provide for the collection of WEEE from holders other than private households. Producers shall provide, as far as it is needed by treatment facilities, appropriate information to identify the different electrical and electronic equipment components and materials, and the location of dangerous substances and preparations in the electrical and electronic equipment.

Appendix B

Annex I A and Annex I B of the Draft Proposal for the European Parliament and Council Directive on Waste Electrical and Electronic Equipment [WEEE02]

Annex I A – Categories of Electrical and Electronic Equipment Covered by the Directive

(1) Large household appliances
(2) Small household appliances
(3) IT & telecommunication equipment
(4) Consumer equipment
(5) Lighting equipment
(6) Electrical and electronic tools
(7) Toys
(8) Medical equipment systems
(9) Monitoring and control instruments
(10) Automatic dispensers

Annex I B – Indicative List of Products Which Fall Under the Categories of Annex I A

1. Large household appliances
    - Large cooling appliances
    - Refrigerators
    - Freezers
    - Washing machines
    - Clothes dryers
    - Dish-washing machines
    - Cooking
    - Electric stoves
    - Electric hot plates

- Microwaves
- Heating appliances
- Electric heaters
- Electric fans
- Air conditioners

2. Small household appliances
    - Vacuum cleaners
    - Carpet sweepers
    - Irons
    - Toasters
    - Fryers
    - Coffee grinders
    - Electrical knives
    - Coffee machines
    - Hair dryers
    - Tooth brushers
    - Shavers
    - Clocks
    - Scales

3. IT & telecommunication equipment
    - Centralized data processing
    - Main frames
    - Minicomputers
    - Printer units
    - Personal computing
    - Personal computers (CPU, mouse, screen and keyboard included)
    - Lap-top computers (CPU, mouse, screen and keyboard included)
    - Note-book computers
    - Note-pad computers
    - Printers

- Copying equipment
- Electrical and electronic typewriters
- Pocket and desk calculators
- User terminals and systems
- Fact-simile
- Telex
- Telephones
- Pay telephones
- Cordless telephones
- Cellular telephones
- Answering systems

4. Consumer equipment
    - Radio sets (clock radios, radio-recorders)
    - Television sets
    - Video cameras
    - Video recorders
    - Hi-fi recorders
    - Audio amplifiers
    - Musical instruments

5. Lighting equipment
    - Luminaries
    - Straight fluorescent lamps
    - Compact fluorescent lamps
    - High intensity discharge lamps, including high pressure sodium lamps and metalhalidelamps
    - Low pressure sodium lamps
    - Other lighting equipment with the exception of filament lamps and household luminaries exclusively equipped with filament lamps

6. Electrical and electronic tools
    - Drills

- Saws
- Sewing machines

7. Toys
    - Electric trains or car racing sets
    - Hand-held video game consoles
    - Video games

8. Medical equipment systems (with the exception of all implanted and infected products)
    - Radiotherapy equipment
    - Cardiology
    - Dialysis
    - Pulmonary ventilators
    - Nuclear medicine
    - Laboratory equipment for in-vitro diagnostic
    - Analysers
    - Freezers

9. Monitoring and control instruments
    - Smoke detector
    - Heating regulators
    - Thermostat

10. Automatic dispenser
    - Automatic dispensers for hot drinks
    - Automatic dispensers for hot/cold, bottles/cans
    - Automatic dispensers for solid products

Appendix C

Electrical and Electronic Equipment Take-Back Policies [D&N01], [Dav97]

End-of-life computers, cell phones, TVs and other electronics have become a major waste management issue in industrialised countries and the problem is worsening. It was estimated that by 2007 there will be almost 500 million obsolete computers only in the U.S. Coupled with the expanding cell phone market and VCRs made obsolete by DVDs, environmentally sound disposal practices for WEEE should be in great demand.

Electronic equipment contains many toxins and heavy metals that leach into groundwater if disposed in landfills and produce carcinogenic dioxins if incinerated. Already, the lead in computer screens and TVs account for 40% of all the lead in landfills.

Most of the policies presented here entail the producer being responsible for the collection, sorting and environmentally sound disposal of electrical equipment with the exception of Denmark, which lays the burden on municipal authorities.

Given the recent evolution of these policies, environmental and economic assessment of their effectiveness has not been forthcoming. Most of the policies ensure that the consumer will not have to pay a fee to dispose of the equipment. If the consumer is buying a replacement product from a retailer, then the retailer can impose a hidden disposal fee on the old product.

Denmark

Statutory order No.1067 on Management of Waste from Electrical and Electronic Products states that virtually all electrical waste will be collected and treated by local authorities.

Collection sites include retailers and central collection sites. The order gives local authorities the main responsibility for recovering WEEE from all sources. The system is funded through local authorities. The estimated total cost of implementing the law is about DKr5 (US$ 0.70) per kg, equivalent to total costs of DKr104m (US$ 15m). Household waste taxes will rise by DKr50 (US$ 7) per year to help fund recovery.

Germany

Germany has drafted legislation called the Draft Ordinance Concerning the Disposal of Information Technology Equipment (1998) that would cover the take-back of Information Technology (IT) equipment including PCs, photocopiers, printers, scanners and communication equipment.

Producers (manufacturers, distributors and importers) must take-back their brand of electronics free of charge from the customer. Producers may charge a fee for equipment sold prior to the enactment date. Municipalities will be responsible for the collection and storage of equipment.

The Netherlands

The Disposal of Brown and White Goods Decree (effective June 1, 1998) requires manufacturers and importers to take back old electrical equipment free of charge when consumers purchase new ones regardless of brand name (until 2005 when producers are required to take-back only their own brands). Retailers take back end-of-life products from consumers and can then sell them or return these items to the municipality, manufacturer or importer.

The manufacturer or importer must pay for the cost of the disposal. Municipalities will be responsible for collection from households and suppliers.

Norway

The Norwegian Regulations Regarding Scrapped Electrical and Electronic Products (effective June 1, 1998) require retailers and municipalities to accept waste equipment from consumers free of charge. Manufacturers and importers are held responsible for the collection, treatment and transportation to a certified treatment centre for remanufacturing/recycling.

Municipalities must accept WEEE from households and can finance this through a levy on waste disposal fees.

Switzerland

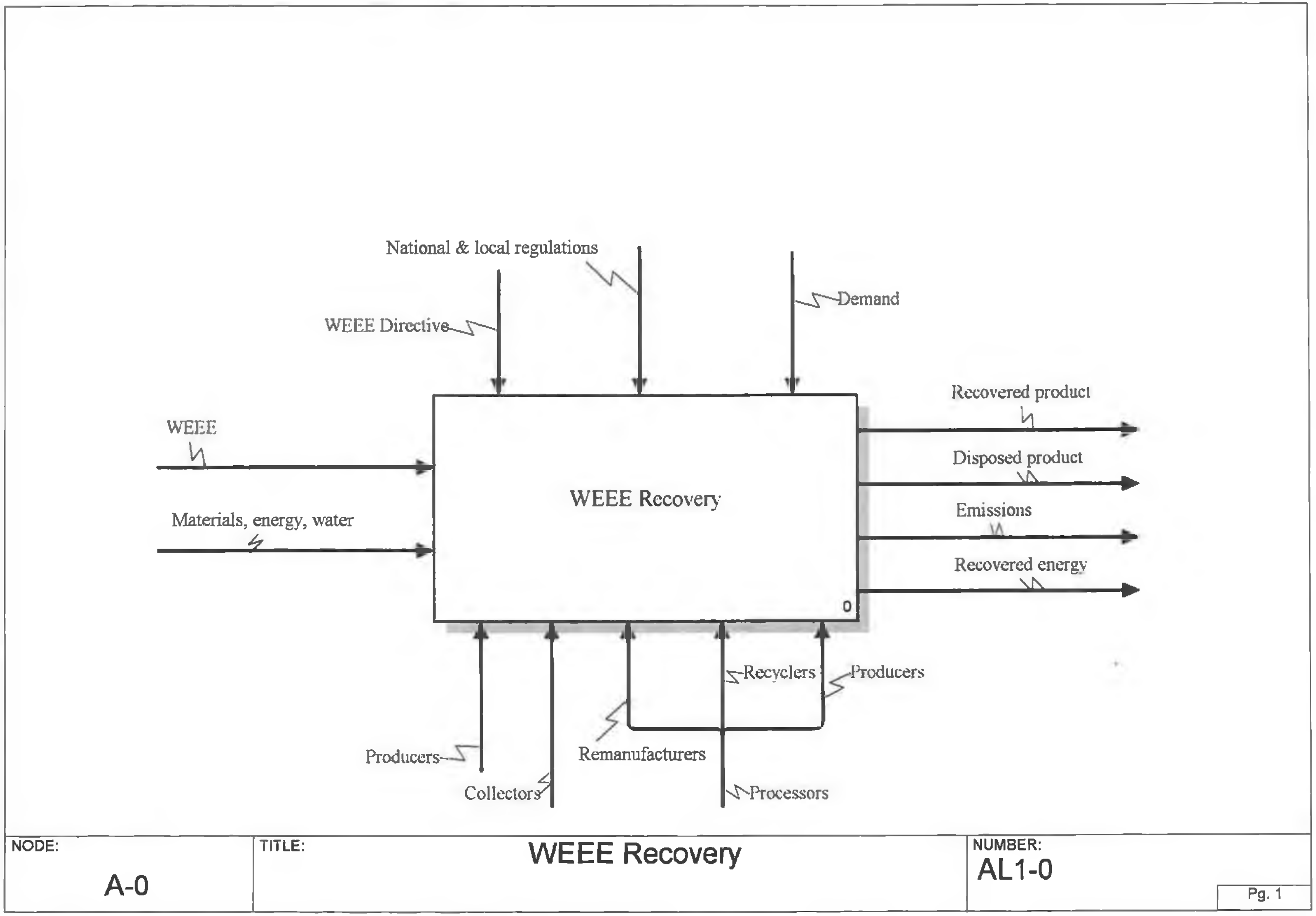
The Swiss Ordinance on the Return, the Taking Back and the Disposal of Electrical and Electronic Appliances (effective July, 1998). This ordinance mandates that retailers, manufacturers, and importers take-back end-of-life electrical equipment free of charge from consumers and dispose of it in an environmentally sound way. Consumers can drop off appliances at retailers, a disposal facility, or at an industry collection site.

