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TOPROCO
TOtal
PROduct-life-cycle
COst-estimation

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Keywords: recycling, design, design for recycling, disassembly, software

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ABSTRACT

Take back legislation is being considered to force equipment manufacturers to be responsible for their products at the end of life. This is causing concern for the whole industry as it is unsure how it will finance such a responsibility. Having their customers to pay for this would jeopardize the competitive position of the European manufacturers and restrict market demand. This scenario creates a clear requirement for the development of a more appropriate economic situation without compromising environmental needs.

The challenge for industry therefore, is to increase the end of life value of its products in order to finance collection and recycling. However, manufacturing industry through its product designers, does not currently have the capability or tools to either influence or monitor the end of life value of their products. There is therefore a need to provide the tools that will direct designers' to optimize their product design to obtain maximum end of life value.

The objective of TOPROCO is to develop a Design for Recycling (DFR) methodology and software tool allowing the calculation of end-of life value of products by taking into account the revenues from the current market for recycled material and the costs of current material recycling technology.

Through the deve[illegible]nt and [illegible] proof will be delivered to the manufacturing industry of the economic benefit of properly designed products for end of life.

KEYWORDS

recycling, design, design for recycling, disassembly, software

1. INTRODUCTION

The EU has identified Waste from Electrical and Electronic Equipment (WEEE) as a priority waste stream. Legislation is being considered to force equipment manufacturers to be responsible for their products at the End Of Life (EOL). This is causing concern for the whole industry as it is unsure how it will finance such a responsibility, particularly with regard to the collection, disposal and recycling cost of their products. The current recycling infrastructure is unable to economically accommodate WEEE because of the nature of its material content (more plastic and glass than metals). This leads to EOL equipment being generally categorized as having little or no residual value and therefore viewed as a financial liability for disposal. This financial liability is further compounded in Europe by dramatic decreases in available landfill sites, rapidly rising' disposal costs and pressure from public opinion for more environmentally conscious behavior from industry.

It is clear that industry will be, forced to pay the bill for increasing amounts of waste from products at EOL. However, to have their customers pay for this would jeopardize the competitive position of the European manufacturers and restrict market demand. This scenario creates a clear requirement for the development of a more appropriate economic situation without compromising environmental needs.

The challenge for industry therefore, is to increase the EOL value of its products in order to finance collection and recycling. This can be made possible through wider material recovery, maximum value achievement and minimization of waste. Research has indicated that the design process is the most appropriate place to influence the value chain. It is recognized that 80% of the total product-life-cycle costs are committed during this phase. However, manufacturing industry through its product designers, does not currently have the capability or tools to either influence or monitor the EOL value of their products. There is therefore a need to provide the tools that will direct designers to optimize their product design to obtain maximum EOL value. ' This approach would be a major extension to Design for Environment (DFE) in that it has to focus on the total economics surrounding material values, current processes and the development of emerging recycling technologies and strategies.

The need for cost-effective yet highly 'fictional and quality-reliable products with ever decreasing time-to-market is putting product design under constant pressure for more complex decision making within reduced time frames. Additionally tightening legislation regarding producer liability and environmental concerns throughout the total product-life-cycle is adding more and more dimensions of considerations for design optimization and compromising. On the other hand improvements of materials and manufacturing processes widen the choice of alternative realizations for a given functional solution.

Thus the design process becomes more complex and more elaborate with the increasing danger to end up in a blind hole of suboptimal product design with respect to the overall balance of trade-offs across the fields of concerns to be taken into account.

Taking all these impacting elements together it is necessary to take a more holistic approach to the product design activities with a specific bias towards incorporating adequate considerations about influences from the after-use phase into the decision making process.

2. EXPECTED ACHIEVEMENTS

The objective of TOPROCO is to develop a Design for Recycing (DFR) tool addressing the calculation of EOL value of products by taking into account the revenues from the market of recycled material and the costs of current material recycling technology.

Through the development and evaluation process, proof will be delivered to the manufacturing industry of the economic benefit of properly designed products for EOL. Satisfying this criteria will lead the way to its commercial development and ultimate adoption as the industry standard practice.

The result of the TOPROCO project will produce a unique system and design procedure that can be evaluated by industry and demonstrate a potential for future commercial exploitation as a separate module to be integrated in the customers design process.

3. THE TOPROCO PROJECT

The TOPROCO project is a 30 months project (from August , 1994 until January 31, 1997). The available resources for this project are almost 20 man years and the total budget is approximately 2.4 MECU of which about 50% is funded by he European Commission. The consortium is consisting of 6 partners from 4 different EU countries.

