METHODOLOGIES TO IMPROVE PRODUCT LIFE CYCLE DECISION MAKING IN THE TELECOMMUNICATIONS INDUSTRY

A thesis submitted for the degree of Engineering Doctorate

by

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Sections

C1 – Six Monthly Reports
C2 – Research Publications
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C1 Six Monthly Reports

Engineering Doctorate in Environmental Technology

Novel Techniques for Integration of Environmental Life Cycle Technologies in the Telecommunications Industry

Six Month Report No: 1

Research Engineer -

Carl Mead

(Brunel University and Nortel Advanced Technology)

1 April 1998

Contents

1. Introduction

This document provides a review of the first six month's of the Research Engineer's (RE) research project for the Engineering Doctorate in Environmental Technology. The project focuses on the development of novel methods for the integration of environmental life cycle technologies into Nortel's product development process. Key areas for research are the investigation of customer and industry demands for product environmental information, extraction of product environmental performance data from suppliers, and the integration of the collected information into the Design for Environment process.

1.1. Key Personnel

Carl Mead	Research Engineer
Prof. J.D. Donaldson	Academic Supervisor (Brunel University)
Dr. Ken Snowdon	Industrial Supervisor (Nortel Advanced Technology)
Dan Francis	Industrial Supervisor (Nortel Advanced Technology)

1.2. Background

1.2.1. Company

Nortel is the industry leader in digital communications for public carrier networks, and is extending its network development capabilities to Internet Service Providers.

Nortel is a leading global provider of communications network solutions with 1997 consolidated revenues of US$15.5 billion. Nortel, which commercialised digital technology to the telecommunications industry in 1976, provides network and telecommunications equipment and related services in North America, Caribbean and Latin America, Europe, the Middle East, and Asia/Pacific. Nortel also provides products and services to the telecommunications and cable television industries, businesses, universities, governments and other institutions world-wide.

Wherever Nortel does business, it will take the initiative to develop innovative solutions to environmental issues that may arise because of its products, operations, and business activities. The corporation is working toward taking responsibility for the environmental impacts of its products throughout their life cycles - from design to final disposition. Product life cycle work in 1996 focused on designing and building the world's first lead-free phones, and piloting the take-back of products for reuse or recycling when they are no longer of use to the customer.

1.2.2. Project

The EngD research project was conceived as a component of the Product Life Cycle Management (PLCM) research programme for the Nortel Materials and Design Technology Department. Research has already been carried out on applying LCA to complex telecommunications systems at Nortel. This work has provided a platform and support for the RE's own research project which aims to develop novel techniques for improving the environmental performance of Nortel products and the company by applying life cycle techniques.

1.3. Problem Definition

Conclusions from previous research suggest that LCA may not be a practical and viable product development tool in organisations using complex concurrent engineering and design. The reasons are:

- complex systems (supplier base - 30 000 suppliers, 100 000 components);
- complex product data management;
- difficulties in product data acquisition; and
- cost and resources.

LCAs need to be carried out by specialists within the organisation. It is not feasible for a designer to conduct a full LCA as a component of a DFE procedure.

However, it may be possible to use LCA data from suppliers as part of the component/raw material selection process or develop an alternative method using available environmental information.

1.4. Aims

The aim of the research is to develop and test novel methods for the integration of environmental life cycle technologies into Nortel's product development process. The research is initially focused on the supply management function and is generating concepts for an optimal system to achieve the following:

- extract data from the supply chain;
- integrate the information into the Design for Environment (DFE) process;
- convey the appropriate information to customers; and
- retrieve the information at end-of-life for the benefit of recoverers of electronic equipment.

Research will also evaluate options for integrating environmental performance criteria into the component selection process both for the design community and purchasers, and will ultimately go further to investigate opportunities for integrating life cycle costing techniques and end-of-life strategy modelling into the product development process.

It is envisaged that the methods, systems and tools developed by the RE over the course of four years research will be considered for integration into Nortel's Product Life Cycle Management (PLCM) process.

2. Research Programme

2.1. Scope

Before it is possible to define objectives of the research it has been necessary to carry out some preliminary scoping work. This involves developing a complete understanding of the project aims and the elements that contribute to it including suppliers, designers and customers.

2.2. Research Objectives

- determine the current and potential capabilities of LCA (Yr 1 and 2)
- determine the current and potential capabilities of DFE (Yr 1 and 2); and
- conduct a literature review to demonstrate my understanding of the concepts and practicalities of the application of LCA and DFE (Yrs 1-4);
- develop a complete understanding of the structure of the Nortel Supply Management function, determine how it works and interfaces with the design groups;
- conduct an evaluation of how environmental information obtained from suppliers can be used (Yr 1);
- conduct an assessment and gap analysis of the information being requested by Nortel's customers, the information Nortel requests from its suppliers, information requested by competitors and the information required for voluntary product declarations (Yr 1);
- determine exactly how Nortel customers use the environmental information provided, particularly how it may affect a bid for business (Yr 1);

- set up a system to obtain product environmental information from suppliers (Yr 1);
- add the information to a database to make it available to designers and those answering customer requests(Yr 2);
- research methods to determine how the system can be used by contracted designers and manufacturers (Yrs 2-3).
- consider the possibilities of expanding the system to generate environmental criteria which could be used in the component selection process either by the design groups or procurement (Yrs 2-3); and
- develop additional methods to improve the DFE process including the incorporation of life cycle costing and possible end-of-life modelling (Yrs 3 - 4).

2.3. Contribution to Knowledge

Within the telecommunications industry, the development of methods for integrating environmental life cycle technologies into the DFE process has not been researched in conjunction with supply management.

The contribution to knowledge will be provided by the development and completion of a system designed to extract and manage appropriate environmental data from sources external to Nortel. The next phase will include the integration of the information into two established data management systems which are central to the Nortel product development process.

2.4. Environmental Technology

The project is clearly environmental technology as it is researching methods to generate a system which provides information for DFE, supports process engineering and product development, and therefore seeks to improve the environmental performance of Nortel products.

3. Progress

3.1. Towards Meeting Objectives

The literature search has been completed for LCA and DFE and a full list of documentation relevant to the research project has been drawn up. Throughout the four years of research the list of relevant documentation will up-dated to include the latest work completed in this subject area. The RE will submit a full literature review document as part of the final dissertation and portfolio submission in 2001 to demonstrate an in-depth understanding of LCA, DFE and Supply Management, and analytical comment on up-to-date research initiatives.

The RE now has an understanding of the relationship/interface between the supply management function and the design community, this will be further developed.

It has been determined that supplier product environmental information can provide a very significant contribution to Nortel's response to customer requests for product environmental information. It can also be integrated with the Nortel DFE process and assist in fulfilling the requirements of ISO 14001.

A multi-functional (design, product data management, supply management, environment) team of senior Nortel staff has been set-up, co-ordinated by the RE, to provide valuable support and input to the research project. The project concept has now gained support form outside the R&D Technology function, in fact from the vice-president of the Corporate Supply Management group.

A comprehensive gap analysis has been completed on the information being requested by Nortel's customers, the information Nortel requests from its suppliers, information requested by competitors and the information required for voluntary product declarations. The results are about to be analysed.

3.2. Supporting Activities

Certain activities are carried out by the RE which, although not directly connected with the core research project, assist in the development of personal, professional, and business skills. They support the RE's candidacy for the qualification of Engineering Doctorate.

They are;

- attendance of EngD modules and completion of assignments (Induction and Leadership, Clean Technology and Sustainability, and Project Management and Life Cycle Assessment);
- representing Nortel at various technical committee meetings for international standards (ECMA TC 38)and other collaborative ventures;
- practical DFE research such as a disassembly study on a Nortel mobile phone including the production of an internal report (IR\1998\1795) distributed to Nortel staff in North America and Europe;
- attendance of relevant conferences and seminars such as the ECTEL Takeback of Electronics Seminar (IR\1998\1796), the Environmental Purchasing conference, and an Ecobilan LCA training seminar;
- contribution to Nortel Harlow ISO 14001 team;
- contributor and participant in Nortel European DFE Council meeting;
- presenter at 1st M&DT External Research Mini-Forum;
- lecturing in environmental management at Kings College.

4. Discussion

The research project is progressing well. The last two months have seen strong support from various members of Nortel staff in a range of business functions. This has given the project momentum. It was essential to contact and obtain support from key members of staff if the project is to develop to its maximum potential on both academic and industrial platforms. This has been achieved. This reflects the committment to the project from the RE and Nortel, and the excellent support from both academic and industrial supervisors. The research is being undertaken with the intention of generating results and tools which can be used practically throughout the corporation.

5. Next Steps

The next steps of the research project are:

- to build a system for product information retrieval from Nortel suppliers. This system will consist primarily of two tools and the intention is to eventually roll out the system at corporate level. The system concept has already been presented to members of Nortel staff and accepted. An internal report will be written to provide details and results of the first phase of the project (April - December, 1998);

- to contact appropriate personnel in a selection of key supplier companies in order to set up open dialogue and to trial the data collection system (April - June, 1998);

- to write EngD conference paper (April - July);

- to contact key customers in order to investigate how environmental information obtained from Nortel is actually used (April - September);

- enter data into the existing component database and analyse (1999); and

- integrate data with formal DFE process (1999 onwards).

6. Conclusions

The research project will develop methods and tools to enable the extraction of component/raw material environmental data from Nortel suppliers and integrate the information into the DFE process to help generate "greener" products.

Once completed, further research will be undertaken to develop methods for integrating environmental criteria into the Nortel raw material selection process. In addition, the RE will investigate various initiatives to improve the DFE process including design-for-end-of-life options incorporating life cycle costing. The research completed by the RE will provide an exciting and interesting contribution to knowledge and will provide Nortel with tools to improve the environmental performance of the company and its products.

The research project is successfully underway and over the next twelve months will produce some interesting results and will quickly start to develop some innovative practical tools for improving product environmental performance.

7. References

IR\1998\1795, *Results of a Nortel Mobile Phone Disassembly Study*, by Carl Mead, M&DT, Nortel Advanced Technology, Harlow, UK.

IR\1998\1796, *The Management of End-of-Life Electronics Products: TakeBack Conference, November 1997*, by Carl Mead, M&DT, Nortel Advanced Technology, Harlow, UK.

Engineering Doctorate in Environmental Technology

Novel Techniques for Integration of Environmental Life Cycle Technologies in the Telecommunications Industry

Six Month Report No: 2

Research Engineer

Carl Mead
(Brunel University and Nortel Advanced Technology)

1 October 1998

Contents

1. Introduction

This document provides a review of the second six month's (end of year 1) of the Research Engineer's (RE) research project for the Engineering Doctorate in Environmental Technology. The project focuses on the development of novel methods for the integration of environmental life cycle technologies into Nortel's product development process. Key areas for research are the investigation of customer and industry demands for product environmental information, extraction of product environmental performance data from suppliers, and the integration of the collected information into the Design for Environment process.

The background to the company and the project, the problem definition and the aims of the project can be found in six month report number 1.

1.1. Key Personnel

Carl Mead	Research Engineer
Prof. J.D. Donaldson	Academic Supervisor (Brunel University)
Dr. Ken Snowdon	Industrial Supervisor (Nortel Advanced Technology)
Dan Francis	Industrial Supervisor (Nortel Advanced Technology)

2. Research Programme

2.1. Research Objectives for Year 1

1. Conduct a literature review to demonstrate my understanding of the concepts and practicalities of the application of LCA and DFE (Yrs 1-4);

2. determine the current and potential capabilities of LCA (Yr 1 and 2);

3. determine the current and potential capabilities of DFE (Yr 1 and 2);

4. develop an understanding of the structure of the Nortel Supply Management function, determine how it works and interfaces with the design groups (Yr 1);

5. conduct an evaluation of how environmental information obtained from suppliers can be used (Yr 1);

6. conduct an assessment and gap analysis of the information being requested by Nortel's customers, the information Nortel requests from its suppliers, information requested by competitors and the information required for voluntary product declarations (Yr 1);

7. set up a system to obtain product environmental information from suppliers (Yr 1); and

8. determine how Nortel customers use the environmental information provided, particularly how it may affect a bid for business (Yr 1).

3. Progress

3.1. Towards Meeting Objectives

This section will review the progress made in meeting the objectives of the first year as described above.

Objective 1

The literature search is continuing for LCA, DFE and relevant supply management documents. The list of documentation relevant to the research project is being added to continually to ensure it remains up-to-date. The RE will submit a full and final literature review document as part of the final dissertation and portfolio submission in 2001 to demonstrate an in-depth understanding of LCA, DFE and Supply Management, and analytical comment on up-to-date research initiatives.

Objectives 2 and 3

The current and potential capabilities of LCA and DFE to improve product environmental performance in the telecommunications industry are continually being determined as a component of the literature review process and from investigations within Nortel regarding their application.

Objective 4

The structure of the Nortel supply management function is partially understood although it is continually developing with the addition of advanced tools designed to improve the process. The RE will continue to interact with Nortel Supply Management to further improve the understanding of the operating systems and plans for future development. Interaction with Nortel Supply Management is considered important to the success of the research project to enable the research concepts and ideas to be tested and to facilitate the eventual implementation of the research recommendations. The research topic is also quickly gaining profile in the company as possible business implications become evident. This may provide an excellent opportunity for the RE to contribute to providing practical business solutions to company environmental problems.

Objective 5

A key concern of the company at the present time is the ability to respond to the increasing number and specificity of customer requests or demands for product hazardous material content data. It is clear that a comprehensive and accurate response will require the capturing of detailed product information from suppliers. Supplier environmental information is also fundamental to improving the DFE process and providing information for ISO 14001 continual improvement systems.

Objectives 6 and 7

Research has focused on interpreting and using the results of the gap analysis conducted earlier in the year. The gap analysis compared the information being requested by Nortel's customers and the information Nortel requests from its suppliers. The analysis showed that customers are asking increasingly more complex questions regarding Nortel product environmental performance and that the information requested is not being currently provided by Nortel supplier assessment questionnaires or supplier interaction programmes.

The gap analysis has provided information for the generation of a new method of supplier assessment, appraisal or interaction. The RE has developed three versions of an improved supplier questionnaire designed to provide information to meet the requirements of customer environmental information requests, the DFE process and ISO 14001 continual improvement systems. Feedback on the questionnaires has been requested from the network of site Environmental Health and Safety primes in Europe to ensure they are suitable for ISO 14001 continual improvement. The questionnaires are about to be tested on key Nortel suppliers.

Objective 8

A questionnaire was also developed to obtain information that would assist in determining how exactly Nortel customers use the environmental information provided by Nortel and specifically how it affected the bid process. Following discussions with a Nortel senior corporate environment manager it was decided for strategic reasons that the questionnaire would not be sent out to customers as the RE intended but that the content of the questionnaire would be included in individual customer interaction focus groups that are planned. Many customers are specifying on their own questionnaires that the environmental information provided will be one criteria on which the decision for contract allocation will be based. This is considered enough information on which to act immediately.

The RE is now working closely with individuals from Nortel Supply Management and ISO 14001 experts and will shortly develop a programme with the design community that coincides with the trialing of a DFE tool.

A Nortel Work Package Description has been written. It details project tasks and deliverables for the next three years of EngD research. The project management plan is provided in Appendix I.

3.2. Supporting Activities

Certain activities are carried out by the RE which, although not directly connected with the core research project, assist in the development of personal, professional, and business skills. They support the RE's candidacy for the qualification of Engineering Doctorate.

They are:

- Attendance of EngD modules and completion of assignments on time (Sociology I, Risk Perception and Communication, Hands-On Environmental Audit and Environmental Measurement);
- representing Nortel at technical committee meetings for international standards (ECMA TC 38);
- practical DFE research such as active participation in the Nortel European DFE Council Meeting, July 1998;
- attendance of relevant conferences, exhibitions and seminars such as Environmental Technology '98 and the Annual EngD Conference (presenting a paper on Supplying DFE in the Telecommunications Industry[1]).
- various presentations of the research project to department colleagues and senior Nortel staff;
- regular attendance of Brunel University Centre for Environmental Research Postgraduate Research Forum;
- EngD Intake Year 1997 Representative; and

- publication of a book co-authored by the RE entitled Environmental Risk Assessment: Approaches, Experiences and Information Sources[2].

4. Discussion

The first year of the research project has involved the completion of strong foundational work required to meet the aims and objectives of the four-year research project. Key contacts have been made within Nortel and the necessary relationships with Nortel staff formed to provide expertise throughout the next three years. Over the last six months there has been significant constructive discussion with industrial supervisors regarding the details of how the project should progress over the next three years. The research can be considered "on-line" research and development. This means that the research objectives when met could be implemented by Nortel within a very short time frame. Also, if the results and recommendations of the research are considered by Nortel to be required very quickly, additional resources may be allocated within the company. Resources are certainly required in the supplier data-gathering programme of the research project. It has been agreed that if further resources are allocated to the problem (the immediate concern being meeting the requests of customers for product hazardous material content declaration) the RE will be able to contribute to programmes that are established.

Aspects of the original project management plan developed for the Project Management Module assignment and some objectives from six month report number 1 have changed due to an improved understanding of Nortel requirements. The revised plan in Appendix I provides a projected breakdown of the final three years of research. The research is comprised of three programmes that are focussed on three key questions:

- What information needs to be obtained from suppliers to meet the requirements of DFE and to answer customer requests?
- What methods can be used to obtain the environmental information from suppliers and how can it be communicated to Nortel internal users?

- How is the suppliers' component environmental information used by the design community, ISO 14001 systems and Nortel sales teams?

The completion dates for each task and the milestone dates are considered to be target dates only.

5. Next Steps

The next steps of the research project for the next six months are:

1. Complete the analysis of customer questionnaires to determine customer information requirements;
2. Complete the assessment of forthcoming product environmental legislation to determine legislative requirements for DFE;
3. Generate final draft of supplier environmental assessment questionnaire;
4. Test supplier environmental assessment questionnaire on suppliers;
5. Conduct VMR supplier study with PACES;
6. Complete gap analysis and generate report;
7. Obtain feedback from EHS primes on ISO14001 suitability and develop scoring system for questionnaires;
8. Determine what information can be made available to designers via PACES and how;
9. Participation in customer interaction programmes;
10. Start comparison study of component material composition data;

11. Start the population of the PACE database with initial approved data from VMRs;

12. Start investigating the possibilities of developing a web-based supplier assessment procedure; and

13. Identify how Nortel Supplier Agreement Management System (SAMS) works and interfaces with PACES.

The remaining project tasks for the final three years are detailed in the project plan calendar (Appendix I).

6. Conclusions

The research project is progressing satisfactorily and is now at a crucial point where detailed plans have been made for the three years of core research which will form the cornerstone of the doctorate. The first year of research has provided an excellent foundation on which to build and has involved interaction with several Nortel business functions, resulting in a comprehensive awareness of the practical need and industrial setting of the research.

The research has yielded an improved supplier environmental assessment questionnaire, compared with existing Nortel supplier environmental assessment questionnaires, which is now about to be tested with key suppliers. The questionnaire is a core tool for obtaining supplier data. The RE will investigate methods enabling rapid transfer of supplier data to Nortel and communication of that data to those business functions within Nortel that can utilise it effectively. These groups include supply management, sales and marketing, designers, and ISO 14001 systems operators.

Later research will concentrate on optimising methods of component selection in terms of environmental performance to further improve the DFE process.

7. References

1. Mead, C.D. *Supplying Design for Environment in the Telecommunications Industry*, Proceedings of the Engineering Doctorate in Environmental Technology Annual Conference 1998, pp. 43 – 53.

2. Fairman, R, Mead, C.D. and Williams, W.P, *Environmental Risk Assessment: Approaches, Experiences and Information Sources*, Office for Official Publications of the European Communities, Luxembourg, 1998.

Engineering Doctorate in Environmental Technology

Novel Techniques for Integration of Environmental Life Cycle Technologies in the Telecommunications Industry

Six Month Report No: 3

Research Engineer

Carl Mead

(Brunel University and Nortel Networks)

1 April 1999

Contents

1. Introduction

This document provides a review of the third six month period (beginning of year 2) of the Research Engineer's (RE) research project for the Engineering Doctorate in Environmental Technology. The project focuses on the development of novel methods for the integration of environmental life cycle technologies into Nortel's product development process. Key areas for research are the investigation of customer and industry demands for product environmental information, extraction of product environmental performance data from suppliers, and the integration of the collected information into the Design for Environment process.

The background to the company and the project, the problem definition and the aims of the project can be found in six month report number 1.

1.1. Key Personnel

Carl Mead	Research Engineer
Prof. J.D. Donaldson	Academic Supervisor (Brunel University, CER)
Dr. Ken Snowdon	Industrial Supervisor (Nortel Networks, Advanced Design Technologies)
Dan Francis	Industrial Supervisor (Nortel Networks, Advanced Design Technologies)

2. Research Programme

In this section the research objectives for Year 2 of the research programme will be provided. Any objectives specified in six month reports 1 and 2 that were forecast to continue beyond year 1 are included and progress is reported in section 3 of this report.

2.1. Research Objectives for Year 2

1. Conduct a literature review to demonstrate my understanding of the concepts and practicalities of the application of LCA and DFE (Yrs 1-4);

2. determine the current and potential capabilities of LCA (Yr 1 and 2);

3. determine the current and potential capabilities of DFE (Yr 1 and 2);

4. Complete the analysis of customer questionnaires to determine customer information requirements (Yr 2);

5. Complete the assessment of forthcoming product environmental legislation to determine legislative requirements for DFE (Yr 2);

6. Complete gap analysis and generate report (Yr 2);

7. Generate final draft of supplier environmental assessment questionnaire (Yr 2);

8. Test supplier environmental assessment questionnaire on suppliers (Yr 2);

9. Obtain feedback from EHS primes on ISO14001 suitability and develop scoring system for questionnaires (Yr 2);

10. Seek standardisation of the final supplier environmental assessment questionnaire (Yr 2);

11. Determine a qualification procedure for each supplier assessment (Yr 2);

12. Conduct VMR supplier study with PACES (Yr 2);

13. Determine what information can be made available to designers via PACES and how (Yr 2);

14. Participation in customer interaction programmes (Yr 2);

15. Start comparison study of component material composition data (Yr 2);

16. Start the population of the PACE database with initial approved data from VMRs (Yr 2);

17. Investigate the possibilities of developing a web-based supplier assessment procedure (Yr 2);

18. Identify how Nortel Supplier Agreement Management System (SAMS) works and interfaces with PACES (Yr 2).

19. Investigate methods of product environmental data transfer and tracking through the product life cycle (Yr2);

20. Complete and submit 2nd year dissertation (six month report No. 4).

The remaining project tasks for the final three years are detailed in the project plan calendar (Appendix I).

3. Progress

3.1. Towards Meeting Objectives

This section will review the progress made in meeting the objectives of the second year as described above and in the project plan (Appendix 1).

Objective 1

The literature search is continuing for LCA, DFE and relevant supply management documents. The list of documentation relevant to the research project is being added to continually to ensure it remains up-to-date. A summarised literature review will be provided in the second year dissertation (six month report No. 4) to place the work in context of previous and current research being conducted in this field. The RE will submit a full and final literature review document as part of the final dissertation and portfolio submission in 2001 to demonstrate an in-depth understanding of LCA, DFE and Supply Management, and analytical comment on up-to-date research initiatives.

Objectives 2 and 3

The current and potential capabilities of LCA and DFE to improve product environmental performance in the telecommunications industry are continually being determined as a component of the literature review process, from investigations within Nortel regarding their application, and through the work conducted in the research project.

Objective 4

The research for the customer questionnaire analysis has been completed as a component of the gap analysis (Objective 6) and from data collected since the gap analysis was conducted. The resulting information (customer requirements) was used in the development of the three trial versions of the New Nortel Networks Supplier Environmental Assessment Questionnaire. A database of customer requests is being maintained. Customer requirements need to be continually monitored to ensure DFE and supplier interaction programmes remain customer focused.

Objective 5

Research has been conducted by both the RE and by project placement MSc students on current and proposed product-related environmental legislation. A summary of the findings to date will be provided in six month report No. 4 and the Programme 1 report (see the project plan in Appendix 1). The main item of legislation driving DFE and Product Life Cycle Management is the proposed EU Directive on Waste from Electrical and Electronic Equipment. Legislation is continually being developed and implemented. A system for tracking environmental regulations has been introduced at Nortel Networks.

Objective 6

The gap analysis between Nortel customer environmental questionnaires and Nortel supplier environmental questionnaires has been completed and issued as a Nortel internal report (IR\1998\1825[1]). The report forms one section of the Programme 1 report and will be submitted to the portfolio within the Programme 1 report. The results of the analysis were used in the development of the three trial versions of the New Nortel Networks Supplier Environmental Questionnaire.

Objective 7

A final draft version of the New Nortel Networks Supplier Environmental Questionnaire has been developed. This document (Excel file) was finalised by the RE after:

- the results of the trial of the three versions of the new questionnaire with suppliers were received;
- feedback from the Nortel Networks European site Environment, Health and Safety primes was received; and
- feedback from the Nortel Networks Corporate Environmental Services group.

The questionnaire development procedure, trial and finalisation process will be written up in the Programme 2 report. The questionnaire has been put forward for standardisation as the Nortel Networks global supply management procedure for assessing the environmental performance of production suppliers (Objective 10).

Objective 8

The finalised questionnaire is undergoing extended trials with twenty five suppliers of Nortel Networks. The core objective of the extended trial is to identify the level of product environmental information suppliers can, or will be able to provide. The resulting information will indicate the size of the challenge of obtaining product environmental data from the supply base. In addition the trial will highlight potential logistical problems associated with the electronic questionnaire. Suppliers have been selected so that a wide range of commodities are covered and on the basis that they are considered long-term suppliers of Nortel Networks. In view of the current Manufacturing 2000 strategy being implemented at Nortel Networks, a contract manufacturer has also been included in the trial.

Trial details and results will be included in the Programme 2 report.

Objective 9

To be standardised and used globally, the New Nortel Networks Supplier Environmental Questionnaire has to meet the requirements of ISO 14001 in terms of facilitating continual improvement in environmental performance. A scoring system was developed for the new questionnaire that would enable scores to be allocated to the suppliers' responses to each question. The supplier will be informed of their score and made aware of areas where improvements can be made. When assessed again any improvements can be identified. The scoring method, score allocation procedure and the questionnaire itself has been approved by the Nortel Networks European site EHS primes.

Objective 10

Nortel Networks global standardisation of the new questionnaire as the standard method of assessing the environmental performance of production suppliers is being sought. This will require ownership from the Nortel Networks Supply Management group and formal approval of the questionnaire as a corporate standard.

Objective 11

When a supplier is assessed it is necessary to qualify or verify the assessment in some way to ensure that the information provided by the supplier is accurate and complete. This can be achieved through a site survey or audit or some other mechanism. The verification procedure needs to be developed for the New Nortel Supplier Environmental Questionnaire, particularly if it is developed into an automated web procedure which is currently being researched.

Objective 12

The first part of the VMR (Value Managed Relationship) supplier study has been completed, the second part is in progress. The first part consisted of identifying the percentage of qualified components on the PACES database that potentially could be supplied by VMR suppliers. The second part consists of selecting example products and identifying the percentage of components that could be supplied by VMR suppliers.

The hypothesis driving the study is that VMR suppliers are more likely to be able to provide product environmental data. The first part identifies the number of components in the PACES database for which environmental data is more likely to be available. The second part will identify the percentage of components in example Nortel Networks products for which environmental data is more likely to be available. The hypothesis will be partly proved or disproved by the extended trial of the New Nortel Networks Supplier Questionnaire as the majority of VMRs are included in the study.

Objective 13

It has been determined that product environmental data can be entered into the PACES database. The preferred field being the product compliance field. It is recognised though that the compliance field is restricted in size, accepting only a limited number of characters, and it may only be feasible to enter brief warning information on the presence of hazardous materials in each component. Discussions are taking place with the PACES team to investigate further options. Various methods of product environmental data storage, tracking and transfer within Nortel Networks will be investigated.

Objective 14

It has not been possible for the RE to participate directly in customer interaction programmes as only one customer workshop has been conducted recently in North

America. However, feedback from the workshop has been provided. No customer workshops are planned in the next six months.

Objective 15

A project proposal has been drafted for a comparison study of product material composition data. The proposal has been submitted to Brunel University Centre for Environmental Research who have agreed to identify a suitable MSc student to conduct the study as their MSc in Environmental Science research placement project. The main focus of the study would be to conduct chemical analyses on selected components procured from suppliers of Nortel Networks and to compare the resulting data on chemical composition to the data provided by the supplier and generic component material composition data available in a commercial database.

This study can only be conducted if a suitable student is identified. If Brunel University cannot identify a suitable student it may be possible to find a suitable student at another university.

Objective 16

As soon as product environmental data becomes available from suppliers selected data will be added to the PACES database as part of a trial. Data have been received for some components from one supplier as part of the first questionnaire trial. Adding some of this data to the PACES database will be attempted in the next six months.

Objective 17

Investigations regarding the possibilities of developing a web-based supplier assessment and information retrieval procedure have commenced. Discussions are taking place with software tool specialists within Nortel Networks. It is anticipated that a web version of the New Nortel Networks Supplier Environmental Questionnaire will be developed within the next six months.

Objective 18

From discussion with supply management personnel it is unclear whether the Nortel Supplier Agreement Management System (SAMS) that was envisaged as a "one-stop shop" warehouse for all supply management data will actually be deployed. SAMS could have been used as a data management system for product environmental data.

The Nortel Networks supply management function is currently undergoing strategic changes in its operational procedures. Further investigations with supply management will identify which tools and strategies for data management are being considered for development and deployment.

Objective 19

The investigation of methods of product environmental data transfer and tracking through the product life cycle will commence in the next six months and in conjunction with Objective 17.

Objective 20

Planning of the 2nd year dissertation has commenced.

3.2. Supporting Activities

Certain activities are carried out by the RE which, although not always directly connected with the core research project, assist in the development of personal, professional, and business skills. They support the RE's candidacy for the qualification of Engineering Doctorate.

For this six month period they are:

- research paper accepted for the 1999 Institute of Electrical and Electronics Engineers International Symposium on Electronics and the Environment, 11-13 May, 1999, Boston, USA.
- practical DFE research such as active participation in the training of Nortel Networks designers and the co-running of a DFE workshop at the Third European Surface Mount Conference, 10-12 November 1998, Brighton;
- attendance of relevant conferences, exhibitions and seminars such as

  - Towards Sustainable Product Design Conference 26-27 October 1998, London;

  - Environmental R&D Needs in the UK Electronics Sector: Driving Eco-Innovation, 29 October 1998, DTI Conference Centre, London; and

  - Euro Forum – Preparing Your Organisation for the Introduction of the EU Directive on Waste from Electrical and Electronic Equipment, 22-23 March 1999, London.

- various presentations of the research project to department colleagues and senior Nortel staff;

- regular attendance of Brunel University Centre for Environmental Research Postgraduate Research Forum;

- EngD Intake Year 1997 Representative;

- Regular attendance and chairman of the EngD feedback forum;

- Attendance of EngD LCA forum;

4. Discussion

The research has progressed well over the last six months of the research project. The majority of the targets set for the six months have been reached. Work concentrated on the preliminary trial of the three versions of the questionnaire and the extended trial of the final questionnaire. This exercise and the feedback from the suppliers has resulted in the development of a method of product environmental data capture from the supply base. The core goals of the next year of the research project will be to transfer the electronic data capture method to a web-based tool and to develop a suitable data management and transfer system for product environmental data based on existing system architectures within Nortel Networks if possible.

Any proposals for a system obviously need to be feasible and workable using data management systems that are currently deployed at Nortel Networks. Various options will be considered and recommendations made after suitable tests have been conducted. One of the challenges of the research is that both the Nortel Networks environmental procurement procedure and the supply management strategy is undergoing review and radical change. These changes will certainly have an effect on product environmental data collection from suppliers. The consideration of such changes is an integral part of the system research and development but as yet the future structure of the supply base is not agreed.

The decision to implement any recommendations will ultimately be a Nortel Networks business decision that is made according to the needs of the company.

Any recommendations will require the allocation of significant resources to the project. A sound business case for any proposed product environmental data management system would be need to be demonstrated to result in deployment.

5. Next Steps

The next steps of the research project for the next six months are:

1. Complete the extended trial of the New Nortel Supplier Environmental Questionnaire (Objective 8);

2. Seek standardisation of the New Nortel Supplier Environmental Questionnaire (Objective 10);

3. Determine a qualification procedure for each supplier assessment (Objective 11);

4. Conduct the comparison study of component material composition data if possible (Objective 15);

5. Populate the PACE database with some initial product environmental data (Objective 16);

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6. Develop an interactive web version of the New Nortel Supplier Environmental Questionnaire (Objective 17);

7. Start investigating methods of product environmental data transfer within Nortel Networks (Objective 19);

8. Generate Programme 1 report;

9. Complete 2^{nd} year dissertation (six month report No. 4).

The remaining project tasks for the final two years are detailed in the project plan calendar (Appendix I).

6. Conclusions

The research project is progressing satisfactorily. The last six months have focused on interacting with various suppliers, testing the new questionnaire and generating the first externally published conference paper of the research project. A method for product environmental data capture has been derived through the development of the New Nortel Networks Supplier Environmental Questionnaire. Further development of the method will take place in the next six months in addition to the development and realisation of data transfer methods and Nortel Networks end-of-life data requirements.

7. References

1) Mead, C.D. A Gap Analysis Between Nortel Customer Environmental Questionnaires and Nortel Supplier Environmental Assessment Questionnaires, IR\1998\1825, 1998.


Month
Year
Week
Task Name
1.1 Project Management
1.2 Project Stages
1.3 Project Milestones
1.4 EngD Courses

Engineering Doctorate
in Environmental Technology

Novel Techniques for Integration of Environmental Life Cycle Technologies in the Telecommunications Industry

Six Month Report No: 4

Research Engineer

Carl Mead

(Brunel University and Nortel Networks)

1 October 1999

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Introduction

This document is the fourth six monthly report completed for the Engineering Doctorate Programme. The aims of this report are five-fold:

- to clearly define the overall objectives of the research project and the methodology deployed (Section 1);
- to provide a concise background to the project and an overview of research conducted in the subject area (Section 2);
- to detail progress made to date on meeting planned objectives (Section 3) ;
- to provide full details of planned objectives for the next two years (Section 4);
- to provide a discussion of the research in terms of a contribution to knowledge (Section 5);

Section 1

Research Objectives, Methodology and Project Management

Section 1 – Research Objectives, Methodology and Project Management

1.1 Overall Research Objectives

The title of this EngD project is Novel Techniques for the Integration of Environmental Life Cycle Technologies in the Telecommunications Industry. The core research project focuses on product life cycle environmental data management and decision-making in product development and manufacturing supply chain management.

The underlying aim is to contribute to improvements in the environmental performance of Nortel Networks products through the development of product environmental information management systems.

The core objective is to investigate the feasibility of integrating supplier-specific product-specific environmental data into the ecodesign process and the Nortel Networks Product Life Cycle Management (PLCM) system. The project is one component of a response of Nortel Networks to the increasing need for improved environmental performance of products and company activities. The need for improved product environmental performance in the telecommunications industry and the integration of "green" design practices (ecodesign/DfE) into the product development process are driven by three key pressures:

- customer requests for eco-friendly products and the inclusion of environmental criteria in customer supplier selection processes;
- legislative requirements; and
- ISO 14001 requirements.

The research project involves the investigation and development of methods and tools to meet the information and product environmental performance requirements of customers of Nortel Networks, legislation and ISO 14001 and consequently to improve product environmental performance.

1.2 Research Methodology

The research is regarded as being very much "hands-on" or "real world" in nature. It essentially involves the generation of innovative solutions to problems through a process of change in a specific environment. The outcome will be a solution to the problem and also a contribution to knowledge. The research is not conducted in isolation but involves considerable interaction with Nortel Networks business functions. The researcher is therefore part of a team. This approach is essential if the methods or tools that are developed and proposed stand any chance of being implemented and integrated into current or future systems within the company. Ensuring the "team" remains informed of all progress and is included in any decision-making that results in impacts upon the project is very important. In addition it is necessary to remain abreast of all developments that may affect the project as both the ecodesign and the telecommunications fields are fast moving and dynamic.

Action research methodology is considered to be the most suitable methodology for the research project, at least in terms of the use of the core elements of the methodology. Action Research is generally accepted as having been developed initially by Kurt Lewin (Robinson, 1993, pp. 263) in the 1940s as a method of research for the social sciences. However, since Lewin's early work both the definition of action research and it's application have varied considerably. This is understandable as researchers seek to apply new concepts and models to their work, which necessarily require adaptation and modification to suit the needs of the project.

According to Bennett and Oliver, Action Research is "concerned with systematic data collection and research, leading to action and change.... it is a process that involves the "key actors", so bringing about a commitment to action and change..... action research combines rigor and relevance in moving towards high levels of performance, as well as leading to innovation and making a contribution to knowledge." (Bennett and Oliver, 1999).

Action research is a problem or issue centred approach. The core objectives are to solve a problem through the development of a practice or solution that will advance the pool of knowledge in the specific situation environment and will improve the understanding of the practice by all involved in the project. This suggests an integrated approach where the researcher is a member of a team and the team is involved in all aspects of the project including planning, acting, observing and reflecting (adapted from Carr and Kemmis, 1986, pp. 165). This is, of course, an idealised model and is often in practice difficult to implement in totality as dilemmas and conflicts arise between the two collaborative parties (researcher and organisation) that require additional resolution. This leads to the uneasy relationship between Action Research and the traditional positive pure science approach because of the involvement of the researcher in the study and the potential impacts of the two-party relationship on the research. It is important, however, to understand that one of the objectives of the research is to foster and implement change within the organisation through the improvement of practice and therefore it is essential that the organisation is closely involved in the project.

In addition, a criticism of the approach is that it is perhaps unlikely that "Action Research will result in universally acceptable generalisations" (Warmington, 1980, pp. 25) because the results will be contingent on the situation being studied. This could be a possibility in some applications but is not considered an issue in this specific research project as the results and findings from the study should be applicable across the telecommunications industry.

An overview of the research methodology used in the EngD research project is depicted in Figure 1. The process consists of defining the problem, investigating relevant previous work conducted in the field, generating options, planning, implementing, testing and reviewing solutions in a cycle until a decision is made to implement the recommended solution. After implementation the practice should be monitored and evaluated for performance and continued effectiveness and a revision plan developed if necessary before entering the improvement loop again.

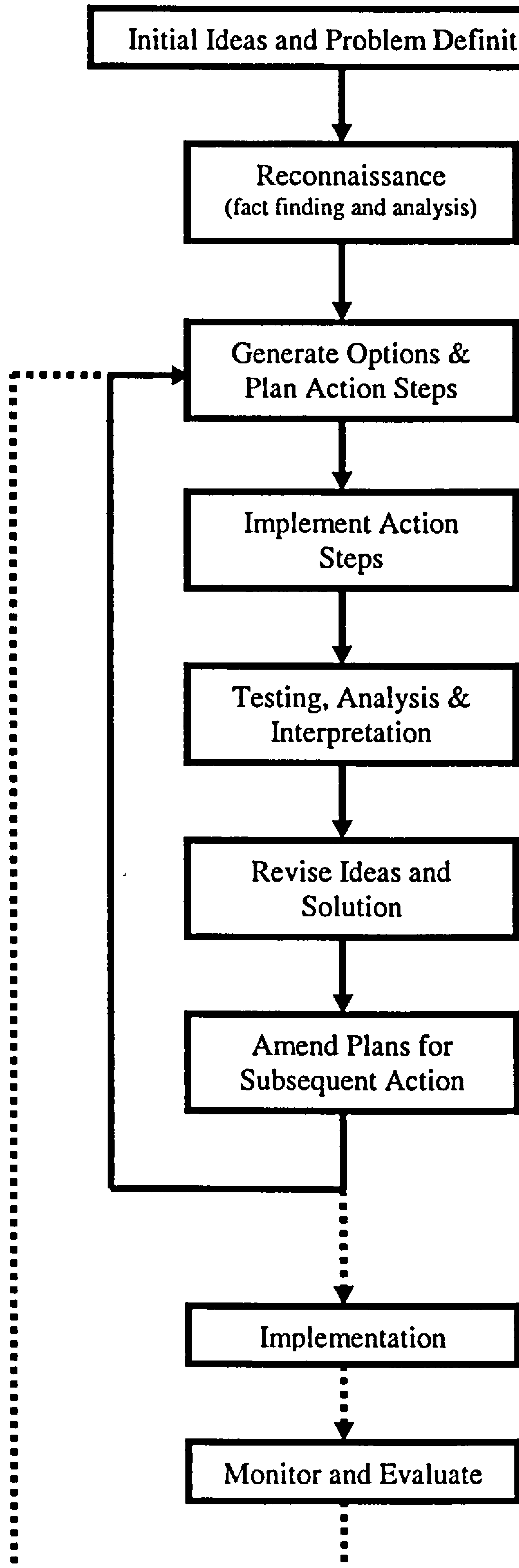

Figure 1. Overview of the Research Methodology (adapted from Robson (1995), cited as adapted from Elliot, (1982)).

1.3 Project Management

The Action Research methodology provides a top-level research framework for the research project. The project management plan provides a detailed road-map in terms of specific objectives, activities and time frames for completion of the project. The research project is driven by a top-level research question and the research is broken down into three core programmes of work, each with a further research question. The research questions and the structure can be seen in Figure 2.

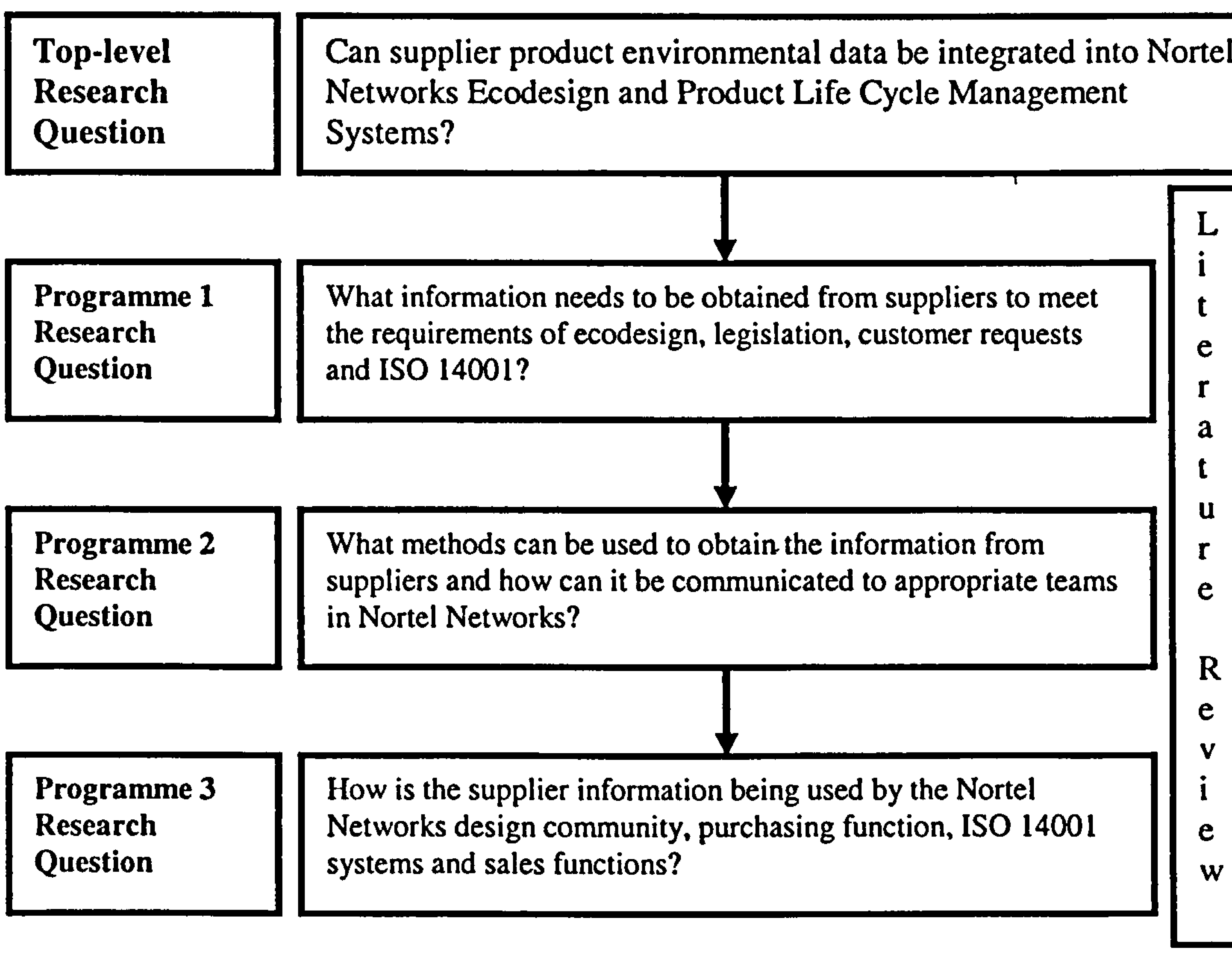

Figure 2. Research questions and programmes of work.

Project details are documented in a Nortel Networks "Work Package Description" (see Appendix I) and in the Research Project Management Plan (see Appendix II). Progress on meeting the objectives is provided in Section 3 of this report and stated objectives for the final two years are reiterated in Section 4 as well as being in the Research Project Management Plan. In terms of portfolio management, the RE plans to write a comprehensive report on each of the three programmes. The reports will be included in the portfolio on completion of the programme together with the executive summary and literature review.

Section 2

Background and Literature Review

Section 2 – Background and Literature Review

2.1 Introduction

The aim of this section is to provide an overview of work conducted in the field of research that provides a context for the research project. It serves as an abridged literature review to demonstrate the RE's understanding of the field of research and an awareness of research previously conducted in the selected area of study. The final review of all literature relevant to the research project will be included in the submitted EngD portfolio on completion of the programme.

Due to the nature of the project several core bodies of literature have been consulted, each focusing on a particular aspect of the overall research. They can be simply categorised as:

- Ecodesign and LCA;
- Supplier environmental assessment;
- Customer request responses; and
- Supply chain management.

Additional bodies of literature have also been consulted on relevant environmental legislation, ISO 14001, and information systems. A detailed overview will be provided in the final literature review.

All relevant literature was identified by conducting searches in various databases for books, journal articles, conference proceedings, PhD dissertations, newspaper articles, company documentation and web sites. A list of the literature identified and obtained for each of the above sections is provided in Appendix III.

2.2 Ecodesign and LCA

The research project is focused on ultimately improving the environmental performance of Nortel Networks products. Ecodesign is therefore a design concept and technique that is pivotal to the research. Life Cycle Assessment (LCA) is another tool that can be used to improve the environmental performance of products and can be complimentary to the ecodesign process in terms of quantifying environmental impacts and identifying areas for improvement. However, conclusions from previous research conducted at Nortel Networks (Francis, 1999) suggest that LCA may not be a practical and viable product development tool in organisations using complex concurrent engineering and design. The reasons are:

- complex systems;
- complex product data management;
- difficulties in product data acquisition; and
- cost and resources.

Francis (1999) concluded that LCAs need to be carried out by specialists in the organisation and that it is not feasible for a designer to conduct a full LCA as a component of an ecodesign procedure. This conclusion is not dissimilar to general opinion that has been voiced on the application of LCA in the electronics industry. In contrast ecodesign is widely accepted in the electronics industry as a suitable design technique for improving the environmental performance of products. In some scenarios LCA can also be utilised.

2.2.1 Definitions

As the field of ecodesign (also known as Design for Environment (DFE)) has grown phenomenally over the last five years a plethora of definitions have developed. Examples are provided below.

"Design for Environment is an objective technique for making environmental considerations an integral part of the design of the product, process or technology." (White, 1999).

"Design for Environment is a novel approach to systematically reduce or eliminate environmental impacts throughout the life cycle of a product or process by accounting for potential impacts at the outset and during the continuing course of the design process" (Digital Equipment Corporation et al, 1997).

"Environmentally Conscious product Design, often referred to as Design for Environment or Ecodesign, aims to make efficient use of natural resources over the entire life cycle of products. It is not simply improving a product, it means embedding the environmental issues in the product policy and strategies and in the product creation process." (Philips Electronics N.V, 1997).

"Integrating environmental considerations systematically into the design of products, processes and services is called Design for Environment (DfE). DfE practices are intended to develop environmentally compatible products and processes while maintaining or improving price, performance, and quality standards." (The Environment Council, 1997).

Ecodesign is "Design which addresses all environmental impacts of a product throughout the complete life cycle of the product, without unduly compromising other criteria like function, quality, cost and appearance."(Eco_2-IRN, 1998).

DFE is "systematic consideration of design performance with respect to environmental, health and safety objectives over the full product and process life cycle" (Fiksel, 1996).

Each of the above definitions contains individual subtleties but most include the terms environmental impacts or considerations, and life cycle. Both The Environment Council and Eco2-IRN also incorporate the other important criteria that product design must take into account such as cost, quality and function. This is an important practical consideration as ecodesign principles must be complimentary to other DFX (Design for "X") practices such as those suggested by Graedel and Allenby (1995) which include assembly, regulatory compliance, manufacturability, reliability and testability.

In addition to the term ecodesign, there are two other terms that characterise the level of environmental consciousness deployed in the design process. Poyner (1998) suggests that "green design" sits at the bottom of the environmentally conscious design hierarchy as it treats the environmental design of the product as an objective rather than a constraint (Mackenzie, 1991). Ecodesign is next on the hierarchy and "sustainable design" is at the top as it concerns the societal need for the production of the product in the first place, consumer attitudes and ownership.

2.2.2 Ecodesign Principles

A comprehensive ecodesign approach for products will consist of the application of a combination of practices developed to improve eco-efficiency and perhaps to achieve a certain set of environmental performance goals. Some practices result in improvements that are self-evident, others may require further analysis to establish the degree of improvement. The fundamental targets for the practices are reduction in resource use and reduction in pollution over the entire life cycle of the product while satisfying costs and performance requirements in order that the product remains competitive.