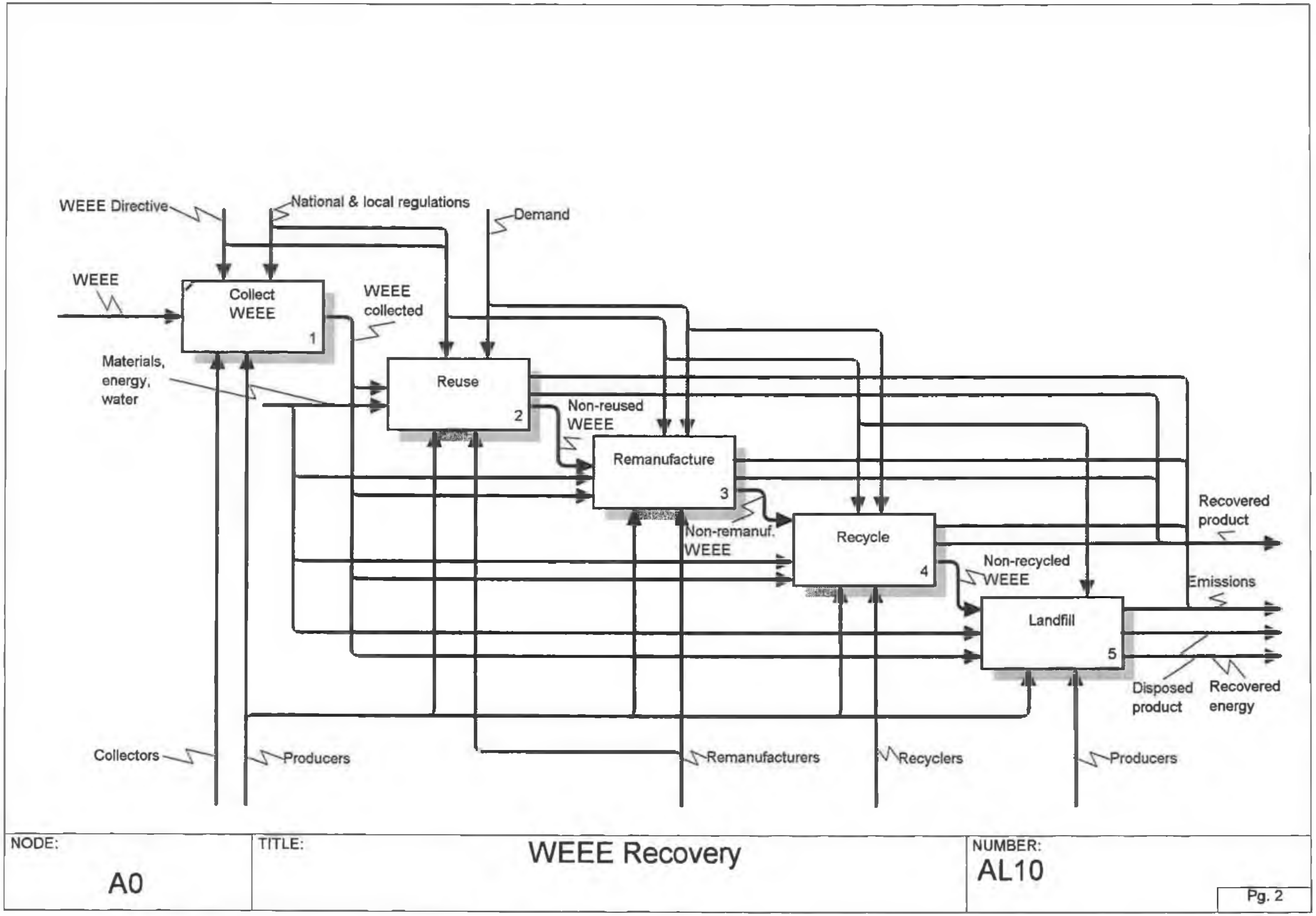
Manufacturers and importers are responsible for the cost of recycling

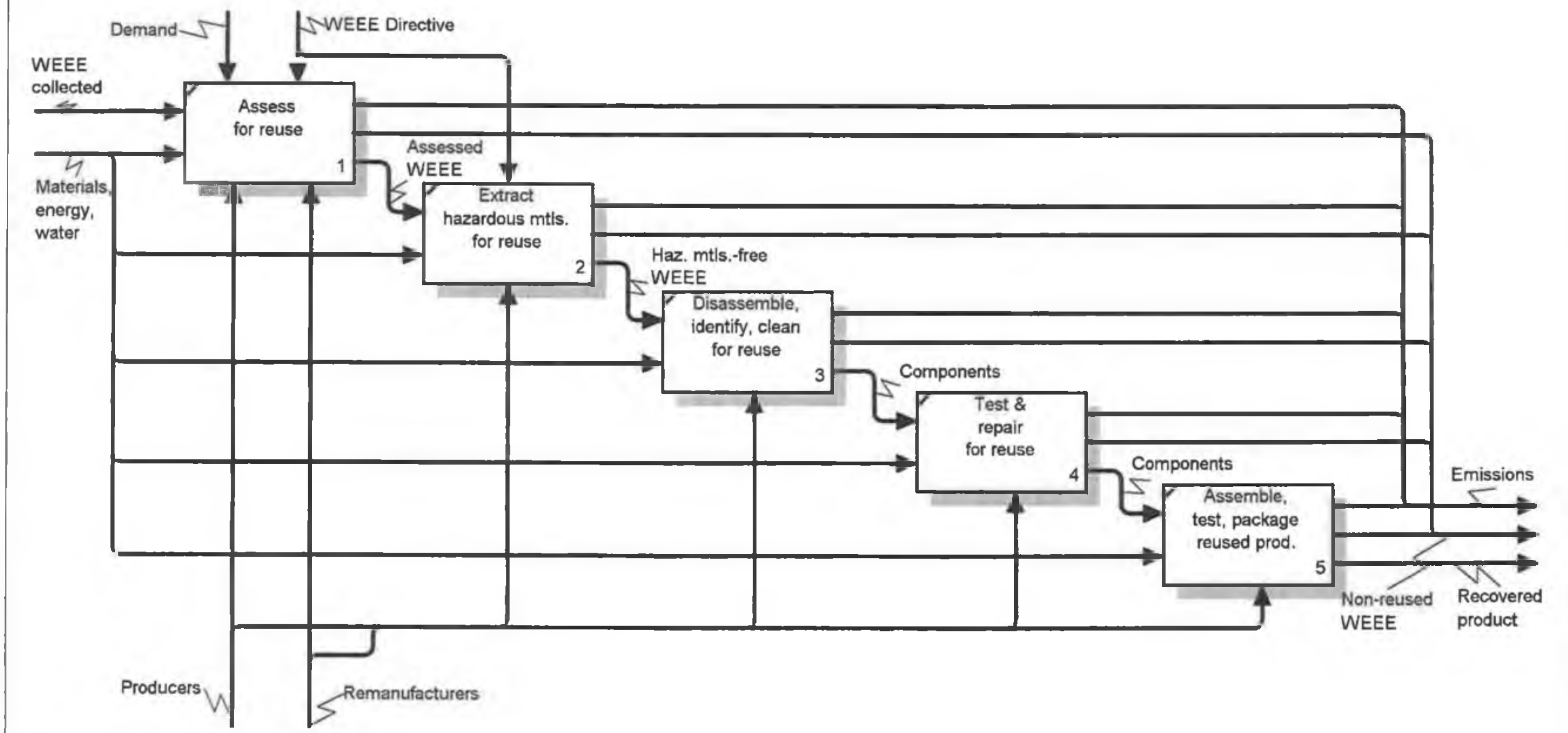
Appendix D

Activities and Processes in WEEE Recovery Modelled with IDEF0

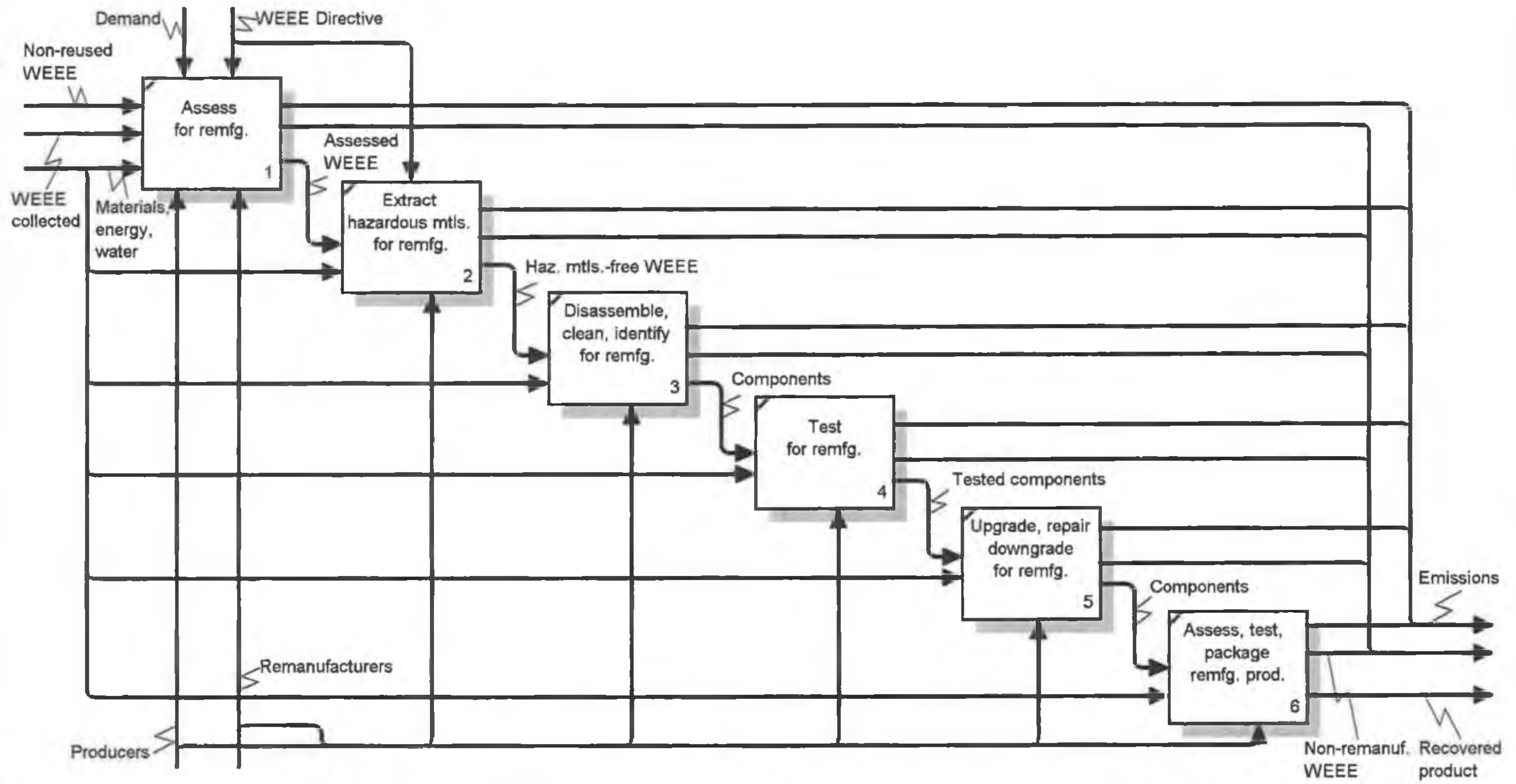
The processes in WEEE recovery modelled with IDEF0 are presented in this appendix.


National & local regulations
WEEE Directive
Demand
WEEE
Materials, energy, water
WEEE Recovery
0
Recovered product
Disposed product
Emissions
Recovered energy
Recyclers
Producers
Remanufacturers
Producers
Collectors
Processors
NODE:
A-0
TITLE:
WEEE Recovery
NUMBER:
AL1-0
Pg. 1

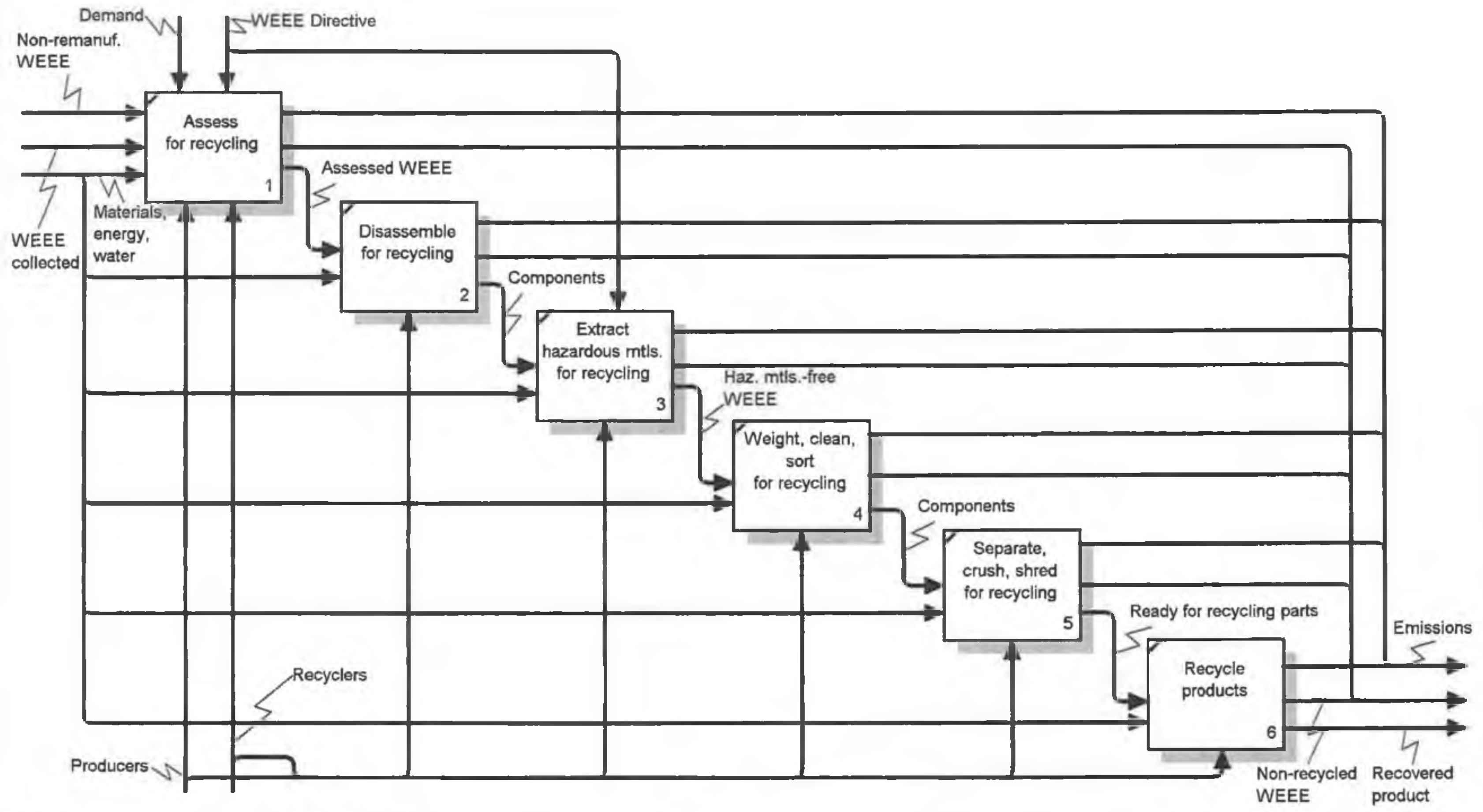

WEEE Directive
National & local regulations
Demand
WEEE
Collect WEEE
1
WEEE collected
Materials, energy, water
Reuse
2
Non-reused WEEE
Remanufacture
3
Non-remanuf. WEEE
Recycle
4
Non-recycled WEEE
Landfill
5
Recovered product
Emissions
Disposed product
Recovered energy
Collectors
Producers
Remanufacturers
Recyclers
Producers
NODE:
A0
TITLE:
WEEE Recovery
NUMBER:
AL10
Pg. 2