Fiksel (1996) describes the core ecodesign practices as:

- Material substitution;
- Waste source reduction
- Substance use reduction;
- Energy use reduction;
- Life extension;
- Design for seperability and disassembly;
- Design for recyclability;
- Design for disposability;
- Design for re-usability
- Design for remanufacture; and
- Design for energy recovery.

The concept of life cycle thinking is very important in ecodesign. The designer needs to consider the entire life cycle of the product from "cradle to grave" or even "cradle to cradle" to ensure that environment impact reduction in one phase of the life cycle does not result in greater environmental impact in another and that responsibility for the product exists beyond the factory gate right to end-of-life. The typical product life cycle with end-of-life loops is shown in Figure 3.

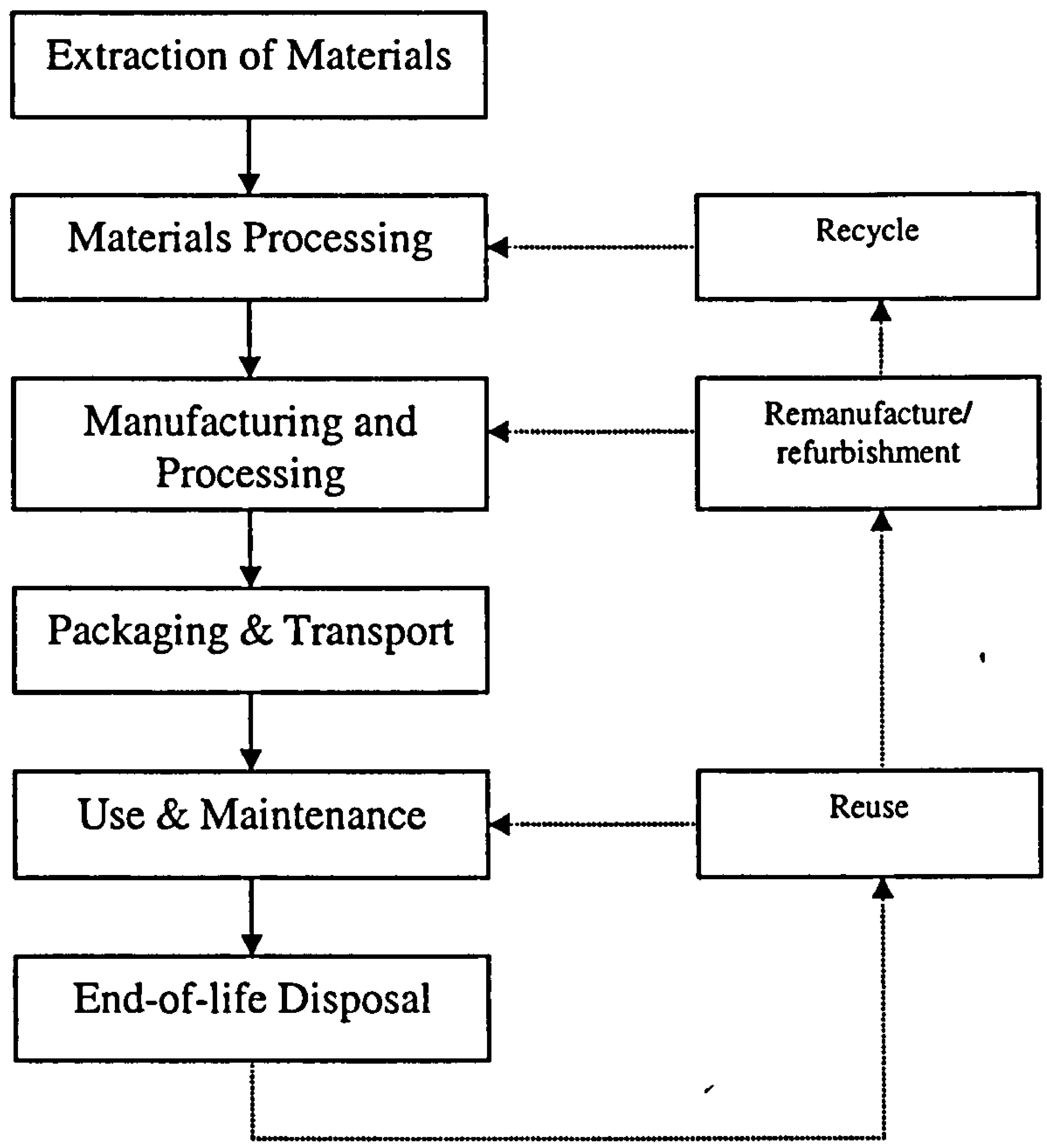

Figure 3. The Product Life Cycle

2.2.3 Ecodesign at Selected Electronics Organisations

This section consists of brief overviews of leading ecodesign programmes in the electronics industry.

2.2.3.1 Philips Electronics.

The following details are taken from the 1998 Philips 1998 Environmental Report – Ecovision (Philips, 1999).

"Philips strives to integrate functionality and sustainability by balancing innovation with ecological impact. This means continuous improvement in both areas, with a focus on products, packaging and processes. Philips is building an extensive experience and a knowledge of how to green products with Ecodesign."

In order to enhance environmental performance, Philips focuses on five green focal areas during ecodesign:

- Weight;
- Hazardous substances;
- Energy consumption;
- Recycling and disposal;
- And packaging.

Product developers analyse every stage of the product life cycle. In most divisions the EcoScan computer program is used to calculate the environmental impact of the product, which is expressed in terms of an Eco-Indicator. The Eco-Indicator makes it possible to compare the environmental impact of the different life stages of the product. If a product meets the Ecodesign criteria and has a better environmental performance than the chosen reference in one or more of the Green Focal Areas (and is equal in the rest) it can be selected as a Green Flagship product. The Ecodesign programme is an integral component of the ISO 14001 environmental management process.

2.2.3.2 IBM

The following details are taken from the IBM 1998 Environmental Report (IBM, 1998).

"IBM's Environmentally Conscious Products (ECP) program was established in 1992. Unique to the industry in its technical breadth, the program has pioneered the industry's best practices in design for the environment (DFE), product recycling technologies and product environmental metrics. The program has established five environmental design objectives for IBM products:

- Develop products with consideration for their upgradeability to extend product life;
- Develop products with consideration for their reuse and recyclability at the end of product life;
- Develop products that can safely be disposed of at the end of product life.
- Develop and manufacture products that use recycled materials where they are technically and economically justifiable; and
- Develop products that will provide improvements in energy efficiency and /or reduced consumption of energy."

The ECP requirements have been incorporated into IBM's Integrated Product Development process.

2.2.3.3 Lucent Technologies

The following details are taken from the Lucent Technologies 1997 Environment, Health and Safety Report (Lucent Technologies, 1998).

" Lucent Technologies knows that Design for Environment (DFE) is a key in distinguishing our processes, products and services. We have established a cross-functional DFE team to implement the changes necessary to support our vision of being a responsible company that fully integrates life cycle consequences into each of its business decisions and activities. We have also established a Product Lifecycle Team to facilitate company-wide minimisation of potential cost and liability associated with equipment disposal, electronic and contaminated scrap, asset recovery and product reuse."

Lucent aims to develop and apply design for the environment criteria for all its operating units by the year 2000. "20 products have been subjected to an "environmentally responsible product" evaluation using a methodology developed internally.

2.2.4 Ecodesign at Nortel Networks

Ecodesign was first considered at Nortel Networks in the early 1990s although the approach has been somewhat fragmented with several research and development groups investigating the development and implementation of various tools and approaches. Significant early milestones include the issue of Design for Environment Guidelines for Nortel Physical Designers (White, 1997) and the application of ecodesign in the development of the world's first lead-free demonstration telephones.

Over the last four years a programme to develop and implement a corporate-wide ecodesign strategy incorporating several decision-making tools has been underway. The RE has been a participatory team member in this programme. The work included research on LCA (Francis, 1999) and ecodesign software tools (Poyner, 1998). Several design teams in different Lines of Business (LOBs) have been trained to use ecodesign. The programme has culminated in the launch of an Ecodesign Solutions Set – an ecodesign tool suite.

The Solutions Set consists of three developed web-based tools (see Figure 4.):

1. Product Environmental Compliance Checklist (PECC)
2. Nortel Ecodesigner (NED)
3. Environmental Product Opportunity Assessment (EPOA)

Each tool is used in chronological order as above during the product development process. PECC is used at the product conception stage to identify potential compliance risks associated with the product in terms of legislation, possible market restrictions and customer requirements. NED is used during the product design stage. It is a simple, practical tool that facilitates effective ecodesign. The designer selects ecodesign strategies to apply to the design of the product from categories such as hazardous materials, mechanical, electrical (see Figure 5.). The application of the strategies is then documented and version controlled using Livelink on the web. The process forms a part of the ISO 14001 programme for each site.

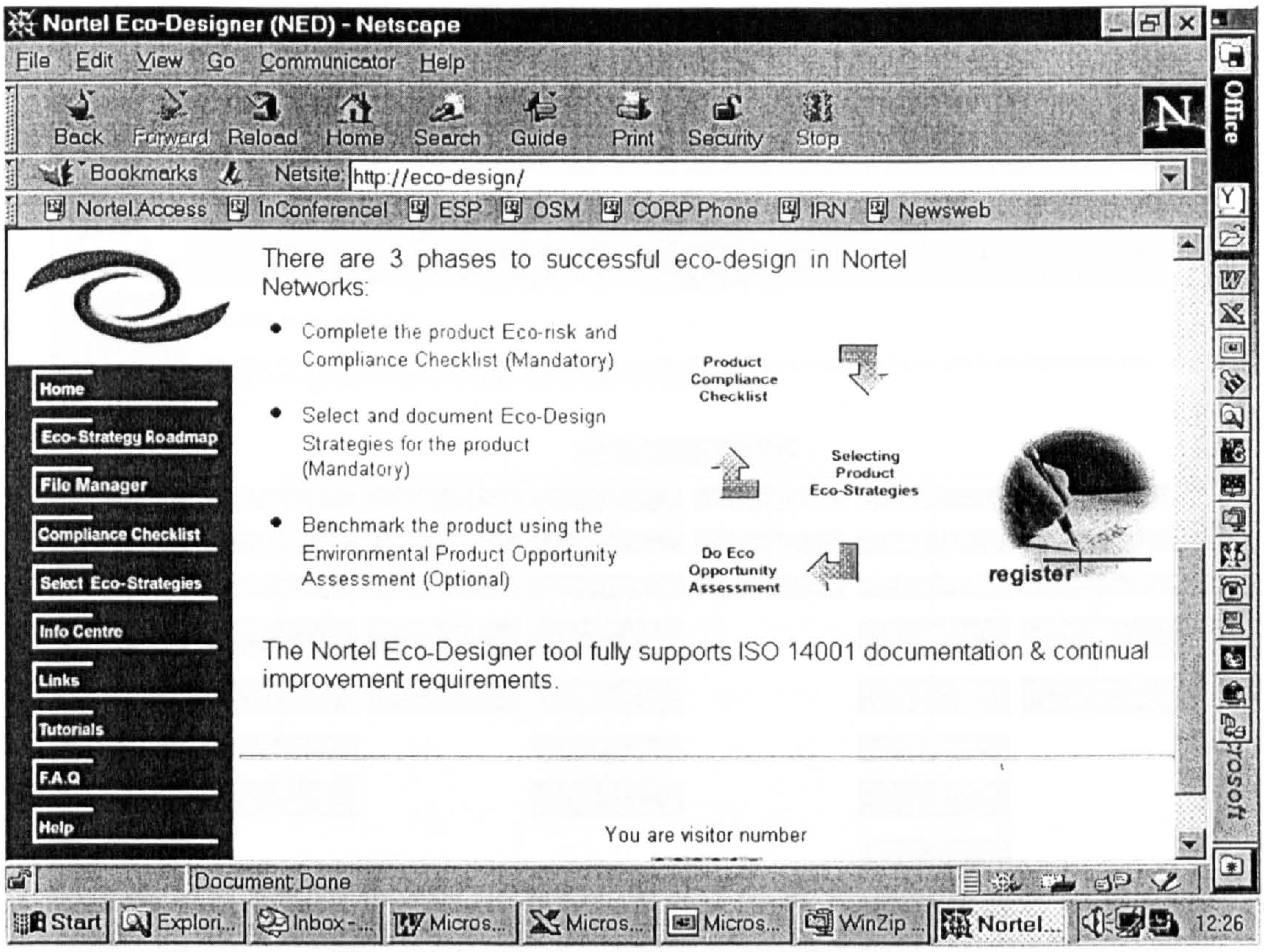

Figure 4. Ecodesign Solutions Set Web Tools

EPOA is a method developed internally to quantify the environmental performance of products. It is used to establish a baseline for continuous environmental improvement and to assist in meeting the requirements of legislation and customers.

Certain aspects of NED and EPOA focus on materials present in the product and opportunities for recycling and recovery. However, strategies for avoidance of certain hazardous materials and use of recyclable materials in NED and the identification of the presence of hazardous and recyclable materials in EPOA require detailed information of the material composition of components within products. Such detailed information can only be provided by the supply base. The possibilities for the creation of the fourth piece of the jigsaw are investigated in this EngD research project (see Figure 6). SEAP (Supplier Environmental Appraisal Procedure) is a method developed by the RE and is revealed in Section 3 of this report.

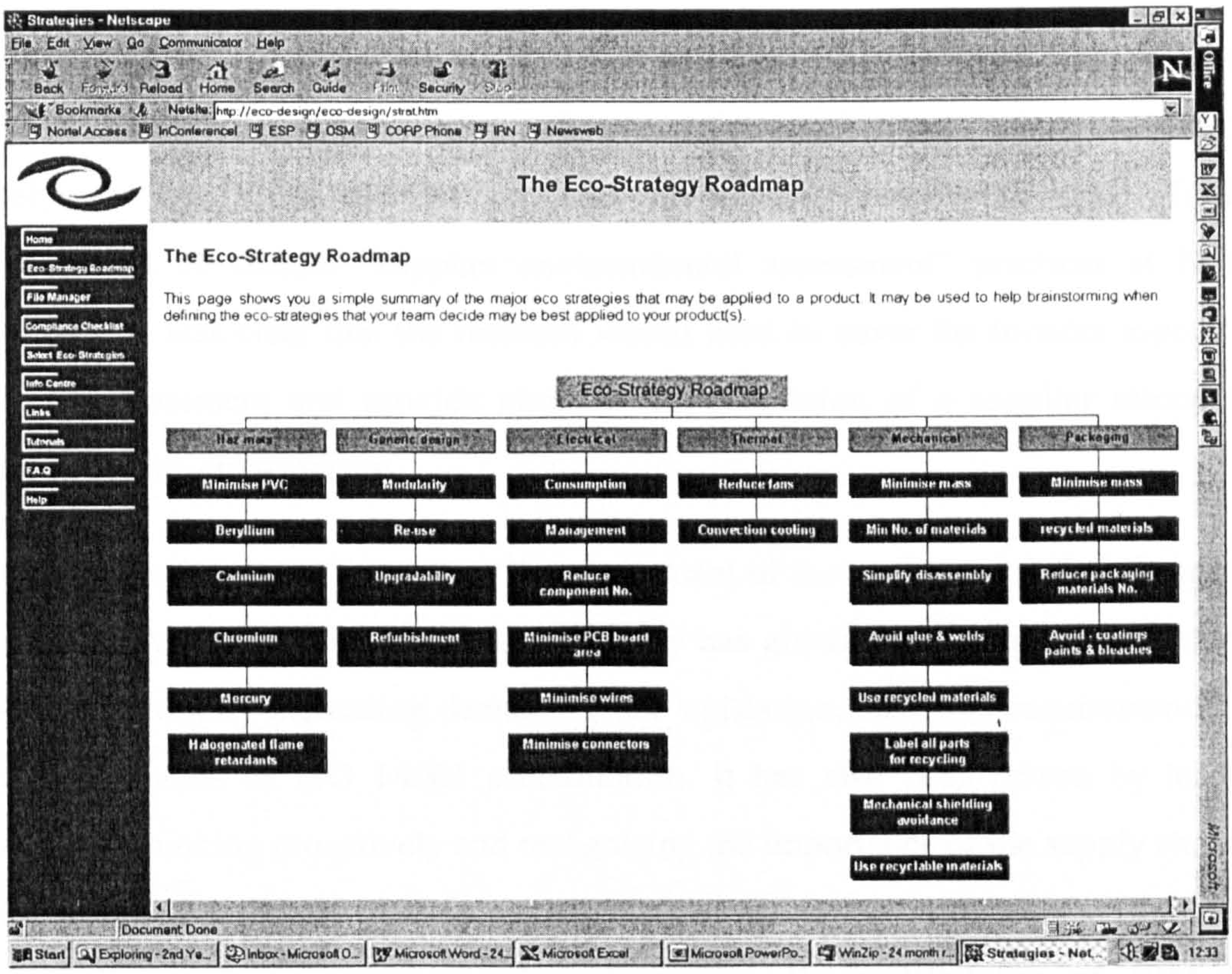

Figure 5. Ecodesign Strategies

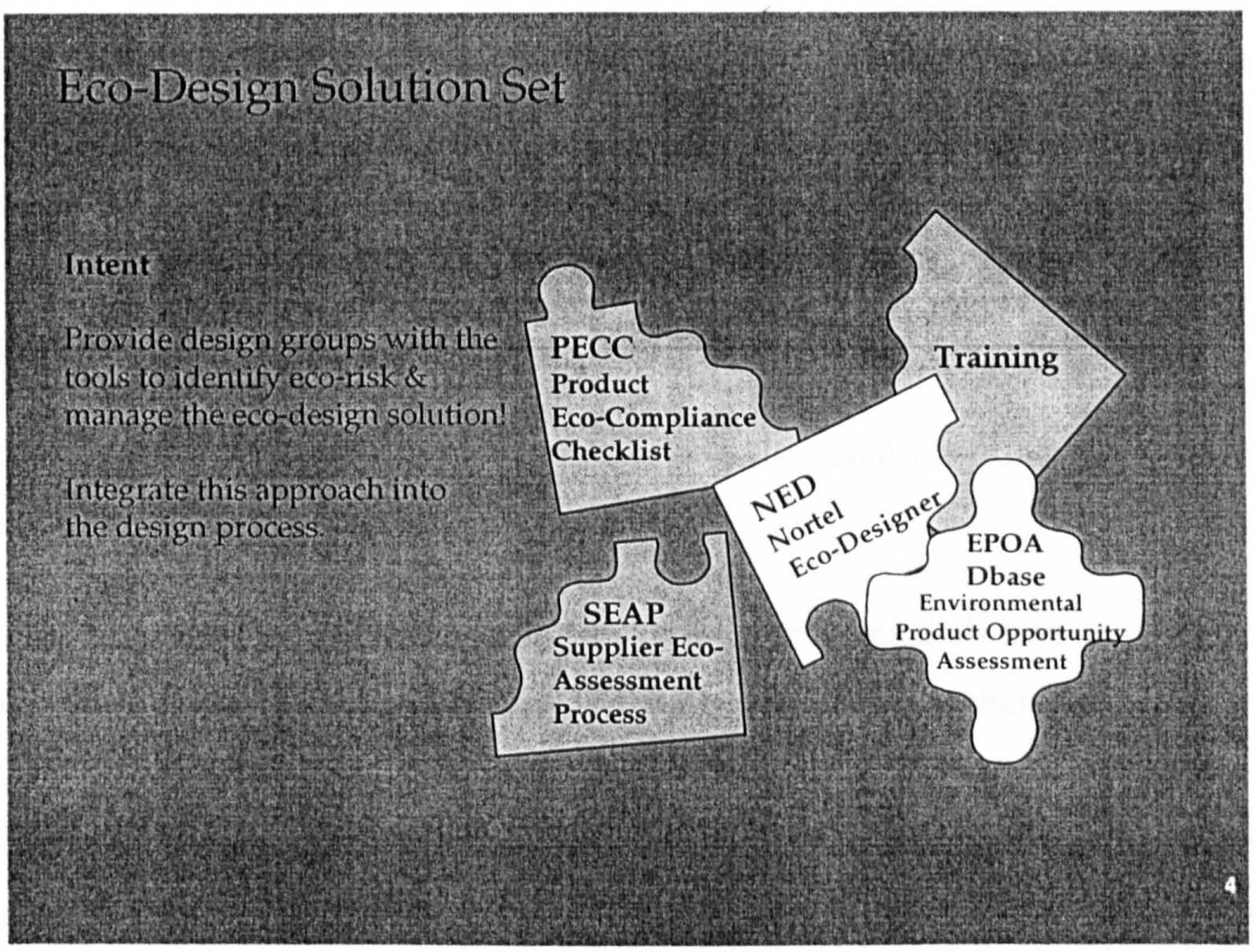

Figure 6. SEAP and the Ecodesign Solutions Set

2.3 Supplier Environmental Assessment

Methods of interaction with the supply chain are a core element of the EngD research project. When the project commenced it was thought that the project could focus purely on product/component environmental performance but upon further investigation of current "supplier environmental assessment" practices at Nortel Networks, it was clear that the research would need to cover the broader aspects of supplier assessment and provide input to the generation of a supplier interaction strategy for the environment.

Over the last five years, interest in the assessment of the environmental performance of the supply chain in the electronics industry has grown considerably. The interest has been driven by increasing demands from legislation, customer, requirements and the requirements of ISO 14001 accreditation. It has also been driven by leading companies thinking proactively and recognising the importance of the supply chain in terms of the affect it can have on a company's environmental performance and more specifically product environmental performance. Brian Whitaker of IBM has recognised the importance of supply management:

> "..it is fair to say that the supply chain is one of the most powerful weapons available in the pursuit of improved environmental performance, but like so many other such weapons, we have not yet learned how best to use it. But unlike these other weapons, we really have no choice but to learn to use it properly for the benefit of the human race"(Whitaker, 1995).

Sarkis et al stress the need for strong inter-organisational relationships in order to meet the demands of industrial ecology:

> "The growth of an industrial ecology paradigm requires that there must be an increased focus on interorganizational relationships. Supply chain management is one vehicle that addresses the importance of interorganizational relationships. There are a number of initiatives that can be pursued that make procurement, purchasing and subcontract management functions environmentally conscious. A strong supply chain will provide an

environmentally benign product or service to the ultimate customer" (Sarkis et al, 1995).

Two other examples of the growing recognition of the importance of supply chain environmental performance are the establishment of an Ecodesign and Supply Chain Management Project by the Centre for Sustainable Design in collaboration with the Department of Trade and Industry in the UK (Charters, 1999) and the presence of the following statement in the North American Electronics Manufacturing Industry (NEMI) 1998 technology roadmap:

" There is a major need for industry to develop an efficient method to exchange environmental data between supplier and customer" (NEMI, 1998).

This section consists of a brief review of some of the key supplier environmental assessment and material selection initiatives developed by electronics companies and collaborative organisations that have been published as conference or journal papers. Brief notes on each initiative are presented in Table 1. The possible development of an innovative supplier environmental assessment and information retrieval method for Nortel Networks is at the centre of the EngD research project. The initiatives listed in Table 1 represent work already conducted in this area.

2.3.1 Supplier Interaction Initiatives

Title	Author	Organisation/Publisher	Details
Supplier Performance and the Environment	Maxie, E.	IEEE, ISEE, 1994, pp. 323 - 327.	Hewlett Packard's initiative on supply management – 3 categories of supplier expectations – policy, implementation plan, ODS elimination. Emphasis on working with suppliers – to improve both customer and supplier environmental performance.
The Role of Supply Chain Management within the Industrial Ecosystem	Sarkis, J. et al	IEEE, ISEE, 1995, pp. 229 - 234	Industrial – ecology based paper. Promotes long-term supply management strategies - good for supply management. Stresses customer – organisation – supplier relationships.
Environmentally-Conscious Supply Chain Management	Beckman, S. et al	IEEE, ISEE, 1995, pp 235 - 239	Explains industry response to supply management challenges – cost, quality, timeliness. Parallels environment with these previous challenges. The research looks at one computer company and its suppliers and will look at other companies – U.S. and Japan.

Life Cycle Assessment as a Communication Tool in Customer-Supplier Relationships	Lizotte, R.	IEEE, ISEE, 1995, pp. 240 - 244	Using abridged LCAs in customer-supplier relationships. Comparing data from suppliers.
Harmonising Environmental Management Throughout the Supply Chain	Whitaker, B.	IEEE CONCEPT Conference 1995, pp. 182 - 185	IBM Env Man – views on the importance of the supply chain / standardisation of information requests advocated - What, Why and How?
Information About Materials in Electronics - A Necessary Condition for Recycling and Clean Construction of Electronic Devices	Bauman, J.R. et al	IEEE CONCEPT Conference 1995, pp. 191 - 195	Experimental method for analysing the elemental content of electronics components. Database of chemical data of selected components generated. Elemental content of each component is divided into categories based on their environmental impact and material character. The objective is to provide information for component selection and the eventual total greening of electronic components using market forces.
Procurement of Environmentall y Responsible Material	Choong, H.	IEEE, ISEE, Conference 1996, pp. 236 – 241.	Update of the HP 1994 paper. Addition of commodity specific "E" criteria within PERM (Procurement of Environmentally Responsible Material) in combination with the global "E" criteria. Emphasising product specific environmental requirements. Example: Recycling, Environmental Awareness, Waste Reduction.
Meeting OEM Customer Product Environmental Performance Expectations through Environmental Product Design (EPD) Roadmaps and Specifications	Chambers, G.C. and Cox, D.G.	IEEE, ISEE, Conference 1996, pp. 242 – 247.	Introduction of Environmental Product Design (EPD) programme at Quantum (disk drive manufacturer). Driven by customer requests and leg. EH&S group educated themselves (design issues) and the organisation at large (benefit to the business). EPD – aligned with corporate strategies, EPD roadmap co-ordinated with technology roadmap. EPD goals converted to engineering specs. 1st spec – Environmentally Relevant Substance Spec. Based on use and disposal. Engineering guidelines produced, procurement and risk assessment procedures developed. Database produced on component hazardous material content. Co-operation of suppliers vital – ongoing process. ERSS – part of ISO 9000 and supplier qualification. Close relationship between Quantum and customers. Communication of product environmental info early in the product qualification process.
Procurement of Environmentall y Responsible Material Program (PERM)	Choong, H.	CARE Innovation '96, Eco-Efficient Concepts for the Electronics Industry Towards Sustainability, pp.258 – 262.	Update of the HP IEEE 1994 paper. Addition of commodity specific "E" criteria within PERM (Procurement of Environmentally Responsible Material) in combination with the global "E" criteria. Emphasising product specific environmental requirements. Example: Recycling, Environmental Awareness, Waste Reduction.
Procurement of	Bergendahl, C.G.	IEEE, ISEE	Collaborative development of an

Components for Environmentall y Compatible Electronic Products	and Segerberg, T.	1997, pp. 172 - 175	environmental procurement tool – IVF and 16 companies including Ericsson, Philips, Nokia and SGS Thompson. The tool consists of a questionnaire and evaluation process and aims to enable designers, procurers and engineers to acquire product environmental data to assist in the supplier and component selection processes and provide product data for marketing and end-of-life options.
The Development of an Industry Standard Supply-Base Environmental Practices Questionnaire	Andersen, J. and Choong, H.	IEEE, ISEE 1997, pp. 276 – 281.	PIBA and CIQC (US computer industry associations) developed a "standard" environmental practices questionnaire. The questionnaire is in two parts, Part I consists of questions on continual improvement and compliance assurance addressing the fundamental elements of an environmental management systems , Part II consists of risk assessment which addresses environmental practices and risks. The questionnaire does not address product environmental performance. The associations want to promote use of the questionnaire beyond the computer industry and the US for supplier management/supplier guidance/information requests.
Green Purchasing: Does it Make Sense?	Mulder, L.	IEEE, ISEE, 1998, pp. 123 - 128	Digital environment person provides an overview of the current methods and approaches used in green procurement. Strong emphasis on asking exactly what info the customer wants when they request env info and what they will use it for. Advocate of the ECMA declaration method for promoting product env attributes.
Eco-Quest, An Ecodesign Self Audit Tool for Suppliers of the Electronics Industry	Brink, S. et al	IEEE, ISEE, 1998, pp. 129 - 132	Delft Research Laboratory for Sustainable Product Innovation and industry partners (Sony, Digital, Philips) development of a supplier self audit ecodesign tool —ECO-QUEST. A questionnaire-based ecodesign tool downloadable from the Internet. Targeted at SMEs from Newly Industrialised Countries. The user is required to answer product and company environmental management questions. The answers are then evaluated and a score provided. Environmental priorities and suggestions for improvement are then offered. Information on ecodesign is also provided on the web site.
Material Selection for Life Cycle Design	Stuart, J.A.	IEEE, ISEE, 1998, pp. 151 - 158	This paper stresses the importance of material selection in life cycle design for both component selection and assembly. It describes the need to adopt a life cycle approach and to consider options for manufacture and end-of-life. Methods of evaluating designs are described such as financial approaches, LCA, environmental indices and analytical models for recycling. The author advocates the use of the emerging product process and consideration of environment (EPPACE) model to analyse the economic, environmental and quality differences among different product and process alternatives.

Environmental Quality in the Supply Line: A New Approach	Nagel, M.H.	IEEE, ISEE, 1998, pp. 180 - 185	Supply Line Engineering – eco-supplier development. Development of criteria and a tool to measure the environmental performance of components and suppliers by using environmental design practices associated with the development and production of electronic components. The final tool will use environmental load scores. 144 suppliers have been surveyed and scored on the basis of whether they have an environmental policy. The author describes goals and objectives for supply line engineering including: • Operational analysis of the component realisation process, the component packaging realisation process and the component itself to define design practice references in order to determine the environmental quality level for a specific commodity and to develop a tool that can measure the environmental performance of a supplier. • Measurement and comparison of the environmental performance of selected suppliers providing the same commodity. The scores will be added to the GCIMS (Global Component Information Management System) to be used by designers for component selection. • Develop environmental requirements per commodity in the procurement process.

Table 1. Supplier Assessment Initiatives

The work of Menno Nagel at Lucent is particularly interesting and relevant to the research project. The supply line engineering project at Lucent aims to integrate supply chain environmental data into Lucent's product development process. The main objective is to attempt to use supplier environmental data in the component selection process and ultimately for procurement decision-making. The initial scoring system for environmental performance of suppliers is extremely crude (based on the presence of an environmental policy) but it does provide an indication of the environmental awareness of the supply chain. The proposed method for the determination of the "environmental quality" of purchased components is complex and it will be interesting to discover the feasibility of its implementation in a large electronics company. Certainly the objectives are challenging. There are many parallels to be drawn between Nagel's work and my own research project. A comparison of final results and recommendations would prove interesting.

In addition to the material summarised in the case studies there is also a vast range of company and industry group supplier assessment, requirements and specifications publicly available including a huge range of restricted/banned substance lists. Details of those used in the research project will be made available in the appropriate programme report.

2.4 Customer Request Response

One of the objectives of the research project is to develop an information management method that will assist in the provision of product environmental data to meet customer requests for information. At the start of the project no formal system for answering the environmental information requests of customers of Nortel Networks was in place. A web-based "Environmental Toolkit" has now been developed within Nortel Networks that provides generic answers to commonly asked questions from customers. It is envisaged that supplier component information could be integrated into the toolkit and also the EPOA tó provide customers with detailed product information. Details of customer requests are provided in the Programme 1 report. Both Hewlett Packard and Sun Microsystems have published case studies on the development of customer response systems. The RE's comments on each case study are provided.

2.4.1 The Hewlett Packard Approach

The case study provides an indication of the current demands placed upon manufacturers of electronics products by customers. HP are receiving an increasing number of requests for increasingly more detailed environmental information. HP have responded to the challenge by developing a specific approach. The approach involves working with selected customers to determine what environmental information is generally required by customers for decision-making purposes. The mechanisms for the provision of the environmental information are not described in the case study. However, the provision of product and process environmental information will have to include the capture of information from the supply base. HP are keen to develop a standard acceptable declaration in order to avoid any need to generate a customised response to customer requests. It is questionable though whether it will be acceptable to all customers and whether supplier data will be available.

2.4.2 The Sun Microsystems Approach

The case study describes the Sun Microsystem strategy for responding to the increasing number of customer requests. Rather than engaging in direct dialogue with customers, Sun systematically logged all the questions present in each customer questionnaire and set out to provide the information for all topics mentioned twice (80% of the total requested information) and place the information on a web site to make it available to the sales teams. Sun do not describe in detail what information would be posted on the web site. It is likely that some customers ask for specific material composition of products. It is not known whether Sun provide or intend to provide product environmental data for customers on all products. If they do, some process must be in place to capture the data from the supply base.

2.5 Supply Chain Management

The research project requires a detailed knowledge of the principles of supply chain management and specifically the processes in operation within Nortel Networks. The main sources of information were Nortel Networks policies, procedures and management plans. In addition several sources of information on supply chain management have been consulted. Due to the constraints of this report it is not possible to provide an overview here but a list or sources is provided (see bibliography). A full review will be provided in the final literature review.

2.6 Conclusions

The research project is problem-orientated. The research question being: "Can Supplier product Environmental Data be Integrated into Nortel Networks Ecodesign and Product Life Cycle Management Systems?" This section has provided a brief overview of the work that already exists as a pool of knowledge in the relevant areas of research that are directly relevant to the generation of a solution to the research question. Due to the scope of this report and the vast quantity of literature relevant to the research project it is impossible to provide a comprehensive review in this report. A list of available literature in certain subject areas is provided in Appendix III. Awareness and understanding of existing work and research is fundamental in the quest to improve and extend the pool of knowledge in the given field of expertise. This is a continuing process that will be completed on conclusion of the project.

Section 3

Progress Made Towards Achieving Research Project Objectives

Section 3 – Progress Made Towards Achieving Research Project Objectives

3.1. Introduction

In this section details of the progress made towards achieving the specific project objectives as defined in the Work Package Description (Appendix I) and the Project Management Plan (Appendix II) are provided. The reader is requested to refer to the Work Package Description or the Project Management Plan to identify the objective tasks.

3.2 Progress to Date

Programme 1

Objective 1

The research for the customer questionnaire analysis has been completed as a component of the gap analysis (Objective 5) and from data collected since the gap analysis was conducted. The resulting information (customer requirements) was used in the development of the three trial versions of the Nortel Networks Supplier Environmental Appraisal Procedure (SEAP) Questionnaire (Objective 12). A database of customer requests is being maintained by a group in Canada. The information is used in the web-based "Environmental Toolkit" which provides information on questions commonly asked by customers and standard Nortel Networks responses. Customer requirements are of vital importance and need to be continually monitored to ensure ecodesign and supplier interaction programmes remain customer focused.

Objective 2

The determination of designers' information requirements for component selection was to commence in November 1998. Meeting this objective is very much dependent on the ecodesign programme. It has been decided to conduct structured interviews with designers. The problem with this exercise is that few electronic designers are actively doing ecodesign and using the ecodesign tool. Those designers that have been trained are mechanical designers. It may be possible to work directly with designers in a team at NMC (Nortel Matra Cellular) in France who are engaged in an active ecodesign project. Discussions are currently taking place between the RE and the project manager in NMC. The RE is hoping to use the ecodesign project as a test vehicle for the research. If this plan does not come to fruition another test vehicle will be selected.

Objective 3

Research has been conducted by both the RE and by project placement MSc students on current and proposed product-related environmental legislation. A summary of the findings to date will be provided in the Programme 1 report (see the project plan in Appendix 1). The main item of legislation driving ecodesign and Product Life Cycle Management is the proposed EU Directive on Waste from Electrical and Electronic Equipment. Legislation is continually being developed and implemented. A web-based system for tracking environmental regulations has been introduced at Nortel Networks.

Objective 4

The determination of what information from suppliers can be made available to designers for ecodesign via partSMart (component database) has been completed. Both "eco-risk" data and "eco-information" data can be made available in partSMart. The eco-risk data could be provided in terms of a risk warning (high or low risk) and associated description fields. The eco-information data can be provided as a web link to detailed product specific material composition data posted on the web. The eco-information category has been added to the PACES (Product Assurance Component Engineering System database (system previous to partSMart)) product data window and links set up for some CPCs (Common Product Codes) as a demonstration. The eco-information links at the moment link to a temporary web page containing supplier eco-appraisals and captured supplier product data from the second pilot study (Objective 16). It is anticipated that further product eco-information will be posted on the partSMart web server as it becomes available from suppliers.

Objective 5

The gap analysis between Nortel customer environmental questionnaires and Nortel supplier environmental questionnaires has been completed and issued as a Nortel internal report (IR\1998\1825). The report forms one section of the Programme 1 report and will be included in the portfolio within the Programme 1 report. The results of the analysis were used in the development of the three trial versions of the New Nortel Networks Supplier Environmental Questionnaire. The summary of the report is provided here. Figure 7 shows the gap that exists between the sub-category scores of the Nortel Environmental Toolkit Questionnaire (widely used Nortel supplier assessment questionnaire) and a comprehensive customer questionnaire.

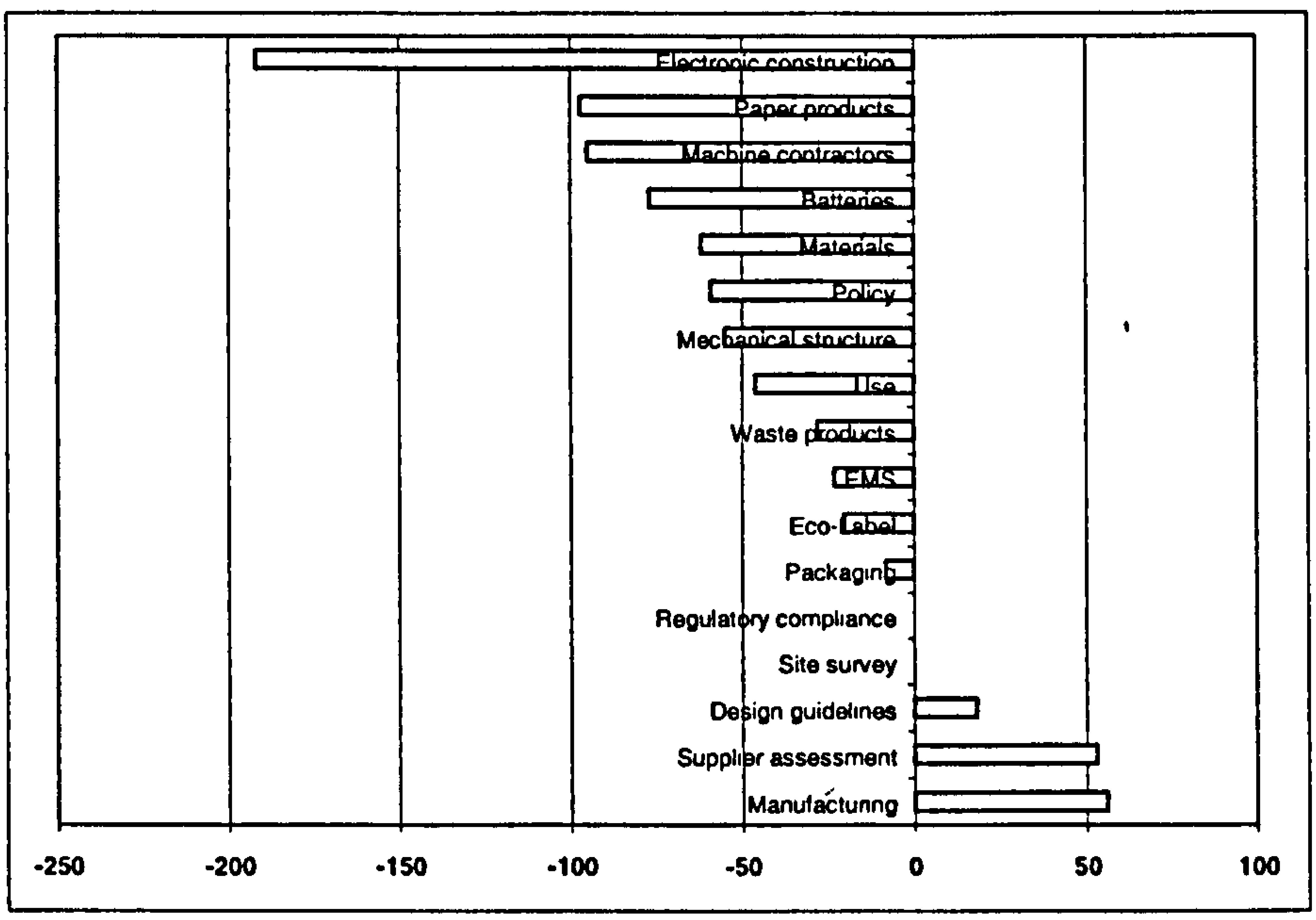

Figure 7. Performance Gap for "Best" Nortel Networks Questionnaire Compared to "Best" Customer Questionnaire

Summary of Report IR\1998\1825

This report presents the results of a gap analysis conducted on the environmental questions being asked by customers of Nortel Networks and the environmental questions that Nortel Networks asks their suppliers. The objective of the analysis was to determine customer environmental information requirements and to discover whether the Nortel Networks supplier environmental assessment questionnaires are effective in requesting and acquiring the data needed to answer specific sections of customer environmental questionnaires. This was achieved by comparing directly the questions in customer questionnaires with those of Nortel Networks supplier environmental assessment questionnaires.

The results clearly show that customers of Nortel Networks are requesting detailed environmental information about products, particularly their hazardous material content and, at the present time, Nortel Networks supplier environmental assessment questionnaires do not contain detailed questions about the product. Nortel Networks is not able to provide a satisfactory response to customer requests in terms of product environmental information. Nortel Networks do not know the material composition of their products.

It is recommended that a new supplier environmental assessment questionnaire is adopted at corporate level that is focused on the following objectives:

- Providing data to assist in the response to requests from customers for environmental information;
- providing data to meet the requirements of European Legislation (WEEE Directive);
- providing data for ecodesign; and
- aligning the ISO 14001 supplier environmental assessment procedure at corporate level.

New Nortel Networks supplier environmental assessment questionnaires focused on the above objectives are currently being tested with suppliers in two component portfolios. They form one component of a detailed long-term Ecodesign and Technology research programme on integrating supply chain environmental data into Nortel Networks Product Life Cycle Management and ISO 14001 continual improvement processes.

Objective 6

The results of the gap analysis were used in Programme 2.

Objective 7

Customer interaction is a steady and continuous process. The customer-facing Corporate Environmental Services (CES) team is responsible for interaction (with the account teams) with customers on environmental issues. The CES team is responsible for facilitating the completion of customer environmental questionnaires which they may receive via the account teams. The CES team also regularly hosts interaction sessions on environmental issues with key customers. A database of customer information requests is maintained.

Objective 8

The component composition comparison study was designed to compare averaged data for component composition from the EIME and Delta databases with supplier data and destructive analysis data. The average data and some supplier data are now available but the destructive analysis data are not. The destructive analysis was to be obtained by an MSc student but unfortunately an appropriate student could not be found in the 1998-99 academic year. The search for a student continues. The comparison of averaged data from the EIME and Delta databases with data potentially supplied by suppliers is discussed in a research paper presented at the 1999 Institute of Electrical and Electronic Engineers International Symposium on Electronics and the Environment (Appendix IV).

Objective 9

An investigation of manufacturing processes for selected components has been started. Work has commenced on semi-conductors. The RE has discussed this objective with Motorola SPS and Texas Instruments. There are possible problems associated with disclosure of information as many electronics companies consider their manufacturing processes to be proprietary. The RE will continue to develop this idea. Work on this objective is not planned to officially start until November 1999.

Objective 10

Supplier interaction has been initiated with twenty-seven suppliers using the SEAP questionnaire (Objective 16). Further interaction is planned to start in November on environmental technology advances that will concentrate on materials substitution such as lead-free technology, non-halogenated flame retardant. Nortel Networks is already spear-heading industry collaborative effort in these technology advances as part of the HDPUG (Hight Density Packaging Users Group) initiative.

Objective 11

The Programme 1 report will be completed by the end of October 1999.

Programme 2
Objective 12

Three versions of a new Nortel Networks supplier environmental assessment questionnaire were developed. Each version was designed to obtain information from the supply chain that could be used:

- in Nortel Networks responses to customer requests for product environmental data;
- to meet the possible requirements of the proposed EU Directive on Waste from Electrical and Electronic Equipment;
- to support ISO 14001 compliance; and
- to provide information for ecodesign practices.

Each version of the questionnaire differed in format, structure and question content. The questions were selected to request information that would meet the requirements of Nortel Networks.

Details of the questionnaire development will be included in the Programme 2 report.

Objective 13

Feedback was obtained from the European Nortel Networks site Environment, Health and safety primes on the content, feasibility, ease of use and compatibility with the continual improvement process for ISO 14001, of the questionnaires.

Objective 14

The RE developed a scoring system for each questionnaire. The methods were presented to the EHS primes at a quarterly meeting and approval was obtained after discussion. Details of the methods are provided in the Programme 1 report.

Objective 15

Each of the three questionnaires was piloted with three selected suppliers. Each participating supplier was sent the three versions of the questionnaire in electronic format (Excel spreadsheet) and was asked to complete them in electronic format and to supply additional feedback. This included:

- comment on the ease of completion of the questionnaire in terms of an understanding of what was being asked and layout;
- rank the three versions from 1 (best) to 3 (worst); and

- comment on the ability of the supplier to provide environmental data on all products supplied to Nortel.

All feedback was considered and taken into account when the final version of the questionnaire was selected and approved. Guidelines on questionnaire completion for suppliers and information use for site users have also been developed. Feedback on the entire process was provided to the participating suppliers in the form of a report (Pilot Study One Report). The pilot study report will form part of the Programme 2 report.

Objective 16

The final approved version of the SEAP questionnaire was tested in a second pilot study with 24 additional suppliers. The core objective of the extended trial was to identify the level of product environmental information suppliers can, or will be able to provide. The resulting information provided an indication of the size of the challenge of obtaining product environmental data from the supply base. In addition the trial highlighted potential logistical problems associated with the electronic questionnaire. Suppliers were selected to ensure a wide range of commodities were covered and on the basis that they are considered long-term suppliers of Nortel Networks. In view of the current Manufacturing 2000 strategy being implemented at Nortel Networks, a contract manufacturer was also been included in the pilot study. Feedback on the suppliers' performance was provided as supplier specific individual reports. A summary report was written detailing the entire second pilot study (IR\1999\1895). These reports will form part of the Programme 2 report.

Objective 17

Each of the suppliers participating in the first and second pilot studies were asked to provide sample component environmental data. These data have been placed on an internal web-site. Links have been set up for some components between the web site and the PACES component database. In September 1999 the entire PACES system will be web-based. This means that component environmental data can be stored on a separate web-server, which will mean the data is easier to manage. An "eco-risk" field will be tested in the new web version of PACES (partSMart).

Objective 18

The percentage of components in the PACES database that could potentially be supplied by VMRs (Value Managed Relationship suppliers) has been determined. The percentage of components potentially supplied by VMRs in selected products still has to be determined. It is questionable whether this is now appropriate in the light of the radical changes that are about to occur in the approved Nortel Networks list of suppliers. However it would be useful to identify the range of suppliers that could supply components in selected products as a list of suppliers with better environmental performance could then be compiled for each product. Incomplete bills of materials have been obtained for two products. Analysis is still on hold – changes in the supply base mean that such a study at the current time is not appropriate.

Objective 19

In pilots studies one and two the questionnaire was completed in Excel and e-mailed. The information was then converted to HTML and placed on the web. In an attempt to make the questionnaire completion process and transfer of data as automated as possible a web version of SEAP was investigated. The alpha version of web-SEAP is now complete (see Figures 8 and 9). It consists of a form for the main questionnaire and a form for the submission of product material composition data. All the information is entered into the web forms and submitted to a database in Filemaker Pro, which is running on a PC. The data is then made readily available on the web for Nortel Networks users. Details of the development of web-SEAP will be included in the Programme 2 report.

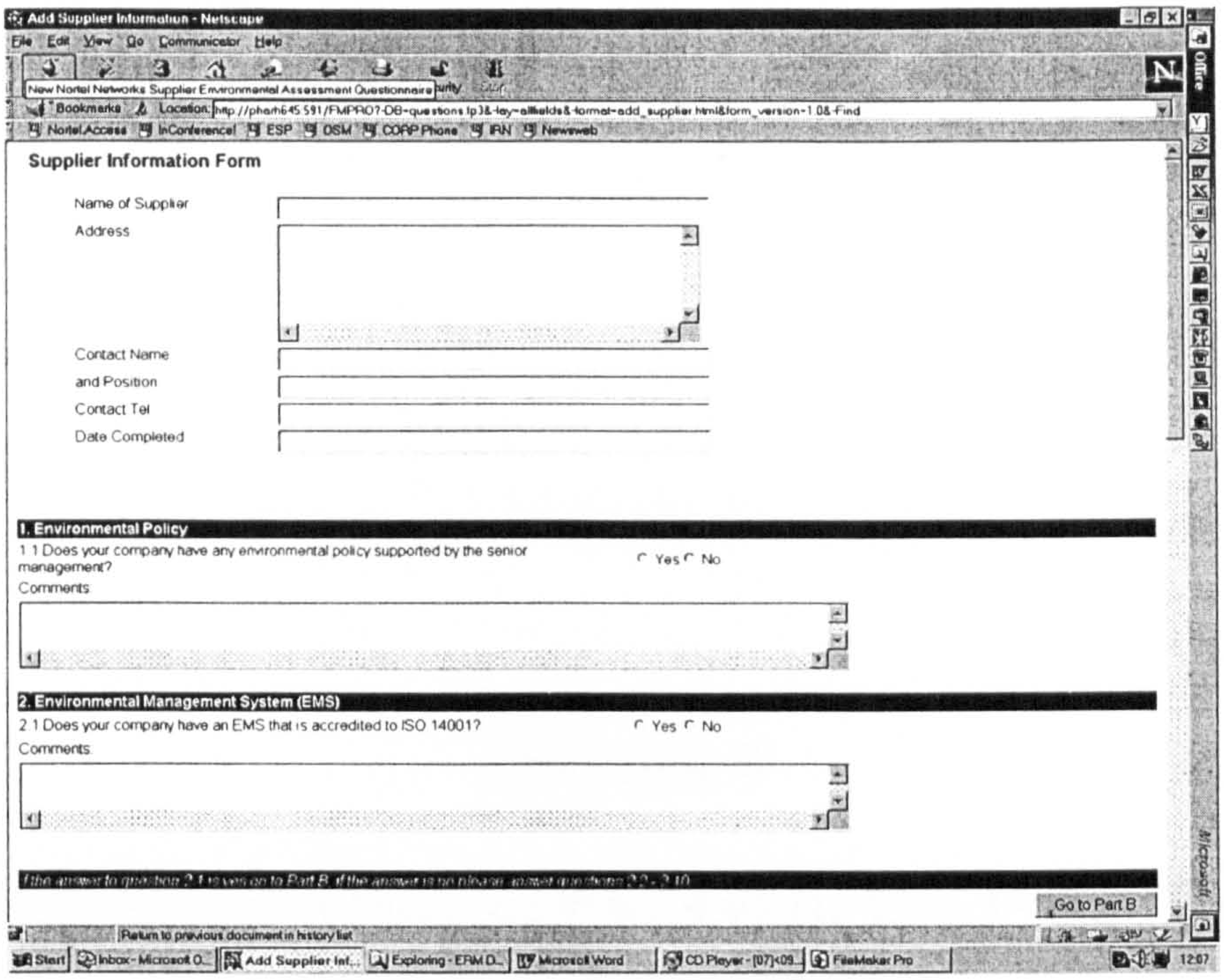

Figure 8. Web SEAP

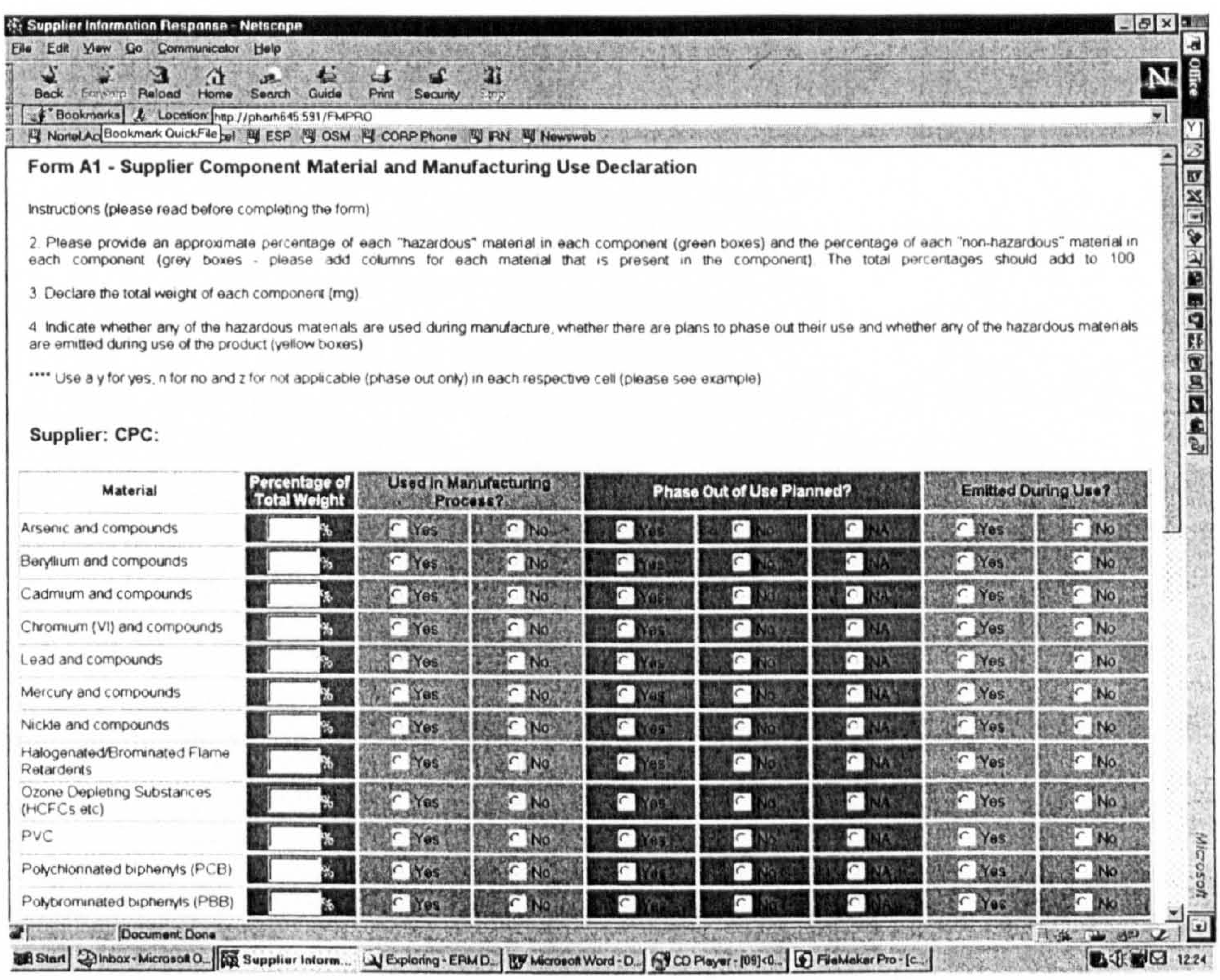

Figure 9. Web SEAP Product Data Form A1

Section 4

Objectives to be Achieved in the Final Two Years of the Project

Section 4 – Objectives to be Achieved in the Final Two Years of the Project

4.1 Introduction

In this section details of the objectives to be achieved in the final two years of the research as defined in the Work Package Description (Appendix I) and the Project Management Plan (Appendix II) are provided. The objectives to be achieved start at Objective 20 in Programme 2 in the Work Package Description. Objectives one to nineteen that have not been completed to date will, of course, also be finished. The time schedule for completing the objectives is provided in the Project Management Plan (Appendix II).

4.2 Details of Planned Objectives

Objective 20

Web-SEAP will be piloted with selected suppliers. This will involve selecting a number of suppliers, providing them with a secure identification pass for access to a Nortel Networks internal web site and requesting them to complete the questionnaire and provide sample product data. All the information will be entered by the supplier onto the web and will be automatically entered into the database on submission.

Objective 21

Each supplier assessment that is conducted needs to be qualified or validated as part of the Nortel Networks quality process if SEAP is implemented. This simply means that the information provided by the supplier via the web needs to be verified through an approved procedure. It is possible that the GAP (Global Audit Plan) could be used for this purpose. The supplier would be audited against the information provided on the web. A solution will be generated with the PACE (Product Assurance and Component Engineering) teams.

Objective 22

Using SEAP to assess the environmental performance of the top 100 suppliers of Nortel Networks may or may not be a feasible objective. If SEAP is not approved as a formal Nortel Networks procedure it would not be possible to assess more suppliers. Changes in the structure of the supply chain will also influence this objective.

Objective 23

Objective deleted because the SAMS tool was discontinued.

Objective 24 and 25

Once environmental information on components from suppliers is available in partSMart at the design stage, further investigations will determine whether this information can be compiled for the final Nortel Networks product. This may mean tracking the components through the manufacturing stage using the bill of materials and purchasing agreements and cross referencing the bill of materials with the database of material compositions. Options will be investigated with members of appropriate business functions.

Objective 26

The supplier information and retrieval system will be linked to the information tracking system.

Objective 27

The product environmental information management system will be tested using a selected product.

Objective 28

The Programme 2 report will be written.

Programme 3
Objective 29

Once product environmental data are available to the designer via partSMart its use as part of the ecodesign process will be evaluated by conducting a survey amongst designers actively doing ecodesign.

Objective 30

The product environmental information will be re-evaluated depending on the response of the designers in Objective 29.

Objective 31

Supplier environmental performance assessment is an important part of the continual improvement process for Nortel Networks sites with ISO 14001 accreditation.

Monitoring of the success of SEAP for this purpose will be conducted. However, considering the current strategy of divestiture of Nortel Networks manufacturing sites, this objective will need to be re-evaluated.

Objective 32

The contribution of the information management system to meeting customer requests for product data will be monitored and evaluated.

Objective 33

The product environmental information could be used to generate a quantitative or qualitative environmental performance evaluation for each component. This evaluation could then be used to provide criteria for component selection by the designer at the design stage. The possibility of integrating component production environmental information into the evaluation method will be considered. Criteria and methods will be investigated.

Objective 34

Component environmental evaluation methods if developed will be tested with designers.

Objective 35

The product environmental performance evaluation method could also be used by purchasers of components. This possibility will be explored with close liaison with supply management groups at Nortel Networks.

Objective 36

The product environmental information management system and methods of component environmental performance evaluation will be critically reviewed, areas for improvement will be identified and final recommendations made to Nortel Networks.

Objective 37

All the details of Programme 3 will be written up in the Programme 3 report.

4.3 Conclusions

The planned objectives for the next two years can be achieved systematically according to the Project Management Plan. However, due to the rapidly changing structure of Nortel Networks as a company and action taken by Corporate Environment Services team members which may create implementation issues, certain elements of the plan may change accordingly. At the start of the research project, Nortel Networks had no formal corporate strategy, policy or procedure on supply chain management environmental considerations. During 1999, official responsibility for the development of a suitable strategy, policy and procedure has been given to the Nortel Networks CES team. The RE is providing input and recommendations to this process.

Section 5

Report Conclusions and Contribution to Knowledge

Section 5 –Contribution to Knowledge and Report Conclusions

5.1 Contribution to Knowledge

To satisfy the requirements of the EngD programme it is necessary to make a contribution to knowledge through applied research. This section outlines how the research project will result in a contribution to knowledge.

In order to establish how a contribution to knowledge can be made it is necessary to place the project in the context of the field of study. The pool of knowledge that the research will contribute to is that which improves product environmental performance in the telecommunications industry. More specifically the research will result in the development of Product Life Cycle Management tools and initiatives through environmental information management systems and decision-support tools. This will include contributions to ecodesign practice, ISO 14001 continual improvement facilitation and supply chain management.

The research project will provide a contribution to knowledge in the following specific areas:

i) Supplier/customer interaction on product environmental issues;
ii) Measuring supplier environmental performance in the telecommunications industry;
iii) Development of continual improvement systems for ISO 14001;
iv) Automated product environmental data transfer;
v) Product Life Cycle Management information systems architecture;
vi) Component selection in ecodesign; and
vii) Environmental performance and purchasing decision-making.

Through the answering of the research question and the resulting contributions to knowledge it is hoped that the feasibility of implementing an holistic product environmental information management system and associated tools to provide data for decision-support in ecodesign, continual improvement for ISO 14001, meeting the requirements of legislation and customers, and improving product environmental performance will be ascertained. The RE plans to publish two journal papers and several conference papers to support the contributions to knowledge in addition to the one conference paper already published in 1999.

5.2 Report Conclusions

The research question for this EngD project is: Can supplier product environmental data be integrated into Nortel Networks Ecodesign and Product Life Cycle Management Systems? The supporting hypothesis to this research question is that only the systematic management of supplier specific/product specific environmental information as opposed to average information will meet the requirements of customers, legislation and ecodesign.

By achieving the objectives defined in the Work Package Description (Appendix I) the research question will be answered, the hypothesis tested and a contribution to knowledge made.

Significant progress has been made towards achieving the planned objectives. An improved method of appraising the environmental performance of suppliers has been developed with suppliers to meet the information requirements of customers, legislation, ISO 14001 and ecodesign. The method has been tested further on 27 suppliers and an internal web site developed to display the information and results. The alpha version of a web-based automated supplier information retrieval system has been developed. When the beta version is complete it will be tested with selected suppliers and linked with the partSMart component database. Methods of component environmental evaluation will be investigated during the final two years of the project to provide decision-support for ecodesigners and possibly purchasers. Tracking and collating the component data for Nortel Networks products will also be attempted using bill of materials and supplier contracts and the system will be tested and reviewed.

The first two years of the research project have been busy and productive. The project is well planned and on-schedule. The main problems revolve around the testing and implementation of developed tools and strategies and the rapid changes taking place in the supply management function. Some aspects of the use of the action research methodology have proved difficult and particularly the involvement of certain business functions in decision-making. The fact that the project is a student-led research project and not totally a company managed project has proved challenging. Because of the size of the company communication is often difficult and the situation is made more challenging with many individual agendas being presented. However, such a situation could prove beneficial, as it demands the growth of effective communication and people management skills within the RE. The research will result in a potential solution to a problem, a contribution to knowledge, greater understanding of the problem by the organisation and substantial individual development for the RE.

The changes in the structure of the Nortel Networks supply chain, particularly the divestiture of manufacturing, could also have a significant impact on the implementation of the tools and strategies to emerge from the research project. The situation will be followed closely and recommendations changed accordingly.

In addition to the research itself, the RE has completed all the mandatory professional development courses averaging 6.9 in the assignments and has developed experience and skills by conducting additional work within the company.

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Appendix I

Advanced Design Technologies 0V 21

NORTEL

NORTHERN TELECOM

NORTEL NETWORKS PROPRIETARY

Can Supplier Product Environmental Data be Integrated into Nortel Networks Ecodesign and Product Life Cycle Management Systems?

Work Package Description
(note - Brunel Engineering Doctorate/Nortel Networks WPD)

Approvals

Function	Name	Dept.	Signature	Date
Project Prime	Ken Snowdon	OV21		01/10/98

Distribution

Name	Dept.	Location
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Document History

Issue	Date	Doc. Ref.	Author	Reason for Change
1.0	01/10/98		Carl Mead	
2.0	03/2/99		Carl Mead	Review of plan
3.0	07/09/99		Carl Mead	Review of Plan

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0.1 Background

There are currently several drivers within the telecommunications industry for the integration of green design issues (ecodesign/DFE) into the product development process including: customer requests for eco-friendly products and the inclusion of environmental criteria in customers' supplier selection processes; legislative requirements; and ISO 14001 requirements.

Part of the Nortel Networks response to these drivers is the development of an eco-design process that is a component of the product development process. The objective of eco-design is to improve the environmental performance of the product throughout the life cycle.

Conclusions from previous research conducted at Nortel Networks suggest that Life Cycle Assessment (LCA) may not be a practical and viable product development tool in organisations using complex concurrent engineering and design. The reasons are:

- complex systems (supplier base - 30 000 suppliers, 100 000 components);
- complex product data management;
- difficulties in product data acquisition; and
- cost and resources.

LCAs need to be carried out by specialists within the organisation. It is not feasible for a designer to conduct a full LCA as a component of an ecodesign procedure.

However, it may be possible to use LCA data or product environmental data from suppliers as part of the component/raw material selection process.

The purpose of this research project is to answer one question:

Should supplier-specific environmental data on components be integrated into the Nortel Networks eco-design process and Nortel Networks PLCM systems and if so, how?

0.2 Document Administration

This document has been produced on Word and the latest issue is maintained on the Harlow generic file server: Zhary001:/cmead/EngD/Six Month Reports/Project Plan3.

Table of Contents

1.0 Objectives

The objectives of this EngD research project are to develop and test novel methods for the integration of environmental life cycle technologies into the Nortel Networks product development process. The research is focused on the supply management function and aims to investigate optimal systems to:

- extract product environmental information from the supply chain;
- integrate the information into the Nortel Networks ecodesign process via established systems;
- provide environmental information requested by customers; and
- provide environmental information that meets the requirements of ISO 14001 and environmental legislation.

2.0 Scope

The scope of the project is described within the following three areas:

2.1 Project Management

2.1.1. Create and maintain WPD.

2.1.2. Develop & agree resources, milestones, and a project development plan with the project primes/industrial supervisors and academic supervisor.

2.1.3. Management and reporting of progress, issues and actions (monthly reports to Nortel Networks, six monthly reports to Brunel University, regular bi-monthly meetings, internal reports).

2.1.4. EngD portfolio management

2.2 Research

2.2.1 Detailed literature search – ecodesign, LCA and Supply Management.
2.2.2 Define research methodology.
2.2.3 Familiarisation with current supply management and PLCM systems.
2.2.4 Development and testing of method for gathering supplier data.
2.2.5 Integration of supplier data into supply management, PLCM and design systems.
2.2.6 Testing of systems.
2.2.7 Supplier interaction development programmes.
2.2.8 Investigate methods of component selection by designers and procurement.

2.3 Project Stages

Programme 1 Question: what information needs to be obtained from suppliers to meet the requirements of ecodesign, legislation, customer requests and ISO 14001?

2.3.1 Analyse customer questionnaires to determine what end-user information is required.

2.3.2 Determine what information is required by designers to make decisions on component selection in terms of ecodesign. **Action:** Interview selected designers in PD&E using eco-design tool.

2.3.3 Assess forthcoming legislation to identify what information is needed at the design stage to meet legislative requirements.

2.3.4 Determine what information from suppliers can be used in the ecodesign process. **Action:** Placement in PACE group to identify what fields are available for environmental data and how it can be entered.

2.3.5 Conduct a gap analysis to determine the ability of current supplier assessment techniques to provide the data required for DFE and customer requests. The gap analysis will compare the questions being asked of Nortel Networks by customers and the questions Nortel Networks asks of its suppliers. **Action:** conduct analysis and generate report.

2.3.6 Results are used for Programme 2.

2.3.7 Participation in customer interaction programmes to identify how they are using environmental information obtained from Nortel Networks and identify their future requirements. **Action:** Attendance of focus groups/workshops. Attempt to incorporate developed customer questionnaire into focus group strategy to identify exactly how customers use Nortel Networks environmental information..

2.3.8 Tabulate and compare component compositions of selected components from a range of suppliers (VMRs and some preferred) and averaged data – Delta database and EIME/TEAM database. A selection of components will undergo destructive testing for verification. **Action:** Analysis of results.

2.3.9 Investigate and compare manufacturing processes of selected components to identify where any major differences exist.

2.3.10 Develop supplier interaction programme and possible collaborative efforts for technology advances in terms of product and process improved environmental performance.

2.3.11 Write programme 1 report.

Programme 2 **Question: What methods can be used to obtain the information from suppliers and how can it be communicated to appropriate teams in Nortel Networks?**

2.3.12 Develop 3 questionnaires for information retrieval. **Action:** Construct 3 supplier environmental appraisal questionnaires – Simple questionnaire, Telia-based questionnaire and decision tree questionnaire.

2.3.13 Obtain feedback from EHS primes for each UK site on content, feasibility, ease of use, and compatibility with continual improvement process for ISO 14001.

2.3.14 Development of an EHS prime approved scoring system for the supplier environmental appraisal questionnaires. **Action:** Discussion at EHS Steering Group Meetings.

2.3.15 Trial and test each questionnaire with selected VMR suppliers to obtain feedback and initial input of data. **Action:** Trial each questionnaire using the supplier on site programme.

2.3.16 Trial the final/approved questionnaire with the VMRs.

2.3.17 Populate PACE/partSMart database with initial approved data from VMRs.

2.3.18 VMR supplier study.

- Identification of the number of active components in the PACES/parSMart database available to designers;

- Identify the number and type of components supplied by each VMR;
- Calculate the percentage of components in four or five selected products potentially supplied by VMRs to assist in determining the contribution of VMR interaction programme data to DFE and customer requests.

Action: This information will be provided by direct contact with the PACES group.

2.3.19 Investigate the possibilities of developing a web-based version of the supplier appraisal and information retrieval method in order to automate the process including interfaces with Nortel Networks supply management databases. This will include identifying database systems within supply management that can receive and store the supplier environmental data in a suitable format and with interfaces for transfer to Nortel Networks internal target users. **Action:** Identify appropriate IT personnel within Nortel Networks and discuss options.

2.3.20 Pending the findings of 2.3.18, trial/test web-based version with VMRs, particularly the transfer of data via material composition forms for each component. Investigate alternative methods if this approach cannot work i.e. e-mail/floppy transfer.

2.3.21 Determine how each supplier assessment will be qualified, perhaps using the GAP (Global Audit Plan).

2.3.22 Finalise supplier questionnaire and use on Nortel Networks top 100 suppliers initially – Task deleted – not feasible.

2.3.23 Task deleted – SAMS no longer exists.

2.3.24 Determine whether PACES/partSMart and DDME can communicate to enable tracking and communication of supplier data.

2.3.25 Investigate methods of product environmental data transfer and tracking throughout the product life cycle to ensure information on released products can be provided to the customer. **Action:** Set up research programme with PACE, DDME, manufacturing and sales representatives to discuss possible options.

2.3.26 Develop complete system including information retrieval and transfer to Nortel Networks internal users (on web).

2.3.27 Test system on a selected product, from design to customer.

2.3.28 Write programme 2 report.

Program 3 **Question: How is the suppliers' component environmental information used by the design community, ISO 14001 systems and Nortel Networks sales teams?**

2.3.29 Once supplier component environmental information is available to designers via PACES/partSMart its contribution to ecodesign must be evaluated. **Action:** set up structured interviews with a team of designers to obtain feedback and suggestions.

2.3.30 Re-evaluate data provided to designers.

2.3.31 Set up a monitoring programme to record the use and effectiveness of the supplier assessment questionnaire for ISO 14001 system continual improvement.

2.3.32 Monitor the use of product environmental information in answering customer requests (monitoring programme set up with sales teams).

2.3.33 Develop environmental criteria for component selection.

2.3.34 Test criteria with designers on a number of components.

2.3.35 Discuss using criteria as part of the procurement process with supply management.

2.3.36 Review total system architecture and identify areas for improvement and recommendations.

2.3.37 Write programme 3 report.

3.0 Deliverable Items

3.1	Reports detailing project progress.	Mead, C	Monthly
3.2	EngD six month reports detailing project progress	Mead, C	Six monthly
3.3	Department internal technical reports	Mead, C	As required
3.4	Annual EngD conference papers	Mead, C	Annually
3.5	Four published papers	Mead, C	Unspecified
3.6	Final EngD portfolio executive summary	Mead, C	2001

4.0 Assumptions & Agreements

Funding from Nortel Networks has been agreed for the duration of the research project.

5.0 End Event

Completion of this Work Package will be achieved by the reaching of all the milestones and the completion of all the deliverables, and submission of the portfolio to Brunel University for the award of Engineering Doctorate in Environmental Technology.

6.0 Resources & Organisation

Resource	Manager/Supervisor
Carl Mead	Ken Snowdon

Organisation	Department	Phone No.
Ken Snowdon	OV21	742 2409
J.D. Donaldson	Brunel University CER	01895 274 000

7.0 Liaison

Liason is an essential part of this research project as it will require the input from many individuals in several business functions

Function	Name	Phone No.
OV21	Amanda Ellis	393 5781
PACES	Paul Tomlinson	742 5645
CES	Georges Michaud	445 6353
OV21	Larry Marcanti	444 4135

Design	Various	-
Supply Management	George Hepburn	742 5643
Supply Management	Dave Smith	742 2502
Supply Management	Various	-
EHS	Various	-

8.0 Estimated Programme Duration

This work package is valid from the October 1 1998 up to and including the work package target completion date of 30 September 2001. This work package covers the final three years of research of the four year research project.

9.0 Project Milestones

9.1	WPD sign off	1/10/98
9.2	Identification of environmental information Nortel Networks needs to obtain from suppliers to meet customer requests, DFE and legislation.	30/04/99
9.3	Gap analysis report.	31/10/98
9.4	Component composition analysis.	29/10/99 On hold
9.5	Programme 1 report.	29/10/99 29/12/99
9.6	Development of supplier assessment questionnaires.	09/10/98
9.7	Questionnaire trial and test report.	31/02/99 31/10/99
9.8	Identify potential VMR information contribution.	30/11/98
9.9	Develop and test web/electronic version of supplier assessment questionnaire.	22/10/99 30/11/99
9.10	Develop and test Nortel Networks internal information transfer system.	28/04/00
9.11	Test model of complete system.	04/08/00
9.12	Programme 2 report.	04/08/00
9.13	Analyse supplier product information suitability for DFE and evaluate designers' further requirements.	31/07/00
9.14	Develop, test and evaluate environmental criteria for component selection.	01/12/00
9.15	Evaluation of complete system for meeting the requirements of customer requests and ISO 14001.	31/05/01
9.16	Review complete system architecture.	31/05/01
9.17	Programme 3 report.	14/09/01
9.18	Executive summary report/thesis for EngD.	14/09/01

10.0 Documentation

10.1 All technical reports and project documents will be created in Word.

10.2 Project plans will be prepared using, Microsoft Project or Excel.

10.3 All presentation slides will be created in PowerPoint.

11.0 Programme Costs

The funding for the research project is provided by the Eco-design and Technology department (OV21) and the Engineering and Physical Sciences Research Council (EPSRC).

12.0 Risk Areas / Risk Reduction

12.1 The project requires significant input from various Nortel Networks business functions and supplier interaction to succeed.

12.2 As aspects of the research project gain profile within Nortel Networks some of the programmes may be taken over by project teams. Careful project management is required.

13.0 Changes

1. Title changed
2. Approvals and Distribution – Dan Francis removed
3. File sever name changed
4. Programme 1 question clarified
5. DFE changed to ecodesign
6. Programme 2 question clarified
7. SAMS task deleted – SAMS no longer exists
8. Component composition analysis now on hold – hopefully will be completed this academic year.
9. Programme 1 Report milestone extended to 31/12/99 because of time of questionnaire response.
10. Questionnaire trial and test report deadline extended to 31/10/99 because of time of questionnaire response.
11. Testing of web version of questionnaire deadline extended to 30/11/99 – may be extended further due to potential complications with web development team.
12. Liason changed – Emma Prentis and Stephan Saul removed. Larry Marcanti, Amanda Ellis, Georges Michaud, George Hepburn and Dave Smith added.

END OF DOCUMENT

Appendix II


Task Name
1.1 Project Management
1.2 Project Stages
1.3 Project Milestones
1.4 EngD Courses

Appendix III

LCA Literature

	Author	Organisation/Publisher
A Technical Framework for Life-Cycle Assessment	Edited by James A. Fava, Battelle, Richard Denison, Environmental Defense Fund, Bruce Jones, The Procter & Gamble Company, Mary Ann Curran, U.S. Environmental Protection Agency, Bruce Vigon, Battelle, Susan Selke, Michigan State University, James Barnum, The Procter & Gamble Company. Society of Environmental Toxicology and Chemistry (SETAC) 1994, 134 pp., glossary, bibliography and references, tables and figures, ISBN 1-880611-00-7.	SETAC
A Conceptual Framework for Life-Cycle Impact Assessment	Edited by, James Fava, Roy F. Weston, Inc., Frank Consoli, Scott Paper Company, Richard Denison, Environmental Defense Fund, Kenneth Dickson, University of North Texas, Tim Mohin, U.S. Environmental Protection Agency, Bruce Vigon, Battelle. Society of Environmental Toxicology and Chemistry (SETAC) 1992 160 pp.	SETAC
Guidelines for Life-Cycle Assessment: A "Code of Practice"	Frank Consoli, Scott Paper Company, David Allen, UCLA, Ian Boustead, The Open University, U.K., James Fava, Roy F. Weston, U.S.A., William Franklin, Franklin Associates, Allen A. Jensen, DK-Teknik, Denmark, Nick de Oude, SETAC-Europe, Belgium, Rod Parrish, SETAC Foundation, Rod Perriman, ZENECA, U.K., Dennis Postlethwaite, Unilever, U.K., Beth Quay, The Coca-Cola Company, Jacinthe Séguin, Environment Canada, Bruce Vigon, Battelle. Society of Environmental Toxicology and Chemistry (SETAC) 1993, 73 pp.	SETAC
Life-Cycle Assessment Data Quality: A Conceptual Framework	Edited by, James Fava, Roy F. Weston, Inc., Allan Jensen, dk-TEKNIK, Lars Lindfors, IVL, Steven Pomper, ALCAN, LTD., Bea De Smet, Procter & Gamble, John Warren, Research Triangle Institute, Bruce Vigon, Battelle. Society of Environmental Toxicology and Chemistry (SETAC) 1994., 157 pp., glossary, references, tables and figures.	SETAC
ISO 14040 - Environmental Management - Life Cycle Assessment - Principles and Framework - Published 15 September 1997	ISO	**ISO Standards**
ISO 14041 Draft International Standard November 1997.	ISO	ISO

Environmental Management - Life Cycle Assessment - Goal and Scope Definition and Inventory Analysis.		
ISO/TC 207/SC 5 /WG 3 N 18 Technical Report - Working Draft, October 1997. - Illustrative examples on how to apply ISO 14041 - Life Cycle Assessment - Goal and Scope Definition and Inventory Analysis.	ISO	ISO
ISO 14042 Draft for Public Comment October 1997. Environmental Management - Life Cycle Assessment - Life Cycle Impact Assessment.	ISO	ISO
ISO 14043 Draft for Public Comment October 1997. Environmental Management - Life Cycle Assessment - Life Cycle Interpretation.	ISO	ISO
Product Life Cycle Assessment - Principles and Methodology	Nordic Council of Ministers	Nordic Council of Ministers, 1992, Nord1992:9. ISBN 92-9120-012-3
Beginning LCA - A Guide into Environmental Life Cycle Assessment.	van den Berg, N.W., Dutilh, C.E. and Huppes, G.	National Reuse of Waste Research Program, 1995
Life Cycle Assessment	Viaamse Instelling voor Technologisch Onderzoek (VITO)	Stanley Thornes (Publishers) Ltd. 1995, Cheltenham, UK
Life Cycle Assessment: What It Is and How to Do It	United Nations Environment Programme, Industry and Environment	Paris, 1996, ISBN 92 807 1546 1
Environmental Life Cycle Analysis	Ciambrone, D.F.	Lewis Publishers, Boca Raton, 1997, ISBN 1 56670 214 3
Life Cycle Assessment (LCA) - Quo vadis?	Schaltegger, S. (Ed.)	Birkhauser Verlag, Basel, Switzerland, 1996, ISBN 3 7643 5341 4
Evaluation of Life Cycle Assessment Tools	Menke, D.M., Davis, G.A. and Vigon, B.W.	EnvironmentCanada
Product Life Cycle Assessment to Reduce Health Risks and Environmental Impacts	Keoleian, G.A, et al	Noyes Data Corporation, New Jersey, 1994, ISBN 0 8155 1354 2
Guidelines for the Application of Life Cycle Assessment in the EU Eco-lable Scheme	European Commission	Office for Official Publications of the European Communities,Luxembourg, 1997, ISBN 92 827 8684 6
Life Cycle Assessment - Inventory Guidelines and Principles	Vigon, B.W. et al	Lewis Publishers, Boca Raton, 1994, ISBN 1 56670 015 9
Environmental Life Cycle Assessment	Curran, M.A	McGraw-Hill, New York, 1996, ISBN 0 07 015063 X
Environmental Assessment of Products – A Text Book on Life Cycle Assessment	Ed: Bo Pedersen Weidema	UETP-EEE – The Finnish Association of Graduate Engineers, ISBN 951-9110-85-2
Environmental Assessment of a Computer Workstation	Ferrone, R. and O'Brien, C.M.	IEEE 1993 International Symposium on Electronics and the environment (ISEE)
Applications of Life Cycle Assessment in the Electronics Industry for Product Design and Marketing Claims	Rhodes, S.P.	IEEE, ISEE, 1993, pp. 101 - 105

Life Cycle Evaluation of Packaging Materials	Shapiro, K.	IEEE, ISEE, 1993, pp. 106 - 111
Life Cycle Improvements Analysis: Procedure Development and Demonstration	Vigon, B.W.	IEEE, ISEE, 1993, pp. 151 - 156
The New Economics of Life Cycle Thinking.	Henn, C.L.	IEEE, ISEE, 1993, pp. 184 - 188
Hewlett-Packard's Approach to Creating a Life Cycle (Product Stewardship) Program.	Bast, C.	IEEE, ISEE, 1994, pp. 31 - 36
Prioritizing Impacts: The Second Stage of Life Cycle Assessment	Graedel, T.E.	IEEE, ISEE, 1994, pp. 89 - 93
Models for Life Cycle Assessment of Manufactured Products	Lal Tummala, R. and Koenig, B.E.	IEEE, ISEE, 1994, pp. 94 - 99
Environmental Tools in Product Development	Wenzel, H. et al	IEEE, ISEE, 1994, pp. 100 - 105
Towards a Comprehensive Methodology for Competing on Ecology: How to Integrate Competitive Strategy and Corporate Financial Objectives with Life Cycle, Environmental Impact and Improvement Analyses?	Tipnis, V.A.	IEEE, ISEE, 1994, pp. 139 - 148
Integrated Life Cycle Management	Cohan, D. and Gess, D.	IEEE, ISEE, 1994, pp. 149 - 154
Development of an Integrated Life Cycle Cost Assessment Model	Warren, J.L. and Weitz, K.A.	IEEE, ISEE, 1994, pp. 155 - 163
Life Cycle Assessment, An Analytical Tool for Designing Environmentally Sound Electric and Electronic Devices	Besnainou, J and Coulon, R.	IEEE, ISEE, 1994, pp. 199 - 200
Development and Assessment of a Pre-LCA Tool	Tolle, D. et al.	IEEE, ISEE, 1994, pp. 201 - 206
Pragmatic Use of Priority Life Cycle Assessment Elements to Help Drive Product Stewardship	Korpalski, T.	IEEE, ISEE, 1994, pp. 207 - 210
Economic Input/Output Analysis to Aid Life Cycle Assessment of Electronic Products	Cobas, E et al	IEEE, ISEE, 1995, pp. 273 - 278
Cost Model for the End-of-life stage of Electronic Goods for Customers	Breouwers, W.C.J. and Stevels, A.L.N.	IEEE, ISEE, 1995, pp 279 - 284
Comparative Life Cycle Assessment of Modern Interconnection Techniques for Printed Board Assemblies	Hedemalm, P. and Segerberg, T.	Conference Proceedings – 1995 Japan IEMT Symposium Proceedings, pp. 212 – 217.
Life Cycle Assessment: A Competitive Tool in the Electronic Industry	Epelly, O	IEEE CONCEPT Conference 1995,pp. 7 - 11
The Life Cycle Assessment of a Telecommunications Semi-conductor Laser	Francis, D.P. et al	IEEE CONCEPT Conference 1995, pp. 12 - 17
FRET – Technical Dinosaur or Environmental Alternative? Application of a Life Cycle Concept in a Manufacturing Industry	Hook, E. F.	IEEE CONCEPT Conference 1995, pp. 18 - 24
Life Cycle Assessment of Tin-Lead Solder and Siver-Epoxy Conductive Adhesive	Costic, M. et al	IEEE, ISEE, Conference 1996, pp. 64 – 65.
Life Cycle Inventory of PVC: Manufacturing and Fabrication Process	Brinkley, A. et al	IEEE, ISEE, Conference 1996, pp. 94 - 101

LCA for Telecommunication Cables	Terho, M.	IEEE, ISEE, Conference 1996, pp. 109 – 111.
Life Cycle Analysis of Batteries Using Economic Input-Output Analysis	Cobas-Flores, E.	IEEE, ISEE, Conference 1996, pp. 130 – 134.
Life Cycle Assessment of an Inkjet Print Cartridge	Pollock, D. and Coulon, R.	IEEE, ISEE, Conference 1996, pp. 154 – 160.
Life Cycle Assessment at Xerox	Calkins, P.A.	IEEE, ISEE, Conference 1996, pp. 161 – 166.
Life Cycle Assessment of Electronics Manufacturing Processes	Graedel, T.E.	1996 IEEE/CPMT International Electronics Manufacturing Technology Symposium, pp. 255 – 261.
A Simplified Approach for the Environmental Assessment of Populated Printed Circuit Boards	Nissen, N.F. and Middendorf, A.	Conference Proceedings: EUPAC '96
Eco-Compass: The Comprehensive Life Cycle Assessment Tool	Zeininger, H. et al	Siemens Review Special, Fall 1996, pp. 8 – 10.
Life Cycle Assessment: An Approach to Environmentally Friendly PCs	Tekawa, M. et al	IEEE, ISEE 1997, pp. 125 - 130
An Environmentally Conscious Evaluation/Design Support Tool for Personal Computers	Zhang, H-C. and Yu, S.Y.	IEEE, ISEE 1997, pp. 131 - 136
Environmental Load of Magnetic Recording Media: LCA Case Study	Tomita, H. et al	IEEE, ISEE 1997, pp. 137 - 140
Life Cycle Assessment of a Business Telephone	Brickman, L. et al	IEEE, ISEE, 1998, pp. 255 - 259
Life Cycle Assessment of a Telecommunication Product	Scheller, H. and Hoffman III, W.F.	IEEE, ISEE, 1998, pp. 304 – 309.

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Design for the Environment - Creating Eco-Efficient Products and Processes	Fiksel, J.	McGraw-Hill, New York, 1996, ISBN 0 07 020972 3
Design for the Environment: Product Life Cycle Design Guidance Manual	U.S. Environmental Protection Agency Office of Research and Development	Government Institutes, Inc, Rockville, 1994, ISBN 0 86587 384 4
Design for Environment	Graedel, T.E. and Allenby, B.R.	Prentice Hall, Inc, Upper Saddle River, 1996, ISBN 0 13 531682 0
Industrial Ecology	Graedel, T.E. and Allenby, B.R.	Prentice Hall Inc, Englewood Cliffs, New Jersey, 1995, ISBN 0-13-125238-0
Environmentally Improved Production Processes and Products: An Introduction (SOME)	Reijnders, L.	Kluwer Academic Publishers, Dordrecht, 1996, ISBN 0 7923 3786 7
Green Technology and Design for the Environment	Billatos, S.B. and Basaly, N.A.	Taylor and Francis, Washington, 1997, ISBN 1 56032 460 0
Innovation: Design Environment and Strategy (3)	Open University	Open University 1996.
The Integration of Environmental Information with the Product Development Process Using an Expert System	Poyner, J.	PhD Thesis – Department of Mechanical Engineering, Design and Manufacture, Manchester Metropolitan University.
Asset Recycle Management - A Total Approach to Product Design for the Environment	Berko-Boateng, V. et al	IEEE, ISEE, 1993, pp.19 - 31

Designing Business Machines for Disassembly and Recycling	Kirby, J.R. and Inder Wadehra	IEEE, ISEE, 1993, pp. 32 - 36
Design for Environmental Quality: Reap the Benefits of Closing the Design Loop	Ryberg, B.A.	IEEE, ISEE, 1993, pp. 37 - 42
Life Cycle Thinking: Application to Product Design	-	IEEE, ISEE, 1993, pp. 69 - 73
Green Design: A review of Issues and Challenges	Glantschnig, W.J.	IEEE, ISEE, 1993, pp. 74 - 77
Design for Environment: An Integrated Systems Approach	Fiksel, J.	IEEE, ISEE, 1993, pp. 126 - 131
An Introduction to EPA's Design for the Environment Program	Parker, J.E and Boyd, B.L.	IEEE, ISEE, 1993, pp. 144 - 150
Plastic Recycling in Business Machines - Reuse and Recovery Assessment	Ching, S., Kirby, J.R. and Pitts, O.D.	IEEE, ISEE, 1993, pp. 189 - 193
Developing a Business Structure for Recycling	Nutter, D.	IEEE, ISEE, 1993, pp. 203 - 206
Toxics Use Reduction Planning by Massachusetts Electronics Firms	Reibstein, R.	IEEE, ISEE, 1993, pp. 138 – 143.
The Strategic and Competitive Implications of Recycling and Design for Disassembly in the Electronics Industry	Clegg, A.J. and Williams, D.J.	IEEE, ISEE, 1994, pp. 6 - 12
Designing Revolution: Policy for a Clean and Healthy Electronics Industry	Chakrabarti, P.	IEEE, ISEE, 1994, pp. 21 - 25
Development of Environmental Guidelines for Electronic Appliances	Legarth, J. et al	IEEE, ISEE, 1994, pp. 69 - 74
How to Design for Environment and Minimise Life Cycle Cost	Fiksel, J. and Wapman, K.	IEEE, ISEE, 1994, pp. 75 - 80
Disassembly of Electronic Products	Feldman, K. and Scheller, H.	IEEE, ISEE, 1994, pp. 81 - 86
"Green" Hardware Development Process	Kaiser, L.	IEEE, ISEE, 1994, pp. 121 - 127
Design for the Environment Can Be Profitable - A Case Study of the Paper Feeder in the IBM Printer 4234	Lundgren, J. et al.	IEEE, ISEE, 1994, pp. 128 - 133
Life Cycle Design: AT&T Demonstration Project	Keoleian, G.A. et al	IEEE, ISEE, 1994, pp. 135A - 135H
The NCMS Green Design Advisor, A CAE Tool for Environmentally Conscious Design	Wixom, M.R.	IEEE, ISEE, 1994, pp. 179 - 182
An Electronic, On-Line Database for Quantitative Environmental Assessment of New Designs	Schutzenberger, C.	pp. 183 - 186
A First Step in Electronic Ecodesign	Holt, R.	IEEE, ISEE, 1994, pp. 191 - 195
Design Considerations for Remanufacturability, Recyclability and Reusability of User Interface Modules	Seaver, W.B.	IEEE, ISEE, 1994, pp. 241 - 245
Design Considerations for Potential Environmental Implications Driving Selection of Semiconductor Starting Material	McCall, J. and Anderson, S.	IEEE, ISEE, 1994, pp. 246 - 251
A Systematic Methodology of Material Selection with	Chen, R.W.	IEEE, ISEE, 1994, pp. 252 - 257

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Development of DFE Practices at AT&T Global Information Solutions	Anderson, R.	IEEE, ISEE, 1995, pp. 5 - 8
A Practical, Customer-Orientated DFE Methodology	Johnson, E.F. and Gay, A.	IEEE, ISEE, 1995, pp.47 – 50.
An Examination of Alternative Software Technologies that Facilitate Life Cycle Management (LCM)	Kabjian, M. and Veroutis, A.	IEEE, ISEE, 1995, pp. 62 – 67.
Imselection – An Approach for Material Selection that Integrates Mechanical Design and Life Cycle Environmental Burdens	Chen, R.W. et al	IEEE, ISEE, 1995, pp.68 - 82
Restricted Substances in Products in the European Union	Herman, F. and Urbach, H.P.	IEEE, ISEE, 1995, pp. 216 – 219.
On-Line Information System for Environmental Product Regulations and Standards	Holbrook, L.	IEEE, ISEE, 1995, pp. 301 – 303.
Price Setting for Green Design	Matthews, H.S. and Lave, L.B.	IEEE, ISEE, 1995, pp. 304 - 313
Agent of Change: Xerox Design for Environment Program	Azar, J. et al	IEEE, ISEE, 1995, pp. 51 - 61 ,
The Application of a Computer Simulation to Economically Justify the Design of a Life-cycle Approach	Rose, E.P. et al	IEEE CONCEPT Conference 1995, pp. 28 - 34
Towards an Environmental Design Toolbox for Complex Products: Preliminary Results and Experiences from Selected Projects	Kortman, J. et al	IEEE CONCEPT Conference 1995, pp. 35 - 40
A Tiered Approach to Design for Environment	Hoffman, W.F.	, pp. 41 - 47
Environmentally Conscious Product Design	Beeteson, J.S. and Hare, M.	IEEE CONCEPT Conference 1995, pp. 48 - 53
Integration of DFE Tools with Product Development	Poyner, J.R. and Simon, M.	IEEE CONCEPT Conference 1995, pp. 54 - 59
A Financial Model for Environmentally-friendly Changes in Designs of Electronic Products	Willems, M.L.A. and Stevels, A.L.N.	IEEE CONCEPT Conference 1995, pp. 83 - 87
A Method and Case Study of Integrating Engineering Analysis with LCA for Material Selection and its Uncertainty	Chen, R.W.	IEEE CONCEPT Conference 1995, pp. 88 - 93
Combining Business Decisions with Environmental Design Analysis	Eagan, P.	IEEE CONCEPT Conference 1995, pp. 94 - 99
Design Practices for Improving the End-of-Life disposal of Telecommunications Equipment	Low, M.K. and Williams, D.J.	IEEE CONCEPT Conference 1995, pp. 111 - 116
Risk, Benefits and Strategies for Responding to the Green Consumer: A Global Perspective	Wegner, S.F.	IEEE CONCEPT Conference 1995, pp. 117 - 122
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Appendix IV

(see Section C2 of Vol II of the dissertation – Research Publications

Engineering Doctorate in Environmental Technology

Novel Techniques for Integration of Environmental Life Cycle Technologies in the Telecommunications Industry

Six Month Report No: 5

Research Engineer

Carl Mead

(Brunel University and Nortel Networks)

1 April 2000

Contents

1. Introduction

This document provides a review of the fifth six month period (beginning of year 3) of the Research Engineer's (RE) research project for the Engineering Doctorate in Environmental Technology. The project focuses on the development of novel methods for the integration of environmental life cycle technologies into Nortel's product development process. Key areas for research are the investigation of customer and industry demands for product environmental information, extraction of product environmental performance data from suppliers, and the integration of the collected information into the Design for Environment process.

The background to the company and the project, the problem definition and the aims of the project can be found in six month report number 1.

1.1. Key Personnel

Carl Mead	Research Engineer
Prof. J.D. Donaldson	Academic Supervisor (Brunel University, CER)
Dr. Ken Snowdon	Industrial Supervisor (Nortel Networks, Advanced Design Technologies)

2. Research Programme

In this section the research objectives for Year 3 of the research programme will be provided as defined in the 24 month report (2nd year dissertation and fourth six month report). Any objectives specified in previous reports that were forecast to continue beyond year 1 and 2 are included and progress is reported in section 3 of this report. The objectives are numbered according to the Project Management Plan.

2.1. Research Objectives for Year 3

Objective 2
Determine information requirements for component selection in ecodesign.

Objective 8
Comparison study of component material composition data.

Objective 9
Investigate and compare manufacturing processes of selected components.

Objective 10
Supplier interaction programme to investigate possible collaborative efforts on new product/process initiatives.

Objective 19
Investigate the possibilities of developing a web-based version of the supplier appraisal and information retrieval method.

Objective 20
Trial and test web-version with VMRs.

Objective 21
Determine how each supplier assessment will be qualified.

Objective 22
Finalise supplier questionnaire and seek standardisation.

Objective 23
Removed from plan.

Objective 24 and 25
Investigate methods of product environmental data transfer and tracking through the product life cycle.

Objective 26
Develop complete system for information retrieval and transfer.

Objective 27
Test system on a selected product from supplier to customer.

Objective 28
Write Programme 3 report.

Objective 29
Evaluate product environmental data in PACES provided by suppliers and its contribution to the component selection process.

Objective 30
Re-evaluate data provided to designers.

Objective 31
Set up a monitoring programme to record the use and effectiveness of the supplier assessment questionnaire for ISO 14001 system continual improvement.

Objective 32
Monitor the use of product environmental information in answering customer requests (monitoring programme set up with sales teams).
Objective 33
Develop environmental criteria for component selection.

3. Progress

3.1. Towards Meeting Objectives

This section will review the progress made in meeting the objectives of the third year as defined above and in the Project Management Plan and Work Package Description.

Objective 2

There are no design groups within Nortel Networks that are actively using environmental criteria as part of the component selection process. The design groups that are using the Nortel Networks ecodesign tool are all mechanical design groups. Discussions with hardware design groups have suggested that the hardware or electronic circuit designer is not in a position to make decisions about component selection because components are selected from the Nortel Networks database according to functionality. The components in the database are pre-qualified by the engineering group (Product Assurance and Component Engineering). It is this group that could assess components in terms of their eco-performance as part of the component or technology qualification process. The information requirements for component qualification could range from simple hazardous material compliance data to detailed material content and manufacturing life cycle inventory data. This issue will be addressed in Objective 33.

Objective 8

The component material composition comparison study was designed to compare averaged data for component composition from the EIME and Delta databases with supplier data and destructive analysis data. The average data and some supplier data are now available but the destructive analysis data are not. A research project has been set up for an MSc student from Brunel University that focuses on destructive analysis of selected components. The project has commenced.

Objective 9

No further progress has been made on the investigation and comparison of manufacturing processes of selected components. Supplier-specific information on manufacturing processes is proving to be particularly difficult to obtain.

Objective 10

Supplier interaction on environmental initiatives for Nortel Networks has now been officially reduced to participation in the HDPUG lead-free and halogenated flame retardants working groups and formal interaction through the Supply Management function supported by the corporate Employee Well-Being and Environment function. Any interaction that the RE wishes to initiate will be through the Core Environmental Requirements (CER) programme (a formal process that has now been established for liasing with, and specifying environmental requirements of, suppliers that the RE assisted in developing).

Objective 19

The web beta version of the SEAP questionnaire with associated links to a FilemakerPro database has been completed. This tool has been used to demonstrate to the corporate Employee Well-Being and Environment group and the Nortel Networks supply management function the possibilities of a web-based system for supplier eco-data capture. Elements of the tool are being considered for integration into the CER programme.

Objective 20

Web-SEAP (the supplier eco-appraisal questionnaire developed by the RE) will no longer be piloted with selected suppliers. The questionnaire has been incorporated into the Core Environmental Requirements Programme and adapted accordingly. The CER programme will initially use a self-declaration questionnaire that is "downloadable" from the web but there are plans in place to possibly convert it to an HTML form on the web similar to that which the RE developed for web-SEAP. Secure access to specific areas in the Nortel Supply management web space has already been established for suppliers to enable the provision of quality and service performance data. This secure access can also be used for the CER data. The CER programme at the moment is not seeking to capture component data from suppliers. This is a fundamental aspect of the RE's research and was part of web-SEAP. The RE will seek to test the product data capture and transfer element of web-SEAP as an element of the CER programme web site, possibly with Motorola.