NODE:	TITLE:	NUMBER:
A2	Reuse	AL12
		Pg. 3

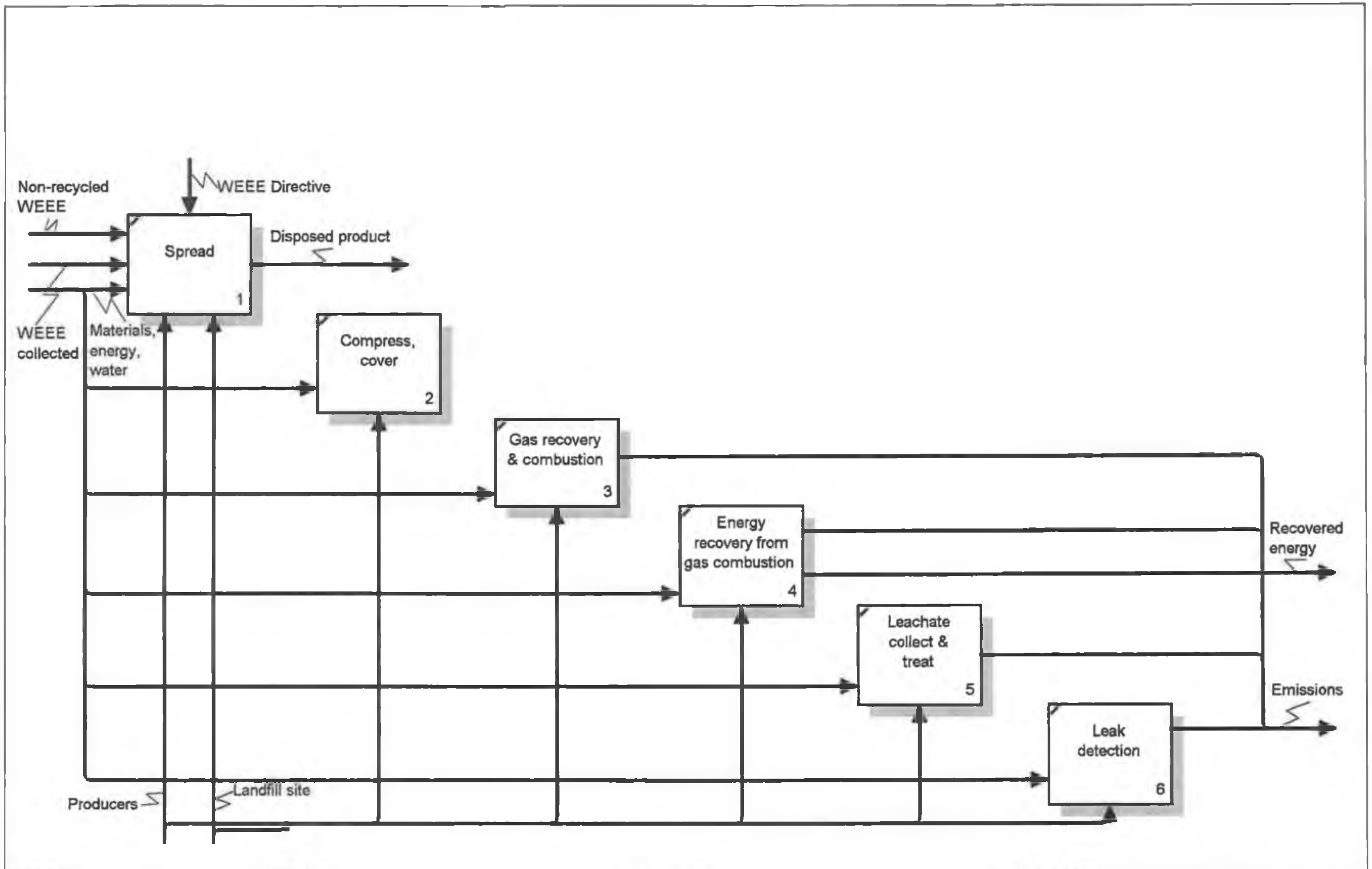


NODE: A3	TITLE: Remanufacture	NUMBER: AL13
		Pg. 4



NODE:	TITLE:	NUMBER:
A4	Recycle	AL14

Pg. 5



NODE: A5

TITLE: Landfill

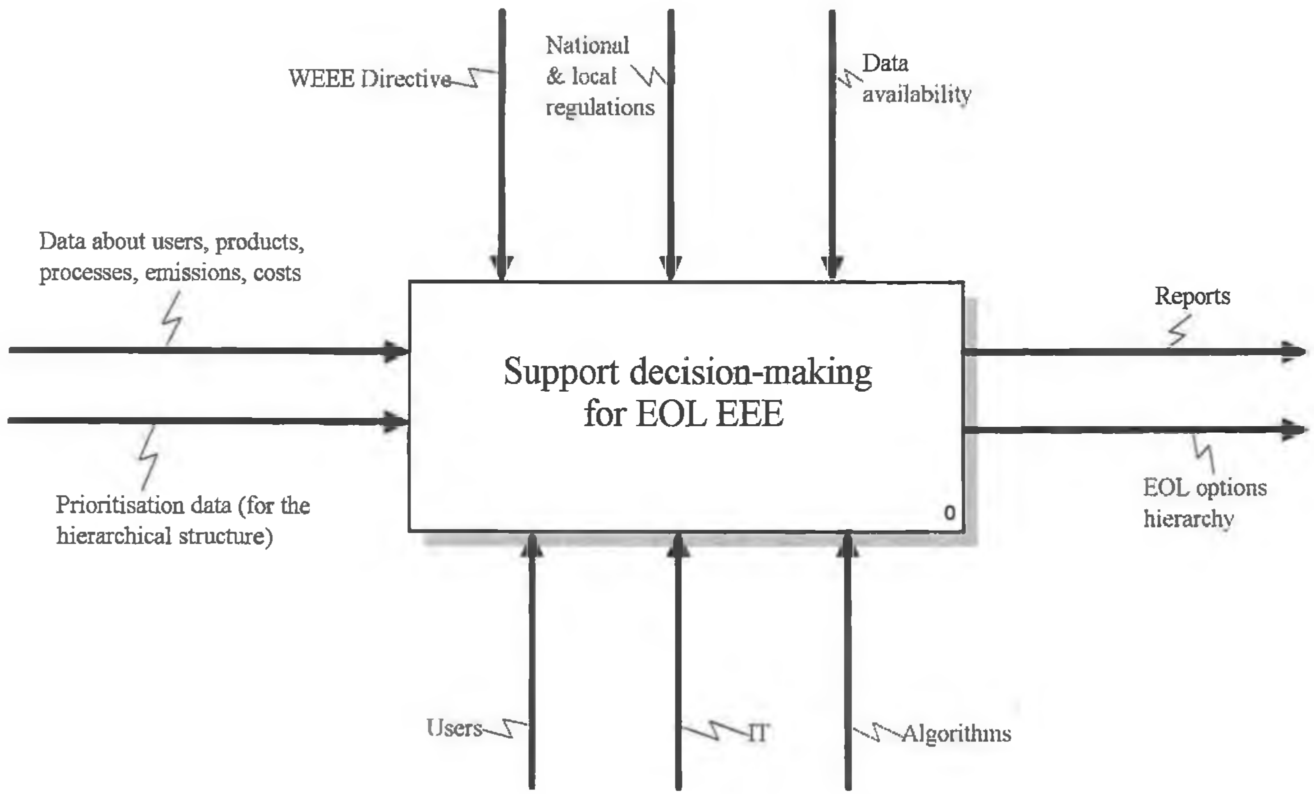
NUMBER: AL15

Pg. 6

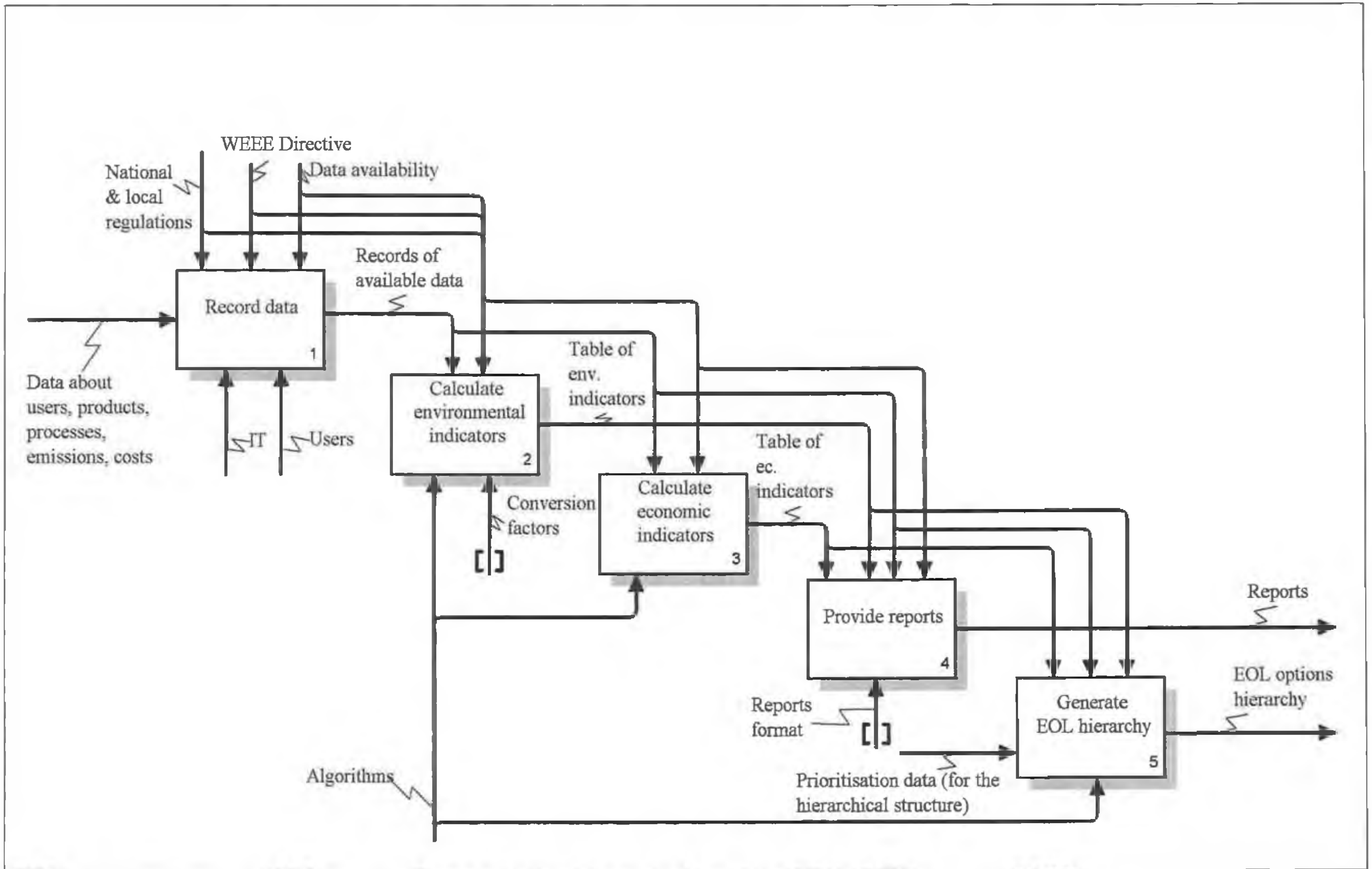