Objective 21

As each supplier will now be assessed using the CER programme this objective now becomes partially redundant. However, it may be possible for a validation process for product eco-data provision to be integrated into the GAP (Global Audit Plan) for component/technology qualification. This will be investigated as part of the component eco-evaluation methodology to be generated in Objective 33.

Objective 22

This objective becomes redundant as the CER programme will now become the standardised method of assessing the eco-performance of suppliers.

Objective 23

Objective deleted because the SAMS tool was discontinued.

Objective 24 and 25

Although a programme for active product data collection has not as yet been put in place because of a reluctance to do so by the Supply Management function of Nortel Networks, investigations have continued into possible data transfer methods that result in material content or performance profiles being generated for products of Nortel Networks.

A software tool called WebCROP used by supply management, design and manufacturing functions has been identified. WebCROP (Component Rationalization

Optimization and Planning web tool) is a "tool that analyses stocklists to help the best selection of the components in the light of corporate needs and experience, corporate standards and local requirements"[1]. Further investigation will determine the feasibility of using WebCROP as a product eco-data transfer tool.

Objective 26

Because of implementation difficulties it is unlikely that the information retrieval and tracking system will be fully realised. It may be possible to scenario-test elements of the proposed system.

Objective 27

At least one Nortel Networks product will be selected and an attempt made to generate a material content profile from available data using the systems developed.

Objective 28

The Programme 2 report will be written.

Programme 3

Objective 29

The data provided by suppliers will be evaluated in terms of a contribution to the component selection process. Product data is no longer being collected from suppliers and added to the partSMart database by the RE. Some data may be collected as part of the CER initiative. It is likely that the main decision-making point determining component selection will be component qualification which is conducted by the engineering group – PACE. Data evaluation will form part of Objective 33.

Objective 30

Recommendations for obtaining product eco-data will be made following the meeting of objectives 29 and 33.

Objective 31

The SEAP questionnaire has now been incorporated into the Nortel Networks CER programme and subsequently adapted. The CER programme will become the formal process for assessing the eco-performance of suppliers and setting requirements. It will, therefore, become the formal process for supplier assessment for ISO 14001 continual improvement. This has been a corporate decision. The merits of both tools for supplier assessment will be discussed in the Programme 3 report.

Objective 32

The contribution that the eco-data information management system could make to meeting customer requests for product data will be evaluated. An attempt will be made to generate an eco-profile, in terms of material composition, of a Nortel Networks product using either data from suppliers entered into partSMart or alternative generic data that is available. The feasibility of generating such profiles will be assessed and the value of generating them to provide customers with product information determined.

Objective 33

Product environmental information could be used to generate a quantitative or qualitative environmental performance evaluation for each component. Such an evaluation could then be used to provide criteria for component selection by the designer at the design stage, or more likely, component engineering as part of component qualification. The possibility of integrating component production environmental information into the evaluation method will also be considered. Criteria and methods will be investigated.

3.2. Supporting Activities

Certain activities are carried out by the RE which, although not always directly connected with the core research project, assist in the development of personal, professional, and business skills. They support the RE's candidacy for the qualification of Engineering Doctorate.

For this six month period they are:

- research paper abstract submitted for the Electronics Goes Green 2000 International Conference and Exhibition in Berlin, September 11-13 2000.

- practical ecodesign implementation such as achieving the objectives on the ecodesign continual improvement plan for ISO 14001 on the Harlow site and generating new plans for 2000 to extend the ecodesign programme and train more engineers.

- attendance of relevant conferences, exhibitions and seminars such as:

  - The International Tin Research Institute new launch as Soldertec on behalf of Nortel Networks on 20th October 1999;
  - The EngD Board of Studies meeting, representing the research engineers on 27th October 1999;
  - The ETMUEL workshop at the Centre for Sustainable Design on 23rd November 1999;
  - Presented at ERM Seminar on Environment in the Supply Chain 26th January 2000, London;
  - EngD Management Executive Meeting, 6th March 2000, Runnymede.
  - The ETMUEL workshop at the Centre for Sustainable Design on 6th March 2000;
  - WEEE – A Global Approach Seminar, 23rd March 2000, London.

- various presentations of the research project to department colleagues and senior Nortel staff;

- EngD Intake Year 1997 Representative

- Regular attendance and chairman of the EngD feedback forum;

- Completion of EngD finance and marketing modules.

4. Discussion

The research has progressed reasonably well over the last six months of the research project. The majority of the targets set for the six months have been reached. Work focused on the development and completion of the beta version of web-SEAP. Eco-performance data on 27 suppliers and some sample product material composition data have been submitted to the database. The tool was initially developed with a view to it being implemented as the Nortel Networks supplier eco-assessment tool. However, it has emerged that total implementation will not be possible and subsequently it has been used to demonstrate to the Nortel Networks employees responsible for the CER programme the possibilities for electronic supplier eco-data capture and management. Elements of the tool have been integrated into the CER programme.

Because of the formal responsibility for supplier appraisal and interaction on environmental concerns being placed with the CER programme, certain elements of the research project management plan have been made redundant. They are primarily proposed implementation activities. Furthermore, because of the launch of the CER programme and the increasing lack of interest from Nortel Networks in product eco-issues beyond minimal compliance it is now inappropriate for the RE to approach suppliers on eco-issues outside the programme. This situation may hinder further data capture and will certainly affect the completion of objectives 9 and 10.

Work has commenced and will continue on the development of a methodology for integrating eco-evaluation into the component selection process for design or component qualification and assessing the feasibility of implementation. Life cycle costing will also be considered in the methodology, particularly end-of-life costs or benefits. The methodology should be applicable industry-wide and will be dependant on data availability.

Customers of Nortel Networks are increasingly requesting specific data on the material content of Nortel Networks products, particularly hazardous material content. Nortel still does not have a formal procedure in place for generating a hazardous material content product profile. Work will continue on investigating the possibilities for component data transfer from PACES using WebCROP and correlating the data with a bill of materials for a given product.

5. Next Steps

The next steps of the research project for the next six months are:

1. Complete the comparison study of component material composition data if possible (Objective 8);

2. Investigate further the possibility of using WebCROP as a product eco-data transfer tool (Objectives 24 and 25);

3. Attempt to generate a material content profile from available data (Objective 28 and 32);

4. Write the Programme 2 report (Objective 28);

5. Develop a methodology for integrating component eco-evaluation into the component selection process (Objective 33).

6. Write and present paper for the Electronics Goes Green conference if the abstract is accepted.

7. Consider suitable papers for journal publication.

The remaining project tasks for the final year are detailed in the project plan calendar (Appendix I).

6. Conclusions

The research project is progressing satisfactorily. The last six months have focused on completing the beta version of web-SEAP, developing the component material composition study, starting research on component eco-data tracking and starting the component eco-evaluation methodology development. The responsibility for implementation of the tools developed to date in the project have now been transferred and integrated into the CER programme within the supply management function.

Research in the next six months will focus on the component eco-evaluation methodology and attempts to generate a material composition profile of a Nortel Networks product.

7. References

1) CAMEng Information Systems, Nortel Networks, *WebCROP User Guide V2C.2.0*, 1998.


Appendix I Version IV
Month
Year
Week
Date (week commencing)
Task Name
1.1 Project Management
1.2 Project Stages
Programme 1
Programme 2
Programme 3
1.3 Project Milestones
1.4 EngD Courses
Task to complete
Completed task
Task deleted
Milestone to reach
Milestone reached and completed

Engineering Doctorate in Environmental Technology

Novel Techniques for Integration of Environmental Life Cycle Technologies in the Telecommunications Industry

Six Month Report No: 6

Research Engineer

Carl Mead

(Brunel University and Nortel Networks)

1 October 2000

Contents

1. Introduction

This document provides a review of both the fifth and sixth six month period (whole of year 3) of the Research Engineer's (RE) research project for the Engineering Doctorate in Environmental Technology. The project focuses on the development of novel methods for the integration of environmental life cycle technologies into Nortel's product development process. Key areas for research are the investigation of customer and industry demands for product environmental information, extraction of product environmental performance data from suppliers, and the integration of the collected information into the Design for Environment process.

The background to the company and the project, the problem definition and the aims of the project can be found in six month report number 1.

1.1. Key Personnel

Carl Mead	Research Engineer
Prof. J.D. Donaldson	Academic Supervisor (Brunel University, CER)
Dr. Ken Snowdon	Industrial Supervisor (Nortel Networks, Advanced Material Systems)

2. Research Programme

In this section the research objectives for Year 3 of the research programme will be provided as defined in the 24 month report (2nd year dissertation and fourth six month report). Any objectives specified in previous reports that were forecast to continue beyond year 1 and 2 are included and progress is reported in section 3 of this report. The objectives are numbered according to the Project Management Plan.

2.1. Research Objectives for Year 3

Objective 2
Determine information requirements for component selection in ecodesign.

Objective 8
Comparison study of component material composition data.

Objective 9
Investigate and compare manufacturing processes of selected components.

Objective 10
Supplier interaction programme to investigate possible collaborative efforts on new product/process initiatives.

Objective 19
Investigate the possibilities of developing a web-based version of the supplier appraisal and information retrieval method.

Objective 20
Trial and test web-version with VMRs.

Objective 21
Determine how each supplier assessment will be qualified.

Objective 22
Finalise supplier questionnaire and seek standardisation.

Objective 23
Removed from plan.

Objective 24 and 25
Investigate methods of product environmental data transfer and tracking through the product life cycle.

Objective 26
Develop complete system for information retrieval and transfer.

Objective 27
Test system on a selected product from supplier to customer.

Objective 28
Write Programme 2 report.

Objective 29
Evaluate product environmental data in PACES provided by suppliers and its contribution to the component selection process.

Objective 30
Re-evaluate data provided to designers.

Objective 31
Set up a monitoring programme to record the use and effectiveness of the supplier assessment questionnaire for ISO 14001 system continual improvement.

Objective 32
Monitor the use of product environmental information in answering customer requests (monitoring programme set up with sales teams).
Objective 33
Develop environmental criteria for component selection.

3. Progress

3.1. Towards Meeting Objectives

This section will review the progress made in meeting the objectives of the third year as defined above and in the Project Management Plan latest issue and Work Package Description latest issue. Details of progress achieved in the first six months of the third year of the project were also provided in the fifth six month report and may be replicated here.

Objective 2

There are no design groups within Nortel Networks that are actively using environmental criteria as part of the component selection process. The design groups that are using the Nortel Networks ecodesign tool are all mechanical design groups. Discussions with hardware design groups have suggested that the hardware or electronic circuit designer is not in a position to make decisions about component selection because components are selected from the Nortel Networks database according to functionality. The components in the database are pre-qualified by the engineering group (Product Assurance and Component Engineering). It is this group that could assess components in terms of their eco-performance as part of the component or technology qualification process. The information requirements for component qualification could range from simple hazardous material compliance data to detailed material content and manufacturing life cycle inventory data. An eco-evaluation hierarchical methodology based on data availability is being developed to meet objective 33.

Objective 8

The component material composition comparison study was designed to compare averaged data for component composition from the EIME and Delta databases with supplier data and destructive analysis data. The average data and some supplier data are now available but the destructive analysis data are not. A research project has been set up for an MSc student from Brunel University that focuses on destructive analysis of selected components. This project is progressing well and is due for completion in October 2000. The aims of the project are to provide material content data of selected components from selected suppliers to compare to the commercial database sets and supplier data; to develop a potential validation method for supplier data; and to assess the feasibility of implementing the validation methodology particularly in terms of financial viability.

Objective 9

No further progress has been made on the investigation and comparison of manufacturing processes of selected components. Supplier-specific information on manufacturing processes is proving to be particularly difficult to obtain. Work will continue on achieving this objective in the next year.

Objective 10

Supplier interaction on environmental initiatives for Nortel Networks has now been officially reduced to participation in the HDPUG lead-free and halogenated flame retardants working groups and formal interaction through the Supply Management function supported by the corporate Environment, Safety and Worklife function. Any interaction that the RE wishes to initiate will be through the Core Environmental Requirements (CER) programme (a formal process that has now been established for liasing with, and specifying environmental requirements of, suppliers that the RE assisted in developing). One area related to this objective which will be explored further is the possible stimulation of product eco-performance innovation amongst suppliers through customer requirements. This will focus on whether a partnership approach or an openly competitive approach best stimulates product eco-innovation.

Objective 19

The web beta version of the SEAP questionnaire with associated links to a FilemakerPro database has been completed. This tool has been used to demonstrate to the corporate Environment, Safety and Worklife group and the Nortel Networks supply management function the possibilities of a web-based system for supplier eco-data capture. Many aspects of the tool have been incorporated into the official supply management supplier core environmental requirements procedure which is about to be implemented. However, the product data transfer element of the tool has not been authorised.

Objective 20

Web-SEAP (the supplier eco-appraisal questionnaire developed by the RE) will no longer be piloted with selected suppliers. The questionnaire has been incorporated into the Core Environmental Requirements Programme and adapted accordingly. The CER programme will initially use a self-declaration questionnaire that is "down-loadable" from the web but there are plans in place to possibly convert it to an HTML form on the web similar to that which the RE developed for web-SEAP. Secure access to specific areas in the Nortel Supply management web space has already been established for suppliers to enable the provision of quality and service performance data. This secure access can also be used for the CER data. The CER programme at the moment is not seeking to capture component data from suppliers. This is a fundamental aspect of the RE's research and was part of web-SEAP. The RE will seek to test the product data capture and transfer element of web-SEAP as an element of the CER programme web site, possibly with Motorola, although this will be unlikely due to the slow progress being made on implementation of the CER initiative.

Objective 21

As each supplier will now be assessed using the CER programme this objective now becomes partially redundant. However, it may be possible for a validation process for product eco-data provision to be integrated into the GAP (Global Audit Plan) for component/technology qualification. This will be investigated as part of the component eco-evaluation methodology being generated to achieve Objective 33. A

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Objective 26

Because of implementation difficulties it is unlikely that the information retrieval and tracking system will be fully realised. It may be possible to scenario-test elements of the proposed system. In principle, the majority of the tools needed to realise a product data capture and transfer system are now in place or available. Certain software would need to be modified. The two major issues that problematic are the availability of supplier specific product material content data and the complexity of the majority of the products of Nortel Networks.

Objective 27

Two products have initially been selected to demonstrate the principle of product material data capture and transfer and the difficulties associated with such an exercise. The products are a next generation internet telephone and a local switching system. At this stage the bill of materials for each product has been captured and tabulated. The next step is to identify all potential suppliers that have been qualified for each component and attempt to generate a material profile using data that are available.

Objective 28

The Programme 2 report will be written.

Programme 3

Objective 29

The data provided by suppliers was to be evaluated in terms of a contribution to the component selection process. Product data is no longer being collected from suppliers and added to the partSMart database by the RE. Some product eco-data may be collected as part of the CER initiative. Earlier in the project it was anticipated that at this point in time product eco-data would possibly be captured from suppliers by the supply management function. This has not materialised and only limited data on products have been collected as part of the SEAP pilot studies. From the research and particularly from discussions with designer groups, it has emerged that the main decision-making point determining component selection will be component qualification which is conducted by the engineering group – PACE rather than the design groups. In electronic design components are selected according to functionality from a database of pre-qualified components form approved suppliers. It is apparent that it is not the electronic designer who will use component eco-performance as part of the selection process unless it is incorporated into a tool to compare fundamental design choices such as application specific integrated circuits versus conventional layout or embedded technology versus conventional surface mount technology.

Objective 30

Currently no component eco-data are provide to designers and as stated in Objective 29 it is not the designers who will use component eco-performance as part of the component/supplier selection process unless it is used as part of an integrated decision-support tool for design options. Once Objective 33 has been completed further conclusions can be drawn regarding designers and their role in the potential use of component eco-data for component/supplier selection.

Objective 31

The SEAP questionnaire has now been incorporated into the Nortel Networks CER programme and subsequently adapted. The CER programme will become the formal process for assessing the eco-performance of suppliers and setting requirements. It will, therefore, become the formal process for supplier assessment for ISO 14001 continual improvement. This has been a corporate decision. The merits of both tools for supplier assessment will be discussed in the Programme 3 report.

Objective 32

The contribution that the eco-data information management system could make to meeting customer requests for product data will be evaluated. An attempt will be made to generate an eco-profile, in terms of material composition, of a Nortel Networks product using either data from suppliers entered into partSMart or alternative generic data that is available. The feasibility of generating such profiles will be assessed and the value of generating them to provide customers with product information determined. Work on the generation of an eco-profile has commenced. Customer requests for eco-information are constantly monitored.

Objective 33

Product environmental information could be used to generate a quantitative or qualitative environmental performance evaluation for each component. Such an evaluation could then be used to provide criteria for component selection by the designer at the design stage, or more likely, component engineering as part of component qualification. The first phase of the methodology development has commenced and resulted in an evaluation hierarchy. This element of the research project has been presented at the EngD conference 2000 and also the Electronics Goes Green 2000+ conference in Berlin. The papers will be submitted to the portfolio.

3.2. Supporting Activities

Certain activities are carried out by the RE which, although not always directly connected with the core research project, assist in the development of personal, professional, and business skills. They support the RE's candidacy for the qualification of Engineering Doctorate.

For this twelve month period they are:

- research paper presented at the Electronics Goes Green 2000 International Conference and Exhibition in Berlin, September 11-13 2000;

- research paper presented at EngD conference, September 12-13 2000;

- research presented at North West Product Stewardship Conference, Seattle, Washington, April 2-5 2000;

- practical ecodesign implementation such as achieving the objectives on the ecodesign continual improvement plan for ISO 14001 on the Harlow site and generating new plans for 2000 to extend the ecodesign programme and train more engineers.

- attendance of relevant conferences, exhibitions and seminars such as:

    - The International Tin Research Institute new launch as Soldertec on behalf of Nortel Networks on 20th October 1999;
    - The EngD Board of Studies meeting, representing the research engineers on 27th October 1999;
    - Various ETMUEL workshops at the Centre for Sustainable Design;
    - Presented at ERM Seminar on Environment in the Supply Chain 26th January 2000, London;
    - EngD Management Executive Meeting, 6th March 2000, Runnymede.
    - WEEE – A Global Approach Seminar, 23rd March 2000, London.
    - Attendance of Federation of Electronics Industry Health, Safety and Environment Committee meetings.

- various presentations of the research project to department colleagues and senior Nortel staff;

- EngD Intake Year 1997 Representative

- Regular attendance and chairman of the EngD feedback forum;

- Completion of EngD finance, marketing, risk II, materials and environmental economics modules.

- Supervision of MSc project on component analysis;
- Development of case study project for PhD student on end of life electronics

4. Discussion

This section will provide the discussion on progress made in the last six months. The research has progressed well with the majority of the targets set for the six months being reached or nearing completion. Work has focused on four main areas:

- identifying the possible mechanisms for transferring supplier eco-data on components through the Nortel Networks design and manufacturing processes;
- identifying two suitable Nortel Networks products to use in the generation of material profiles and generating bill of materials;
- developing the component comparison study through supervision of an MSc student; and
- developing a component evaluation methodology.

The potential generation of product material profiles for conveyance to customers and to assist in decision-making at end-of-life requires data transfer throughout the life cycle. The product data element of the SEAP questionnaire is one mechanism of obtaining and storing data from suppliers. These data can then be inserted into a specific field in the generic corporate component database. When a bill of materials is generated for a specific Nortel Networks product design and given to a Nortel Networks manufacturing site or a contract manufacturer the eco-data for each component could be collated and held in the Integrated Engineering Database. The specific final product material profile could then be captured from the database and presented to the customer. In principle all the necessary tools for such data transfer exist. They only need to be modified.

Two very different products have been selected to demonstrate the difficulties in generating material profiles. The respective bill of materials have been tabulated. The next step is to identify the suppliers for each component.

Work on the component comparison study has continued through a Brunel MSc project, supervised by the RE. The project was initially going to provide component material analysis data to compare to supplier and available generic data and to provide a methodology for validation of supplier data. Unfortunately due to the limited nature of the available analysis at Brunel, detailed material analysis may not have been possible. The results of the work will be available in October 2000.

The main focus of the research over the last six months has been the development of a methodology for component eco-evaluation with a view to potentially differentiate between suppliers of the same component and thus provide eco-criteria for component and supplier selection in the framework of product life cycle management. A four-stage hierarchy of evaluation has been generated. Preliminary evaluations have been made on an integrated circuit package type using rudimentary analysis. Refinement of the method should be completed in the next three months. It is anticipated that the method would be applicable industry-wide and of most use in component qualification and procurement.

5. Next Steps

The next steps of the research project for the next six months are:

1. Complete the comparison study of component material composition data if possible (Objective 8);

2. Attempt to investigate further the component manufacturing processes of selected suppliers if possible (Objective 9);

3. Develop the theory of supplier eco-innovation stimulation (Objective 10);

4. Test the product data capture and transfer element of SEAP if possible (Objective 20);

5. Once Objectives 8 and 33 are complete recommendations will be made to Nortel Networks supply management function regarding a procedure for integrating eco-evaluation into component qualification (Objective 21);

6. Attempt to generate a material profile of the two selected products (Objective 27);

7. Finish the Programme 2 report (Objective 28);

8. Complete the eco-evaluation methodology and test on selected components (Objectives 33 and 34);

9. Generate abstracts for journal papers.

The remaining project objectives will be completed in the final six months of the project. The Project Management Plan (Appendix I)'details the time frame.

6. Conclusions

The research project is progressing satisfactorily. The last six months have focused on developing the component material composition study, identifying mechanisms for transferring product eco-data, identifying suitable products for the generation of material profiles, and developing the component/supplier eco-evaluation methodology.

Research in the next six months will focus on completing the component eco-evaluation methodology and testing it and the generation of material composition profiles of selected Nortel Networks products.

7. References

1) CAMEng Information Systems, Nortel Networks, *WebCROP User Guide V2C.2.0*, 1998.

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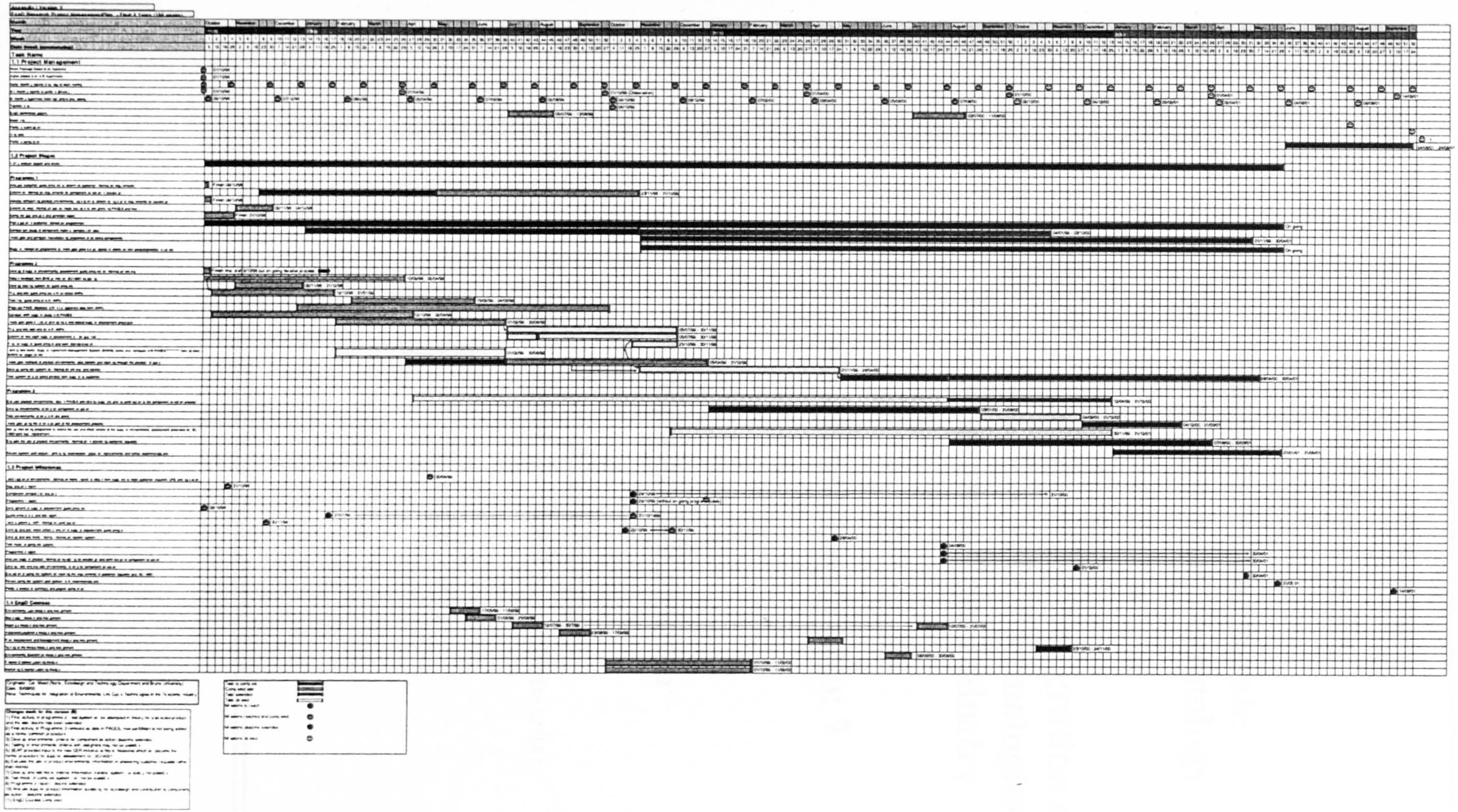
Month
Year
Week
Task Name
1.1 Project Management

Engineering Doctorate in Environmental Technology

Novel Techniques for Integration of Environmental Life Cycle Technologies in the Telecommunications Industry

Six Month Report No: 7

Research Engineer

Carl Mead

(Brunel University and Nortel Networks)

1 April 2001

Contents

1. Introduction

This document provides a review of both the seventh six-month period (first half of year 4) of the Research Engineer's (RE) research project for the Engineering Doctorate in Environmental Technology. The project focuses on the development of novel methods for the integration of environmental life cycle technologies into Nortel's product development process. Key areas for research are the investigation of customer and industry demands for product environmental information, extraction of product environmental performance data from suppliers, and the integration of the collected information into the Design for Environment process.

The background to the company and the project, the problem definition and the aims of the project can be found in six month report number 1.

1.1. Key Personnel

Carl Mead	Research Engineer
Prof. J.D. Donaldson	Academic Supervisor (Brunel University, CER)
Dr. Ken Snowdon	Industrial Supervisor (Nortel Networks, Advanced Material Systems)

2. Research Programme

In this section the research objectives for Year 4 of the research programme will be provided as defined in the sixth six-month report (36 month report) and Work Package Description and the 2nd year dissertation. Any objectives specified in previous reports that were forecast to continue beyond year 1 and 2 are included and progress is reported in section 3 of this report. The objectives are numbered according to the Project Management Plan.

2.1. Research Objectives for Year 4

Objective 8
Comparison study of component material composition data.

Objective 9
Attempt to investigate further the component manufacturing processes of selected suppliers if possible.

Objective 10
Develop the theory of supplier eco-innovation stimulation.

Objective 20
Test the product data capture and transfer element of SEAP if possible.

Objective 21
Once objectives 8 and 33 are complete, recommendations will be made to the Nortel Networks supply management function regarding a procedure for integrating eco-evaluation into component qualification.

Objective 27
Attempt to generate a material profile of the two selected products.

Objective 28
Finish programme 2 report.

Objective 33
Develop environmental criteria for component selection.

Objectives 34 and 35
Test eco-evaluation methodology on components and determine at what stage of the product development process it can be used.

Objectives 36
The product environmental management system and methods of component environmental performance evaluation will be critically reviewed, areas for improvement identified and final recommendations made to Nortel Networks.

Objective 37
All the details of Programme 3 will be written up in the Programme 3 report.

3. Progress

3.1. Towards Meeting Objectives

This section will review the progress made in meeting the objectives of the fourth year as defined above and in the Project Management Plan latest issue and Work Package Description latest issue.

Objective 8

The final element of the component material composition comparison study (destructive analysis project) was completed in October 2000. The study highlighted the complex material structure of electronic components, the difficulties in preparing suitable samples for analysis and the difficulties and costs associated with quantifying material content. The main recommendation was the development of a standard methodology for quantitative elemental analysis of electronic components to ensure a sound basis for comparison between suppliers and transparent validation of supplier component material declarations. Due to the analytical techniques available a direct comparison of primary analytical data with supplier material declarations was limited.

Objective 9

No further progress has been made on the investigation and comparison of manufacturing processes of selected components. Suppliers are reticent in providing information regarding their manufacturing processes. Technology roadmaps that include environmental initiatives are generated by the semi-conductor industry and national electronics industry groups. This area will be interpreted and explored further in the final thesis.

Objective 10

Theories and observations on stimulating eco-innovation in the supply chain will be detailed in the final thesis. The prime driver for eco-innovation is legislation. Legislative requirements that need to be met by OEMs (Original Equipment

Manufacturers) result in requirements being driven down the supply chain. Proactive OEMs may also drive eco-innovation in the supply chain by implementing rigorous eco-purchasing strategies. Occasionally the supply chain may force change or increase the pace of change amongst customers. This is occurring to some extent with the introduction of lead-free components.

Objective 20

The product data capture element of SEAP will not be tested with suppliers. The Nortel Networks supply management function has not as yet implemented the appropriate element of the web site to enable a trial to be conducted. Secure data transfer technology has already been proven in other areas though so there is no need to test this aspect. An electronics industry group initiative us under way in Europe to develop a web-based system for component material data capture from the supply chain. This work seeks to gain common agreement amongst OEMs on format and content of data and the means of capturing it and making it available. Preliminary tests will take place in 2001. The RE is recommending that Nortel Networks utilises this system if it becomes workable.

Objective 21

Final recommendations for integrating eco-performance into component qualification in terms of component material declaration validation and a process for eco-qualification will be provided as an element of objective 37 and when the eco-evaluation methodology is finalised.

Objective 27

Investigations have been initiated on four Nortel Networks products to demonstrate the principle of product material data capture and transfer and the difficulties associated with such an exercise. It is likely that only three will be used ultimately. The products are a next generation internet telephone, an established business telephone and a local switching system. Work has concentrated on the generation of complete bill of materials for each product, the collection of images and drawings of each, the identification of data management systems and the end-of-life management routes and options. The next step is to attempt to identify all potential suppliers that have been qualified for each component and to identify any material data that is or may be available and how it can be aggregated to form material profiles for each stage of the product build.

Objective 28

The Programme 2 report will form one of the chapters in the final thesis.

Programme 3

Objective 33

The second phase of the supplier and component eco-evaluation methodology development has commenced and is currently undergoing revision and refinement. The methodology consists of a quantitative evaluation from material content data in terms of potential human toxicity and ecotoxicity, resource depletion and recyclability and supplier environmental appraisal results. Details will be provided in the final thesis.

Objectives 34 and 35

The eco-evaluation methodology will be sensitivity tested and demonstrated using "real" data from suppliers. Recommendations will be made regarding what stage of the product development process components should be evaluated for eco-performance – either during designer selection of components or engineering qualification of components.

Abstracts for journal papers need to be generated.

3.2. Supporting Activities

Certain activities are carried out by the RE which, although not always directly connected with the core research project, assist in the development of personal, professional, and business skills. They support the RE's candidacy for the qualification of Engineering Doctorate.

For this six month period they are:

- Regular attendance of the Federation of the Electronics Industry Health Safety and Environment committee meetings on behalf of Nortel Networks;
- Attendance of the 3rd ETNO Telecommunications and the Environment Conference, Ipswich, 14th –16th November 2000;
- Attendance of EICTA Supply Management Task Force meetings in Brussels, 28th November 2000 and 7th March 2001.
- Attendance of ecodesign and supply chain management workshops at Surrey Institute of Art and Design.
- Practical ecodesign implementation such as achieving the objectives on the ecodesign continual improvement plan for ISO 14001 on the Harlow site and generating new plans for 2001;
- Various presentations of the research project to department colleagues and senior Nortel staff;
- Continued support for PhD student on end of life electronics

4. Discussion

This section will provide the discussion on progress made in the last six months. The research has progressed well with the majority of the targets set for the six months being reached or nearing completion. Work has focused on two main areas:

- Generating information to provide input to the feasibility assessment of generating detailed product material profiles;
- Continued development of a supplier and component eco-evaluation methodology.

The potential generation of product material profiles for conveyance to customers and to assist in decision-making at end-of-life requires data transfer throughout the life cycle. The product data element of the SEAP questionnaire is one mechanism of obtaining and storing data from suppliers although databasing mechanisms would need to be increased in scale. Data could also be generated through the EICTA industry group activities on supply chain management in a standard format. An industry collaborative effort is the preferred option for data capture in terms of cost and proliferation of data. The data captured can then be inserted into a specific field in the generic corporate component database. When a bill of materials is generated for a specific Nortel Networks product design and given to a Nortel Networks manufacturing site or a contract manufacturer the eco-data for each component could be collated through communication between the component material database and the manufacturing database systems that track unique product configuration data for each product. In theory a calculated material profile could be generated for the customer and held on a data system for deployed products. This information could then be used after product decommissioning for end-of-life management. It could also be used for predictive end-of-life costing modelling.

Three different products have been selected to demonstrate the difficulties in generating material profiles. The Meridian M7310 business telephone is an established and relatively simple product. The Inca 2004 one of an innovative new generation of internet protocol telephones. The DMS Supernode SE is an established and complex telecommunication switch, consisting of a rack with five shelves of sub-assembly units. The bill of a materials (parts lists) for each product consists of many levels or layers that are built from a top level product code or order number. The respective bill of materials for each product are now being finalised and the potential suppliers of components are being identified. It is unlikely that suppliers will be identified for all components in the Supernode for this study as the process is a manual one. Sample circuit packs will be selected to demonstrate the principle.

Work has continued on the development of a methodology for component and supplier eco-evaluation with a view to potentially differentiate between suppliers of the same component and thus provide a basis for decision-making for component and supplier selection in the framework of product life cycle management. A four-stage hierarchical approach has been developed that involves increasing complexity in terms of evaluation. The simplest level of evaluation involves prescriptive minimum requirements for the absence of certain substances in components. The most complex level of evaluation requires the consideration of four component and one supplier performance criteria. The component criteria selected are human toxicity, ecotoxicity, resource depletion and recyclability. The objective is to attempt to generate eco-performance scores independently for each component per supplier during engineering qualification that can be added to the component database and then used in the decision-making process for procurement during manufacturing.

5. Next Steps

The next steps of the research project for the next six months are:

1. Attempt to investigate further the component manufacturing processes of selected suppliers if possible (Objective 9);

2. Develop the theory of supplier eco-innovation stimulation (Objective 10);

3. Once Objectives 8 and 33 are complete recommendations will be made to Nortel Networks supply management function regarding a procedure for integrating eco-evaluation into component qualification (Objective 21);

4. Attempt to generate a material profile of the two selected products and demonstrate the complexity of the task (Objective 27);

5. Finish all Programme reports (Objective 28);

6. Complete the eco-evaluation methodology (Objective 33);

7. Test methodology and determine at what stage of the product development process it can be used (Objectives 34 and 35)

8. Critically review the product data management system and eco-performance evaluation methodology, identify areas for improvement and make final recommendations to Nortel Networks (Objective 36);

9. Write at least one journal paper;

10. Complete portfolio and submit.

6. Conclusions

The research project is starting to reach a conclusion. The last six months have focused on generating information to demonstrate the complexity of product material profile compilation and continued development and refinement of the component/supplier eco-evaluation methodology.

The final six months of the project will involve completion of the objectives and of the project as a whole. It is planned for each of the programme reports to form the basis for three respective chapters of the final thesis document. Submission is scheduled for September.

C2 - Research Publications

Advancing Ecodesign Decision-Making Through Eco-Supply Chain Management In The Telecommunications Industry

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Abstract

Improving the environmental performance of telecommunications products can be achieved through the application of ecodesign and life cycle assessment tools during the design phase of products. Decision-making and selection trade-offs in component and material selection processes can present difficulties for both mechanical and hardware designers because of the short design cycles and "time to market" pressures.

Ideally components would be "eco-evaluated" (including life cycle costs/revenues) as a standard part of the component qualification process. This leaves the designer to freely select components and materials according to functionality knowing that environmental performance had been taken into account. Component selection decisions in terms of circuitry power management would, of course, be made by the designer. The main purpose of the evaluation is to provide an input to evaluating the eco-performance of Nortel Networks products and predicting end-of-life financial scenarios.

The development of a component eco-evaluation and predictive end-of-life cost/value procedure is introduced in this paper. The feasibility of integrating such a procedure into current processes for component selection at Nortel Networks is discussed. In addition the possibilities for implementation of a similar process by contract manufacturers is presented as the supply chain management strategy of Nortel Networks changes.

Improving product eco-performance, minimising costs over the life cycle, and extending material life through effective materials management are some of the aims of a research programme at Nortel Networks. The work presented in this paper is a step towards realising those aims and making a contribution to sustainability.

1 Introduction

In the drive to develop telecommunications or network solutions with improved eco-performance there is a need to refine and tailor ecodesign and product life cycle management tools and strategies. Research at Nortel Networks and Brunel University is currently being conducted to investigate methods of component data capture, transfer through the life cycle and component eco-evaluation for improved product life cycle management and decision making. The aim is to develop opportunities for improving and communicating product eco-performance through eco-supply chain management. In this paper we explore possibilities for the integration of eco-performance into the electronic component selection process with particular emphasis on hazard potential and life cycle cost.

2 Ecodesign Decision-Making

Decision-making is fundamental to the ecodesign process. For many ecodesign practices and strategies decisions can be relatively straightforward and both the environmental and financial benefits are clearly evident. An example is mass minimisation for mechanical components of a product. It is logical to assume that reducing material input will result in reduced inventory for product manufacture (reduced product cost) and reduced resource use, therefore environmental performance improvement. Other examples include reduction in material type, improved "use" phase energy efficiency and hazardous material avoidance.

Some decisions however, are more difficult with the benefits less obvious due to complexities in the interpretation of environmental impacts, thus requiring trade-offs to be made. Examples are material and component selection. The electronics product ecodesign decision-maker needs to consider the environmental impacts associated with the decision on a life cycle basis and also the economic considerations. Ecodesign and life cycle assessment tools can provide assistance through knowledge, information and analysis to assist the ecodesign decision-maker. The tools can provide environmental evaluations of product design decisions indicating where improvements could be made. Difficulties, though, arise in the "eco-selection" of both materials for mechanical parts and components for electronic construction in electronics products.

Ecodesign practices such as "select recycled and recyclable materials" and "avoid hazardous materials", if adopted, are difficult to implement if material composition data are not available for materials and components. LCA tools are data dependent and would require LCA or LCI data on components from different suppliers for any comparative selection process to be used. LCI and LCA data are notoriously difficult to obtain. Electronics ecodesign or product life cycle management would benefit from a flexible component eco-selection tool using more readily available data that also considers end-of-life economic issues. Product data issues are discussed in the next section.

Component and mechanical part "eco-selection" assumes that eco-performance can provide differentiation between components with the same functionality, from different suppliers, in addition to factors such as cost, reliability and supplier company performance issues. The contribution of the eco-performance of the component will have on the decision to select it will depend on the individual company's degree of commitment to ecodesign or improved environmental performance. Eco-performance has to compete particularly with quality, reliability, technology and cost. The consideration of full life cycle cost is becoming increasingly important. Components with less hazardous materials and improved recyclability or re-use potential could have cost benefits at end-of-first-life. These benefits could off-set any "up-front" higher purchase costs for components with improved environmental performance.

The proactive electronics company will seek to explore opportunities to improve component eco-performance through active supply chain partnerships. Supply base reduction strategies throughout the electronics industry will result in opportunities for strong partnership building but such strategies will also restrict component sourcing opportunities and perhaps, therefore, access to eco-innovation. This could lead to increased benchmarking by component users and subsequent pressure being applied to suppliers for improved product eco-performance.

3 Component "Eco-Selection" Decision-Makers

Three core groups of decision-makers for component selection can be identified:

- Designers
- Component Engineering Qualification Groups
- Manufacturing supply management groups (purchasers)

Discussions with design groups within Nortel Networks have revealed that because of the time to market pressures regarding new product introduction, designers would prefer that any form of component eco-evaluation be made before components are made available for use in design. Hardware (electrical) designers focus primarily on functionality. Components are selected from a database of components that have been pre-approved from preferred suppliers according to a range of criteria by the component engineering group. Components not available in the database are recommended by the designer and are subsequently subjected to the approval process. Designers do not have the time to evaluate the eco-performance of components and to consider possible alternatives.

The component engineering qualification group does have an opportunity to consider the eco-performance of components during the qualification process, particularly for new technologies, and to capture "eco-evaluations" and document them by posting the evaluations as a feature of the component attribute dataset in the component database. Currently the component engineering group uses supplier environmental assessment information obtained through the supply management function to screen a supplier's environmental performance. The supplier environmental assessment procedure has recently undergone a review and development phase. The new procedure includes a section that addresses product specific eco-issues. The strategy will be outlined in section five. The research presented in this paper seeks to assess the feasibility of going beyond simple compliance declarations and on to a comprehensive supply chain materials management approach.

Manufacturing supply management groups also have an opportunity to make component "eco-selections" in the selection of components to complete a bill of materials for a production run. Components are multi-sourced from different approved suppliers. It may be possible to differentiate between suppliers of components on an environmental performance level (company and product) as most preferred suppliers would meet minimum requirements on quality, delivery, service, cost, business risk, and technology.

4 Product Data

Making any kind of eco-performance evaluation of electronic components and materials requires data. To benchmark components or to differentiate between suppliers (and to provide accurate product material profiles for customers and end-of-life management), data on components specific to each supplier are required. Industry averaged data that are available in ecodesign, LCA and product databases do not capture the differences that may exist between component material composition and production techniques between one supplier and another.

The type of data that can be used for eco-evaluations can be categorised as follows [1]:

A. Generic hazardous material declaration
B. Product specific hazardous material declaration
C. Total material content declaration
D. Life cycle data including material composition

Previous research has indicated that data availability varies greatly and data are generally difficult to obtain [1,2]. In **Figure 1** we attempt to demonstrate the availability and utility of data type.

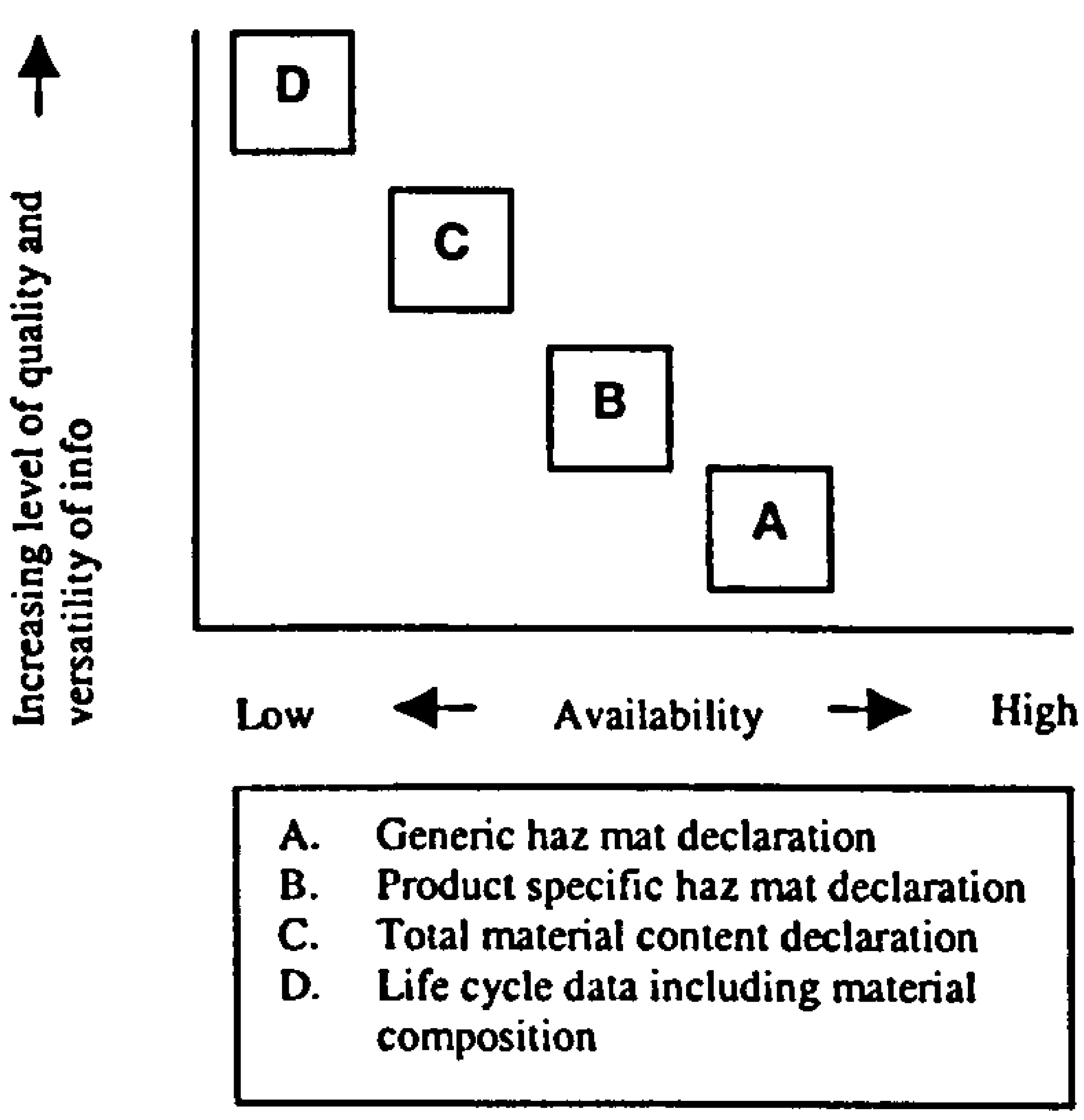

Fig. 1. Data Utility and Availability

Ideally, full material composition would be available accompanied by LCA or LCI data. The life cycle data would enable an eco-evaluation of the production process also to be considered. This is an important consideration but the probability of obtaining detailed production process environmental burden data for each supplier is low. Suppliers generally consider such data as commercially sensitive, particularly yield data. This is despite the fact that many component suppliers suggest that component production technology is common across the industry. Variations in production techniques are likely to exist but identifying them is particularly difficult. Nagel has developed a supply line engineering methodology that attempts to incorporate production process environmental burdens [3,4].

Total material composition data would facilitate the identification of hazardous materials present in the component and provide information for assessing its "re-usability" or "recyclability". It would also facilitate the generation of Nortel Networks product material composition profiles for legislative compliance, customer requests and end-of-life management.

Product specific hazardous material declarations enable hazard-based eco-evaluations and Nortel Networks product hazardous material declarations to be made. They also provide data for end-of-life management.

Generic hazardous material declarations that are generally negative e.g. "our products do not contain asbestos" are of limited value although they are useful as an initial screen and for minimal compliance.

In a previous study a selection of suppliers were asked what type of product material data they could provide. **Figure 2** shows the results. The first target score is hazardous material content and the preferred target score is total material content and end-of-life recommendations. From this relatively small selection of suppliers, covering a range of commodities, it can be seen that data availability varies greatly. Example data were also requested from the suppliers. **Figure 3** presents a comparison of total material composition of Plastic Leaded Chip Carriers from four suppliers.

It can be seen from the data in Figure 3 that component material content can vary between suppliers. The variation may be due to uncertainties and differences in material identification techniques. The techniques used would have to be compared and evaluated. Generally the data provided by suppliers has to be considered accurate. Data could be validated by way of an audit if necessary. The variation in material content supports the theory that an eco-evaluation based on material content could provide a differentiating factor for components from different suppliers. How can components be eco-evaluated?

The evaluation is based upon the sum of the toxicity ranking scores for each material. The ranking scores

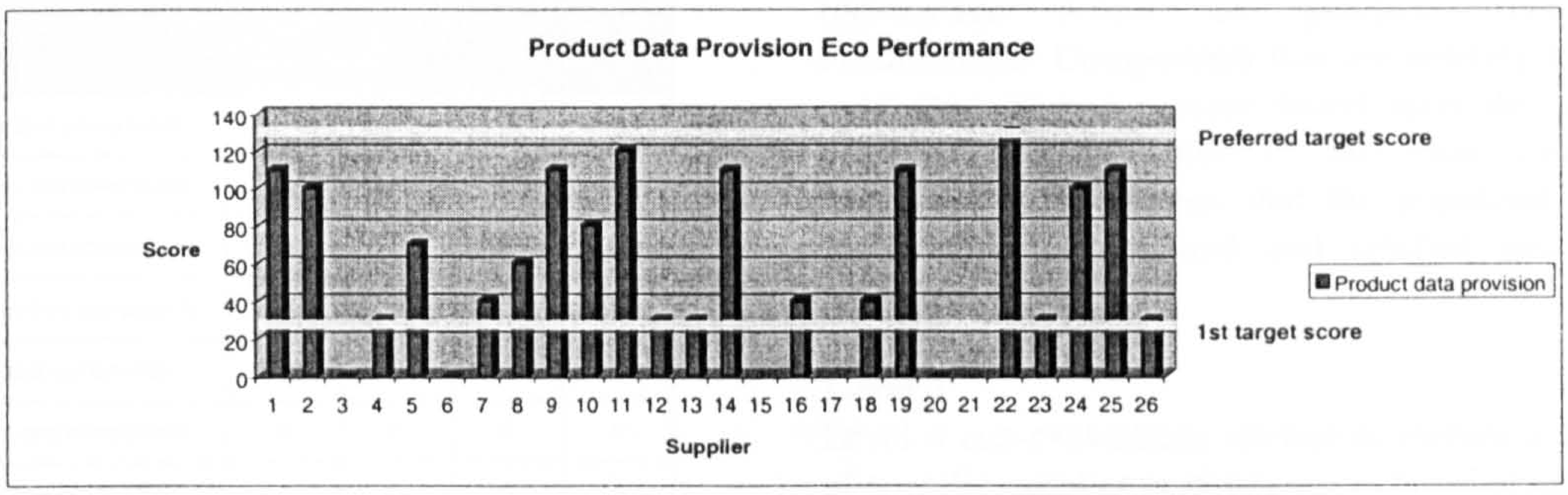

Figure 2. Supplier Product Data Provision Scores

5 Component Eco-Evaluation

Based on potentially available material content data an eco-evaluation method hierarchy is presented for component eco-evaluation qualification (see **Figure 4**.). At the time of writing the individual eco-evaluation methods have not been fully realised. Refined methods and examples of application will be provided at the conference.