Appendix E

Functionalities of DSS Modelled with IDEF0

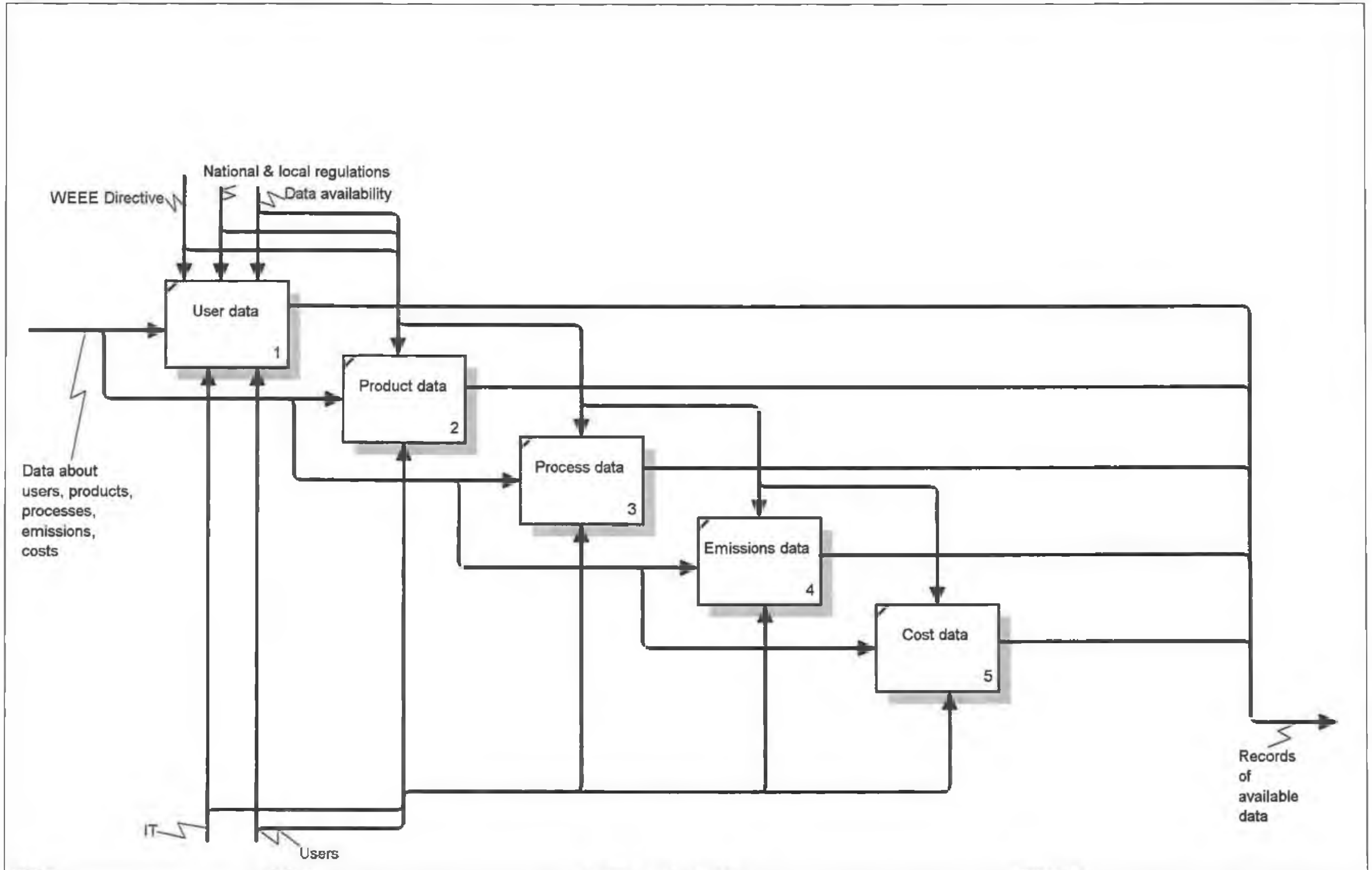
The functionality of the decision support system modelled with IDEF0 is presented in this appendix.



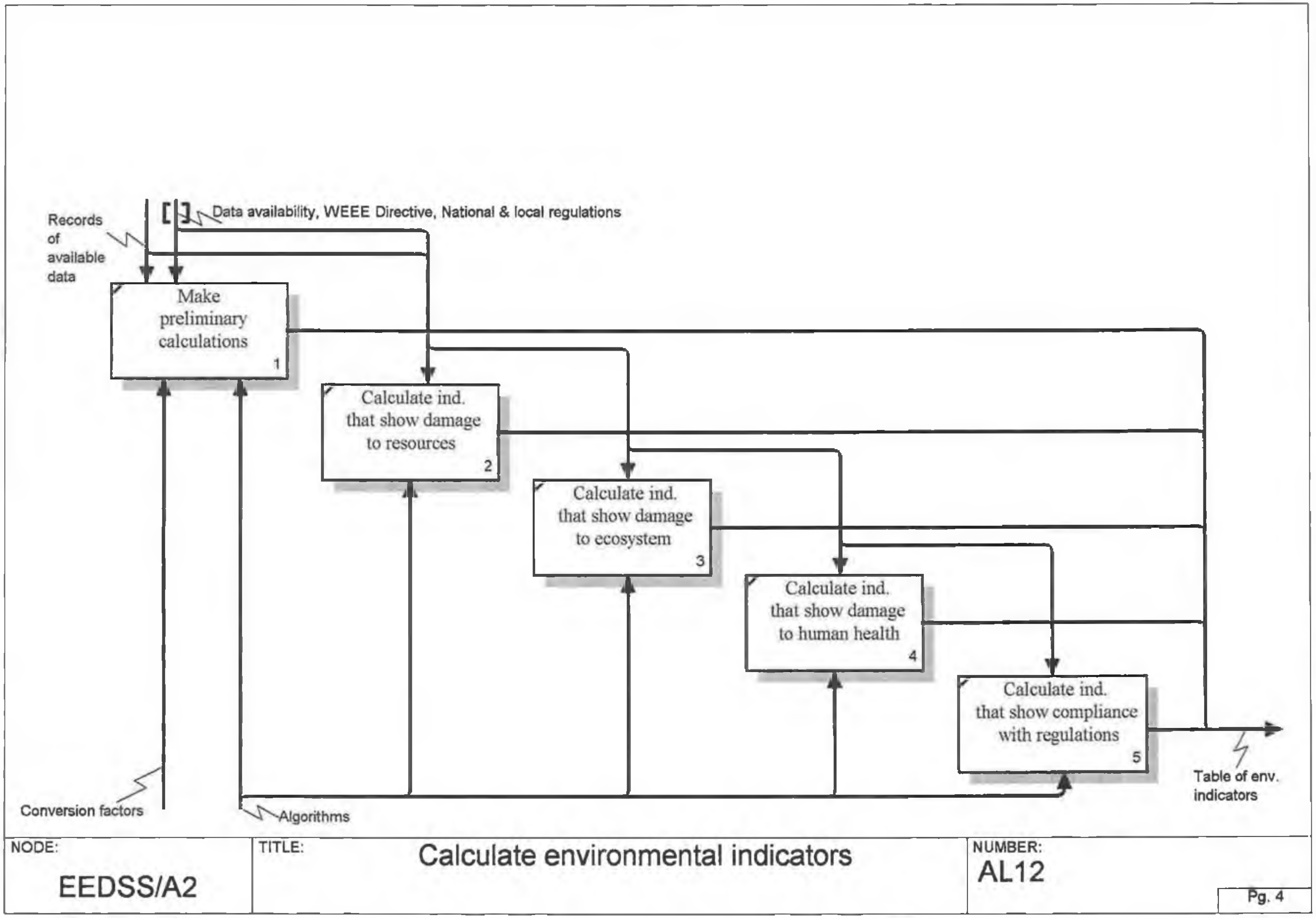
NODE:	TITLE:	NUMBER:
EEDSS/A-0	Support decision-making for EOL EEE	AL1-0 Pg. 1