Level 1

Level 1 eco-evaluations consist of the setting of prescriptive minimum requirements regarding the absence of specified hazardous materials in components. This has become a common approach in the electronics industry with companies setting material constraints for suppliers that revolve around one or two lists of banned and restricted substances. The banned and restricted substances may actually be banned or restricted under regional or international law or may be targeted for banning or restriction. Some of the restricted substances on company lists will be considered harmful to the environment due to available documented evidence and are open for negotiation between customer and supplier. The focus of a Level 1 eco-evaluation is essentially hazardous material compliance. Nortel Networks are currently implementing a supplier product hazardous material declaration as part of supplier eco-assessments. This ensures compliance with current hazardous material regulations and anticipatory compliance with the EU WEEE (Waste from Electrical and Electronic Equipment) Directive [5] material bans.

Level 2

Level 2 eco-evaluations focus on the intrinsic hazardous nature of the materials within a component.

include toxicity to human health and ecological toxicity. It is difficult to include likelihood of exposure and therefore generate a risk-based evaluation in a component selection scenario because of the uncertainty concerning the fate of the component. Examples of ranking systems for toxicity that could be used include:

i) the US EPA's toxicity weight risk screening environmental indicators based on chronic health effects;
ii) the University of Tennessee's (UTN) chemical hazard evaluation method based on a chemical's acute toxicity, chronic toxicity and indications that a chemical can cause multiple adverse health effects;
iii) the UTN ecological and total hazard scores;
iv) the Indiana Relative Chemical Hazard Ranking System.

These methods generally generate relative ranking scores for each material and have primarily been developed to assist decision-making for chemicals management and pollution control. The approaches can be adapted for use as part of a component hazardous material ranking system for eco-evaluation. One limitation may be the lack of availability of data on certain materials and the hazard evaluation is simply additive for the presence of multiple materials and cannot consider the hazard potential of materials in combination in their state as an electronic component.

Level 3

Level 3 eco-evaluations combine the hazardous material ranking scores with a material re-use score.

Material	Percentage by weight			
	Supplier A	Supplier B	Supplier C	Supplier D
Arsenic and compounds	0	0	0	trace
Beryllium and compounds	0	0	0	0
Cadmium and compounds	0	0	0	trace
Chromium (VI) compounds	0	0	0	0
Lead and compounds	0.28	0.08	0.27	0.02
Mercury and compounds	0	0	0	0
Nickel and compounds	0	0	0	0
Halogenated Flame Retardants	1.08	-0.66	2.05	0.74
Ozone Depleting Substances: (HCFCs, other) please	0	0	0	0
PVC	0	0	0	0
Poly-chlorinated byphenyls (PCB)	0	0	0	0
Polybrominated byphenyls (PBB)	0	0	0	0
Polybrominated di-phenyl-ethers (PBDE)	0	0	0	0
Chlorinated Hydrocarbons (Chloroparrafins, other)	0	0	0	0
Nonyl-phenol-etoxilates (NPE)	0	0	0	0
Aluminum Metal/Alloy	0.00	0.01	0.00	0.00
Aluminum Oxides	0.00	0.00	0.00	0.00
Antimony Compounds	2.24	1.32	part of flame retardant	1.11
Carbon Black	0.19	0.00	0.02	0?
Chromium	0.00	0.00	0.00	0.00
Cobalt	0.00	0.00	0.00	0.00
Copper	20.96	31.33	34.60	24.50
Gold	0.09	0.07	0.07	0.10
Iron	0.51	0.77	0.72	0.50
Palladium	0.00	0.00	0.00	0.00
Resins	14.93	17.91	13.00	18.90
Silica	55.88	46.26	43.67	53.28
Silicon	1.73	0.91	2.93	0.89
Siloxanes	0.00	0.00	0.00	0.00
Silver	0.47	0.21	1.35	0.07
Tin	1.15	0.44	1.13	0.08
Zinc	0.00	0.00	0.03	0.00
Phosphorous	0.00	0.03	0.00	trace
Total component weight (mg)	2237.0	2300.0	3000.0	2340.0
Total percentage approx	99.50	99.34	99.84	100.19

Figure 3. Component Material Content (PLCC44)

The material re-use score is based upon the potential of the component to be re-used at the estimated product end-of-life, predicted re-sale values (percentage return on purchase cost) and obsolescence. Components that are unlikely to be re-used are assigned a score based upon the additive, predicted recycle value of the main constituent materials. This assumes that the populated printed circuit board is ground and smelted and metals recovered.

Level 4

Level 4 eco-evaluations attempt to include a measure of specific supplier performance in terms of ecodesign implementation and product environmental impact considerations at the company, to try and capture more general eco-performance issues associated with component design and manufacture.

The intention is to complete the research on the eco-evaluation methodologies and to provide example results with applications and a feasibility assessment at the conference.

6 Discussion

In terms of simplicity and feasibility in electronics component eco-selection, a declaration of what is definitely not in a component is preferable (Level 1 eco-evaluation). This should ensure regulatory compliance as long as the appropriate lists of banned or restricted materials is maintained. This is supported by Simon and Yender (1997) [2] and requires a minimum exchange of information between the supplier and the customer. This approach is currently supported by Nortel Networks.

However, to support advanced product life cycle management decision-making, particularly in terms of component or product eco-performance and life cycle costing, a more comprehensive eco-evaluation is required such as those proposed in methods 2 through 4 as described in section 5.

The main issue with the proposed methods is data availability. Until component material composition data are readily available it will be difficult to conduct any of the suggested evaluations. It is also acknowledged that significant data capture and management systems would need to be in place and ideally an industry standard format for material composition declarations would be required. One element of the research project has focused on the development of a web-based supplier product eco-

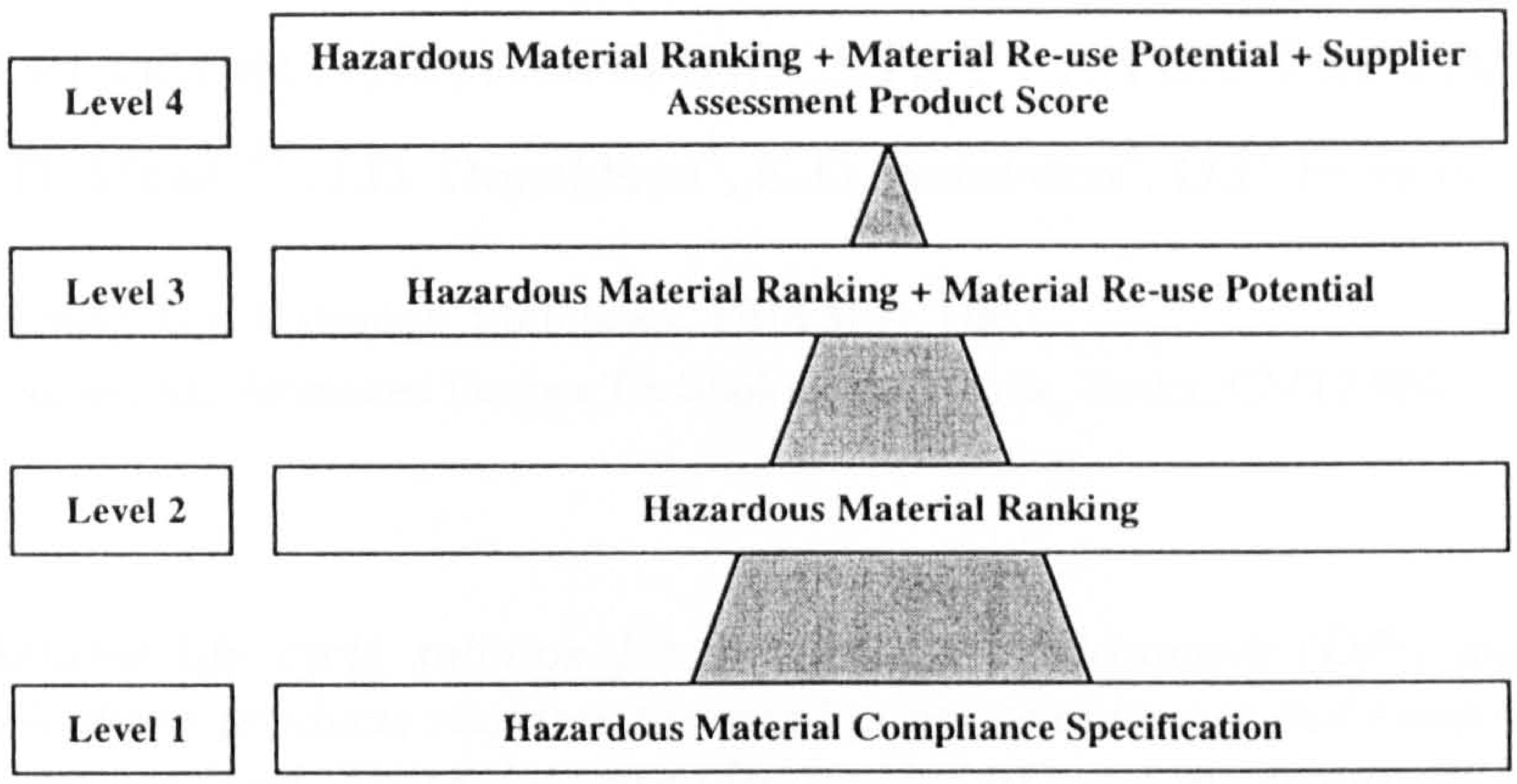

Figure 4. Component Eco-Evaluation Hierarchy

data capture and management system. A beta prototype is complete.

For many relatively simple component types there may be little, if any, difference in material composition between suppliers, which negates any opportunity for differentiation. For more complex and new technology components though, there may be an opportunity for suppliers to demonstrate superior eco-performance. Integrated circuits and connectors are two component types that could exhibit significant eco-performance differences and provide value at end-of-first-life.

One problem that does arise in the generation of Nortel Networks product material profiles from supplier data, is the tracking of component data through the bill of materials generation and the manufacturing stage. The bill of materials is based on functionality and does not currently identify specific suppliers as output. To overcome this problem it would be possible to add an eco-risk field to the bill of materials output specifying preferred suppliers based on eco-performance for each item. It would also be possible to capture material data in the component database and collate it with a modification to current internal data management systems.

The production-related supply base of Nortel Networks is also rapidly changing with a strategic move to reducing the supply base and increased outsourcing of PCB and sub-assembly manufacture to contract electronics manufacturing service (EMS) vendors. This is a move that is currently common in the electronics industry. This strategy will make material content and management more complex and will necessitate a close partnership approach between Nortel Networks and EMS vendors. A minimum requirement of EMS vendors would be a compliance-based declaration of what is not in the product. The strategy also drives strong partnership development between Nortel Networks and core component suppliers that could result in the benefits of aligning environmental goals and objectives through the supply chain, particularly eco-technology development.

7. Conclusions

The research presented in this paper focuses on the development of methodologies for improved component selection in ecodesign or product life cycle management. It is suggested that component and supplier eco-performance could be differentiators in the component selection process or if this is not the case, eco-evaluations of components could be utilised in end-of-life product cost/value predictions. A hierarchy of component eco-evaluation methods has been proposed. The methods attempt to go beyond mere regulatory compliance and consider the hazardous nature of components and the potential for material recovery beyond first use. The next step is to fully develop and refine the methods. Preliminary results will be presented at the conference.

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PRODUCT ENVIRONMENTAL DATA MINING IN THE TELECOMMUNICATIONS INDUSTRY – A PERSPECTIVE

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·Abstract

A comprehensive life cycle solution for Design for Environment (DfE) and within telecommunications products requires the availability of accurate and comprehensive data at component level. These data are also needed to meet the requirements of the proposed European Waste from Electrical and Electronic Equipment Directive and customer information requests. Many databases use generic data for the component bill of materials, hazardous material presence, and environmental impact evaluation. The research described in this paper shows that these generic data do not meet the requirements of a comprehensive Product Life Cycle Management (PLCM) solution particularly for the selection of environmentally preferable components in DfE, satisfying customer requests for product environmental information and determining end-of-life options.

It is suggested that only product specific data direct from the supply base can meet the requirements of PLCM. Capturing the data involves considerable time and resource allocation and significant interaction between complex data management systems. Implementation of a product environmental data management system needs to be considered within the context of any company strategy regarding product environmental performance. It must suit the needs of the company if it is to be effective.

Solutions to the problems of supplier data retrieval, data transfer, the communication of component level environmental data to customers, and determining end-of-life strategies are proposed. Strategies for integrating environmental criteria into component and supplier selection and the role of designers, procurers and component qualifiers in the decision-making process are discussed.

Key words: supply chain management, Design for Environment, data management, product environmental performance, telecommunications

I. Introduction

The research described in this paper is a component of a programme at Nortel Networks aimed at investigating systems for data exchange and product environmental information management throughout the product life cycle and methods to improve product environmental performance.

This part of the research focuses on the development of solutions to the product environmental performance and information transfer challenges currently faced by manufacturers of electronic equipment. These include meeting the requirements of stringent product environmental legislation and customer requests for product environmental information. A situation analysis is provided and solutions are proposed to some of the problems discussed. The structure of a proposed product environmental information management system at Nortel Networks to meet the challenges is illustrated in Fig.1.

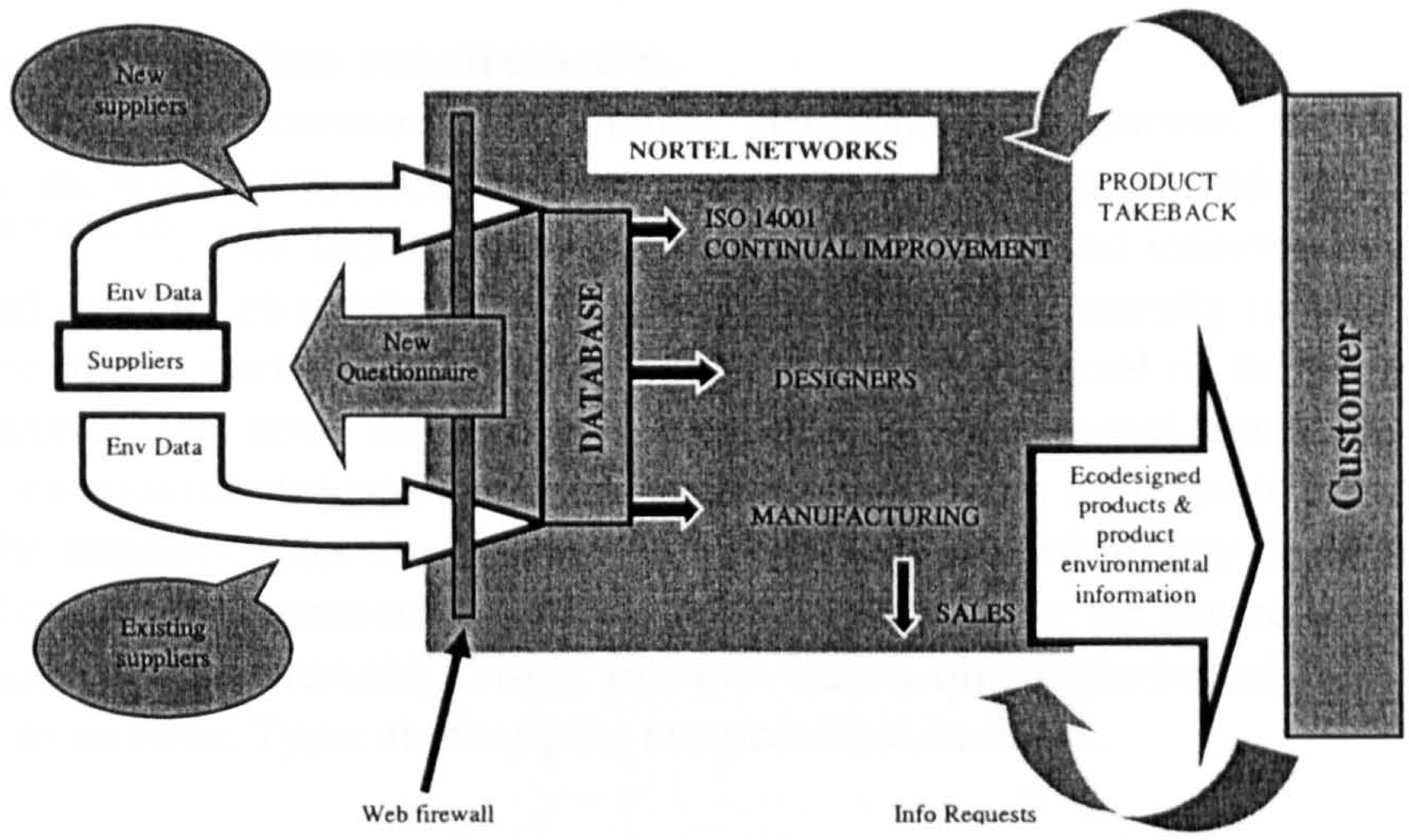

Fig 1.0 Product Environmental Information Management System

II. Background

The focus of environmental initiatives and practices in major electronics companies has changed progressively in the last decade from corporate, company or site based environmental management initiatives to product-based initiatives that strive for improved product environmental performance.

In terms of environmental management it has now largely become a standard requirement of major electronics companies to have an established working Environmental Management System (EMS) in place including an environmental policy with objectives and targets. Increasingly the company environmental performance benchmark is seen as ISO 14001 accreditation. The ISO 14001 requirement of continual improvement, the increasing stringency of product-focused environmental legislation and customer demands for "greener" products has resulted in the need for electronics companies to improve product environmental performance throughout the life cycle (product stewardship). This means adopting the principles of DfE and integrating green design practices into the established product development process by using appropriate DfE tools. It also means developing close and interactive relationships with both customers and suppliers (core stakeholders) to ensure product environmental objectives are transparent both up and down the product lifecycle chain.

DfE practices have now become well established in the electronics industry and many companies have implemented DfE programmes[1-5]. In addition supply management environmental initiatives and customer interaction programmes have also been widely developed [6-12]. Many of the product environmental challenges that electronic equipment manufacturers face are industry-wide but solutions need to be tailored to the systems, structures and cultures of individual companies and their business partners. The solutions presented here are focused on the needs of Nortel Networks but may be appropriate to other electronic equipment manufacturers.

III. Recognising the Need – The Drivers

A. Customer information requirements

Nortel Networks, in common with many electronics equipment manufacturers, receives an increasing number of requests for environmental information from customers [8,9 and 12]. The requests are for increasingly detailed information on both company and product environmental performance. They are usually in the form of a questionnaire that is part of the bid for contract process. Several of the customers of Nortel Networks are now using the answers to environmental questionnaires to generate an environmental performance score for suppliers and use it as one of the criteria in the supplier selection process. Customers are particularly concerned with the material content of purchased products (more specifically the presence or absence of certain hazardous materials). Some product-based questions asked by customers are difficult to answer. Typical examples are provided in Fig.2.

Questions/Requirements
Does the product contain any substances or material, that, at the end of its useful life would be classified as hazardous waste?
Substances which shall not be incorporated in operational and control equipment: (list provided by customer)
Does the product contain any substance listed by (list provided by customer)?
Specify per product in respective category up to 98% of total weight and volume the materials/combination of materials that constitute the largest part.

Fig.2 Typical Product Questions/Requirements In Customer Assessment Questionnaires.

B. Legislation

The quantity, diversity and complexity of environmental legislation continues to increase and there is a distinct change in focus from process-manufacturing-based legislation to that which is product/service-based. The most notable being the proposed EU Directive on Waste from Electrical and Electronic Equipment ("WEEE Directive")[23].

The impact of the WEEE Directive on the operations of individual electronics manufacturing companies will not be completely clear until it is finalised. It is evident, however, that it will result in sweeping, radical change. Significant requirements of the Directive include the targets for equipment recovery and recycling, the phasing-out of specified substances by 2004, the removal of certain substances before end-of-life actions and the provision of detailed product information to recyclers. Meeting many of the requirements of the WEEE Directive will necessitate the development of some form of a product environmental information management system in the companies effected.

IV. Situation Analysis

A situation analysis has been conducted to determine the scale of the problem that Nortel Networks could be facing. The aim was to identify exactly what information was required to answer customer requests, to meet the requirements of the WEEE Directive and to support DfE initiatives.

To identify the information requirements of customers a selection of environmental questionnaires received from customers was analysed. Many customers request information on both environmental management programmes and products. Nortel Networks has been in a very strong position on environmental management programmes for some time so it is a relatively simple task to complete this set of questions. It is, however, considerably more difficult to provide product specific environmental performance data and particularly complete material composition data.

It is clear that from an analysis of the proposals in the WEEE Directive and customer requests for environmental information, that the current problem area is product material composition data and particularly the presence or not of hazardous materials. The next step was to generate solution scenarios to the problem of identifying the material composition of the components in the products of Nortel Networks and communicating the information to customers.

V. Solutions

Four solutions to the problem of product data capture have been considered:

- Database A - component life cycle inventory-based data used for DfE;
- Database B – component environmental specification data;
- Supplier Data – Nortel Networks specific; and
- Supplier Data – industry collaboration.

A simple evaluation of the four solutions in terms of their cost and effectiveness in resolving the data capture problem is illustrated in Fig.3. Detailed evaluation is provided in the next section. Once the data are available they still need to be transferred to the design communities, manufacturing, sales and finally to the customer. Proposals for such a system are provided in section VII and illustrated in Fig.1.

VI. Data Capture and Availability Solutions Evaluation

Each of the four solutions were evaluated by asking the following questions:

1) Are the data the appropriate data (component specific material composition)?
2) How comprehensive are the data in terms of components covered?
3) Are the data easily available?
4) What are the costs of data capture?
5) Can the data be readily updated?

For solutions 1 and 2 the components were selected because they were either identified as being a potential customer specification compliance issue or are just random examples of components.

A. Solution 1 - Database A

Database A is a commercially available database of components and materials used in the electronics industry. It is supplied as part of a DfE software tool. The default categories for product data are: materials in composition; Life Cycle Inventory (LCI) of raw materials; LCI of waste; LCI of air emissions; LCI of water emissions; additive materials in composition; and coating materials in composition. Fig.4 shows the data available on selected components from the database.

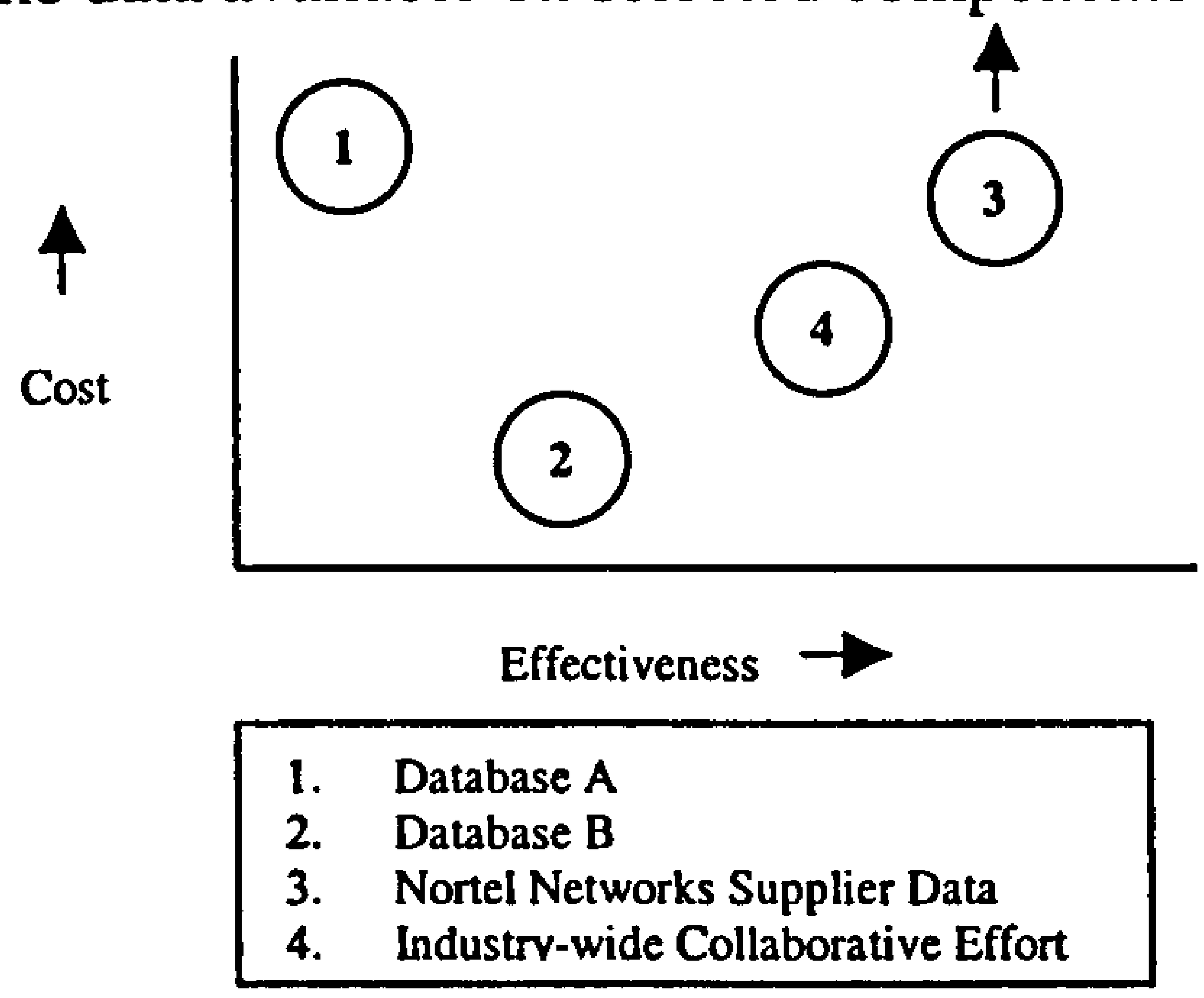

Fig. 3. Basic Evaluation of the Four Solutions

The database, as supplied, contains a limited amount of data on a limited number of electronic components. Only some of the components have material composition data and component data are incomplete as Fig.4 shows. In addition, the data are not comprehensive in terms of components covered. The database is readily available as it is part of a DfE software tool but because of this the data are relatively expensive. It is clear that the data available would not provide the detailed component information required, primarily because the data provided in this version are only representative of a few electronic components. There is, however, a facility for expanding the supplier and component specific data in the database and the latest version of the software contains specific hazardous material data.

B. Solution 2 - Database B

Database B is a commercially available database that provides data on a selection of electronic components. The data are given in a different format to that in Database A. The environmental specification data is presented in four sections: identification; component technology (including a construction schematic and material balance (organic, metal and ceramic)); problematic substances and materials; and resource aspects concerning discarding. Fig.5 shows the data available on selected components.

Database B contains detailed component material composition data, details of possible problematic substances and information on manufacture, assembly, disposal, and component recyclability data for a significant range of components. It also contains data on different types of components in the same family i.e. different specification capacitors.

	Material Composition	LCI of Raw Materials	LCI of waste	LCI of air emissions	LCI of water emissions	Additive materials in composite -on	Coating materials in composite -on	Non element-ary energy
Component I (Connector high current))	•	•	•	•	•	X	X	X
Component II (Connector low current)	X	X	X	X	X	X	X	X
Component III (Integrated circuit)	X	•	•	•	•	X	X	X
Component IV (diode – plastic body)	X	•	•	•	•	X	X	X

Fig.4. Example Component Data in Database

	Identification	Data Sheet	Constructio n Schematic	Materials Composition	Problematic Substances and Materials Data	Resource Aspects Concerning Discarding
Component I (transistor)	•	•	•	•	•	•
Component II (connector socket)	•	•	•	•	•	•
Component III (integrated circuit)	•	X	•	•	•	•
Component IV (aluminium electrolytic capacitor)	•	•	•	•	•	•

Fig.5 Example Component Data in Database B.

Data are available on a better selection of components than in Database A but the data still do not cover enough components or suppliers. However, the data on sample components have been taken from more than one supplier in some cases. The database is readily available at a low cost.

C. Solution 3 – Supplier Data (Nortel Networks specific)

Solution 3 involves capturing data from the suppliers of Nortel Networks. A programme was put in place to investigate this possibility. Potentially many of the product-based questions asked by customers of Nortel Networks can be answered by asking the suppliers similar questions and requesting product material composition data. An analysis was conducted to identify whether the current Nortel Networks supplier environmental assessment questionnaires developed for ISO 14001 asked the type of questions that would generate the information to answer customer questionnaires. Each questionnaire was scored relative to a

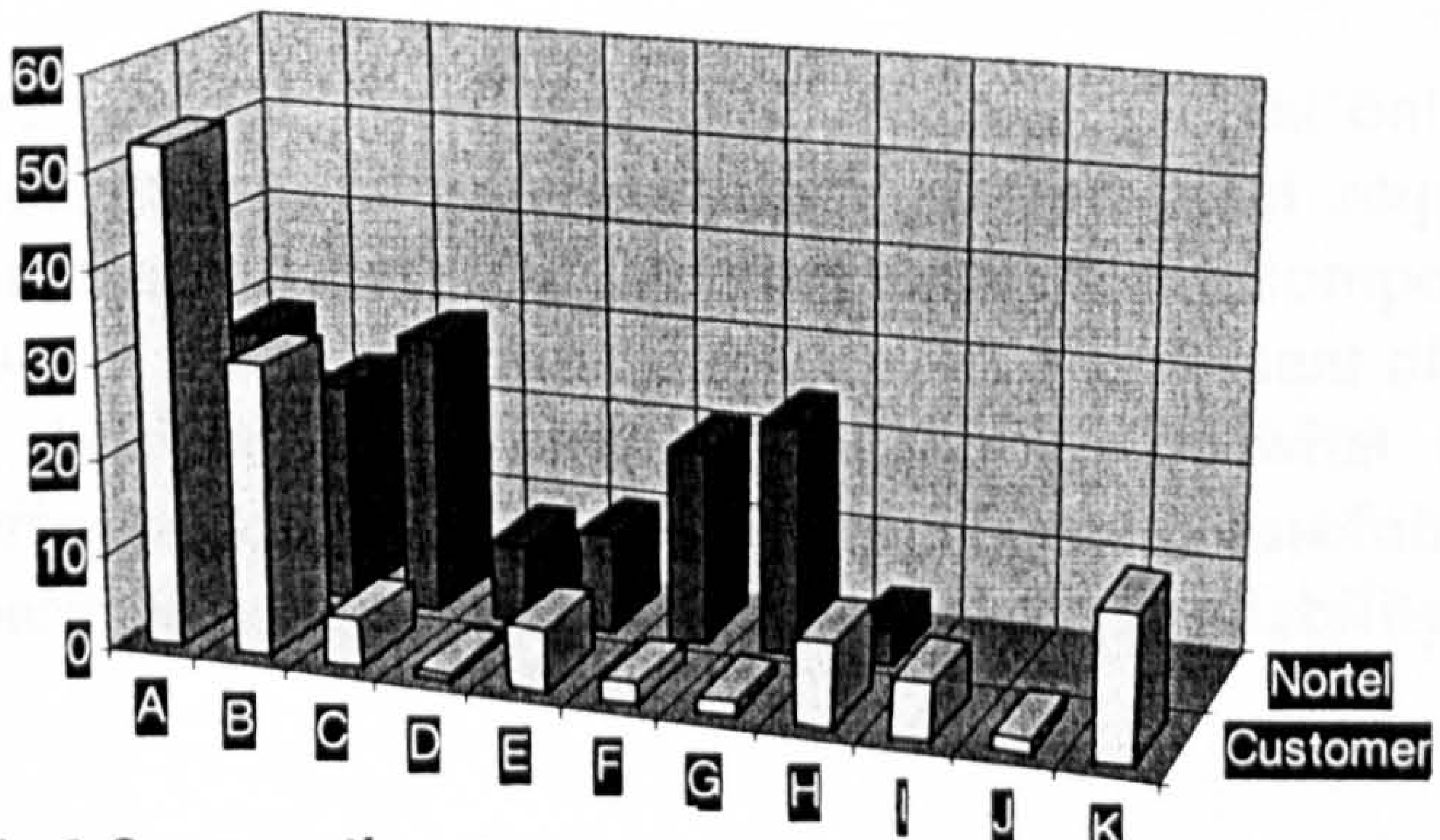

Fig.6 Comparative Scores for Questionnaires

customer benchmark standard questionnaire. The results are shown in Fig 6. Without revealing the origin of the questionnaires it can be seen that certain customer environmental questionnaires were considerably more comprehensive and scored higher than those used by Nortel Networks. The gap between the "best" customer questionnaire and the "best" Nortel Networks questionnaire for each category of question is shown in Fig.7.

Three new versions of a Nortel Networks supplier environmental assessment questionnaire were then developed that met the requirements of providing information for customers, WEEE Directive compliance, DfE, and ISO 14001 continual improvement. Selected suppliers were asked to complete and critically appraise the three different versions. The objective of the exercise was:

- to evaluate the questionnaires in terms of ease of completion and understanding by the supplier; and
- to provide an assessment of the level of product environmental information suppliers can provide.

The questionnaires consisted of sets of questions that are common to many supplier environmental assessment questionnaires, but each questionnaire also contained a specific detailed product environmental information section to complete also. This product section requested material composition data at component level and data on materials used in manufacture and emitted during use of the product. The response to the research from the suppliers was positive. They all valued open dialogue with their customer on these environmental issues as they were rarely provided feedback on how the information captured in questionnaires was used.

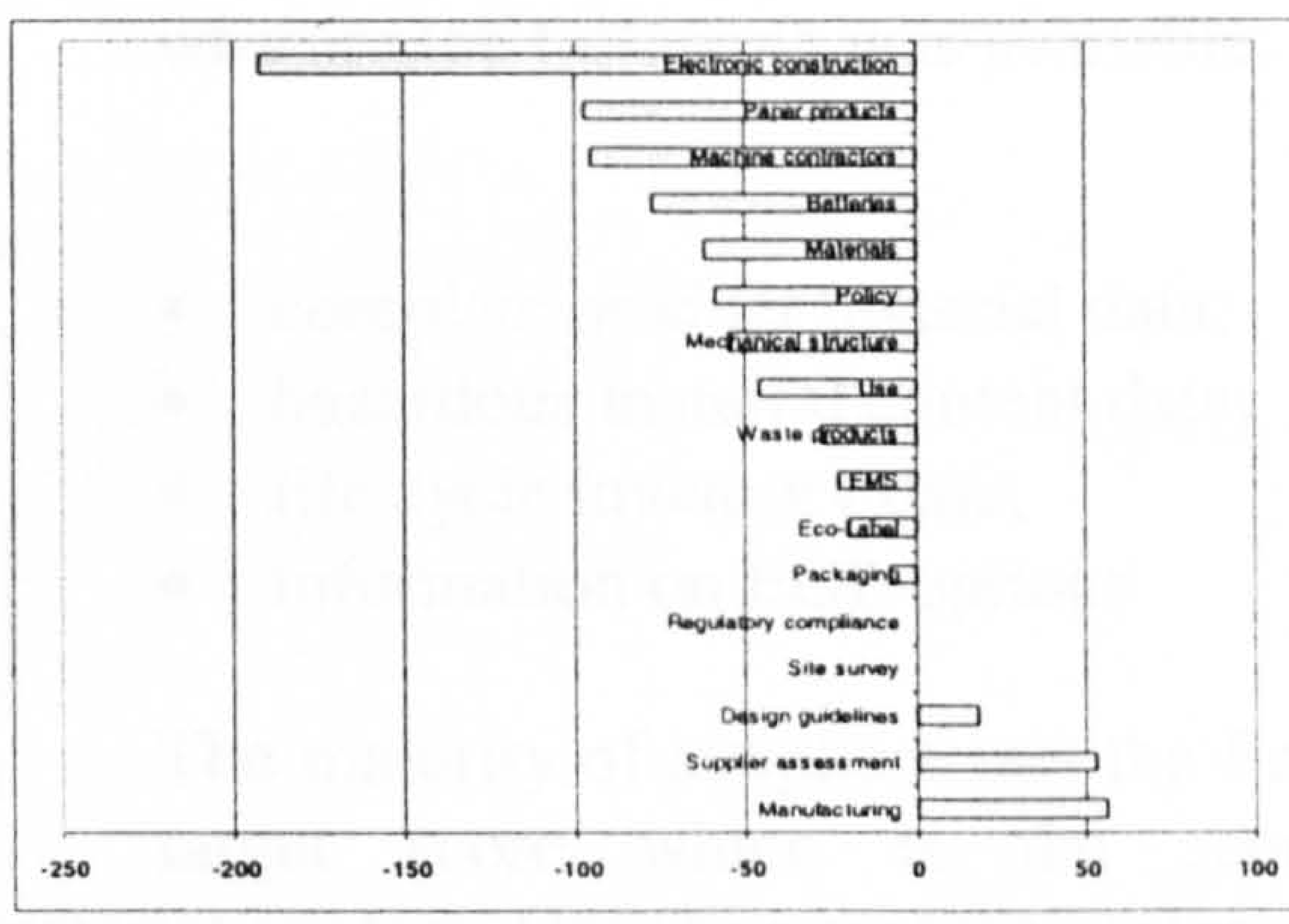

Fig.7 Performance Gap for "Best" Nortel Networks QuestionnaireCompared to "Best" Customer Questionnaire

A large amount of product information was requested through the product environmental questionnaires. Not surprisingly, the suppliers were initially surprised at the quantity and detail of data requested as no customer had actually requested detailed product information on all products supplied (thousands of components). They were, however, all prepared to provide as much information as they could and to develop collaborative programmes in an attempt to formulate a solution. The identification of the suppliers cannot be revealed but some feedback from three suppliers is provided in Fig.8.

The feedback from the suppliers suggests that only one of them is in a reasonably strong position to provide the product data requested (Supplier A has material composition data readily available on some components and is building its dataset). Two of the suppliers have generated a statement of generic composition (what is not in their products, what definitely is and what may be depending on customer performance requests). Fig.9 illustrates the "usefulness" of the type of data suppliers could provide and an indication of its availability. Hazardous material declaration meets some requirements but for Nortel Networks to be able to (1) answer every customers' request for hazardous material content (different customer/legislative lists), (2) select options for end-of-life (economic value of non-hazardous materials) and (3) drive towards the development of more environmentally friendly products, the data type has to move towards D in the diagram and the availability obviously has to increase.

	A	B	C
EMS in place?	•	•	•
DFE programmes running?	•	•	X (planned)
Material composition data available on all products?	X	X	X
Material composition data available on some products?	•	•	•
Systems being developed to obtain product specific data?	•	X	X
General product material composition data available?	•	•	X
LCA data available on any products?	X	•	X

Fig.8 Supplier Feedback

The next step was to select and finalise one of the questionnaires used in the first pilot study using feedback from the participating suppliers and feedback from groups within Nortel Networks. A scoring system was developed to enable a quantified evaluation of the question responses and the questionnaire was then sent to 24 suppliers of various commodities in an extended study. The comparative results for just the product data provision section of the questionnaire for each supplier is provided in Fig. 10. The scores for each supplier are total scores from the data provision section which consists of four questions with scores allocated to each. The suppliers were asked whether the following was available:

- complete product material data;
- hazardous material content data;
- life cycle inventory data;
- information on EOL options

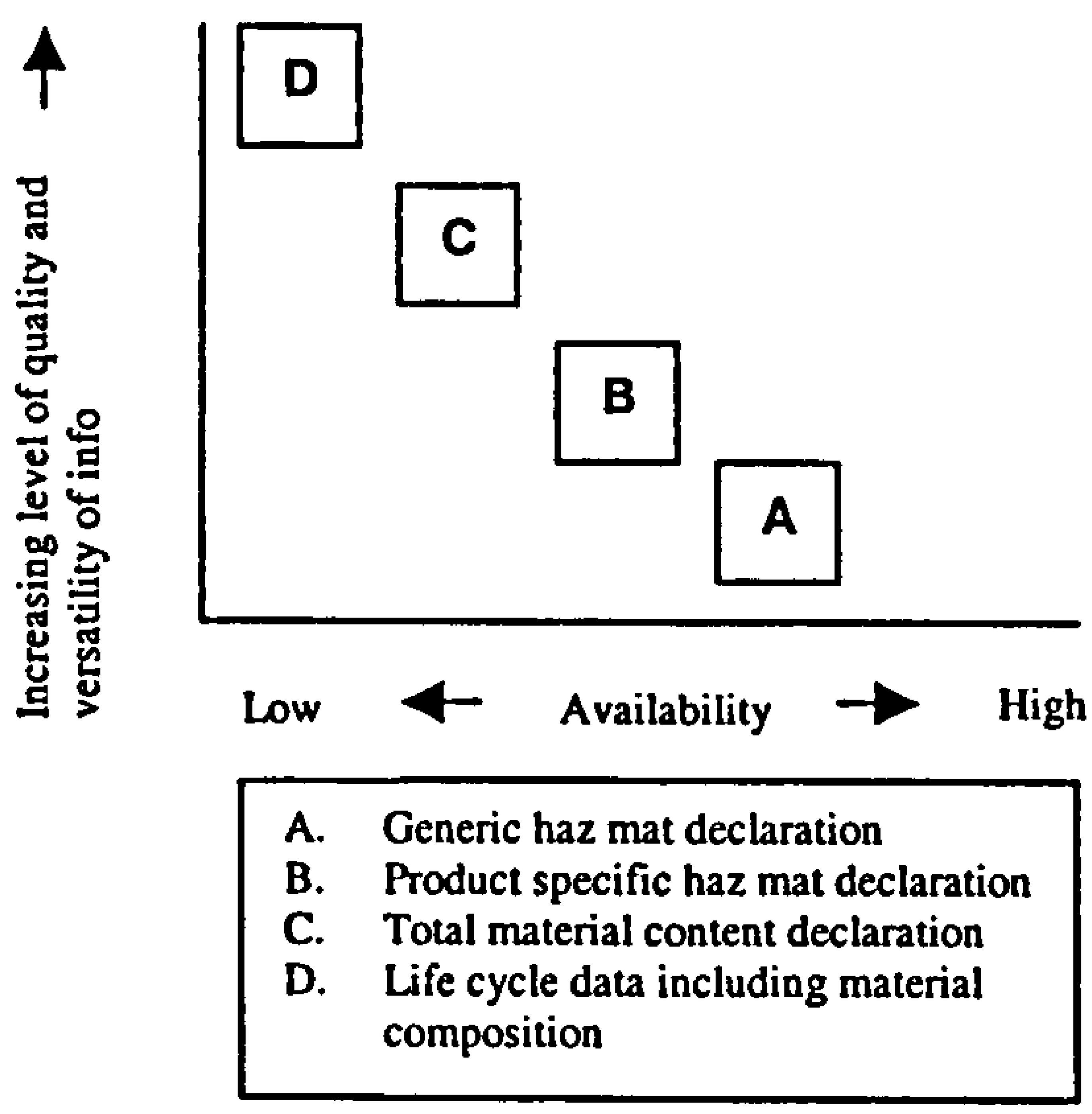

Fig. 9. Data Usefulness and Availability

The majority of suppliers met the first target score which is the score allocated for the provision of hazardous material content. Only two met the preferred score. Data on sample components was requested from each supplier. Only some suppliers could provide it. Suppliers will now be asked to provide the data that they specified for each component and it will be classified according to Fig. 9.

D. Solution 4 – Supplier Data (Industry Collaboration)

Solution 4 involves direct capturing of product environmental data from suppliers but the load is shared in a collaborative venture amongst electronic equipment manufacturers. This would require co-operation and would need agreement particularly on the format in which the data should be provided and method standardisation. The costs of data capture should be reduced but the effectiveness may also be reduced because data obtained by one electronics company may not be suitable for another (see Fig.3).

VII. Data Transfer Systems

Whatever component environmental data are captured they will have to be transferred through existing engineering systems within Nortel Networks and made available to sales teams at a product level before being released to customers. Systems for product data transfer from initial entry into Nortel Networks through the supply management function to the design community, ISO 14001 site primes, manufacturing sites and sales teams are being investigated. The systems architecture would map onto current systems already in place but the mapping, tracking and update of data is extremely complex. The cost and level of resource needed for the system to operate is unclear but will inevitably be substantial. Automation could reduce costs. It is envisaged that the data will be made available to customers and the information then returned with the product during takeback to facilitate end-of-life management options. Innovative methods of data capture and communicating environmental information to the customer are also being developed. The general information system architecture is presented in Fig.1.

VIII. Discussion

For some purposes (e.g. DfE guidance) generic, averaged or "ball park" product environmental data (Databases A and B) may be sufficient. However, requests for product environmental information from customers, product information requirements for the proposed WEEE Directive, ISO 14001 continual improvement and decision-making in DfE programmes all need detailed product environmental information and, specifically product material composition data. The results of analyses described in this paper suggest that the only truly effective way to obtain such data is direct from the suppliers themselves.

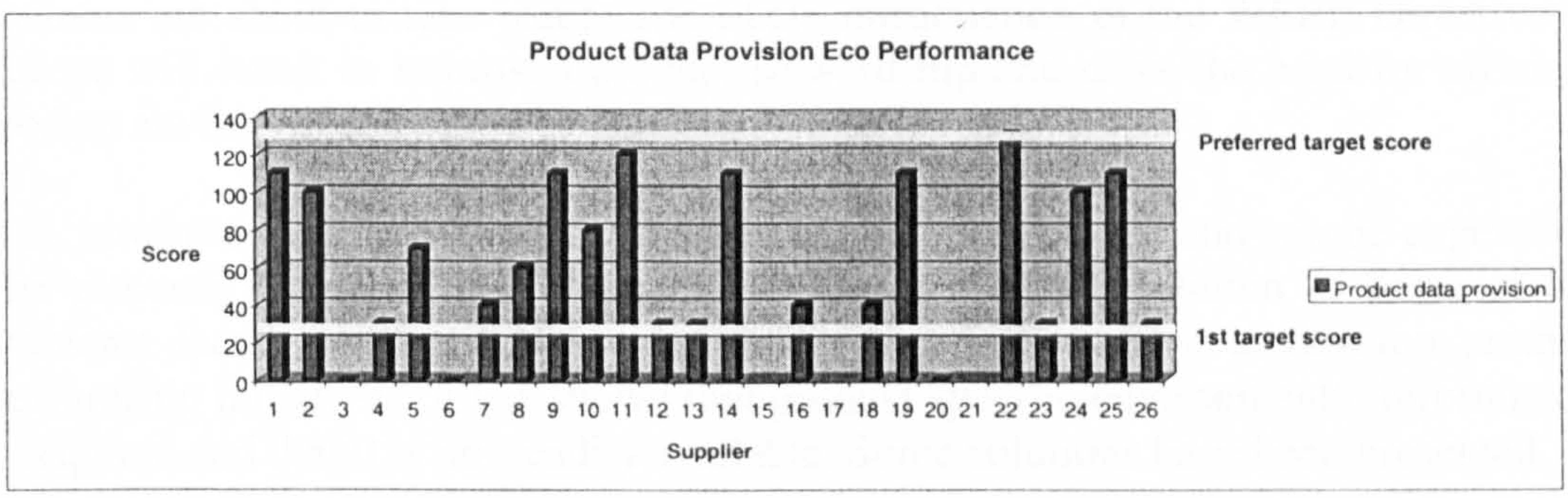

Fig. 10 Supplier Product Data Provision Scores

Initial findings from the questionnaire trial also show that suppliers are not currently in a position to be able to provide comprehensive component material composition data, but they are willing to work towards the provision of such data. There is clearly a need for focused and collaborative effort from final customer right throughout the supply chain and possibly collaborative work between competitors in the electronics industry.

It is reasonable to suggest that the capture of electronic component data should be a pre-competitive issue. It follows that perhaps no competitive advantage can be gained from improved product environmental performance and that it only becomes a differentiator between telecommunications products when all other things are equal. When all other things are not equal environmental performance improvement has to be a requirement. In terms of supplier assessment it is suggested that suppliers of electronic components should drive towards continual environmental performance improvement with the use of environmental management systems, the provision of product environmental data and improving product environmental performance. Environmental performance should, therefore, be removed from the competitive equation and become a standard requirement that is flexible enough to accommodate large corporations and SMEs (Small and Medium-sized Enterprises) alike. This requires careful appraisal of suppliers for the purposes of ISO 14001 and proactive support and development of the supply chain. It also requires careful appraisal of product environmental performance in the component selection process.

There is a need to evaluate components in terms of their environmental performance and to communicate appropriate findings to the supplier in order to identify areas for improvement that do not increase cost or alter reliability and functionality. This raises the issue of who should conduct component environmental evaluations – should it be a task for the designer, the component qualifiers or the procurers when the product is in manufacture? It is suggested that all the above should play a role. In addition, there is a need, of course to develop suitable tools for each to use. Designers and component qualifiers need to evaluate components and work with suppliers to ensure requirements are met for DfE and customer expectations. Procurers also need to communicate component environmental performance requirements to suppliers when procuring for manufacture. A simple tool to evaluate components against a set benchmark criteria or for comparative purposes would be a useful development. Research will continue in this area.

IX. Conclusions

Radical changes in the way manufacturers of electronic equipment conduct their business are about to take place. The likely introduction of the WEEE Directive in Europe will result in improved product stewardship and drive the need for efficient product environmental data management.

It is, however, well known that change is not easy to manage and can be expensive. The research discussed in this paper is a step towards a solution to some of the problems faced by Nortel Networks and is a proactive drive to develop product stewardship initiatives. It has shown that product specific environmental information is required and that it is not readily available. Some solutions have been presented.

The next steps in the research programme will involve further interaction with the supply base to enrich knowledge of data availability, evaluate manufacturing process technologies and component environmental performance, and to investigate the feasibility of data capture and transfer techniques for the system.

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SUPPLYING DESIGN FOR ENVIRONMENT IN THE TELECOMMUNICATIONS INDUSTRY

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Abstract

In the last decade the focus of environmental practices and initiatives within major companies in the telecommunications industry has subtly changed. This can be attributed partly to a progressive shift in focus of environmental legislation away from manufacturing processes to products and services but also to customer and market demands for environmentally preferable products. The challenge is to develop and supply products that have a reduced impact on the environment over the entire product life cycle, while remaining competitive in terms of cost and performance. This challenge can only be met by adopting a "Design for Environment" (DFE) approach at the start of the product development process.

Some of the key issues surrounding the development of DFE practices in the telecommunications industry are presented and discussed. The drivers for DFE and current DFE practices are outlined and the challenges of DFE implementation and the feasibility of using Life Cycle Assessment (LCA) in the product development process discussed.

The focus of the research project is integrating supply chain data into the DFE process. The final section of the paper deals with some of the research issues and outlines the problems and proposed solutions that will result in the improved environmental performance of Nortel products.

Key words: Design for Environment (DFE), LCA, environmental performance, system, telecommunications.

1 Introduction

Environmental policies and environmental management systems are firmly established in most market-leading companies in the telecommunications industry as an integral part of their commitment to environmental management. As organisations increasingly seek accreditation to environmental management system (EMS) standards such as ISO 14001 and EMAS, the range of EU product environmental legislation increases, and customer product specifications begin to include environmental performance, product design issues become increasingly important. A holistic, DFX (Design for "X") life cycle approach to product development is becoming a necessity. "X" is a suite of considerations including established ones such as assembly, manufacture, testability, regulatory compliance and installation but also environment (DFE) including upgradeability, disassembly, recycling, re-manufacture and many other environmental performance considerations.

This paper describes the drivers for DFE in the telecommunications industry which include: ISO 14001, customer requirements, and competitors. It outlines the principles of DFE and its relationship with Life Cycle Assessment (LCA). The importance of customer-supplier interaction throughout the supply chain is emphasised in a discussion of the research area which focuses on supply chain data management and the integration of supplier data into the product development process.

2 Drivers for DFE

DFE can be defined as "..systematic consideration of design performance with respect to environmental, health, and safety objectives over the full product and process life cycle"[3]. The aims are to produce safe and eco-efficient products and processes.

The key drivers for DFE in the telecommunications industry are:

- ISO 14001 Environmental Management Standard requirements (if accredited);
- European Union product legislation e.g. proposed "WEEE Directive";
- Customer requests for "greener" products and product environmental information; and
- Pressure from competitors.

2.1 ISO 14001

In most large telecommunications organisations that develop products, a significant function is research and development. This involves the designing of products and processes. For the EMS of a research and development site to achieve accreditation to ISO 14001 all significant environmental impacts of the activities on-site need to be identified, examined and evaluated. For an R&D site many of the significant impacts will be product related and therefore indirect. These may include: impacts associated with the production of materials used in the product; the energy consumption of the product in the use phase; and disposal.

The design phase of the life cycle has the greatest potential to influence the total environmental performance of the product. ISO 14001 requires the setting of environmental objectives and targets over a one to two year time-scale for the most significant environmental impacts. This can enable continual improvement to be demonstrated. For design activities this could mean targeting certain environmental impacts associated with products at some stage in their life cycle and adopting strategies to reduce them. It is clear that the implementation of a DFE programme will assist in meeting targets set for ISO 14001 compliance.

2.2 Environmental Legislation

Environmental legislation has a significant impact on the telecommunications industry and the way in which it conducts business. The quantity and diversity of legislation is increasing and there is a distinct change in focus from process manufacturing-based to product/service-based legislation. Examples include the various EU Directives on hazardous waste, particularly the "Batteries Directive"[2], various restrictions or bans on hazardous materials and most notably of all the proposal for an EU Directive on Waste from Electrical and Electronic Equipment ("WEEE Directive")[1].

These legislative pressures drive the need for DFE to be integrated into the product development process in the telecommunications industry. The WEEE Directive, when implemented, will have a significant effect on the way in which certain companies operate and will require a change in mindset away from the pure selling of products to product life cycle responsibility.

2.3 Customer Requests

A third driver for DFE in the telecommunications industry is customer requests for "greener" products and product environmental information. Customers are requesting increasingly detailed information on company and product environmental performance. The requests are usually in the form of a questionnaire that is part of the bid for contract process. Several of Nortel's customers are now using the answers to environmental questionnaires to generate an environmental performance score for suppliers.

A alternative approach to meeting customer requests for product environmental information is providing declarations of "product-related environmental attributes" endorsed by an industry association such as ECMA (Electronics and Computer Manufacture Association) or materials declarations. Such declarations can be considered the first generation of ecolabels for telecommunication equipment.

2.4 Competitor Pressure

Competitor activity is also an important driver for DFE. Companies that are proactive and market leaders will respond quickly to market demands and seek to develop new technologies, methods and products. Anticipation of customer requirements, market trends and new industry developments allows a company to be one step ahead of its competitors. Using a DFE approach in the development of products could result in the generation of new "breakthrough" green products and services. Product environmental performance may be a differentiator between products if all other criteria are equal. Some customers may even be willing to pay marginally more for an environmentally superior product particularly if it offers cost savings such as reduced energy consumption. As market leaders integrate DFE into their product development processes and establish a benchmark standard others are pressured into following suit.

All four drivers for DFE have influenced Nortel's DFE development programme and consequently assisted in the shaping of the research project.

The aims of the project are to develop a method of integrating supply chain environmental information with product development systems, to communicate component part environmental performance to the design community and to investigate optimum strategies for component part selection. The first stage of research involved: identifying customer information needs by questionnaire analysis; identifying designer information needs through open dialogue; and identifying the supplier information needed to meet the requirements of ISO 14001 through interaction with Nortel site ISO 14001 primes. The second stage involves the development of a suitable system for extracting environmental information from suppliers and testing it. The third stage will be the integration of the system into the DFE process, ISO14001 continual improvement programmes and customer request response systems. The fourth stage will involve the development of optimum component part selection strategies that are compatible with Nortel product development processes and purchasing procedures.

The project is focused on improving the environmental performance of Nortel products through DFE, meeting customer environmental information requests and providing data to support ISO 14001 certification.

3 DFE Principles

A comprehensive DFE approach for products will consist of the application of a combination of practices developed to improve eco-efficiency and perhaps to achieve a certain set environmental performance goals. Some practices result in improvements that are self-evident, others may require further analysis to establish the degree of improvement. The fundamental targets for the practices are reduction in resource use and reduction in pollution over the entire life cycle of the product while satisfying costs and performance requirements in order that the product remains competitive.

Fiksel [3] describes the core DFE practices as:

- Material substitution;
- Waste source reduction;
- Substance use reduction;
- Energy use reduction;
- Life extension;
- Design for separability and disassembly;
- Design for recyclability;
- Design for disposability;

- Design for re-usability;
- Design for remanufacture; and
- Design for energy recovery.

It is paramount that the chosen DFE practices are integrated into the existing design procedure to facilitate a holistic Design for "X" approach, where "X" is a design practice or consideration. This means that the designer needs to consider DFE practices in addition to established DFX considerations such as those suggested by Graedel and Allenby[4] which include: assembly, regulatory compliance, manufacturability, reliability and testability.

Graedel and Allenby[4] suggest that "the least difficult way to ensure that environmental principles are internalized into manufacturing activities in the short term is to develop and employ DFE as a module of existing DFX systems. Moreover, the fact that DFE is intended to be part of an existing design process acts as a salutary constraint, requiring that DFE methods and analysis be implementable in the real world".

This statement may be true, but the challenge lies in the training of designers in DFE principles, the provision of suitable tools that are compatible with existing Computer Aided Design (CAD) tools, and the development of a transparent procedure for product design environmental impact comparison which also minimises the effect on time to market.

4.0 DFE Implementation Challenges

Fiksel[3] suggests that "to perform DFE consistently and effectively is challenging for several reasons:

- The necessary environmental expertise is not widely available among product development engineers;
- The complex and open-ended nature of environmental phenomena makes them difficult to analyse; and

- The economic systems in which products are produced, used and recycled are much more difficult to understand and control than the products themselves."

The first point highlights the need for an extensive training programme in companies implementing DFE across the company design community as the majority of product designers have no formal training in environmental design issues. This illustrates the cross-functional nature of DFE. The environmental "expert" has to communicate environmental issues effectively to the design engineer.

The second point indicates the potential high complexity of DFE. The use of certain DFE initiatives in the design process, such as mass reduction, will undoubtedly contribute to the reduction in the environmental impact of the product. Many simple DFE practices can result in the improved environmental performance of products. The difficulties arise when the product itself is highly complex, when the total life cycle is considered or when two or more designs of the same product are compared.

If a total DFE approach is taken the decision-making process for improvement of product environmental performance becomes extremely complicated. Certain methods need to be used to aid the decision-making process and to balance a range of trade-offs.

One tool or technique which can be used as a component of DFE to address some of the difficulties is Life Cycle Assessment (LCA). LCA "systematically considers and quantifies the consumption of resources and the environmental impacts associated with a product or process. By considering the entire life cycle and the associated environmental burdens, LCA identifies opportunities to improve environmental performance."[5]

However, Hendrickson et al[5] have criticised LCA, highlighting several problems, including:

- Lack of comprehensive data for LCA;
- Data quality is not uniformly high;
- Defining problem boundaries for LCA is arbitrary and controversial;

- LCA is too expensive and slow for application in the design process;
- There is no single method that is universally accepted;
- Equally credible analyses can produce qualitatively different results;
- Modelling a new product or process is difficult and expensive; and
- LCA cannot capture the dynamics of changing markets and technologies.

A considerable amount of research on the development of LCA techniques is still being conducted both in academia and in industry to try to address some of these problems (ISO standardisation of LCA methodology). It is generally accepted that conducting a comprehensive product/process-specific LCA at the design stage may not be feasible. Particular emphasis in research in industry is placed on the development of "tools to do the job", such as streamlined, quick environmental performance evaluating tools incorporating varying degrees of LCA methodology (Hendrickson et al[5], Nissen et al[6] and Matzke et al[7]).

Other methods or techniques are available to the decision-maker in regard to ascertaining the environmental performance of a product or design. These include qualitative methods such as checklists and matrices and also environmental accounting. Qualitative methods have a number of obvious advantages over quantitative methods (e.g. LCA) - they are easier to apply, require minimal data and can be useful despite of large uncertainities[3].

5.0 Supplying DFE - Supplier /Customer Relationships

A comprehensive approach to DFE requires commitment and co-operation from suppliers throughout the supply chain. Supplier interaction is a focal point of the research project as environmental information from the supply chain is essential. An interaction programme with suppliers will be continually developed throughout the research facilitating exchange of information and ideas. Suppliers can provide Nortel with valuable information and Nortel can assist in the suppliers' technology development.

Specific product environmental performance requirements can be influenced by the end-user of an assembled product, environmental regulations and proactive company initiatives. The demand for environmentally improved products filters down through the supply chain. The approach that needs to be adopted and conveyed to the supply chain for both successful DFE and customer/supplier relationships is that the end-user, as a customer, is a customer of the entire supply chain. There is a need for close co-operation between suppliers and customers including an exchange of data, product environmental information and ideas. Figure 1 illustrates the flows of information between suppliers, Nortel and customers.

The supplier environmental questionnaire is the traditional means of determining the environmental performance of suppliers and gathering useful information. The questionnaires that Nortel receives from its customers vary greatly in content and detail. Some customers ask only very specific questions such as "What percentage of the product or packaging is recyclable", others ask a wide range of questions in varying detail on all aspects of a company's environmental performance. The questions are placed in categories which include environmental policy, environmental management systems, and product related questions on manufacturing processes, use, waste products, materials, packaging, mechanical and electronic structure and regulatory compliance. Some of the questions are DFE related but none of the customer questionnaires actually mention DFE or DFE programmes specifically.

The reasons why Nortel customers ask questions on environmental performance and how they actually use the requested information is also varied and unclear in some cases.

Evidence from customer feedback suggests the information is used:

- For EMS (ISO 14001) compliance;
- To assist in meeting targets and objectives;
- For supplier selection; and
- For "green marketing" initiatives.

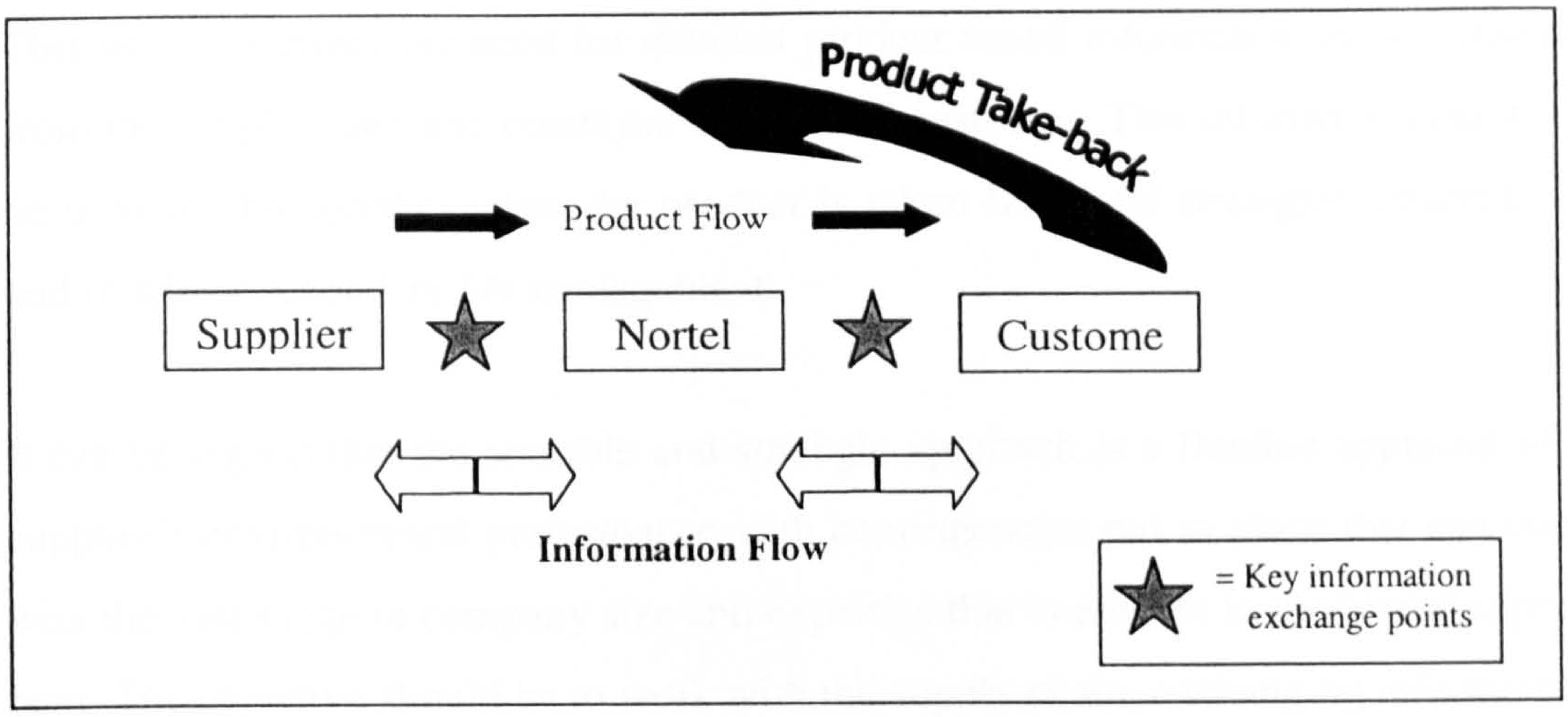

Figure 1. Environmental Information Flow

Several customers including Telia and Bell Canada are now analysing answers to questionnaires quantitatively and assigning a score for the supplier. Some have indicated that the environmental performance score will be used as one criteria in the supplier selection process. As far as the author is aware, no Nortel customer has specifically demanded that the company meets a certain level of environmental performance, apart from one customer requiring that the company was accredited to ISO 14001 as part of the bid process.

There is less evidence of the "big stick" approach being used in the telecommunications industry compared with companies such as B&Q, who in 1994 targets stated that "all suppliers had to have a meaningful environmental policy by the end of November 1994, or risk losing their business with B&Q."[8] Making definite demands certainly results in action but may not be the appropriate strategy in certain industrial sectors. This is particularly true when the supply base is extremely large.

At some point in the future, however, many large telecommunications organisations in the supply chain may be required to have ISO 14001 accredited management systems in place as the standard becomes a benchmark standard similar to ISO 9000. In this case becoming effectively a "license to conduct business". If this does become standard, product environmental performance could be considered a differentiator between products when all other criteria are equal, i.e. cost, quality and reliability. This situation drives the need for detailed product based information to be obtained from the supply chain and conveyed to the final customer. This information can then be used by the supplier when the product is taken back and strategies selected for end-of-life or secondary life management.

It can be argued that the sensible and strategic approach is a flexible appraisal of a supplier's environmental performance with contingencies put in place that can cope with the vast range in company size and expertise that is evident in the Nortel supply base. The objective should be to work with the supply chain, exchanging information and providing added value to all business partners such as the supplier providing accurate environmental product information to the customer and the customer participating in collaborative research programmes with the supplier e.g. "technology choices". Customer-supplier interaction programmes must also ensure that they are focused on the requirements of the market and final customer. This will mean, in Nortel's case that product take-back programmes are implemented.

Research is currently focused towards: identifying the information Nortel requires from suppliers; identifying the optimum method for collecting it; and how the information can be used to meet the requirements of Nortel customers, ISO 14001 and DFE initiatives. A gap analysis has been conducted to identify Nortel customer information requirements and consequently Nortel's requirements of the supply base. Work is now being conducted to determine ISO 14001 requirements, DFE requirements and the information collection system architecture.

6 Conclusions

In this paper the reasons for the need for DFE to be an integral component of the product design process in the telecommunications industry are explained. DFE principles have been outlined and the challenges for effective implementation discussed. The need for close co-operation between suppliers and customers has been emphasised in order to ensure the necessary transfer of environmental information through the supply chain and to the final customer. To be effective DFE requires the availability of accurate and comprehensive data. The present research will focus on developing a system to obtain the necessary data and communicate that data to those business functions within Nortel that can utilise it effectively. These groups include supply management, sales and marketing, designers, and ISO 14001 co-ordinators. Later research will concentrate on optimising methods of component selection in terms of environmental performance to further improve the DFE process.

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ECO-EVALUATION OF ELECTRONIC COMPONENTS FOR PRODUCT LIFE CYCLE MANAGEMENT DECISION-MAKING

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Abstract
Improving the environmental performance of telecommunications products can be achieved through the application of ecodesign and life cycle assessment tools during the design phase of products. Decision-making and selection trade-offs in component and material selection processes can present difficulties for both mechanical and hardware designers because of the short design cycles and "time to market" pressures.

Ideally components would be "eco-evaluated" (including life cycle costs/revenues) as a standard part of the component qualification process. This leaves the designer to freely select components and materials according to functionality knowing that environmental performance had been taken into account. Component selection decisions in terms of circuitry power management would, of course, be made by the designer. The main purpose of the evaluation is to provide an input to evaluating the eco-performance of Nortel Networks products and predicting end-of-life financial scenarios.

The development of a component eco-evaluation and predictive end-of-life cost/value procedure is introduced in this paper. The feasibility of integrating such a procedure into current processes for component selection at Nortel Networks is discussed. In addition the possibilities for implementation of a similar process by contract manufacturers is presented as the supply chain management strategy of Nortel Networks changes.

Improving product eco-performance, minimising costs over the life cycle, and extending material life through effective materials management are some of the aims of a research programme at Nortel Networks. The work presented in this paper is a step towards realising those aims and making a contribution to sustainability.

Keywords: Ecodesign, supply chain, components, eco-evaluation

1 Introduction
In the drive to develop telecommunications or network solutions with improved eco-performance there is a need to refine and tailor ecodesign and product life cycle management tools and strategies. Research at Nortel Networks and Brunel University is currently being conducted to investigate methods of component data capture, transfer through the life cycle and component eco-evaluation for improved product life cycle management and decision making. The aim is to develop opportunities for improving and communicating product eco-performance through eco-supply chain management. In this paper we explore possibilities for the integration of eco-performance into the electronic component selection process with particular emphasis on hazard potential and life cycle cost.

2 Ecodesign Decision-Making
Decision-making is fundamental to the ecodesign process. For many ecodesign practices and strategies decisions can be relatively straightforward and both the environmental and financial benefits are clearly evident. An example is mass minimisation for mechanical components of a product. It is logical to assume that reducing material input will result in reduced inventory for product manufacture (reduced product cost) and reduced resource use, therefore

environmental performance improvement. Other examples include reduction in material type, improved "use" phase energy efficiency and hazardous material avoidance.

Some decisions however, are more difficult with the benefits less obvious due to complexities in the interpretation of environmental impacts, thus requiring trade-offs to be made. Examples are material and component selection. The electronics product ecodesign decision-maker needs to consider the environmental impacts associated with the decision on a life cycle basis and also the economic considerations. Ecodesign and life cycle assessment tools can provide assistance through knowledge, information and analysis to assist the ecodesign decision-maker. The tools can provide environmental evaluations of product design decisions indicating where improvements could be made. Difficulties, though, arise in the "eco-selection" of both materials for mechanical parts and components for electronic construction in electronics products.

Ecodesign practices such as "select recycled and recyclable materials" and "avoid hazardous materials", if adopted, are difficult to implement if material composition data are not available for materials and components. LCA tools are data dependent and would require LCA or LCI data on components from different suppliers for any comparative selection process to be used. LCI and LCA data are notoriously difficult to obtain. Electronics ecodesign or product life cycle management would benefit from a flexible component eco-selection tool using more readily available data that also considers end-of-life economic issues. Product data issues are discussed in the next section.

Component and mechanical part "eco-selection" assumes that eco-performance can provide differentiation between components with the same functionality, from different suppliers, in addition to factors such as cost, reliability and supplier company performance issues. The contribution of the eco-performance of the component will have on the decision to select it will depend on the individual company's degree of commitment to ecodesign or improved environmental performance. Eco-performance has to compete particularly with quality, reliability, technology and cost. The consideration of full life cycle cost is becoming increasingly important. Components with less hazardous materials and improved recyclability or re-use potential could have cost benefits at end-of-first-life. These benefits could off-set any "up-front" higher purchase costs for components with improved environmental performance.

The proactive electronics company will seek to explore opportunities to improve component eco-performance through active supply chain partnerships. Supply base reduction strategies throughout the electronics industry will result in opportunities for strong partnership building but such strategies will also restrict component sourcing opportunities and perhaps, therefore, access to eco-innovation. This could lead to increased benchmarking by component users and subsequent pressure being applied to suppliers for improved product eco-performance.

3 Component "Eco-Selection" Decision-Makers

Three core groups of decision-makers for component selection can be identified:

- Designers
- Component Engineering Qualification Groups
- Manufacturing supply management groups (purchasers)

Discussions with design groups within Nortel Networks have revealed that because of the time to market pressures regarding new product introduction, designers would prefer that any form of component eco-evaluation be made before components are made available for use in design. Hardware (electrical) designers focus primarily on functionality. Components are selected from a database of components that have been pre-approved from preferred suppliers according to a range of criteria by the component engineering group. Components not available in the database are recommended by the designer and are subsequently subjected to the approval process. Designers do not have the time to evaluate the eco-performance of components and to consider possible alternatives.

The component engineering qualification group does have an opportunity to consider the eco-performance of components during the qualification process, particularly for new technologies, and to capture "eco-evaluations" and document them by posting the evaluations as a feature of the component attribute dataset in the component database. Currently the component engineering group uses supplier environmental assessment information obtained through the supply management function to screen a supplier's environmental performance. The supplier environmental assessment procedure has recently undergone a review and development phase. The new procedure includes a section that addresses product specific eco-issues. The strategy will be outlined in section five. The research presented in this paper seeks to assess the feasibility of going beyond simple compliance declarations and on to a comprehensive supply chain materials management approach.

Manufacturing supply management groups also have an opportunity to make component "eco-selections" in the selection of components to complete a bill of materials for a production run. Components are multi-sourced from different approved suppliers. It may be possible to differentiate between suppliers of components on an environmental performance level (company and product) as most preferred suppliers would meet minimum requirements on quality, delivery, service, cost, business risk, and technology.

4 Product Data

Making any kind of eco-performance evaluation of electronic components and materials requires data. To benchmark components or to differentiate between suppliers (and to provide accurate product material profiles for customers and end-of-life management), data on components specific to each supplier are required. Industry averaged data that are available in ecodesign, LCA and product databases do not capture the differences that may exist between component material composition and production techniques between one supplier and another.

The type of data that can be used for eco-evaluations can be categorised as follows [1]:

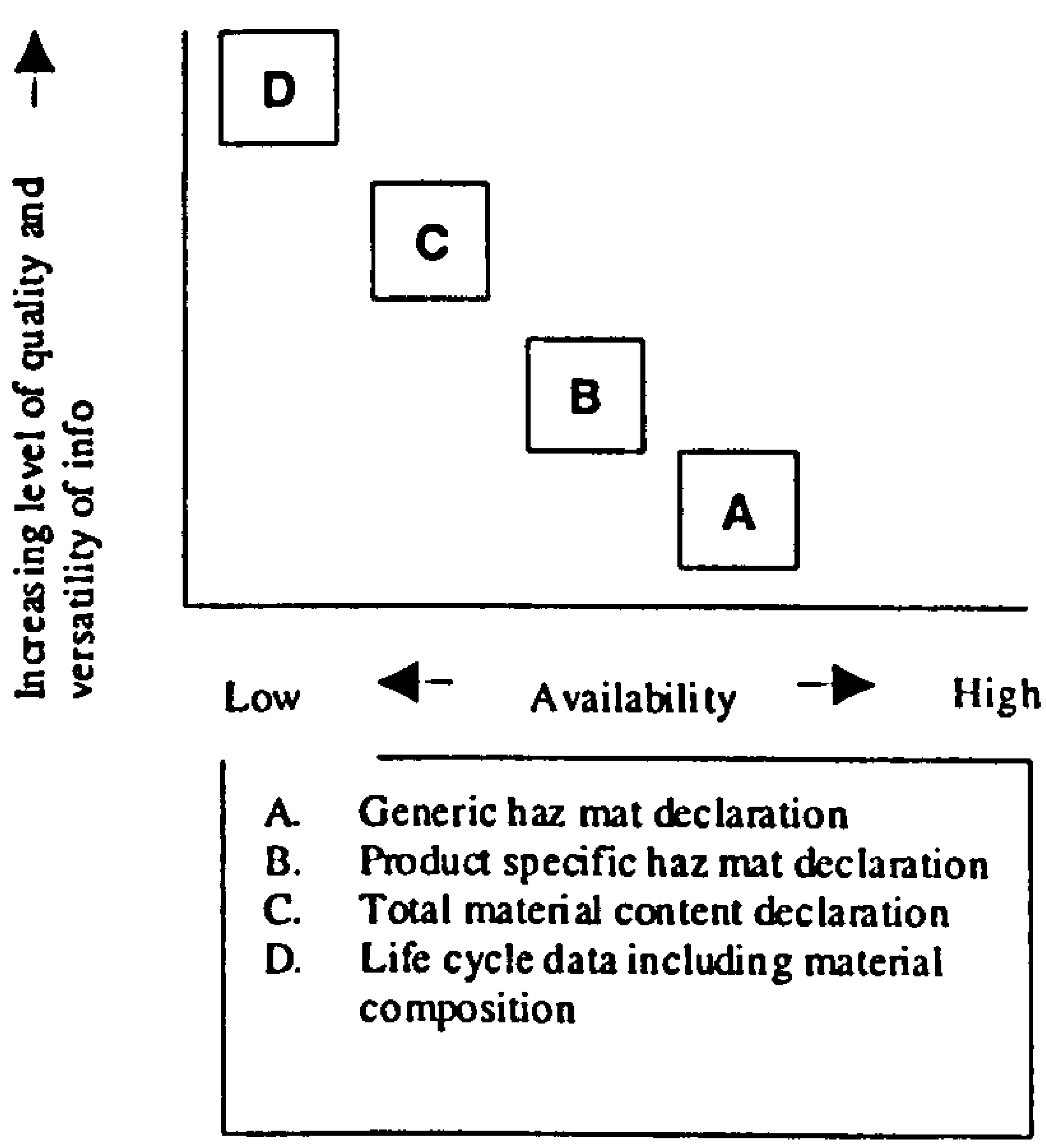


Fig. 1 Data Utility and Availability

A. Generic hazardous material declaration;
B. Product specific hazardous material declaration;
C. Total material content declaration;
D. Life cycle data including material composition.

Previous research has indicated that data availability varies greatly and data are generally difficult to obtain [1,2]. In **Figure 1** we attempt to demonstrate the availability and utility of data type.

Ideally, full material composition would be available accompanied by LCA or LCI data. The life cycle data would enable an eco-evaluation of the production process also to be considered. This is an important consideration but the probability of obtaining detailed production process environmental burden data for each supplier is low. Suppliers generally consider such data as commercially sensitive, particularly yield data. This is despite the fact that many component suppliers suggest that component production technology is common across the industry. Variations in production techniques are likely to exist but identifying them is particularly difficult. Nagel has developed a supply line engineering methodology that attempts to incorporate production process environmental burdens [3,4].

Total material composition data would facilitate the identification of hazardous materials present in the component and provide information for assessing its "re-usability" or "recyclability". It would also facilitate the generation of Nortel Networks product material composition profiles for legislative compliance, customer requests and end-of-life management.

Product specific hazardous material declarations enable hazard-based eco-evaluations and Nortel Networks product hazardous material declarations to be made. They also provide data for end-of-life management.

Generic hazardous material declarations that are generally negative e.g. "our products do not contain asbestos" are of limited value although they are useful as an initial screen and for minimal compliance.

In a previous study a selection of suppliers were asked what type of product material data they could provide. **Figure 2** shows the results. The first target score is hazardous material content and the preferred target score is total material content and end-of-life recommendations. From this relatively small selection of suppliers, covering a range of commodities, it can be seen that data availability varies greatly. Example data were also requested from the suppliers. **Table 1** presents a comparison of total material composition of Plastic Leaded Chip Carriers from four suppliers.

It can be seen from the data in Figure 3 that component material content can vary between suppliers. The variation may be due to uncertainties and differences in material identification techniques. The techniques used would have to be compared and evaluated. Generally the data provided by suppliers has to be considered accurate. Data could be validated by way of an audit if necessary. The variation in material content supports the theory that an eco-evaluation based on material content could provide a differentiating factor for components from different suppliers. How can components be eco-evaluated?

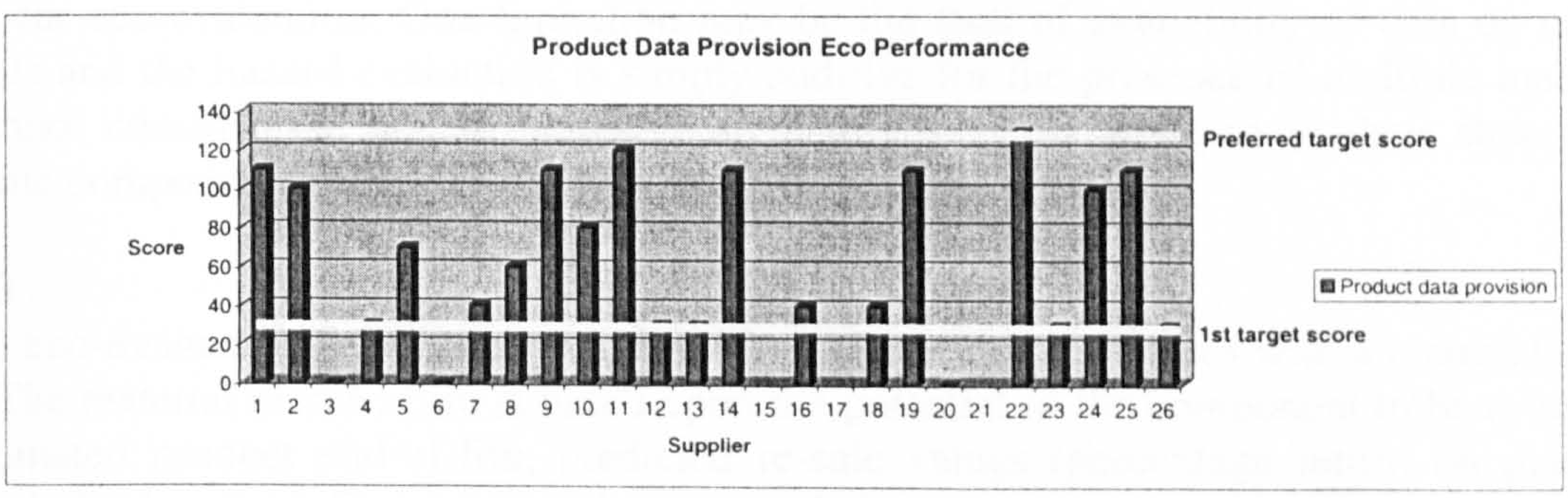


Figure 2. Supplier Product Data Provision Scores

5 Component Eco-Evaluation

Based on potentially available material content data an eco-evaluation method hierarchy is presented for component eco-evaluation qualification (see **Figure 3**.). At the time of writing the individual eco-evaluation methods have not been fully realised. Refined methods and examples of application will be provided at the conference.

Level 1

Level 1 eco-evaluations consist of the setting of prescriptive minimum requirements regarding the absence of specified hazardous materials in components. This has become a common approach in the electronics industry with companies setting material constraints for suppliers that revolve around one or two lists of banned and restricted substances. The banned and restricted substances may actually be banned or restricted under regional or international law or may be targeted for banning or restriction. Some of the restricted substances on company lists will be considered harmful to the environment due to available documented evidence and are open for negotiation between customer and supplier. The focus of a Level 1 eco-evaluation is essentially hazardous material compliance. Nortel Networks are currently implementing a supplier product hazardous material declaration as part of supplier eco-assessments. This ensures compliance with current hazardous material regulations and anticipatory compliance with the material substitution requirements of the EU Directive on the Restriction of use of Certain Hazardous Substances in Electrical and Electronic Equipment [5].

Level 2

Level 2 eco-evaluations focus on the intrinsic hazardous nature of the materials within a component. The evaluation is based upon the sum of the toxicity ranking scores for each material. The ranking scores include toxicity to human health and ecological toxicity. It is difficult to include likelihood of exposure and therefore generate a risk-based evaluation in a component selection scenario because of the uncertainty concerning the fate of the component. Examples of ranking systems for toxicity that could be used include:

i) the US EPA's toxicity weight risk screening environmental indicators based on chronic health effects;
ii) the University of Tennessee's (UTN) chemical hazard evaluation method based on a chemical's acute toxicity, chronic toxicity and indications that a chemical can cause multiple adverse health effects;
iii) the UTN ecological and total hazard scores;
iv) the Indiana Relative Chemical Hazard Ranking System.

These methods generally generate relative ranking scores for each material and have primarily been developed to assist decision-making for chemicals management and pollution control. The approaches can be adapted for use as part of a component hazardous material ranking system for eco-evaluation. One limitation may be the lack of availability of data on certain materials and the hazard evaluation is simply additive for the presence of multiple materials and cannot consider the hazard potential of materials in combination in their state as an electronic component.

Level 3

Level 3 eco-evaluations combine the hazardous material ranking scores with a material re-use score. The material re-use score is based upon the potential of the component to be re-used at the estimated product end-of-life, predicted re-sale values (percentage return on purchase cost) and obsolescence. Components that are unlikely to be re-used are assigned a score based upon the additive, predicted recycle value of the main constituent materials. This assumes that the populated printed circuit board is ground and smelted and metals recovered.

Level 4

Level 4 eco-evaluations attempt to include a measure of specific supplier performance in terms of ecodesign implementation and product environmental impact considerations at the company, to try and capture more general eco-performance issues associated with component design and manufacture.

The intention is to complete the research on the eco-evaluation methodologies and to provide example results with applications and a feasibility assessment at the conference.

Table 1. Component Material Content

Material	Percentage by weight			
	Supplier A	Supplier B	Supplier C	Supplier D
Arsenic and compounds	0	0	0	trace
Beryllium and compounds	0	0	0	0
Cadmium and compounds	0	0	0	trace
Chromium (VI) compounds	0	0	0	0
Lead and compounds	0.28	0.08	0.27	0.02
Mercury and compounds	0	0	0	0
Nickel and compounds	0	0	0	0
Halogenated Flame Retardants	1.08	-0.66	2.05	0.74
Ozone Depleting Substances: (HCFCs, other) please	0	0	0	0
PVC	0	0	0	0
Poly-chlorinated byphenyls (PCB)	0	0	0	0
Polybrominated byphenyls (PBB)	0	0	0	0
Polybrominated di-phenyl-ethers (PBDE)	0	0	0	0
Chlorinated Hydrocarbons (Chloroparrafins, other)	0	0	0	0
Nonyl-phenol-etoxilates (NPE)	0	0	0	0
Aluminum Metal/Alloy	0.00	0.01	0.00	0.00
Aluminum Oxides	0.00	0.00	0.00	0.00
Antimony Compounds	2.24	1.32	part of flame retardant	1.11
Carbon Black	0.19	0.00	0.02	0?
Chromium	0.00	0.00	0.00	0.00
Cobalt	0.00	0.00	0.00	0.00
Copper	20.96	31.33	34.60	24.50
Gold	0.09	0.07	0.07	0.10
Iron	0.51	0.77	0.72	0.50
Palladium	0.00	0.00	0.00	0.00
Resins	14.93	17.91	13.00	18.90
Silica	55.88	46.26	43.67	53.28
Silicon	1.73	0.91	2.93	0.89
Siloxanes	0.00	0.00	0.00	0.00
Silver	0.47	0.21	1.35	0.07
Tin	1.15	0.44	1.13	0.08
Zinc	0.00	0.00	0.03	0.00
Phosphorous	0.00	0.03	0.00	trace
Total component weight (mg)	2237.0	2300.0	3000.0	2340.0
Total percentage approx	99.50	99.34	99.84	100.19

6 Discussion

In terms of simplicity and feasibility in electronics component eco-selection, a declaration of what is definitely not in a component is preferable (Level 1 eco-evaluation). This should ensure regulatory compliance as long as the appropriate lists of banned or restricted materials is maintained. This is supported by Simon and Yender (1997) [2] and requires a minimum exchange of information between the supplier and the customer. This approach is currently supported by Nortel Networks.

However, to support advanced product life cycle management decision-making, particularly in terms of component or product eco-performance and life cycle costing, a more comprehensive eco-evaluation is required such as those proposed in methods 2 through 4 as described in section 5.

The main issue with the proposed methods is data availability. Until component material composition data are readily available it will be difficult to conduct any of the suggested evaluations. It is also acknowledged that significant data capture and management systems would need to be in place and ideally an industry standard format for material composition declarations would be required. One element of the research project has focused on the development of a web-based supplier product eco-data capture and management system. A beta prototype system has been completed and tested internally using component data. The system enables a supplier to provide component material data in a standard format using a web form. The web form would reside on an internal Nortel Networks supply management web site and be accessed by the supplier through the firewall using a secure identifier. The data are stored according to the component product code and supplier code. These data are then available to Nortel Networks employees via a web interface for the database (see **Figure 4**). In addition links could be created from the corporate component database that also has a web interface to the component material content data including any eco-evaluations.

For many relatively simple component types there may be little, if any, difference in material composition between suppliers, which negates any opportunity for differentiation. For more complex and new technology components though, there may be an opportunity for suppliers to demonstrate superior eco-performance. Integrated circuits and connectors are two component types that could exhibit significant eco-performance differences and provide value at end-of-first-life.

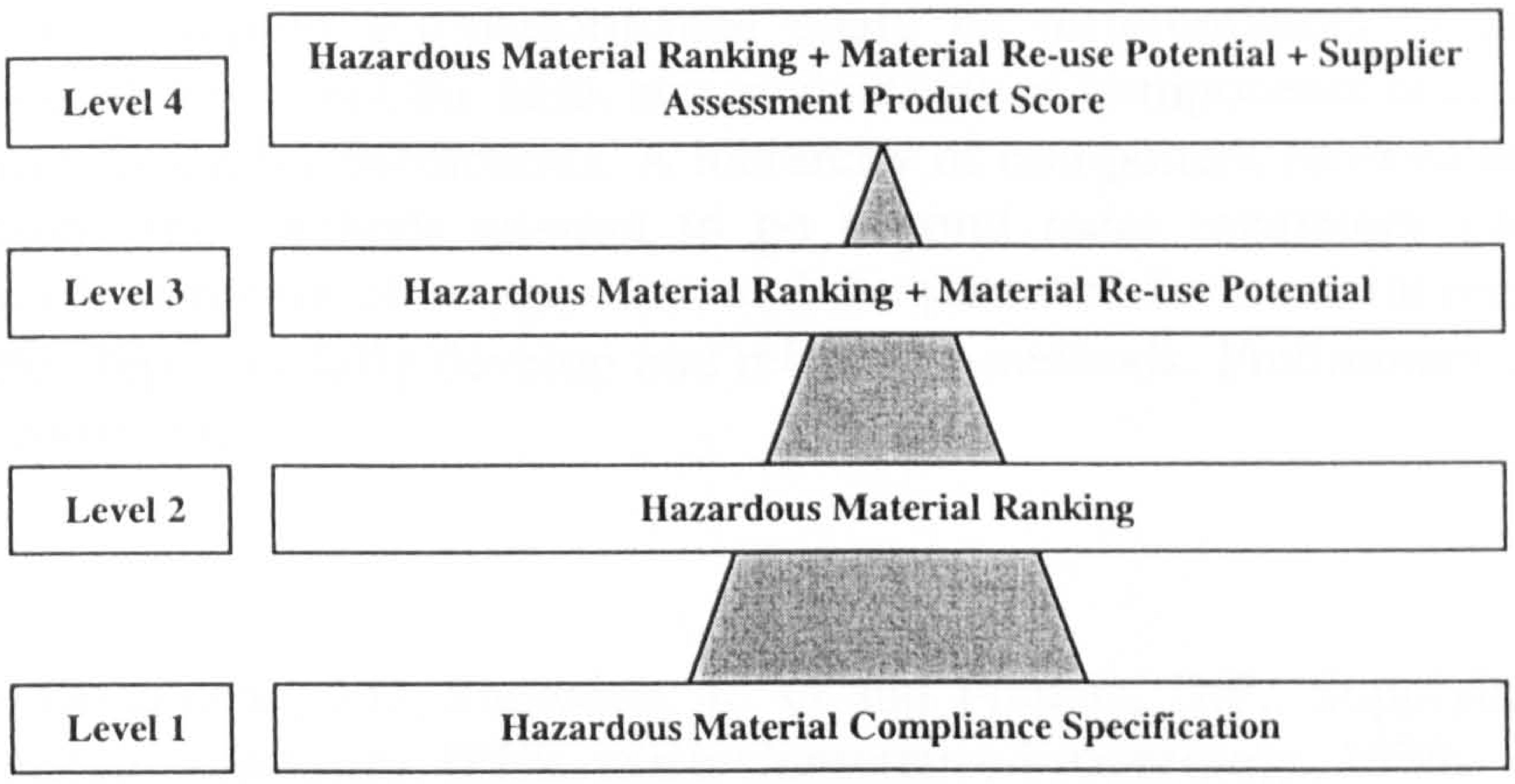
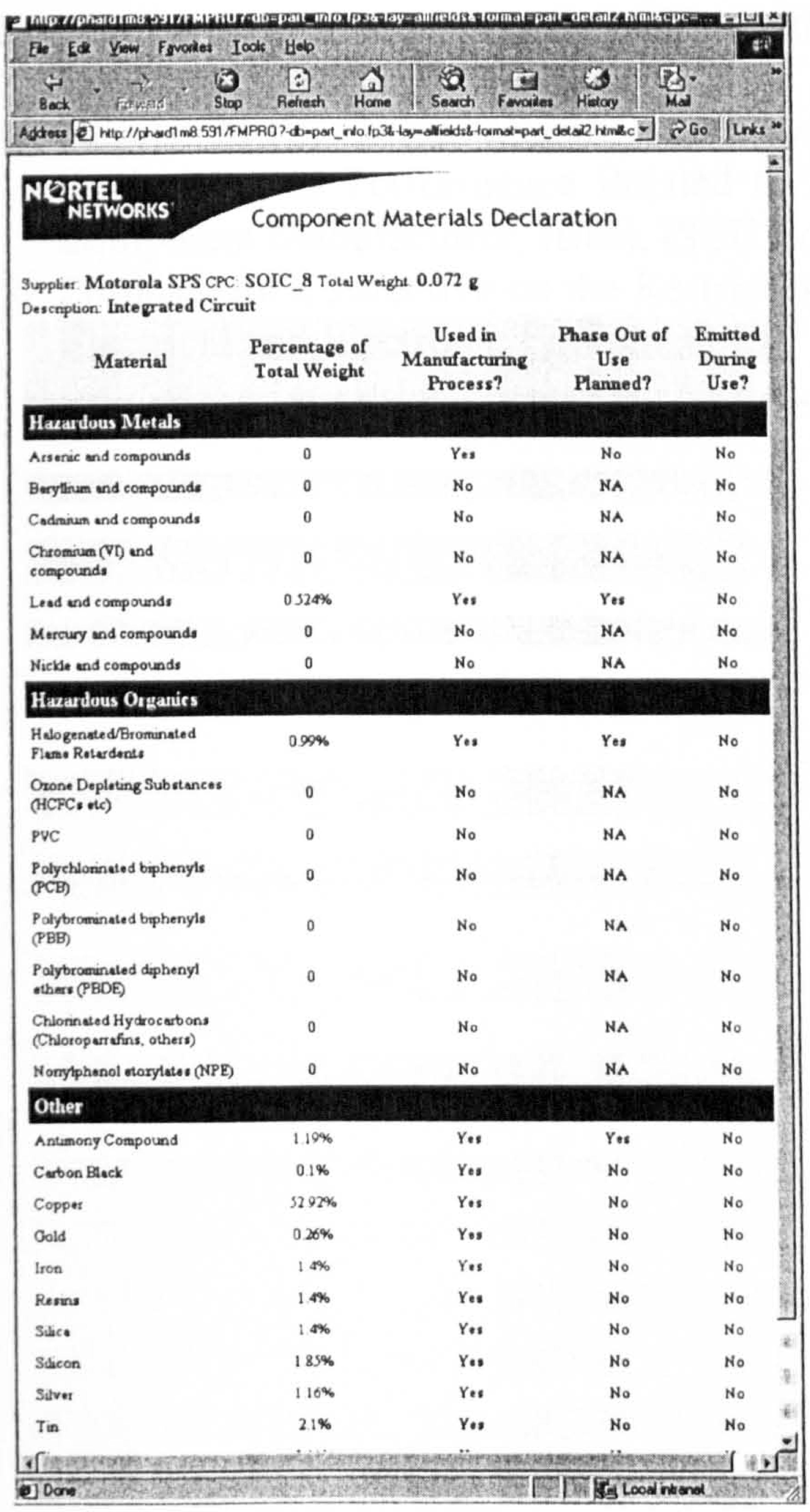


Figure 3. Component Eco-Evaluation Hierarchy



NORTEL NETWORKS

Component Materials Declaration

Supplier: Motorola SPS CPC: SOIC_8 Total Weight: 0.072 g
Description: Integrated Circuit

Material	Percentage of Total Weight	Used in Manufacturing Process?	Phase Out of Use Planned?	Emitted During Use?
Hazardous Metals				
Arsenic and compounds	0	Yes	No	No
Beryllium and compounds	0	No	NA	No
Cadmium and compounds	0	No	NA	No
Chromium (VI) and compounds	0	No	NA	No
Lead and compounds	0.524%	Yes	Yes	No
Mercury and compounds	0	No	NA	No
Nickle and compounds	0	No	NA	No
Hazardous Organics				
Halogenated/Brominated Flame Retardents	0.99%	Yes	Yes	No
Ozone Depleting Substances (HCFCs etc)	0	No	NA	No
PVC	0	No	NA	No
Polychlorinated biphenyls (PCB)	0	No	NA	No
Polybrominated biphenyls (PBB)	0	No	NA	No
Polybrominated diphenyl ethers (PBDE)	0	No	NA	No
Chlorinated Hydrocarbons (Chloroparrafins, others)	0	No	NA	No
Nonylphenol etoxylates (NPE)	0	No	NA	No
Other				
Antimony Compound	1.19%	Yes	Yes	No
Carbon Black	0.1%	Yes	No	No
Copper	52.92%	Yes	No	No
Gold	0.26%	Yes	No	No
Iron	1.4%	Yes	No	No
Resins	1.4%	Yes	No	No
Silica	1.4%	Yes	No	No
Silicon	1.85%	Yes	No	No
Silver	1.16%	Yes	No	No
Tin	2.1%	Yes	No	No

Figure 4. Component Material Content in Database

One problem that does arise in the generation of Nortel Networks product material profiles from supplier data, is the tracking of component data through the bill of materials generation and the manufacturing stage. The bill of materials is based on functionality and does not currently identify specific suppliers in the output. To overcome this problem it would be possible to add an eco-risk field to the bill of materials output specifying preferred suppliers based on eco-performance for each item. It would also be possible to capture material data in the component database and collate it with a modification to current internal data management systems (See **Figure 5**).