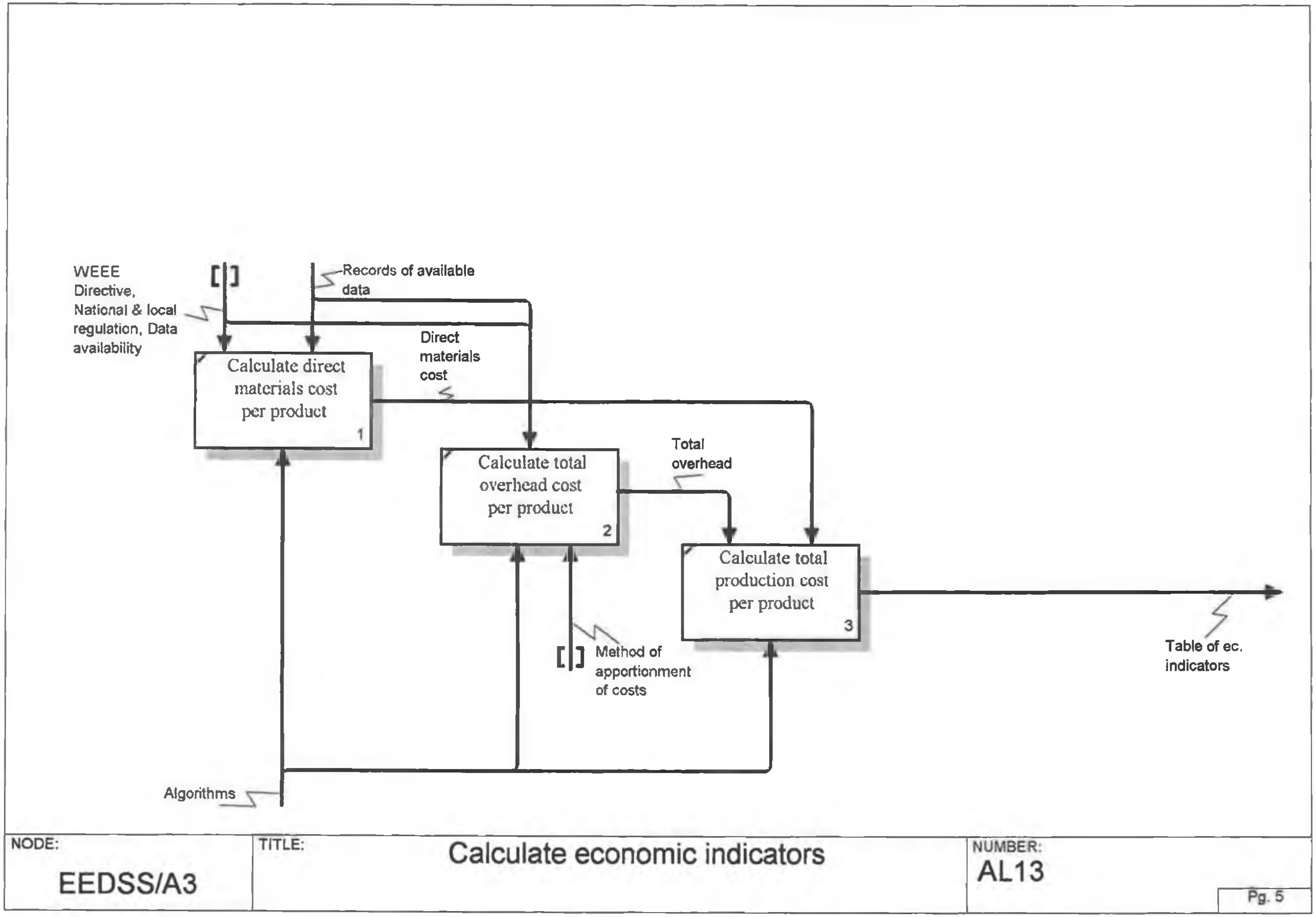


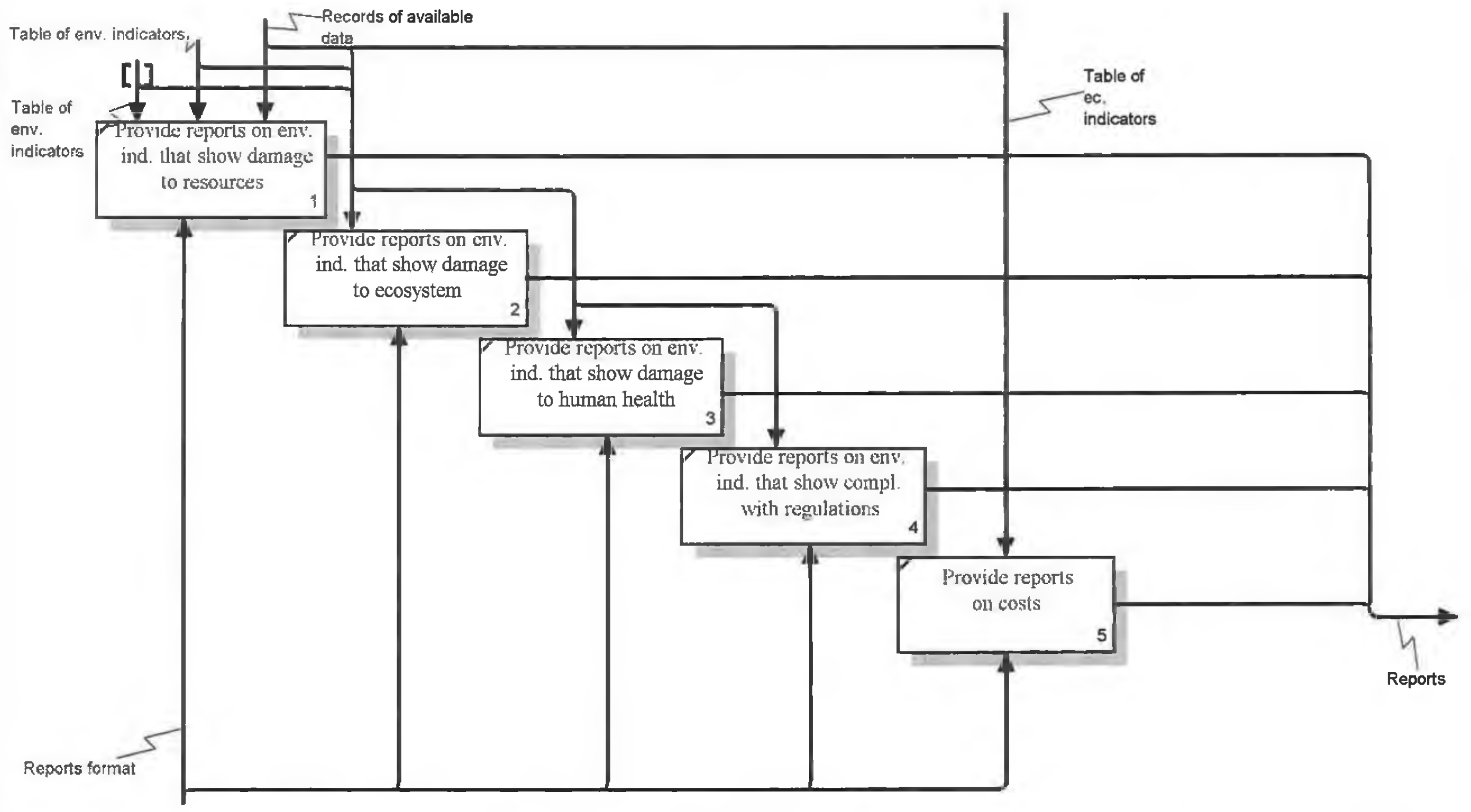
NODE: EEDSS/A0	TITLE: Support decision-making for EOL EEE	NUMBER: AL10 Pg. 2