The production-related supply base of Nortel Networks is also rapidly changing with a strategic move to reducing the supply base and increased outsourcing of PCB and sub-assembly manufacture to contract electronics manufacturing service (EMS) vendors. This is a move that is currently common in the electronics industry. This strategy will make material content and management more complex and will necessitate a close partnership approach between Nortel Networks and EMS vendors. A minimum requirement of EMS vendors would be a compliance-based declaration of what is not in the product. The strategy also drives strong partnership development between Nortel Networks and core component suppliers that could result in the benefits of aligning environmental goals and objectives through the supply chain, particularly eco-technology development.

7. Conclusions

The research presented in this paper focuses on the development of methodologies for improved component selection in ecodesign or product life cycle management. It is suggested that component and supplier eco-performance could be differentiators in the component selection process or if this is not the case, eco-evaluations of components could be utilised in end-of-life product cost/value predictions. A hierarchy of component eco-evaluation methods has been proposed. The methods attempt to go beyond mere regulatory compliance and consider the hazardous nature of components and the potential for material recovery beyond first use. The next step is to fully develop and refine the methods. Preliminary results will be presented at the conference.

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SUPPLYING DFE IN THE TELECOMMUNICATIONS INDUSTRY

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Abstract

A comprehensive life cycle solution for Design for Environment (DfE) and within telecommunications products requires the availability of accurate and comprehensive data at component level. These data are also needed to meet the requirements of the proposed European Waste from Electrical and Electronic Equipment Directive and customer information requests. Many databases use generic data for component bill of materials, hazardous material presence, and environmental impact evaluation. The research described in this paper shows that these generic data do not meet the requirements of a comprehensive Product Life Cycle Management solution particularly for the selection of environmentally preferable components in DfE, satisfying customer requests for product environmental information and determining end-of-life options. Solutions to the problems of supplier data retrieval, data transfer, the communication of component level environmental data to customers, and determining end-of-life strategies are proposed.

I. Introduction

The research described in this paper is a component of a programme at Nortel Networks which is investigating systems for data exchange and product environmental information management throughout the product life cycle and methods to improve product environmental performance.

This part of the research focuses on the development of solutions to the product environmental performance and information transfer challenges currently faced by manufacturers of electronic equipment. These include meeting the requirements of stringent product environmental legislation and customer requests for product environmental information. A situation analysis is provided and solutions are proposed to some of the problems discussed. The structure of a proposed product environmental information management system at Nortel Networks to meet the challenges is illustrated in Fig.1.

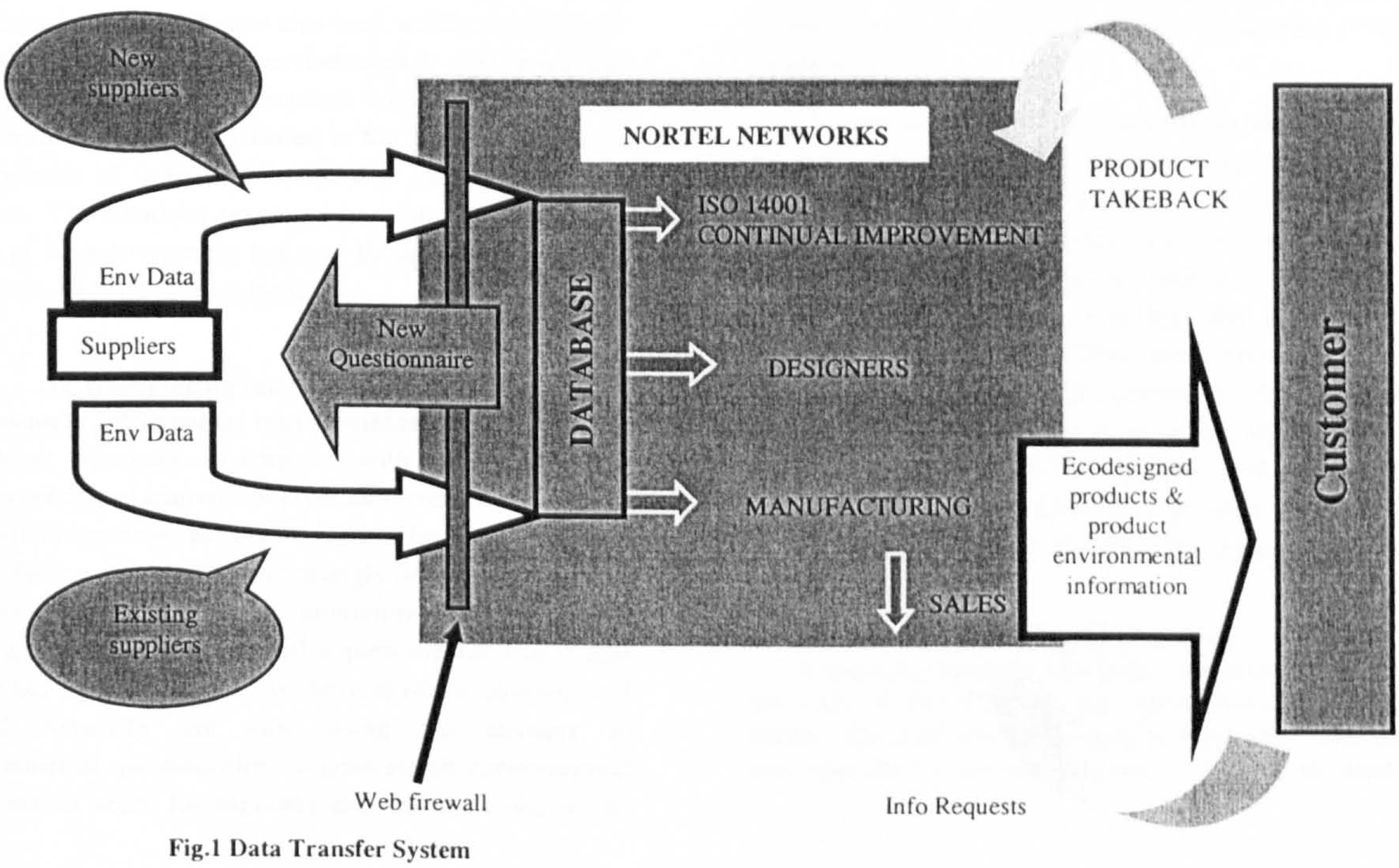


Fig.1 Data Transfer System

II. Background

The focus of environmental initiatives and practices in major electronics companies has changed progressively in the last decade from corporate, company or site based environmental management initiatives to product-based initiatives that strive for improved product environmental performance.

In terms of environmental management it has now largely become a standard requirement of major electronics companies to have an established working Environmental Management System (EMS) in place including an environmental policy with objectives and targets. Increasingly the company environmental performance benchmark is seen as ISO 14001 accreditation. The ISO 14001 requirement of continual improvement, the increasing stringency of product-focused environmental legislation and customer demands for "greener" products has resulted in the need for electronics companies to improve product environmental performance throughout the life cycle (product stewardship). This means adopting the principles of DfE and integrating green design practices into the established product development process by using appropriate DfE tools. It also means developing close and interactive relationships with both customers and suppliers (core stakeholders) to ensure product environmental objectives are transparent both up and down the product lifecycle chain.

DfE practices have now become well established in the electronics industry and many companies have implemented DfE programmes [1-5]. In addition supply management environmental initiatives and customer interaction programmes have also been widely developed [6-12]. Many of the product environmental challenges that electronic equipment manufacturers face are industry-wide but solutions need to be tailored to the systems, structures and cultures of individual companies and their business partners. The solutions presented here are focused on the needs of Nortel Networks but may be appropriate to other electronic equipment manufacturers.

III. Recognising the Need – The Drivers

A. Customer information requirements

Nortel Networks, in common with many electronics equipment manufacturers, receives an increasing number of requests for environmental information from customers [8,9 and 12]. The requests are for increasingly detailed information on both company and product environmental performance. They are usually in the form of a questionnaire that is part of the bid for contract process. Several of the customers of Nortel Networks are now using the answers to environmental questionnaires to generate an environmental performance score for suppliers and use it as one of the criterion in the supplier selection process. Customers are particularly concerned with the material content of purchased products (more specifically the presence or absence of certain hazardous materials). Some product-based questions asked by customers are difficult to answer. Typical examples are provided in Fig.2.

Questions/Requirements
Does the product contain any substances or material, that, at the end of its useful life would be classified as hazardous waste?
Substances which shall not be incorporated in operational and control equipment: (list provided by customer)
Does the product contain any substance listed by (list provided by customer)?
Specify per product in respective category up to 98% of total weight and volume the materials/combination of materials that constitute the largest part.

Fig.2 Typical Product Questions/Requirements In Customer Assessment Questionnaires.

B. Legislation

The quantity, diversity and complexity of environmental legislation continues to increase and there is a distinct change in focus from process-manufacturing-based legislation to that which is product/service-based. The most notable being the proposed EU Directive on Waste from Electrical and Electronic Equipment ("WEEE Directive")[23].

The impact of the WEEE Directive on the operations of individual electronics manufacturing companies will not be completely clear until it is finalised. It is evident, however, that it will result in sweeping, radical change. Significant requirements of the Directive include the targets for equipment recovery and recycling, the phasing-out of specified substances by 2004, the removal of certain substances before end-of-life actions and the provision of detailed product information to recyclers. Meeting many of the requirements of the WEEE Directive will necessitate the development of some form of a product environmental information management system in the companies effected.

IV. Situation Analysis

A situation analysis has been conducted to determine the scale of the problem that Nortel Networks could be facing. The aim was to identify exactly what information was required to answer customer requests, to meet the requirements of the WEEE Directive and to support DfE initiatives.

To identify the information requirements of customers a selection of environmental questionnaires received from customers were analysed. Many customers request information on both environmental management programs and products. Nortel Networks has been in a very strong position on environmental management programmes for some time so it is a relatively simple task to complete this set of questions. It is, however, considerably more difficult to provide product specific environmental performance data and particularly complete material composition data.

It is clear that from an analysis of the proposals in the WEEE Directive and customer requests for environmental information, that the current problem area is product material composition data and particularly the presence or not of hazardous materials. The next step was to generate solution scenarios to the problem of identifying the material composition of the components in the products of Nortel Networks and communicating the information to customers.

V. Solutions

Four solutions to the problem of product data capture have been considered:

- Database A - component life cycle inventory-based data used for DfE;
- Database B – component environmental specification data;
- Supplier Data – Nortel Networks specific; and
- Supplier Data – industry collaboration.

A simple evaluation of the four solutions in terms of their cost and effectiveness in resolving the data capture problem is illustrated in Fig.3. Detailed evaluation is provided in the next section. Once the data are available it still needs to be transferred to the design communities, manufacturing, sales and finally to the customer. Proposals for such a system are provided in section VII and illustrated in Fig.1.

VI. Data Capture and Availability Solutions Evaluation

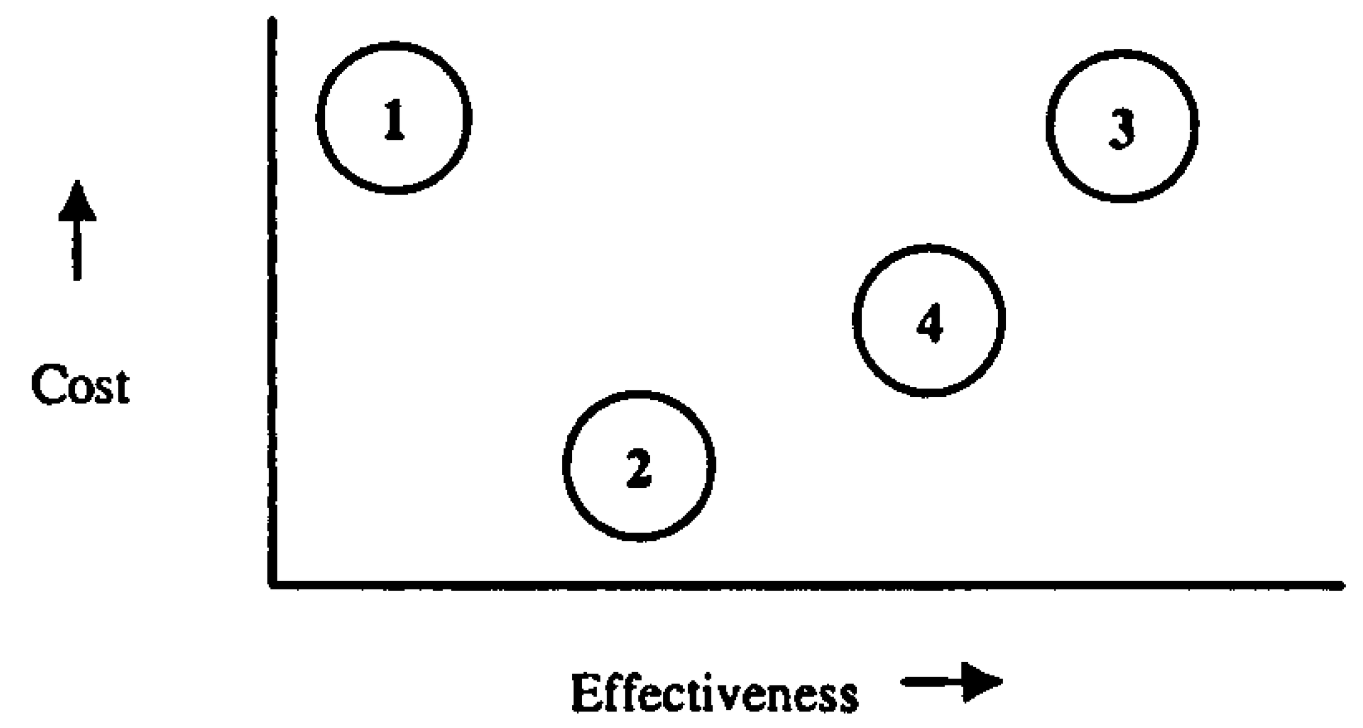
Each of the four solutions were evaluated by asking the following questions:

1) Are the data the appropriate data (component specific material composition)?
2) How comprehensive are the data in terms of components covered?
3) Are the data easily available?
4) What are the costs of data capture?
5) Can the data be readily updated?

For solutions 1 and 2 the components were selected because they were either identified as being a potential customer specification compliance issue or are just random examples of components.

A. Solution 1 - Database A

Database A is a commercially available database of components and materials used in the electronics industry. It is supplied as part of a DfE software tool. The default categories for product data are: materials in composition; Life Cycle Inventory (LCI) of raw materials; LCI of waste; LCI of air emissions; LCI of water emissions; additive materials in composition; and coating materials in composition. Fig.4 shows the data available on selected components from the database.



1.	Database A
2.	Database B
3.	Nortel Networks Supplier Data
4.	Industry-wide Collaborative Effort

Fig.3. Basic Evaluation of the Four Solutions

The database, as supplied, contains a limited amount of data on a limited number of electronic components. Only some of the components have material composition data and component data are incomplete as Fig.4 shows. In addition, the data are not comprehensive in terms of components covered. The database is readily available as it is part of a DfE software tool but because of this the data are relatively expensive. It is clear that the data available would not provide the detailed component information required, primarily because the data provided in this version are only representative of a few electronic components. There is, however, a facility for expanding the supplier and component specific data in the database and the latest version of the software contains specific hazardous material data. In terms of component environmental evaluation, the communication of complex product environmental information to customers and the use of product environmental information for end-of-life strategy formulation the database would require the collection of component data from the supply base of Nortel Networks. Additions to the database and maintenance of the data would be possible.

B. Solution 2 - Database B

Database B is a commercially available database that provides data on a selection of electronic components. The data are given in a different format to that in Database A. The environmental specification data is presented in four sections: identification; component technology (including a construction schematic and material balance (organic, metal and ceramic)); problematic substances and materials; and resource aspects concerning discarding. Fig.5 shows the data available on selected components.

	Material Composition	LCI of Raw Materials	LCI of waste	LCI of air emissions	LCI of water emissions	Additive materials in composition	Coating materials in composition	Non elementary energy
Component I (Connector - high current))	•	•	•	•	•	X	X	X
Component II (Connector – low current)	X	X	X	X	X	X	X	X
Component III (Integrated circuit)	X	•	•	•	•	X	X	X
Component IV (diode – plastic body)	X	•	•	•	•	X	X	X

Fig.4. Example Component Data in Database A

	Identification	Data Sheet	Construction Schematic	Materials Composition	Problematic Substances and Materials Data	Resource Aspects Concerning Discarding
Component I (transistor)	•	•	•	•	•	•
Component II (connector - socket)	•	•	•	•	•	•
Component III (integrated circuit)	•	X	•	•	•	•
Component IV (aluminium electrolytic capacitor)	•	•	•	•	•	•

Fig.5 Example Component Data in Database B.

Database B contains detailed component material composition data, details of possible problematic substances and information on manufacture, assembly, disposal, and component recyclability data for a significant range of components. It also contains data on different types of components in the same family i.e. different specification capacitors. Data are available on a better selection of components than in Database A but the data still do not cover enough components or suppliers. However, the data on sample components have been taken from more than one supplier in some cases. The database is readily available at a low cost

C. Solution 3 – Supplier Data (Nortel Networks specific)

Solution 3 involves capturing data from the suppliers of Nortel Networks. A programme was put in place to investigate this possibility. Potentially many of the product-based questions asked by customers of Nortel Networks can be answered by asking the suppliers similar questions and requesting product material composition data. An analysis was conducted to identify whether the current Nortel Networks supplier environmental assessment questionnaires developed for ISO 14001 asked the type of questions that would generate the information to answer customer questionnaires. Each questionnaire was scored relative to a customer benchmark standard questionnaire. The results are shown in Fig6. Without revealing the origin of the questionnaires it can be seen that certain customer environmental questionnaires were considerably more comprehensive and scored higher than those used by Nortel Networks. The gap between the "best" customer questionnaire and the "best" Nortel Networks questionnaire for each category of question is shown in Fig.7.

Three new versions of a Nortel Networks supplier environmental assessment questionnaire were then developed that met the requirements of providing information for customers, WEEE Directive compliance, DfE, and ISO 14001 continual improvement. Selected suppliers were asked to complete and critically appraise the three different versions. The objective of the exercise was:

- to evaluate the questionnaires in terms of ease of completion and understanding by the supplier; and
- to provide an assessment of the level of product environmental information suppliers can provide.

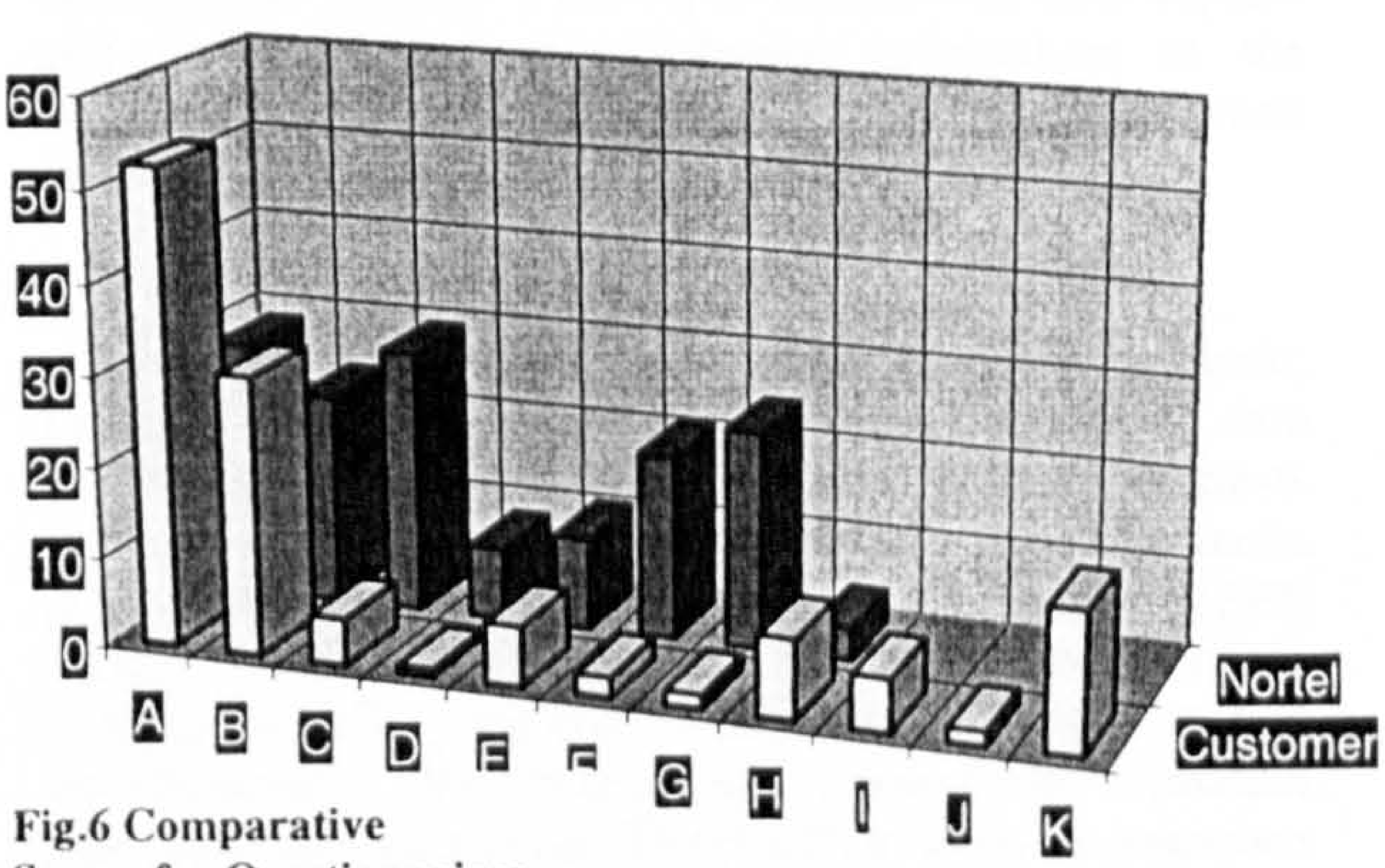


Fig.6 Comparative Scores for Questionnaires

The questionnaires consisted of sets of questions that are common to many supplier environmental assessment questionnaires, but each questionnaire also contained a specific detailed product environmental information section to complete also. This product section requested material composition data at component level and data on materials used in manufacture and emitted during use of the product.

The response to the research from the suppliers was positive. They all valued open dialogue with their customer on these environmental issues as they were rarely provided feedback on how the information captured in questionnaires was used.

A large amount of product information was requested through the product environmental questionnaires. Not surprisingly, the suppliers where initially surprised at the quantity and detail of data requested as no customer had actually requested detailed product information on all products supplied (thousands of components). They were, however, all prepared to provide as much information as they could and to develop collaborative programmes in an attempt to formulate a solution. The identification of the suppliers cannot be revealed but some preliminary feedback from three suppliers is provided in Fig.8. The research programme will continue with an increasing number of suppliers using a selected questionnaire.

The feedback from the suppliers suggests that only one of the them is in a reasonably strong position to provide the product data requested (Supplier A has material composition data readily available

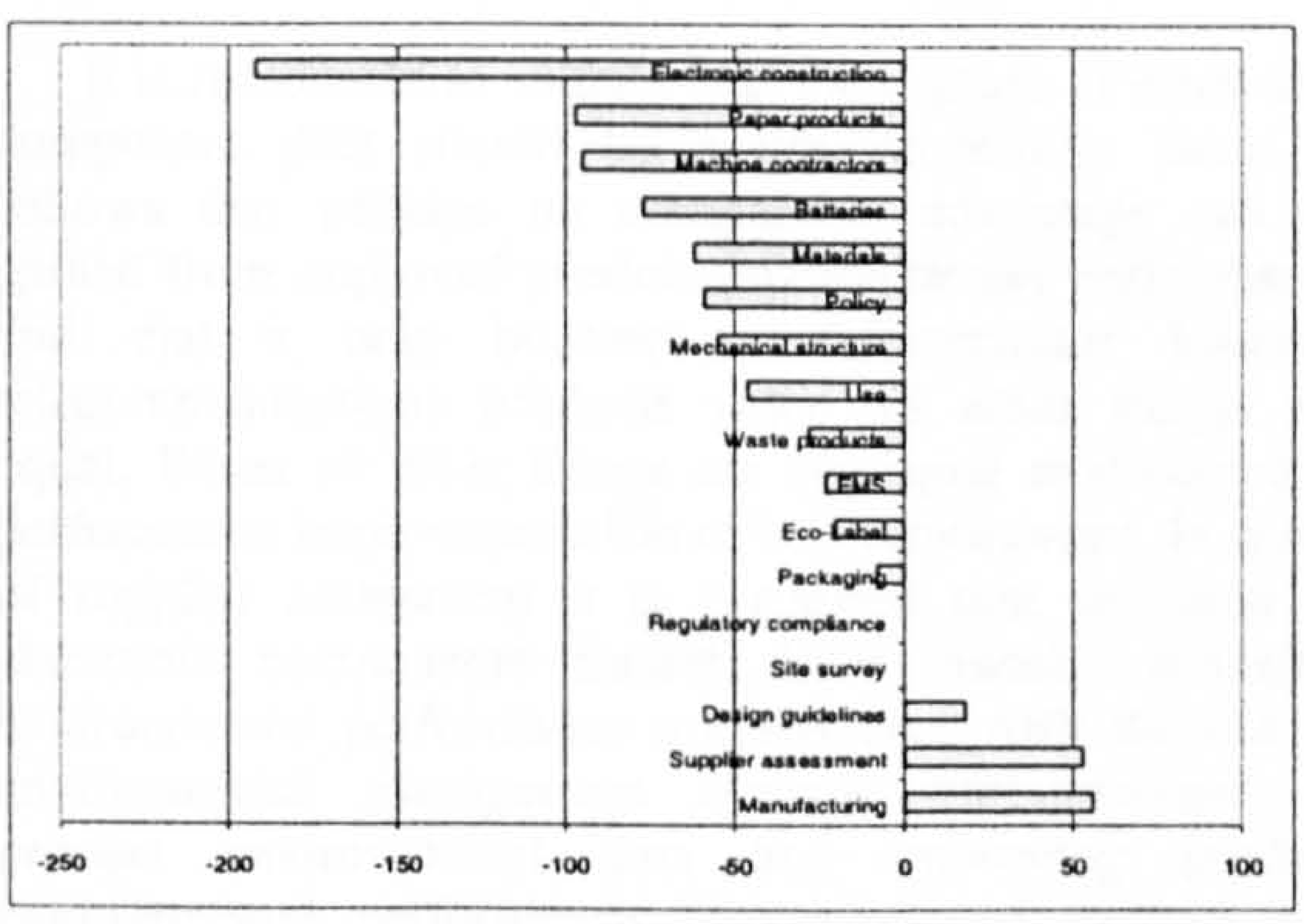


Fig.7 Performance Gap for "Best" Nortel Networks Questionnaire Compared to "Best" Customer Questionnaire

on some components and is building its dataset). Two of the suppliers have generated a statement of generic composition (what is not in their products, what definitely is and what may be depending on customer performance requests). Fig.9 illustrates the "usefulness" of the type of data suppliers could provide and an indication of its availability. Hazardous material declaration meets some requirements but for Nortel Networks to be able to (1) answer every customers' request for hazardous material content (different customer/legislative lists), (2) select options for end-of-life (economic value of non-hazardous materials) and (3) drive towards the development of more environmentally friendly products, the data type has to move towards D in the diagram and the availability obviously has to increase.

	A	B	C
EMS in place?	●	●	●
DFE programmes running?	●	●	X (planned)
Material composition data available on all products?	X	X	X
Material composition data available on some products?	●	●	●
Systems being developed to obtain product specific data?	●	X	X
General product material composition data available?	●	●	X
LCA data available on any products?	X	●	X

Fig.8 Supplier Feedback

D. Solution 4 – Supplier Data (Industry Collaboration)

Solution 4 involves direct capturing of product environmental data from suppliers but the load is shared in a collaborative venture amongst electronic equipment manufacturers. This would require co-operation and would need agreement particularly on the format in which the data should be provided. The costs of data capture should be reduced but the effectiveness may also be reduced because data obtained by one electroniçs company may not be suitable for another (see Fig.3).

VII. Data Transfer Systems

Whatever component environmental data are captured they will have to be transferred through existing engineering systems within Nortel Networks and made available to sales teams at a product level before being released to customers. Systems for product data transfer from initial entry into Nortel Networks through the supply management function to the design community, ISO 14001 site primes, manufacturing sites and sales teams are being investigated. The systems architecture would map onto current systems already in place but the mapping, tracking and update of data is extremely complex. The cost and level of resource needed for the system to operate is unclear but will inevitably be substantial. Automation could reduce costs. It is envisaged that the data will be made available to customers and the information then returned with the product during takeback to facilitate end-of-life management options. Innovative methods of data capture and communicating environmental information to the customer are also being developed. The general information system architecture is presented in Fig.1.

VIII. Discussion

For some purposes (e.g. DfE guidance) generic, averaged or "ball park" product environmental data (Databases A and B) may be sufficient. However, requests for product environmental information from customers, product information requirements for the proposed WEEE Directive, ISO 14001continual improvement and decision-making in DfE programmes all need detailed product environmental information and, specifically product material composition data. The results of analyses described in this paper suggest that the only truly effective way to obtain such data is direct from the suppliers themselves.

Initial findings from the questionnaire trial also show that suppliers are not currently in a position to be able to provide comprehensive component material composition data, but they are willing to work towards the provision of such data. There is clearly a need for focused and collaborative effort from final customer right throughout the supply chain and possibly collaborative work between competitors in the electronics industry.

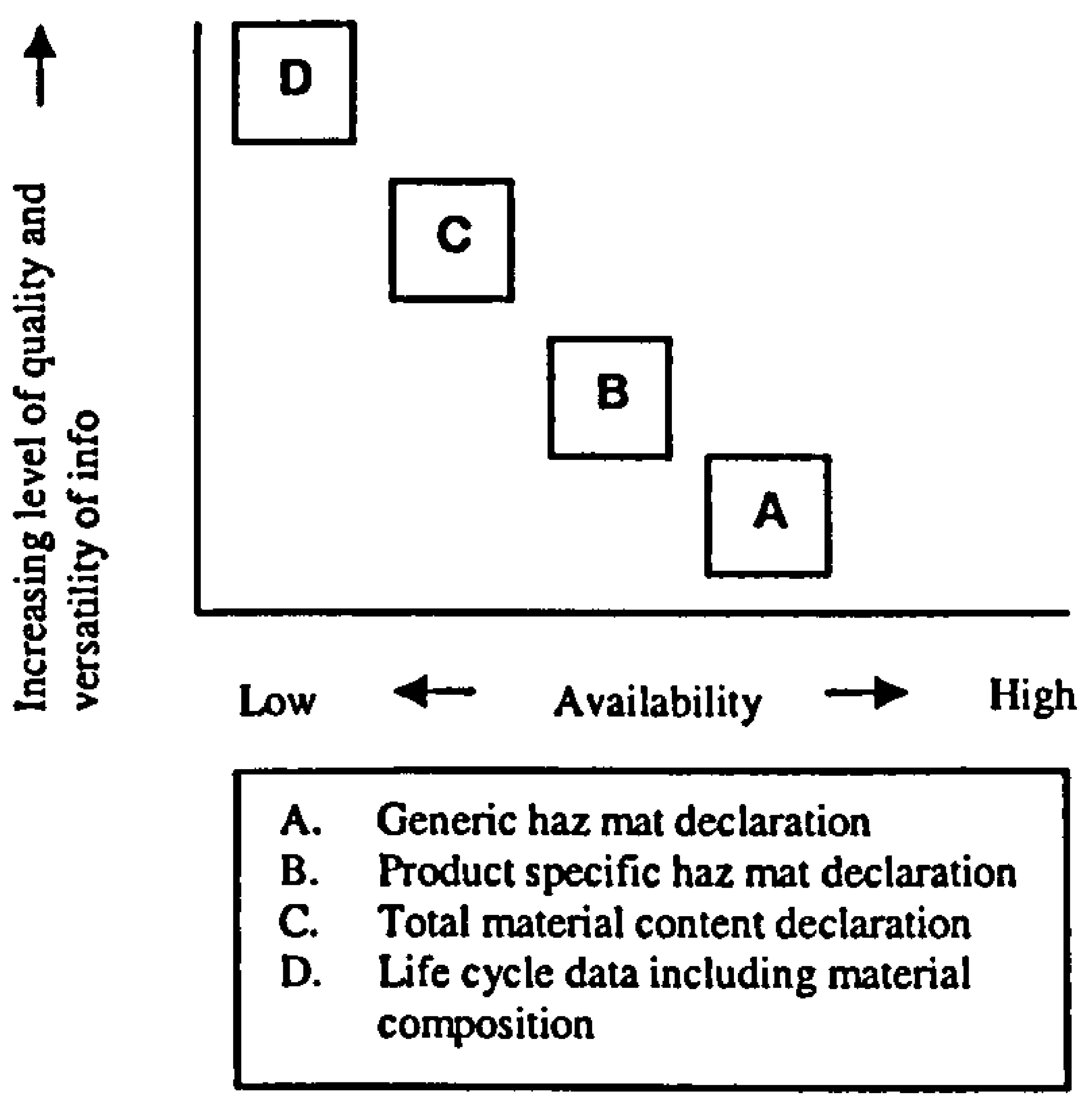


Fig.9 Data "Usefulness" and Availability

It is reasonable to suggest that the capture of electronic component data should be a pre-competitive issue. It follows that perhaps no competitive advantage can be gained from improved product environmental performance and that it only becomes a differentiator between telecommunications products when all other things are equal. When all other things are not equal environmental performance improvement has to be a requirement. In terms of supplier assessment it is suggested that suppliers of electronic components should drive towards continual environmental performance improvement with the use of environmental management systems, the provision of product environmental data and improving product environmental performance. Environmental performance should, therefore, be removed from the competitive equation and become a standard requirement that is flexible enough to accommodate large corporations and SMEs alike. This requires careful appraisal of suppliers for the purposes of ISO 14001 and proactive support and development of the supply chain.

For manufacturers of electronics equipment, meeting the requirements of the WEEE Directive for product environmental data is not enough. Customer requirements are vitally important and may differ in terms of product environmental performance and information provision. The demands may be greater than those of the WEEE Directive. It is suggested that effective product environmental information management is required in order to maximise the benefits of product stewardship.

IX. Conclusions

Radical changes in the way manufacturers of electronic equipment conduct their business are about to take place. The introduction of the WEEE Directive in Europe will result in improved product stewardship and drive the need for efficient product environmental data management. This move should be welcomed as it will improve the long-term sustainability of the electronics industry. It is, however, well known that change is not easy to manage and can be expensive. The research discussed in this paper is a step towards a solution to some of the problems faced by Nortel Networks and is a proactive drive to develop product stewardship initiatives. It has shown that product specific environmental information is required and that it is not readily available. Some solutions have been presented. The next steps in the research programme will involve further interaction with the supply base to enrich knowledge of data availability, evaluate manufacturing process technologies and to investigate the feasibility of data capture and transfer techniques for the system. It may be sensible to attempt to develop an industry standard product environmental data capture process.

Moving towards sustainability will never be easy but maybe "WEEE can help" to achieve it!

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C-3

Professional Development Courses and Assignments

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C4 Support Documents

Evaluating Remanufacturing and Demanufacturing for Extended Producer Responsibility and Sustainable Product Management,

By Michael Johnson

University of Windsor, Windsor, Canada.

Chapter 5

2002

INTRODUCTION

In this chapter, an example of the developed remanufacturing methodology is demonstrated. Nortel Networks, an international telecommunication company, produces a variety of telecommunication products from telephones to switching devices. Nortel is also very proactive in environmental stewardship policies and is actively involved in research into life-cycle analysis, eco-design, product stewardship and remanufacturing. A research contact was established at Nortel in the United Kingdom (Carl Mead, Eco-Design Research Engineer) to establish a cooperative project that would facilitate this research and hopefully provide useful feedback for Nortel's environmental initiatives.

Two of Nortel's telephone products were chosen to demonstrate this methodology in this chapter. The first product is a consumer telephone that was designed and manufactured by Nortel in 1983 and subsequently remanufactured by Nortel in 1993. The second product is a Norstar M7310 business telephone that is ubiquitous within the North American workplace today. Both Nortel and third party independent remanufacturers throughout Europe and North America currently remanufacture the M7310. Both devices were chosen for several important reasons:

(1) Both products are small enough to be easily modeled in an effort to develop and enhance the methodology.

(2) Both products have known life-cycles that includes remanufacturing that can be used to learn from.

(3) Data on the life-cycle of both products is relatively abundant. Nortel has carried out two research projects on the M7310 telephone (a North American Life-Cycle Analysis (LCA) project and a European WEEE project),

(4) Nortel expressed interest in the development of a methodology to carry out a financial analysis of various options that are available at the end-of-life. From Nortel's LCA project on the M7310 telephone, a number of limitations were identified including the need for a financial analysis of the various options that

are available at EOL (instead of a viewpoint that addresses solely environmental issues) (Environment Canada, 2000).

(5) Both products would fall under the proposed WEEE directive for mandatory takeback in Europe.

In this chapter, both products are analyzed independently. First, the consumer telephone is applied to three different situations in an effort to develop and enhance the usefulness of the methodology and optimization model. The same analysis is then applied to the M7310 business telephone.

5.2.1 STEP 1: DATA COLLECTION

In this section, the economic requirements of section 3.3 to be used for both telephones is presented. In this research, Dave Hukulak and Carl Mead of Nortel Networks have provided the necessary economic data to apply the developed methodology. Dave Hukulak is Nortel's Manager responsible for Asset Recovery Operations in NA and has provided the remanufacturing costs for the M7310. Carl Mead supplied the cost of new parts for the M7310 by extracting this information from Nortel's supplier database. The costs of new parts were based upon the average price of purchased parts throughout 2000. All economic parameters in this chapter are presented in Canadian dollars.

The labour rate used in the following analysis is $20 Canadian per hour. The landfill cost used in this study is $44.0052 Canadian per metric tonne that is consistent with the current Canadian and United Kingdom Landfill rates.

Table 5.1 provides the material values used for recycling materials. To determine the recycling values for metals, publications such as *American Metal Market* and a Nortel publication called "Life Cycle Assessment and Life Cycle Financial Analysis of the Proposal for a Directive on Waste from Electrical and Electronic Equipment" (Ecobalance, 1999) were used. This report is a result of an extensive research project on the environmental and economic feasibility of consumer products that fall under the European WEEE Directive. The project was carried out by two independent consultant groups (EcoBalance and DMG

Consulting) for the UK government. Carl Mead also supported the data on recycling value of materials by providing a list of current values that were obtained from a UK recycler.

Table 5.1. Researched Material Recycling Values

Material	Recycle Value per mass (CDN$/Kg)	Source
Steel	0.125	American Metals Market (Dec., 2000), Carl Mead via UK Recyclers (May, 2001)
Copper	1.89	American Metals Market (Dec., 2000), Ecobalance (1999)
Copper Cables (Shredded)	0.3667	Carl Mead via UK Recyclers (May, 2001)
Lead	0.211	Ecobalance (1999)
ABS (Clean)	- 0.01	Carl Mead via UK Recyclers (May, 2001)
ABS + PC	– 0.11	(Crittenden, 2000).
PVC	– 0.11	(Crittenden, 2000).

To determine the value of post-consumer plastics, various research publications were used including *The Plastic News,* which lists prices for recycled materials. The majority of publications specify a cost associated for recycling post-consumer plastics today. This is due to the fact that plastics are relatively inexpensive today (e.g., single resin polymer are priced between $0.10 and $2.00 per Kilogram) and the added cost of reprocessing post-consumer plastics (including collection, transportation, processing, and revenues from sale) ends up being uneconomical. A recent Canadian publication estimates post-consumer plastics recycling costs between $80 and $173 per tonne (including collection, transportation, processing, and revenues from sale) (Crittenden, 2000). This equates to a cost of $0.08 to $0.173 per kilogram to recycle plastics (including revenues from sales). Contaminated plastics are polymers that cannot be separated into their original polymeric composition due to the attachment of adhesives, foams, inserts, additives or other material. Contaminated plastics are assumed to be non-recyclable in this study (i.e., demanufactured as landfill).

5.2 NORTEL'S BUSINESS TELEPHONE – M7310

In this section, the developed methodology is applied to Nortel's M7310 business telephone.

5.2.1 STEP 1: DATA COLLECTION

The M7310 has many of the characteristics as listed in section 3.3.1 of the developed methodology that are necessary and valued for remanufacturing opportunities. The M7310 sells new for approximately $467 Canadian and it's remanufactured counterpart sells for on average for $140 Canadian Dollars (i.e., approximately 30% of the price of the new M7310). Dave Hukulak supplied both the new product price and remanufactured sales price for the M7310.

Unlike the Norstar consumer telephone, the M7310 business telephone is not currently hindered from an obsolescence problem in technology. The 1993 model year M7310 performs many of the important functional options that today's newly manufactured M7310 performs in the workplace. Lastly, the M7310 has a defined takeback system to generate a supply of cores. Nortel has three different mechanisms to generate a supply of cores in Canada for its remanufacturing operations:

(1) Nortel leases and rents the M7310 to its customers and therefore receives a supply of cores through end of leasing and renting contracts,

(2) Nortel has a staff of 3 employees in Canada under Dave Hukulak that buys products back from businesses and core brokers, and

(3) Nortel sometimes receives cores free of charge directly from businesses that have no further use for the product due to various reasons.

Currently, Nortel estimates that they takeback approximately 20,000 M7310s per year in Canada and 30,000 M7310s per year in the United States. The Canadian recovery operations estimates that out of the 20,000 units recovery, 16,000 are remanufactured and 4,000 units are demanufactured. The 4000 units that are demanufactured are used to recover parts for their remanufacturing operations. Parts that cannot be reused for remanufacturing are landfilled. Dave Hukulak also stated that over 3 million kilograms of Nortel equipment (categorized into 3 product families of switching, enterprise and broadband optical products) is processed at Nortel's recovery location in Barrie Ontario. When a product is received by this location, the product is sorted for one of 3 possible options: (1) resale (sometimes with repair), (2) remanufacturing, or (3) demanufacturing. Out of the 3 million kilograms of Nortel equipment received by their Barrie location in year 2000, Nortel states that only 5% of total mass received ended up in the landfill (Hukulak, 2001).

5.2.2 STEP 2: REMANUFACTURING ANALYSIS OF THE M7310

The results of the optimization are shown in Table 5.19. The optimal remanufacturing plan generated demonstrates that the majority of the components are more economical to remanufacture than to demanufacture and purchase new components for the rebuilt product.

Table 5.19. Results from Remanufacturing Optimization Model for the M7310

Part #	Part Name	Decision Variables					
		X1	X2	X3	X4	MaxMRO	Interpretation of Output
A	Handset	0	0	0	1	0	Disassemble for remanufacturing
A1	Upper Handset	0	1	0	0	0	Remanufacture
A2	Lower Handset	0	1	0	0	0	Remanufacture
A3	Handset circuit board	0	1	0	0	0	Remanufacture
A4	Connector	0	0	1	0	RC	demanufacture via recycling
A5	Receiver	0	1	0	0	0	Remanufacture
A6	microphone assembly	0	0	1	0	LF	demanufacture via landfill
B	Telephone Cord #1	0	0	1	0	RC	demanufacture via recycling
C	Telephone Cord #2	0	0	1	0	RC	demanufacture via recycling
D	Telephone Base	0	0	0	1	0	Disassemble for remanufacturing
D2	Upper Plastic Casing	0	1	0	0	0	Remanufacture
D3	Speaker Foam	0	1	0	0	0	Remanufacture
D4	4 screws	0	0	1	0	RC	demanufacture via recycling
D5	Speaker	0	1	0	0	0	Remanufacture
D6	Plastic Plate	0	0	1	0	RC	demanufacture via recycling
D7	PolyFlex CircuitBoard	0	1	0	0	0	Remanufacture
D8	LCD Panel #1 – Subassembly	0	1	0	0	0	Remanufacture
D9	Main Circuit Board	0	1	0	0	0	Remanufacture
D10	elastomer key pad #1	0	1	0	0	0	Remanufacture
D11	elastomer key pad #2	0	1	0	0	0	Remanufacture
D12	elastomer key pad #3	0	1	0	0	0	Remanufacture
D13	Shift Button	0	0	1	0	RC	demanufacture via recycling
D14	12 memory keys	0	0	1	0	RC	demanufacture via recycling

Table 5.21. M7310 Economic Output of Remanufacturing Optimization

Economics	Amount	% of Total
Total Remanufacturing Costs (sum of CRM)	-$9.94	58.57%
Total Disassembly & Assembly Costs (sum of CA and CD)	-$4.79	28.23%
Total Cost of New Parts (sum of CNP)	-$2.24	13.21%
Total Demanufacturing Costs (Landfill and Recycling)	-$0.0002	0.00%
Total Demanufacturing Revenue (Reuse and Recycling)	$0.00	0.00%
Total Rebuild Cost	-$16.97	100.00%

The results demonstrate that remanufacturing is more economical than the costs of acquiring new parts and the added demanufacturing costs of retired components. This demonstrates a potential for remanufacturing this product within both NA and Europe as part of an EPR system. Table 5.22 demonstrates the overall economics of the M7310 based on data gathered from Nortel Networks. Table 5.22 demonstrates an obvious economic justification to remanufacturing the Norstar M7310. The estimated resale price of a remanufactured M7310 dramatically outweighs the costs of remanufacturing and the minor costs associated with demanufactured retired components. Interestingly, even if new parts were purchased and assembled (approximate cost of $35.00 Canadian) and sold at a price equivalent to the remanufactured M7310, there would still be a reasonable profit margin.

Table 5.22. Overall Profitability - M7310

Estimated Resale Price of Remanufactured M7310	$140.00
Costs of Remanufacturing based on ORP	-$16.97
InDirect Costs (transportation, overhead)	-$6.88
Packaging / Manuals Costs	-$7.46
Estimated Core Price	-$14.34
Total Remanufacturing Profit	$94.35

The results generated concur with the current practices used by Nortel in dealing with the M7310 and its EOL management. Remanufacturing the M7310 provides both economic and environmental benefits. Sensitivity analysis was not carried out for the M7310 due to the obvious economic justification for remanufacturing this product.

5.2.3 STEP 3: MATERIAL AND ENERGY ANALYSIS OF REMANUFACTURING THE M7310

In this section, the material savings of remanufacturing and recycling (according to the optimal remanufacturing plan) are used to predict estimated energy savings using the developed technique as shown in section 3.5 of the methodology. Using Appendix C and the mass of individual components, the energy savings that would results from the end-of-life strategies of remanufacturing and recycling (as defined by the ORP) were calculated. Appendix V provides full details of the predicted energy savings. The results are summarized in Table 5.23. Note that the energy lost due to secondary processing has been calculated for the M7310. This energy represents the lost energy of recycling the materials as opposed to remanufacturing or reuse that fully retains the inherent energy embodied in the materials.

Table 5.23. Energy Savings of the M7310's ORP

Energy Disposition	Energy (KJ)	% of Total Energy Embodied (KJ)
Energy Savings of Remanufacturing (KJ)	81461.08	86.81%
Energy savings of Recycling (KJ)	6916.85	7.37%
Subtotal Energy Savings	88377.93	94.18%
Energy Lost to Landfill (KJ)	1327.02	1.41%
Energy Lost due to Secondary Processing - Recycling (KJ)	4136.17	4.41%
Total Energy Embodied in Materials (KJ)	93841.12	100%

Nortel also provided some interesting data that can be used to gain a greater understanding of the calculated energy savings of remanufacturing relative to other life-cycle stages of the telephone.

5.2.3.1 Quantified Energy Savings of Remanufacturing with respect to the Life-Cycle

An LCA report published by Nortel and Environment Canada provides some limited data on the energy of the M7310 over its life-cycle (Environment

Canada, 2000). The publication uses normalized values of environmental impacts in an effort to mask the raw data. For energy consumption, the following statement is provided in the report: "From a total life cycle perspective, the greatest contributors to the environmental impact of the M7310 telephone were 1) the use phase (electricity consumption) for the greenhouse gas and air acidification effects and 2) the component-manufacturing phase for raw material depletion and water eutrophication effects". Even though the business telephone is remanufactured at its end of life, the final report provides no incorporation of remanufacturing into the life-cycle analysis. The report does however provide the a data table (see Table 5.24) for the estimated consumption of energy during the use phase of the consumer telephone. It is estimated that the average life of this product to be 10 years.

Table 5.24. Nortel Networks M7310 Power Consumption (from Environment Canada, 2000)

Modes	Current (mA)	Voltage (v)	Hours per Working Day	% of Working Day	% Weekend	% Whole Week	Energy Consumption (K J/Week)
Idle	24.1	19	19	79.2	100.0	85.1	235.7
Handset	27.7	19	3	12.5	0.0	8.9	28.4
Handsfree	41.1	19	2	8.3	0.0	6.0	28.1
TOTAL			24	100.0	100.0	100.0	292.3

Assumptions:

1. Standard model for proprietary telephones in a business environment.
2. Phone in use 5 hours per business day, 25 hours per week.
3. All power is provided over the line cord from a KSU (Key Switching Unit).

Nortel also estimates an average transportation requirement of 1022 Kilometers (Km) from a customer retail outlet to Nortel's Nashville Repair and Distribution Center (NRDC) in Nashville, TN, USA for remanufacturing. This distance will also be used to calculate the average transportation energy requirements for the Canadian recovery location in Barrie Ontario. Based on this data, the following calculations were generated for the "use" and "transportation" phases of the life-cycle:

(1) Over 10 years, the energy consumed in the "use" phase by the M7310 telephone is 151,840 KJ, and

(2) The average energy requirement for transportation per telephone is 2,561 KJ. This is based on published estimates of energy expenditures via trucking of 1260 KJ/tonne-km from Sullivan and Hu (1995) and an average distance traveled of 1022 Km.