NODE:	TITLE:	NUMBER:
EEDSS/A1	Record data	AL11
		Pg. 3

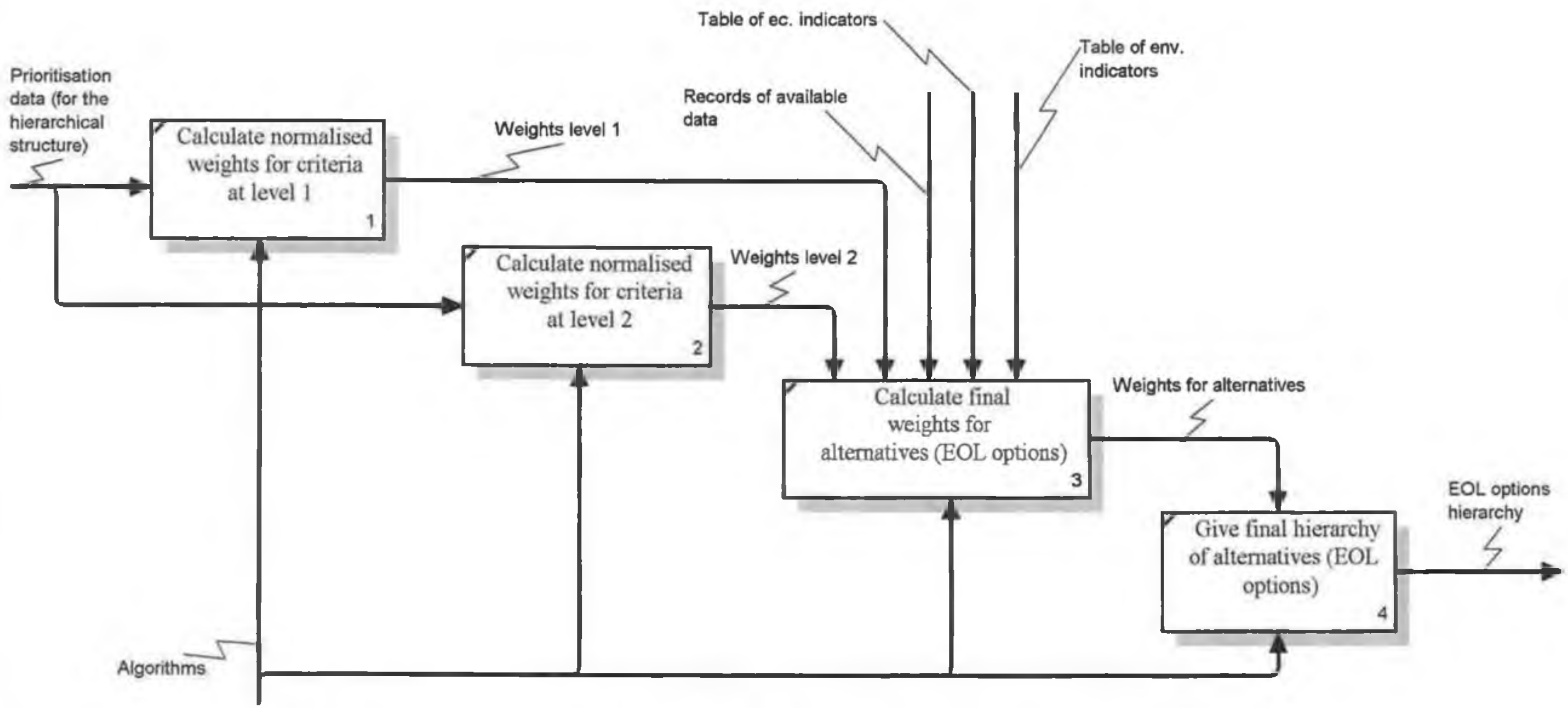

Data availability, WEEE Directive, National & local regulations
Records of available data
Make preliminary calculations
1
Calculate ind. that show damage to resources
2
Calculate ind. that show damage to ecosystem
3
Calculate ind. that show damage to human health
4
Calculate ind. that show compliance with regulations
5
Table of env. indicators
Conversion factors
Algorithms
NODE:
EEDSS/A2
TITLE:
Calculate environmental indicators
NUMBER:
AL12
Pg. 4


WEEE Directive, National & local regulation, Data availability
Records of available data
Direct materials cost
Calculate direct materials cost per product
1
Calculate total overhead cost per product
2
Total overhead
Calculate total production cost per product
3
Method of apportionment of costs
Table of ec. indicators
Algorithms
NODE:
EEDSS/A3
TITLE:
Calculate economic indicators
NUMBER:
AL13
Pg. 5