Figure 5.12 provides the results from the data collected from Nortel and the estimated energy savings of remanufacturing the M7310 according to its ORP.

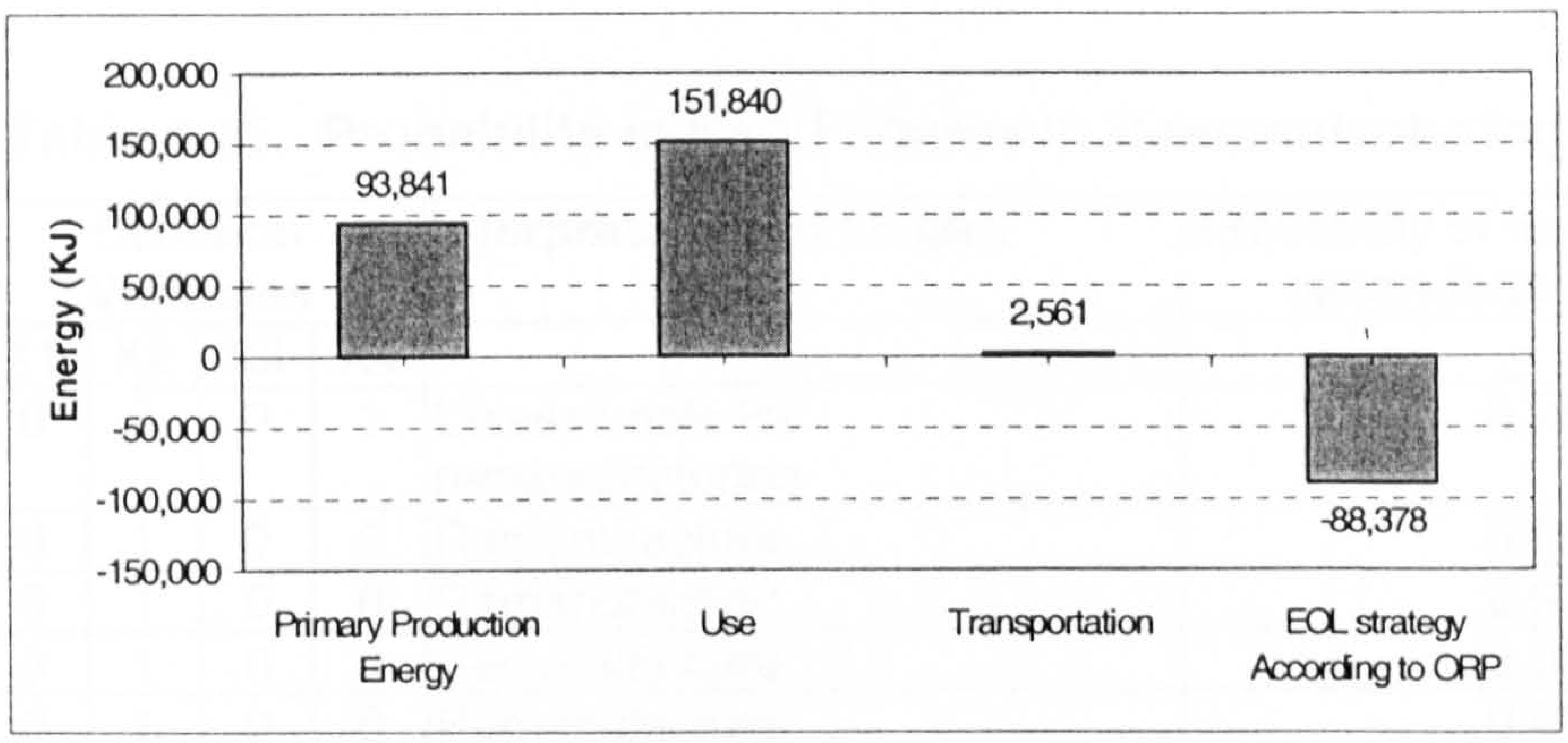

Figure 5.12. Life-Cycle Energy of Nortel's M7310 Telephone

Note that a negative energy requirement is depicted here as an energy credit to the life-cycle energy requirements. Figure 5.12 demonstrates that there is a dramatic energy savings that results from remanufacturing the M7310 with respect to the life-cycle energy requirements. Figure 5.12 also illustrates the relative energy savings with respect to the energy requirements for "primary production" phase and the "use" phase of the telephone. Approximately 36% of the total energy savings of primary production, use and transportation is recaptured through the remanufacturing activities at the end-of-life. Interestingly the greatest energy requirement of the telephone is during its "use" phase when the telephone is actually idle. All power for the telephone is provided over the line cord from a Key Switching Unit that operates 24 hours a day throughout the life of the product (estimated 10 years).

5.2.4 STEP 4: MODELING UNCERTAINTY OF THE ORP FOR THE M7310

Recall from Step 2 that the majority of the M7310 is economical for remanufacturing. Nortel provided data on the probability of failure during remanufacturing and is shown in Table 5.25. Notably, the probability of failures in remanufacturing are very low relative to the data estimated for the Norstar consumer telephone.

Table 5.25. Probability of Part Failures in Remanufacturing

Part #	Decision Variables				Interpretation of Output	Probability of no part failure in remanufacturing (P_{frm})
	X1	X2	X3	X4		
A	0	0	0	1	Disassemble for remanufacturing	0.98
A1	0	1	0	0	Remanufacture	0.98
A2	0	1	0	0	Remanufacture	0.98
A3	0	1	0	0	Remanufacture	0.98
A5	0	1	0	0	Remanufacture	0.98
D2	0	1	0	0	Remanufacture	0.95
D3	0	1	0	0	Remanufacture	1
D5	0	1	0	0	Remanufacture	0.98
D7	0	1	0	0	Remanufacture	0.85
D8	0	1	0	0	Remanufacture	0.90
D9	0	1	0	0	Remanufacture	0.94
D10	0	1	0	0	Remanufacture	0.95
D11	0	1	0	0	Remanufacture	0.95
D12	0	1	0	0	Remanufacture	0.95
D18	0	1	0	0	Remanufacture	1
D19	0	1	0	0	Remanufacture	1
D22	0	1	0	0	Remanufacture	1
D23	0	1	0	0	Remanufacture	1
D25	0	1	0	0	Remanufacture	1
D26	0	1	0	0	Remanufacture	1
D27	0	1	0	0	Remanufacture	1
D28	0	1	0	0	Remanufacture	1
D29	0	1	0	0	Remanufacture	1
D29A	0	1	0	0	Remanufacture	1

The results demonstrate that there is very little variability in both remanufacturing economics and material destinations, given the high probability of parts being successfully remanufactured. Figure 5.14 demonstrates the variability of remanufacturing costs using the Monte Carlo simulation technique. The statistical output of the simulation generates a mean total rebuild cost of $18.18. The total rebuild costs range from $16.87 (the optimal value generated by the ORP) to $27.98. The distribution of total costs is skewed to the left hand side and the peak of the distribution is directed towards the optimal remanufacturing value of $16.87.

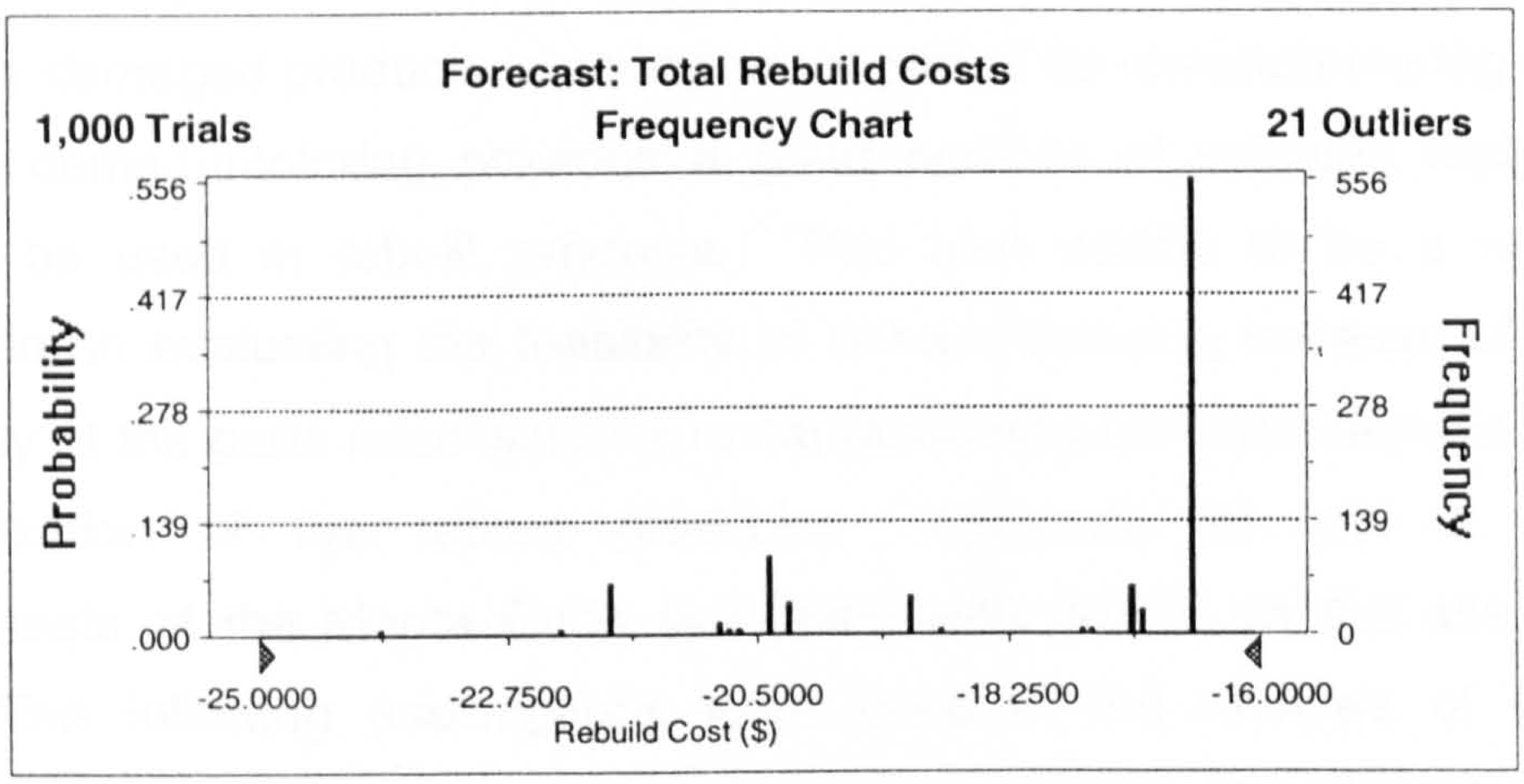

Figure 5.14. Variability in Rebuild Cost for the M7310

Monte Carlo simulations were also carried out to determine the variability of material destinations based on the probability of part failure during remanufacturing as listed in Table 5.25. The results however, demonstrate a similar situation as illustrated by Figure 5.14 whereby the majority of results are centered about the results of the ORP due to the low probability of failure in remanufacturing.

During data collection, it was found that approximately 4,000 out of the 20,000 M7310 telephones collected in the year 2000 were immediately demanufactured because of the condition of the product at its EOL. Upon further investigation, this volume (i.e., 20% for the year 2000) of the returned product that is demanufactured will tend to vary from year to year. The Monte Carlo simulation technique used to investigate the uncertainty within the remanufacturing process can also be applied to the quality of returned items and the uncertainty of being remanufactured in the first place. For example, from

Nortel's historical data of the year 2000, it can be stated that 20% of the returned items are demanufactured and 80% of the returned items are remanufactured. Thus, the probability of undergoing remanufacturing can be modeled to predict the total remanufacturing and demanufacturing activities of the M7310 at its EOL. This type of simulation provides a more global perspective of the total economics and material destinations because it includes the process of demanufacturing. For Nortel's remanufacturing program, demanufacturing old and badly damaged products is an important part of its remanufacturing program because demanufacturing provides a great number of valuable replacement parts to be used in rebuilt products. This also seems to be a necessary component in evaluating the feasibility of remanufacturing because of the fact that many of the parts necessary for remanufacturing are often derived from the cannibalization of the retired products. Appendix W and X provides spreadsheets of the Monte Carlo simulation with details on the assumptions cells. The following assumptions were used in the analysis of the total economics and mass destinations of remanufacturing and demanufacturing activities for the M7310 at its EOL:

- 80% of all M7310 returned are remanufactured and 20% are demanufactured. The 80% of products remanufactured will vary according to a triangular distribution (minimum = 0.7, likeliest = 0.8, maximum = 0.9). If a product is not remanufactured, it will be demanufactured.
- The number of returned products will vary according to a normal distribution with a mean of 20,000 units and standard deviation of 5,000 units per year.
- The average resale price of a remanufactured M7310 will follow a normal distribution with a mean price of $140 and a standard deviation of $10.
- The variation in the total rebuild cost is based on the optimization results of section 5.2.2. The rebuild cost is modeled using a triangular distribution (Maximum Rebuild Cost =$27.98, Minimum Rebuild Cost =$16.97 - based on ORP, and likeliest rebuild cost =$18.18 (mean)).
- For any telephone demanufactured, it was assumed that demanufacturing would also follow an optimal demanufacturing plan. Based on the

demanufacturing economics of disassembly costs, reuse value of parts, and recycling values, it is assumed that only the telephone base and the electrical cords would be recycled (and the handset landfilled). The majority of the parts within the telephone base are recycled and this demanufacturing plan concurs with a study that was carried out by a UK recycler on demanufacturing the M7310. However, the extent of recycling will vary in terms of mass recycled based on the assumption of whether contaminated polymers (i.e., the Upper Plastic Casing and Base Stand) are recyclable or not. If non-recyclable, the recycled mass = 0.587 Kg (minimum). If recyclable, the recycled mass = 0.942 Kg. (maximum recycled mass). Thus, the telephone base is modeled using a simple discrete distribution: 0.5 is the probability of recycling contaminated plastics (total recycled mass = 0.942Kg) and 0.50 is the probability of not recycling contaminated plastics (total recycled mass = 0.587Kg). The remaining of the demanufactured telephone is landfilled.

- It was assumed that the demanufacturing economics for landfill rates and material recycling are consistent with section 5.2.1 It was also assumed that the value of replacement parts in demanufactured telephones to be worth 5% of the cost of new parts.

Figure 5.15 provides an illustration of the results of the simulation model demonstrating the variability in the overall profitability of the combined remanufacturing and demanufacturing program for the M7310. The results demonstrate a profitable stewardship program for M7310 where annual profits may range from $613,000 to $2.4 million dollars (with a mean profitability of $1.45 million dollars). The variability is largely due to the proportion of M7310 remanufactured (profitable) versus demanufacturing (unprofitable).

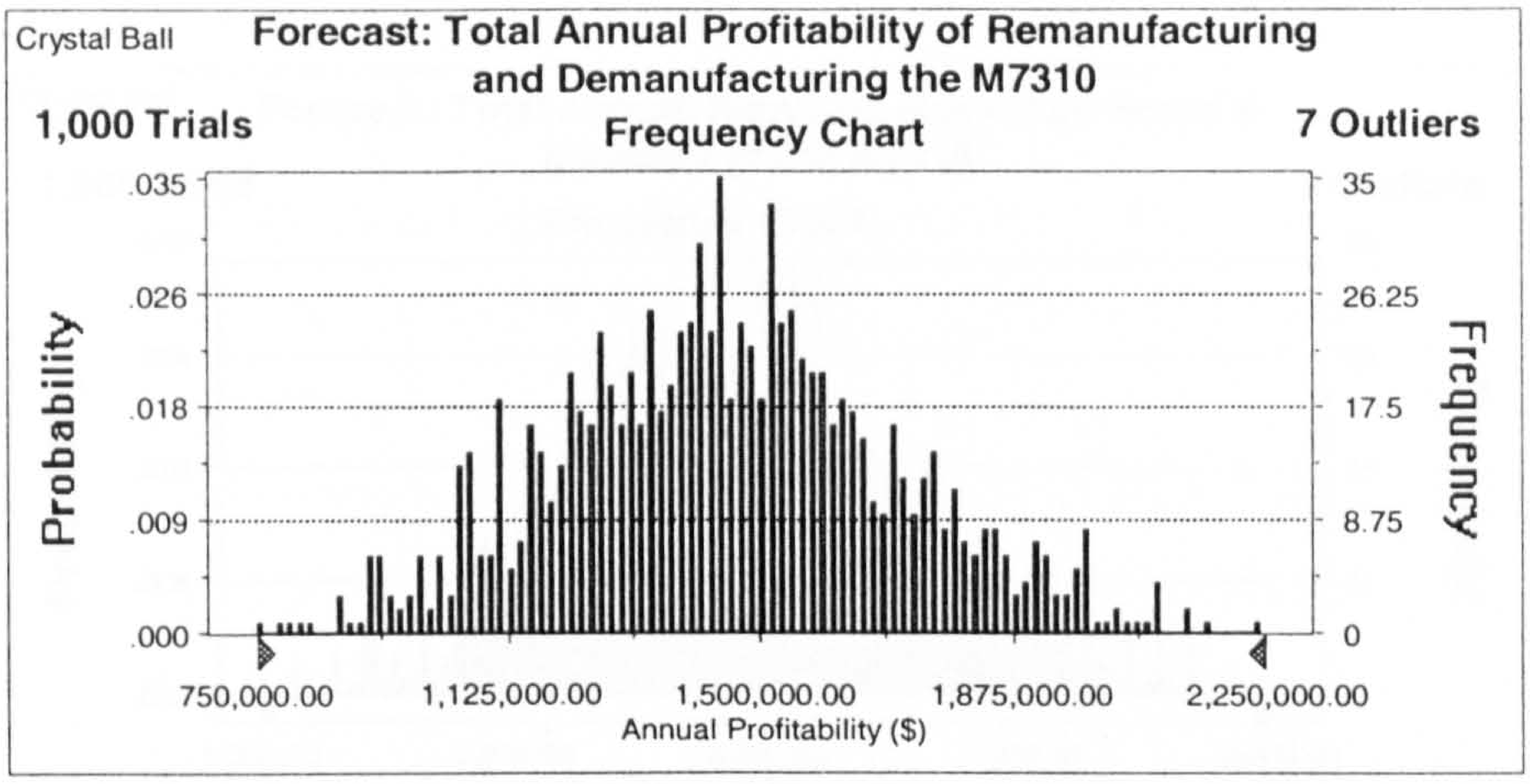

Figure 5.15. Variability in Annual Profitability for the Combined Remanufacturing and Demanufacturing Activities of the M7310

The second set of simulations investigated the variability of the material dispositions based on the proportion of EOL telephones remanufactured and demanufactured. The spreadsheet used for this simulation and its assumptions is provided in Appendix X. Figure 5.16, 5.17 and 5.18 provide respective illustrations of the variability of the total mass reused (i.e., through remanufacturing), the total mass recycled (through both remanufacturing and demanufacturing activities), and the total mass landfilled (through both remanufacturing and demanufacturing activities).

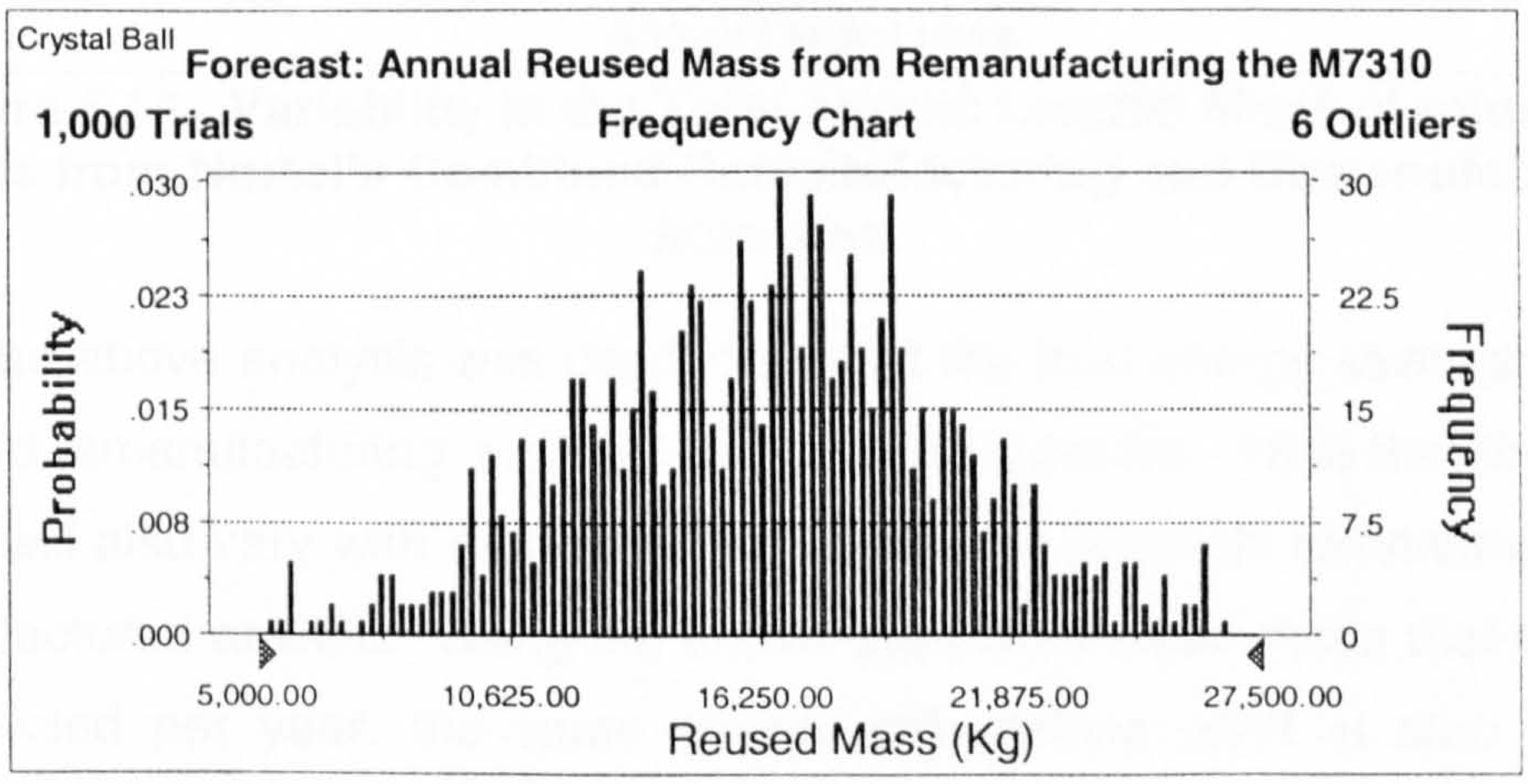

Figure 5.16. Variability in the Total Annual Reuse Mass of returned M7310s from Nortel's Remanufacturing Activities

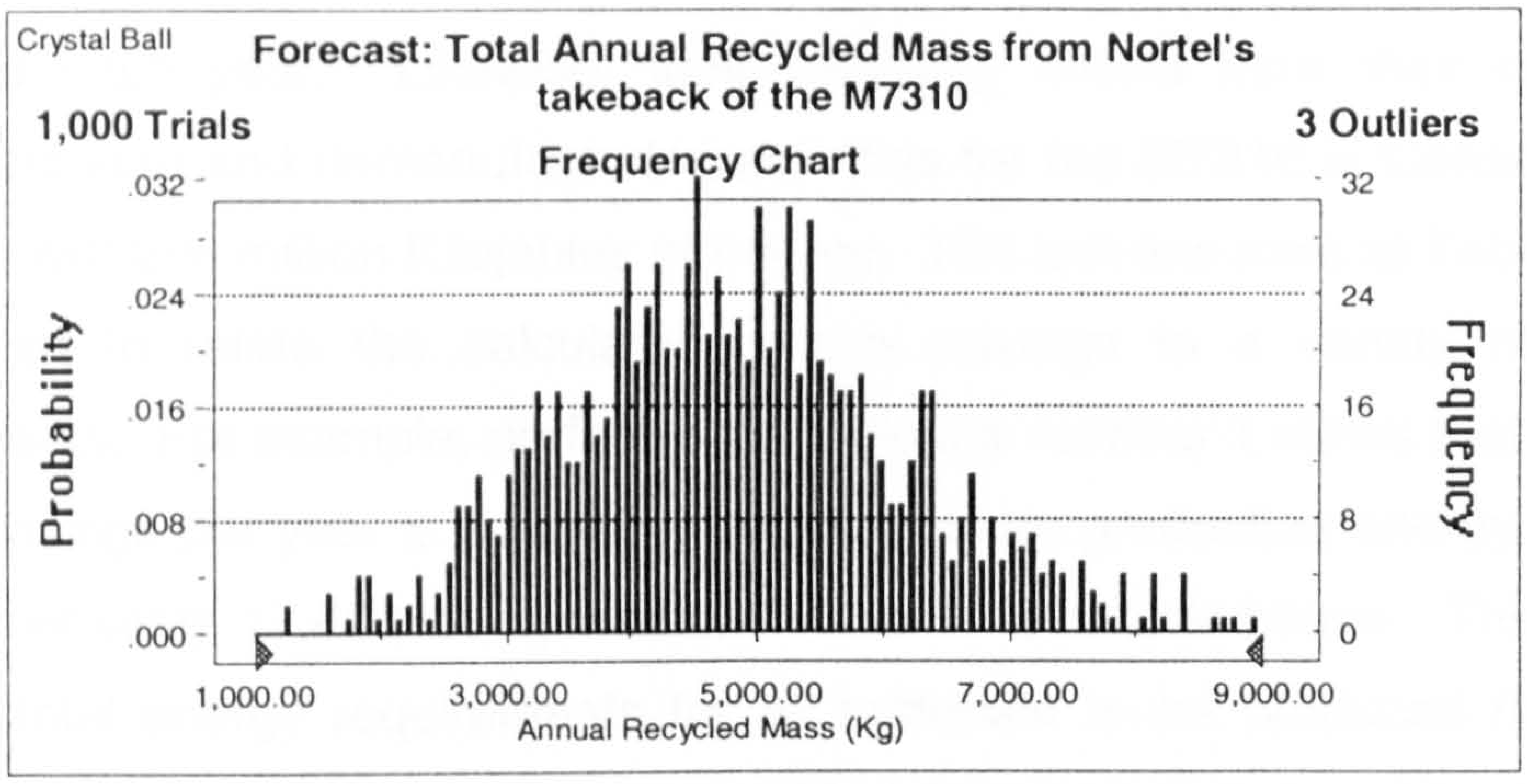

Figure 5.17. Variability in the Total Annual Recycled Mass of returned M7310s from Nortel's Combined Remanufacturing and Demanufacturing Activities

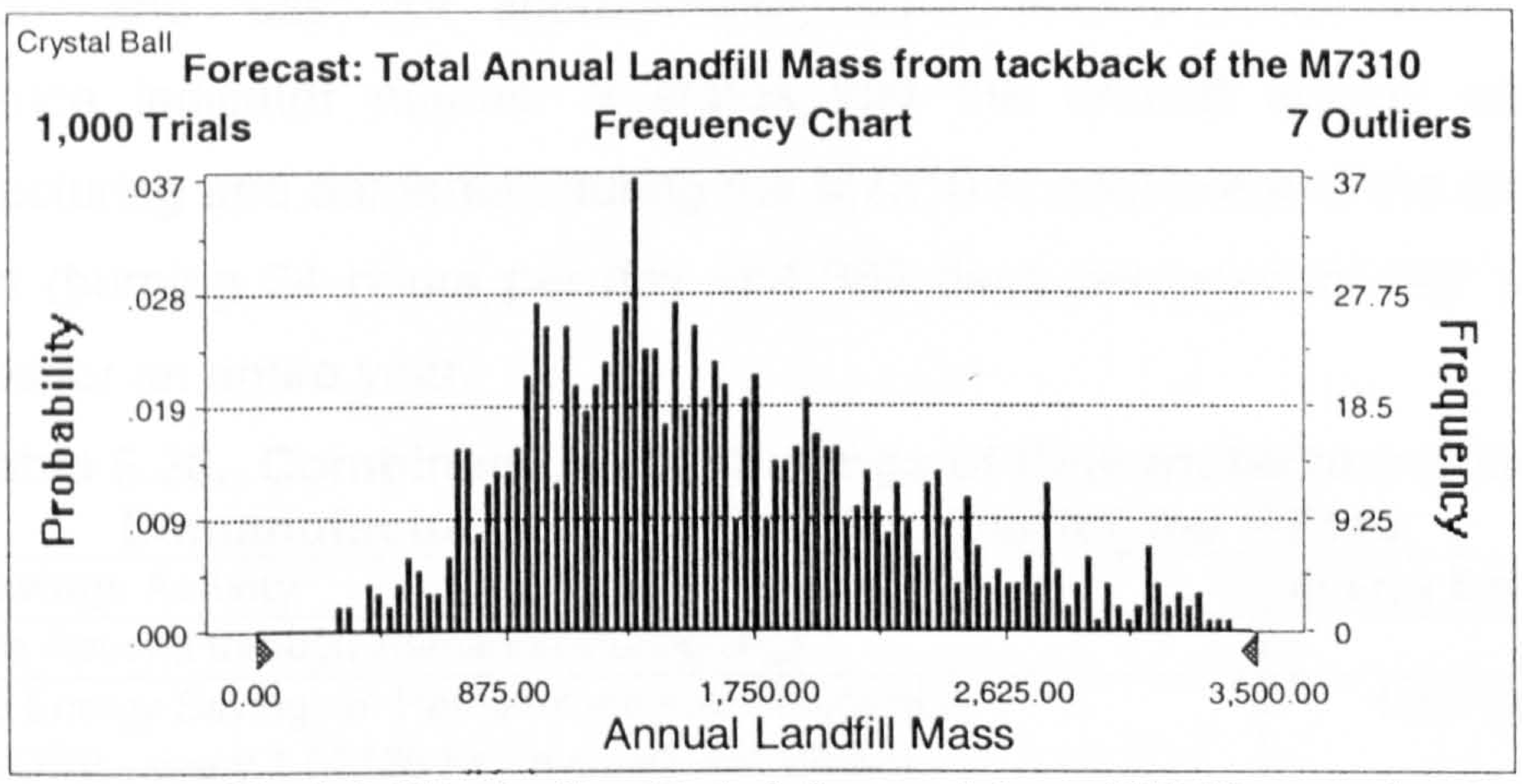

Figure 5.18. Variability in the Total Annual Landfill Mass of returned M7310s from Nortel's Combined Remanufacturing and Demanufacturing Activities

The above analysis was used to predict the total energy savings from the combined remanufacturing and demanufacturing activities. Note that the energy savings will also vary with respect to the number of products remanufactured or demanufactured at EOL. Using the above calculated mean mass that is reused and recycled per year, the same energy calculations used in step 3 of the developed methodology is carried out to determine the mean annual energy savings that would result from the combined remanufacturing and demanufacturing activities. Table 5.26 demonstrates that Nortel's remanufacturing activities on the M7310 in Canada saves on average 1.3 billion Kilojoules each year. Likewise, their recycling efforts from their combined remanufacturing and demanufacturing activities for the M7310 in Canada saves annually over 296 million Kilojoules of energy. The last few rows of Table 5.26 is an attempt to relate the calculated energy savings to a variety of energy requirements. For example, performance indicator number 1 states that the total energy savings per year is equivalent to the primary production energy required for approximately 17,000 newly manufactured M7310 telephones. This means that the total energy requirements for all materials to be produced (from raw material extraction and processing) in 17000 telephones is conserved through one year of Nortel's stewardship activities. Performance indicator number 2 states that the total energy saved is equivalent to the life-cycle stages of "primary production" and "use" for approximately 6500 M7310 telephones. Lastly, performance indicator number 3 states that the annual energy savings of remanufacturing and demanufacturing the M7310 is equivalent to the continuous operation (burning 24 hours per day and 365 days per year) of 847 sixty watt light bulbs for an entire year.

Table 5.26. Combined Energy Savings of Remanufacturing and Demanufacturing Activities Per Year for the M7310

Energy Savings Activity		**Energy Savings (KJ)**
Mean Mass Reused through Remanufacturing (Kg)		16,495.14
Calculated Energy Savings of Remanufacturing Efforts (KJ) (based on ORP - every 1.02788 Kg saves 81,461.08 KJ)		1,307,265,359.91
Mean Mass Recycled through both Remanufacturing and Demanufacturing (Kg)		4,842.37
Calculated Energy Savings of Recycling Efforts (KJ) (based on ORP - every 0.11291 Kg saves 6,916.85 KJ)		296,642,578.47
Total Annual Mean Energy Savings (KJ)		1,603,907,938.38
Indicators of Energy Savings Performance		
1.	Required Primary Production Energy for the M7310	93841
	Energy Savings relative to the energy requirements of the M7310's Life-cycle stage of "Primary Production"	17,091.76
2.	Required "Primary Production" and "Use" Life-cycle Energy requirement for the M7310 (see section 4.?)	245681
	Energy Savings relative to the energy requirements of the M7310's Life-cycle stages of "Primary Production" and "Use" phases	6528.41668
3.	Required Energy to operate a 60 watt light bulb for one year	1,892,160 KJ/year
	The total number of 60 watt bulbs that can be burned for one year as a result of the Nortel's Energy Savings from their combined remanufacturing and demanufacturing activities	847.66

5.3 Conclusions from Applications of the Developed Methodology

The following is concluded from the application of the developed methodology to Nortel's M7310 business telephone:

- Unlike the results generated by the consumer telephone, Step 2 of the methodology clearly demonstrate that there is a positive economic argument for remanufacturing the M7310 within North America or Europe. The results clearly demonstrate the majority of the product's mass (approximately 90% of the total mass) is more economical to remanufacture than the costs to acquire new parts and the added demanufacturing costs. Notably, even if new parts were to be used in the rebuild, remanufacturing the M7310 would still be quite profitable. This is largely a result of the high resale price associated with M7310.
- In Step 3, the calculation of energy savings against the life-cycle energy requirements clearly demonstrates that remanufacturing the M7310 and the consumer telephone would lead to substantial energy savings from a life-cycle perspective.
- Step 4 of the methodology demonstrated that the uncertainty of failures within the remanufacturing process would not have a significant impact on the economics or material destinations generated by the Optimal Remanufacturing Plan. This is due to the small probability of part failures in remanufacturing the M7310. Lastly, the uncertainty of the proportion of the returned products remanufactured versus demanufactured was effectively modeled to demonstrate the impact that quality plays in the determination of the overall stewardship profitability and material disposition of EOL products.

In conclusion, the developed methodology provides an important contribution to the analysis of the economics of takeback and the evaluation of remanufacturing EOL products as opposed to demanufacturing strategies. The four steps of the methodology (data collection, remanufacturing analysis, energy and material savings, and evaluation of uncertainty) provides a necessary framework for an OEM to evaluate the potential economic and environmental advantages (and disadvantages) involved in remanufacturing. From applying this methodology to the 2 Nortel products, the following conclusions are drawn:

- Step 1 and 2 of the developed methodology demonstrate that the economics of product remanufacturing can be quantified and evaluated against strategies of demanufacturing. The results demonstrate that the methodology is useful for analyzing both economical and uneconomical situations of remanufacturing. Sensitivity analysis of the optimization model provides an important technique to evaluating the economic drivers of remanufacturing.
- Step 3 of the methodology provides an important technique for quantifying the environmental benefits of remanufacturing.
- Step 4 of the methodology has effectively modeled two major sources of variability of product remanufacturing and its impact on both the economics and material destinations of remanufacturing. The results demonstrate that a high probability of part failures within the remanufacturing process can dramatically influence both the profitability and material destinations of EOL products. Variability in the quality of the recovered products at the end of life can be effectively modeled to understand the consequences of combined remanufacturing and demanufacturing activities at the EOL.

PROPRIETARY

IR/1998/**

Results of a Nortel 2000 Mobile Phone Disassembly Assessment

Prepared by Carl D. Mead

Approved by K.S Snowdon

1.0 Introduction

The disassembly assessment was carried out as part of Nortel's response to an EU proposal on the management of end-of-life electrical and electronic equipment. The overriding objective of the proposal is "as a first priority, the prevention of waste from end-of-life electrical and electronic equipment and, in addition, the reuse, recycling and recovery to reduce the quantity of waste destined for final disposal..."[1]

Nortel will be required to take back electronic equipment from the user at the end of its useful operating life. It is therefore important to consider the potential costs and possible revenues associated with the take back of Nortel products and the recovery/disposal options available.

This report describes the parts and materials contained in a Nortel mobile phone, the disassembly processes and times involved, and an analysis of the costs and revenues associated with disassembly and the recycling of materials. Figures 1 and 2 (Appendix 1) show the mobile phone assembled and disassembled ("assembled" picture - Nevada model).

The objectives of the excercise are:

- to determine the cost of disassembling a Nortel 2000 mobile phone
- to determine the costs of disposing unrecoverable parts to landfill
- to estimate possible revenues from recyclable/recoverable components/parts
- to discover if it is economically viable to disassemble and recycle the Nortel 2000 mobile phone as it is currently designed and manufactured.

2.0 Method

2.1 Experimental Procedure

The Nortel 2000 mobile phone was disassembled down to the component parts which could be removed by hand or with a power screwdriver. Connections included screws, snap-fits and adhesive bonds.

The procedure (See Table 2):

1) Disassemble mobile phone, numbering the process and describing and naming the operations.
2) Describe each part removed and state the material
3) Determine the time for the removal of each part
4) Determine the cost of removal
5) Determine the weight of each part
6) Estimate the recycling value or landfill cost of each part (landfill costs for each part stated as negative values in the table).
7) Determine the total cost of disassembly (labour only)
8) Determine the total revenue (value of recycled material minus the cost of landfilled material)
9) Subtract the cost of disassembly from the revenue. The resulting figure will either be positive (value of materials for recycling exceeds the costs for disassembly and landfill) or negative (disassembly costs exceed the revenue from recycling recoverable materials).

2.2 Assumptions

- All operation definitions are taken from a Manchester Metropolitan University Report[2].
- All times for operations are taken from a Manchester Metropolitan University Report[2] based on times taken on a factory disassembly line.
- It is assumed that parts are moved a distance of 500 mm.
- The nickel metal hydride battery was not included in the recovery disposal analysis. Further investigations would need to be undertaken to consider possible costs or revenues associated with the recovery, re-use or disposal of this significant component (by weight and toxicity) of a mobile phone.
- All values for scrap materials are taken from a Manchester Metropolitan University Report[3]. Figures are provided in Appendix II.
- A value for the magnesium alloy is estimated at £800 per metric tonne (J. Poyner).
- All costs for disposal to landfill are taken from Manchester Metropolitan University Report[3].
- A cost of £5.00 per hour is assigned as a labour rate for the disassembly cost calculation. This figure does not take into account costs such as collection, storage, transportation and other overheads associated with disassembly and recycling. A figure of £15.00 per hour can be used to take these additional costs into account[3].

3.0 Results

This section provides a summary of the results, outlines the parts and material breakdown for the Nortel 2000 mobile phone and provides a table of the disassembly processes.

3.1 Summary

Time for disassembly of Nortel 2000 mobile phone = **93.3** seconds

Cost of disassembly = **13.1** pence per mobile phone (at £5.00 per hour rate) * PTO

Revenue from recycling = **1.6** pence per mobile phone

Balance = -11.5 pence per mobile phone

* If a figure of £15.00 per hour is used for disassembly the balance/cost is actually 34.5 pence per mobile phone.

3.2 Parts and Material Breakdown

Table 1 shows the part breakdown by weight, and Table 2 shows the breakdown by percentage of material:

Breakdown of parts	**Weight (g)**
Battery	87.29
Clip	3.62
Metal clip	0.819
Antenna	3.64
Keyboard PCB pad	5.41
Rubber membrane	0.92
LED membrane	0.55
LED housing	0.33
Lens	0.08
LED	0.12
LCD screen	2.23
Volume button	0.53
Metal clips	0.14
Key pad and LCD	18.01
Screws	1.98
PCB shield	7.43
Connector	0.25
PCB board	27.54
Speaker cover	0.48
Backing	0.05
Antenna housing	4.00
Connector	0.56
Battery insulator/shield	16.14
Facia molding	17.49
Total	**204.3**

Table 1. Part breakdown by weight

Breakdown of materials	**%**
PC/ABS (uncontaminated)	8.96
Magnesium (alloy)	7.9
Steel (uncontaminated)	1.4
Circuit board	13.5
Battery	42.7
Other (mixed materials e.g ABS/brass)	25.54
Total	**100**

Table 2. Percentage material type

3.3 Process Table

Table 3 (Appendix III) describes the disassembly process, corresponding times and materials involved. It also shows the cost of disassembly and the potential revenue.

4.0 Discussion

4.1 Analysis of Costs and Revenues

The results show that full disassembly of the mobile phone costs 13.1 pence per unit. The revenue available from recycling the product is 1.6 pence per unit.

This incurs a total recovery/disposal cost of 11.5 pence per unit to Nortel. However, if overheads are included the cost of disposal/recovery could be as much as 34.5 pence per unit.

In addition, the battery is not included in the recovery/disposal assessment. Nickel metal hydride batteries may have a value to recyclers in certain quantities. However, if a recycle market does not exist they have to be disposed of as hazardous waste which incurs a significant cost penalty. This will of course alter the cost/revenue for disassembly and recycling of the unit. An alternative course would be to forge an alliance with the battery manufacturers/suppliers and develop a take back scheme resulting in the batteries being returned to the supplier.

If one million phones were disassembled and recycled it would, according to this study, cost Nortel £115000 (at a disassembly rate of £5.00 per hour and not including battery recovery/disposal).

The cost of simply removing the battery and just sending a million phones to landfill would be in the region of £2000 using a current landfill levvy of £20 per tonne!

However, wholesale landfill is becoming an unacceptable option for the end-of-life disposal of electronics. It is necessary to develop and design products, such as the mobile phone, with take back and environmental performance considered at the design stage. This means applying concepts of Design for the Environment throughout product development. Designing for end-of-life is an important concept and should consider all end-of-life options such as re-sale, re-manufacture, recovery, recycling and incineration.

This assessment shows that takeback, disassembly and recovery of the Nortel 2000 mobile phone, as it is currently designed and manufactured, using the information available, would prove an expensive end-of-life option. A comparison of the Nortel results with the ECTEL Cellular Phone Takeback Scheme results for disassembly and recovery is useful (see IR/1998/**). For products released onto the market between 1992-1994 (data used is an average of four different products) the net revenue is - **44.0** pence per phone. For products released onto the market between 1995 - 1996 (data used is an average of three different products) the net revenue is **+10.0** pence per phone. Phone models used in the ECTEL study are not stated and sources for labour costs are uncertain.

Of course, the results are data and assumption dependent but it could mean that the design of the Nortel mobile phone used in the this study could be a significant distance behind Nortel's competitors in terms of Design for the Environment techniques.

It is possible to make design changes which could improve the environmental performance of the phone and which consider end-of-life costings for Nortel. Such design changes would include making the phone easier to disassemble, improving recyclability and reducing the toxic content. Examples are:

- ensuring materials can be easily seperated on disassembly - e.g. brass insert in aerial housing
- using alternative recyclable materials - possibly aluminium instead of plated ABS
- using recycled materials - e.g. 10-20% recycled ABS
- minimising the toxicity of materials used on the PCB by supplier environmental assessment

These are possible suggestions which of course would need further assessment. A full DfE study can be carried out if required by M&DT.

5.0 Conclusions

Due to EU legislation disposal of a complete mobile phone to landfill is unlikely to remain a viable option.

Takeback, disassembly and recycling of the current design of the Nortel 2000 mobile phone is not presently economically viable. An option to consider would be the development of an alliance with other telecoms manufacturers and suppliers to share costs. Contributing to the ECTEL Cellular Phone Takeback Working Group might be appropriate.

Nortel products need to be designed with consideration to their take back, disassembly and recovery as an end-of-life option - this requires the application of DfE principles and practices.

Recommendations For Further Work

Materials and Design Technology (M&DT) have developed DfE practices and training that may be integrated with product development processes at Nortel. These are currently supported by customised DFE software developed by the environment team in M&DT and Product Design and Engineering at Harlow.

It is recommended that given the potential costs associated with product take back of the Nortel 2000 phone, that awareness is raised at a design group level and appropriate training/action is taken to minimise the financial risks.

A recommendation for futher work would be to conduct disassembly assessments of competitors' mobile phones as a bench-marking excercise and to generate eco-label criteria for Nortel mobile phones in anticipation of a European eco-label scheme which may be generated in 1998/99 for a mobile telephone.

Acknowledgements

The following people are acknowledged for contributing information and support:

J. Poyner (PD&E - HAL02)

D. Francis (M&DT - HAL02)

A. Dalby (CDG - HAL02)

References

1. End-of-life Electrical and Electronic Equipment - EU DGXI Working Paper, October 1997.

2. Dowie, T, Disassembly Time Estimation, Manchester Metropolitan University, Oct 1994, DDR/TR 15.

3. Poyner, J, Results of RPI and BS1r/g Disassembly - BNR Europe, Manchester Metropolitan University, Mar 1995. DDR/TR22.

Appendix I removed because of commercially sensitive material

Appendix II

Material	Price Used £/tonne
Acrylic	250
PB/ABS	200
Copper	1500
Steel	30
Brass	800
PCB	12
Magnesium	800
Landfill	20

Price per tonne of scrap metal

Appendix III

Table 3. Disassembly Table for the Nortel 2000 Mobile Phone

Process	Description	Operation	Time (s)	Cost (p) (£5/hr)	Part	Material	Weight (g)	Value (p)
1	Push button		1	0.14				-
	Remove part	Disconnection	1.5	0.21	Battery and clip	Nickel/metal hydride	87.29	0
2	Remove clip	Clip removal	1	0.14	Clip	PC/ABS & steel	3.62	-0.007
	Move clip		0.7	0.1				-
		Pick up tool	0.7	0.1				-
	Remove metal component	Opening of snapfits (2)	4	0.56	Metal clip	Sprung steel	0.819	0.01
		Put down tool	0.7	0.1				-
	Move clip		0.7	0.1				-
3	Unscrew antenna	Screw removal	1.3	0.18	Antenna	PC/ABS + steel insert	3.64	-0.007
	Move antenna		0.7	0.1				-
4	Remove chassis	Breaking	1	0.14	-	-		-
5	Remove key pad membrane	Removal	1	0.14				-
	Removal of key pad from PCB pad	Seperation of adhesive bonds	1	0.14	Keyboard PCB pad	Plastic/rubber	5.41	-0.01
					Rubber membrane	Rubber	0.92	-0.002
	Move PCB pad and rubber membrane		1.4	0.2				
6	Removal of LED membrane	Removal	1	0.14	LED membrane	Rubber	0.55	-0.001
	Move membrane		0.7	0.1				-
7	Removal of LED lens and housing	Removal	1	0.14	Housing	PC/ABS	0.33	0.006
			1	0.14	Lens	Acrylic PMMA	0.08	0.002
	Move lens and housing		0.7	0.1				-
8	Removal of LED	Pick up tool	0.7	0.1				-
		Removal	1	0.14	LED	Acrylic PMMA	0.12	0.003
		Put down tool	0.7	0.1				-
	Move LED		0.7	0.1				-

Appendix III

9	Removal of speaker	Breaking	1	0.14	Speaker	Various	4.70	-0.009
	Move speaker		0.7	0.1				-
10	Removal of LCD screen	Seperation of adhesive bonds	1	0.14	LCD screen	Polycarb-onate	2.23	-0.005
	Move screen		0.7	0.1				-
11	Removal of volume button	Removal	1	0.14	Button	PC/ABS & rubber	0.53	-0.001
	Move button		0.7	0.1				-
12	Remove snapfit clips	Pick up tool	0.7	0.1				-
		Opening of snapfits (x2)	4	0.56	2 metal clips	Spring steel	0.14	0.0004
		Put down tool	0.7	0.1				-
	Move clips		0.7	0.1				-
13	Remove key pad	Removal	1	0.14	Key pad and LCD	Various	18.01	-0.04
	Move key pad		0.7	0.1				
14	Remove screws (x 9)	Pick up tool	0.7	0.1				-
		Screw removal	30	4.2	Screws	Steel	1.62	0.004
		Put down tool	0.7	0.1				-
	Move screws		0.7	0.1				-
15	Remove PCB shield	Removal	1	0.14	Shield	Plated ABS	7.43	-0.01
	Remove PCB connector	Removal	1	0.14	Connector	Rubber	0.25	-0.0005
	Move shield and connector		1.4	0.2				-
16	Removal of PCB board	Removal	1	0.14	PCB board	Various (gold tracks)	27.54	0.03
	Move PCB		0.7	0.1				-
17	Removal of speaker cover	Removal	1	0.14	Speaker cover	PC/ABS	0.48	0.009
	Removal of backing	Removal	1	0.14	Backing	Nylon?	0.05	-0.0001
	Move cover and backing		1.4	0.2				-
18	Remove 2 screws	Pick up tool	0.7	0.1				-
		Screw removal	6.7	0.94	Screws (x 2)	Steel	0.36	0.001
		Put down tool	0.7	0.1				-
	Move screws		0.7	0.1				-
19	Remove antenna housing	Remove	1	0.14	Antenna housing	PC/ABS with brass insert	4.00	-0.008
	Move housing		0.7	0.1				-
20	Clip removal	Clip removal	1	0.14		-		-
	Remove copper connector	Remove	1	0.14	Copper/plastic connector	PC/ABS and copper	0.56	-0.001
	Move connector		0.7	0.1				-
21	Removal of battery	Removal	1	0.14	Battery insulator	Mg alloy	16.14	1.29

Appendix III

	insulator connector				connector	shield		
	Move connector		0.7	0.1				-
	Move molding		0.7	0.1	Face-plate molding	PC/ABS	17.49	0.35
TOTAL			**93.3**	**13.1**			**204.3**	**1.6**

If you would be a real seeker after truth, it is necessary that at least once in your life you doubt, as far as possible, all things.

Rene Descartes