NODE:	TITLE:	NUMBER:
EEDSS/A4	Provide reports	AL14

Pg. 6



NODE:	TITLE:	NUMBER:
EEDSS/A5	Generate EOL hierarchy	AL15

Pg. 7

Appendix F

Examples of Database Tables Design Views

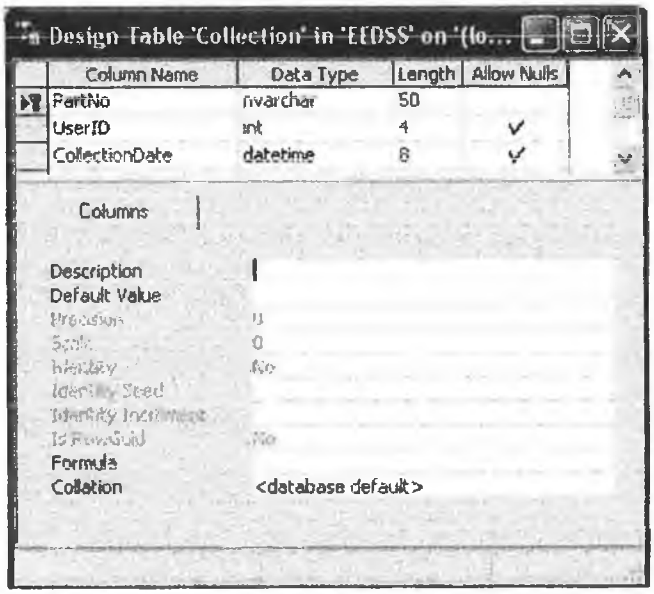


Figure F1. Design view of Collection table

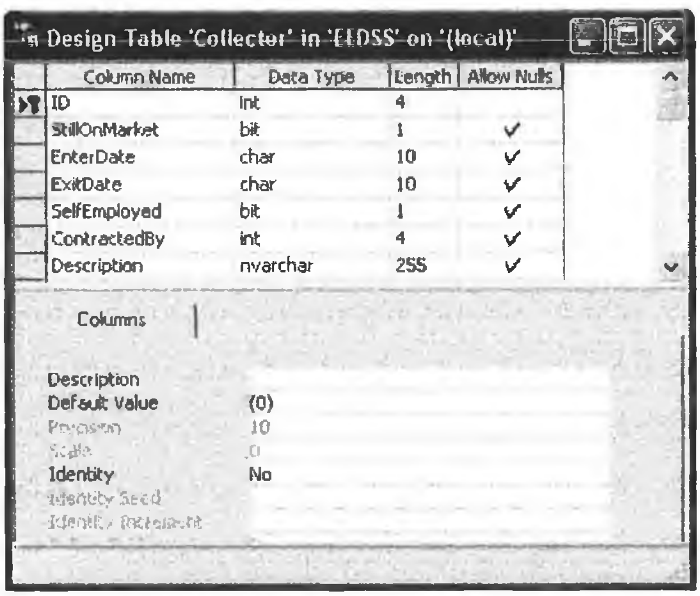


Figure F2. Design view of Collector table

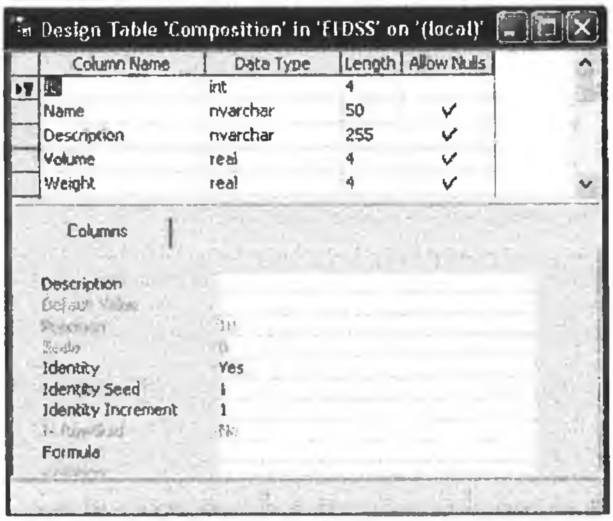


Figure F3. Design view of Composition table

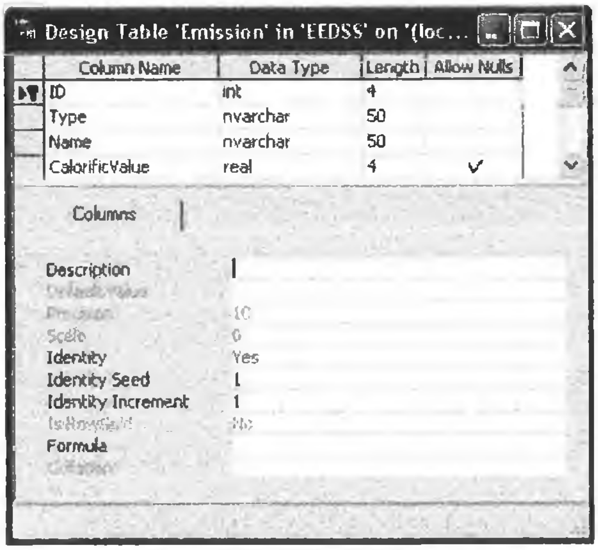


Figure F4. Design view of Emission table

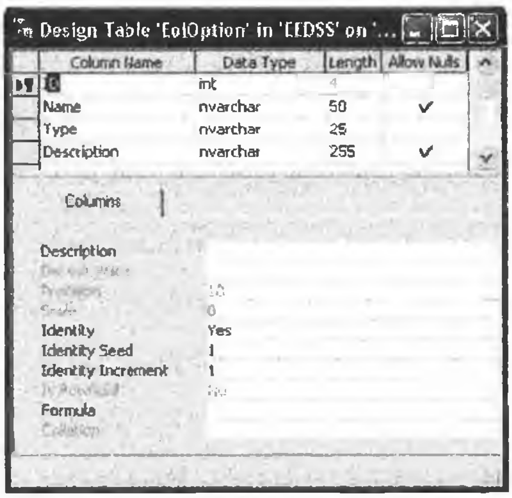
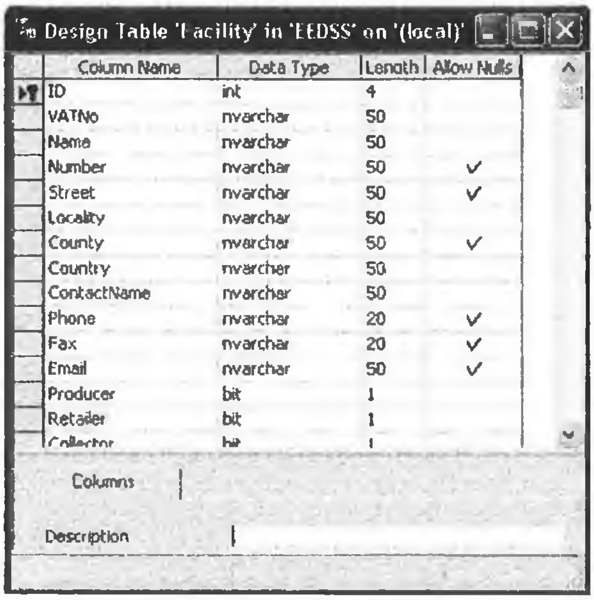


Figure F5. Design view of EolOption table



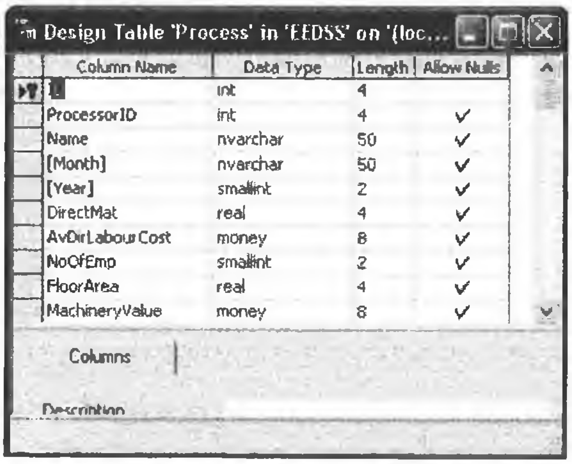
Design Table 'Facility' in 'EEDSS' on '(local)'

Column Name	Data Type	Length	Allow Nulls
ID	int	4	
VATNo	nvarchar	50	
Name	nvarchar	50	
Number	nvarchar	50	✓
Street	nvarchar	50	✓
Locality	nvarchar	50	
County	nvarchar	50	✓
Country	nvarchar	50	
ContactName	nvarchar	50	
Phone	nvarchar	20	✓
Fax	nvarchar	20	✓
Email	nvarchar	50	✓
Producer	bit	1	
Retailer	bit	1	
Collector	bit	1	

Columns

Description

Figure F6. Design view of Facility table



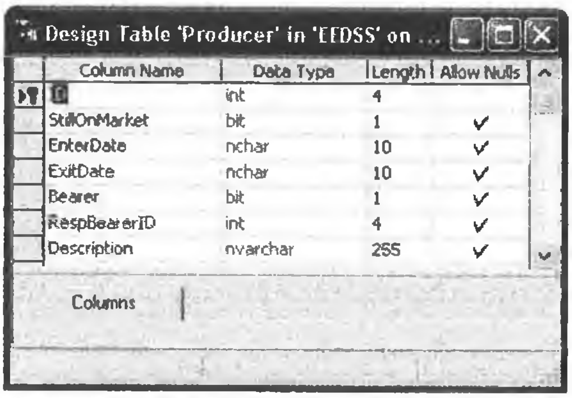
Design Table 'Process' in 'EEDSS' on '(loc...

Column Name	Data Type	Length	Allow Nulls
[illegible]	int	4	
ProcessorID	int	4	✓
Name	nvarchar	50	✓
[Month]	nvarchar	50	✓
[Year]	smallint	2	✓
DirectMat	real	4	✓
AvDirLabourCost	money	8	✓
NoOfEmp	smallint	2	✓
FloorArea	real	4	✓
MachineryValue	money	8	✓

Columns

Description

Figure F7. Design view of Process table



Design Table 'Producer' in 'EEDSS' on ...

Column Name	Data Type	Length	Allow Nulls
[illegible]	int	4	
StillOnMarket	bit	1	✓
EnterDate	nchar	10	✓
ExitDate	nchar	10	✓
Bearer	bit	1	✓
RespBearerID	int	4	✓
Description	nvarchar	255	✓

Columns

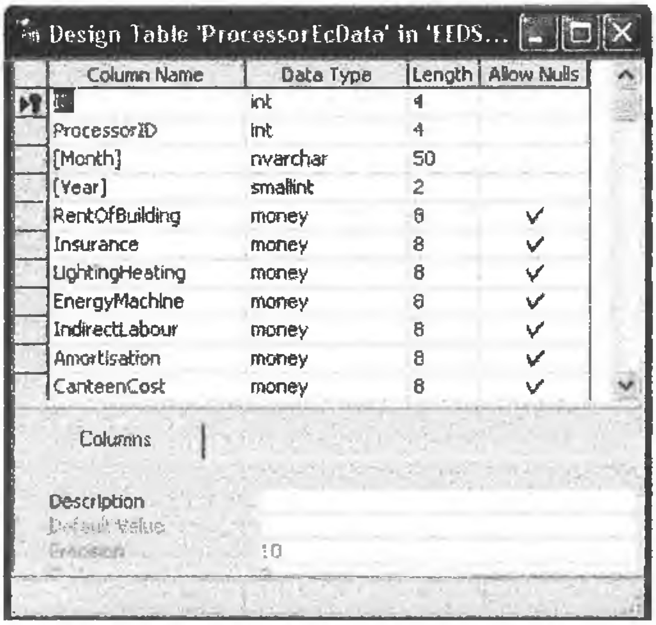
Figure F8. Design view of Producer table

Design Table 'Product' in 'EEDSS' on '...

Column Name	Data Type	Length	Allow Nulls
PartNo	nvarchar	50	
TypeOfEEE	int	4	
ModelName	nvarchar	50	✓
PartOf	bit	1	
Paren	nvarchar	50	✓
Composition	bit	1	
CompID	int	4	
ProducerID	int	4	
ManDate	char	10	✓
Disassembly	bit	1	
Reman	bit	1	
Recycling	bit	1	
Repair	bit	1	
EnvCat	bit	1	
Lev	smallint	2	

Columns

Figure F9. Design view of Product table



Design Table 'ProcessorEcData' in 'EEDS...

Column Name	Data Type	Length	Allow Nulls
[illegible]	int	4	
ProcessorID	int	4	
[Month]	nvarchar	50	
[Year]	smallint	2	
RentOfBuilding	money	8	✓
Insurance	money	8	✓
LightingHeating	money	8	✓
EnergyMachine	money	8	✓
IndirectLabour	money	8	✓
Amortisation	money	8	✓
CanteenCost	money	8	✓

Columns

Description
Default Value
Precision 10

Figure F10. Design view of ProcessorEcData table