TOtal PROduct-life-cycle COst estimation Brite- EuRam II project BE-7314

Figure 1: The TOPROCO logo

Mann Organisation is located in the UK where it is the major company handling the recycling of post-consumer and post-industrial electronic equipment. Products handled include stereo systems, electronic games, personal computers, workstations, mainframes, disc storage systems, printers, photo-copiers, and fax machines.

Products are disassembled and separated into material stream:;, many of which are processed within the organization. In 1993 the Mann Organisation introduced plastics processing to create the first fully closed loop plastic recycling in the UK. Electronic equipment manufacturers are now producing new plastic assemblies using 100% recycled material from end of life electronic equipment processed by the Mann Organisation.

The knowledge of materials and disassembly techniques over a wide range of equipment delivers the facility to understand downstream reprocessing and the relevant issues to successfully re-manufacture. This includes product design guidelines.

Mann's role in the project focuses on the knowledge acquisition since the recycling company will give the project input on the existing and future recycling technology; But in its role as consultant an important contribution is given in (he demonstration task, in which the project software results will be tested and compared with the real world recycling costs and revenues.

Mann Organisation is a member of an organization called "EMERG" (Electronics Manufacturers Equipment Recycling Group). It is made up of 20 multi-national companies, leaders in the electronics and business equipment field who manufacture or distribute in Europe, (including the European plants of companies like IBM, Panasonic, Hewlett-Packard, Motorola, and Rank Xerox). These companies are grouped into a "User Interest Group" that serves as a sound board for the project and potential user group of a commercial spin-off.

GEP is a German subsidiary (GEP - Gesellschaft für Entwicklungsberatung und Produkt-Recycling) of Dain-tier-Benz, which is active in consulting geared towards " Design-For-Environment" (DFE), including the analysis and evaluation of existing and newly designed products with respect to their environmental y friendliness as well as dismantling, sorting and recycling of electrical and electronic equipment mainly for such product categories as data processing equipment and control' instruments.

The dismantling activities are set up to meet the German regulation for scrapping electrical and electronics equipment (Kreislaufwirtschaftsgesetz, Elektronik-Schrott-Verordnung), due in 1996.

GEP provides the project management function to the project. Its other tasks in the TOPROCO project are comparable to MANN's tasks: providing the other partners with recycling knowledge and testing the concepts and software with demonstration product designs.

ELCO VAYONIS S.A. is a major Greek manufacturer of household electrical appliances. The two main product categories are hot water tanks and cooking appliances. The company employs about 400 people and the manufacturing site is located in Athens, Greece.

ELCO has a strong tradition in being self-sufficient in terms of the related know-how. The projects of the R&D department [illegible] from basic research to machine design. However, recycling-oriented product design is a new area of expertise. ELCO realizes that recyclable products will have the competitive edge on the markets in the near future and is therefore interested in implementing a product design which will minimize the cost of recycling.

IAT is a university institute of the University of Stuttgart, which currently has 75 employees. IAT's main activities are in the area of technical design, design methodologies, life-cycle engineering, Simultaneous Engineering, information systems and tools for development and production" planning, as well as business management. In these areas knowledge is spread by consulting projects with manufacturing companies out of various branches and sizes., which contribute up to 40°/0 of the annual budget of approx. 6 MECU (app. $ 4".5 million).

IAT sees its role in bridging the gap between research and industry due to knowledge transfer and applied research. Therefore the I AT closely collaborates with the Fraunhofer-Institute for Industrial Engineering, which is active in similar fields of work and employs another 110 people.

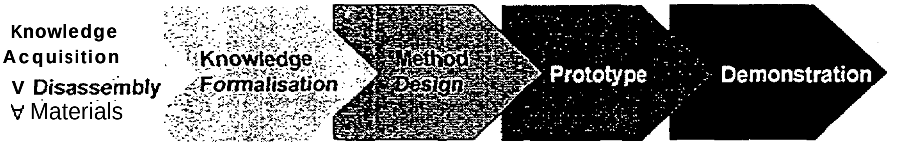
The experience, methods and software gained in "the project are expected to bring benefit to future developments and to European cooperation with research and industry, thus contributing to environmental awareness and recycling and cost optimized products.

IAT's task in the project is to design the methodology together with WTCM and prepare the input for the actual software development.

WTCM-CRIF is the private research center for the Belgian Metal working industry. It represents i 800 member companies involved a wide variety of activities ranging from basic products to complex industrial installations, 'l-he institute has 7 departments covering various technological] fields (Mechanical Engineering, Plastics, Foundry, Steel Construction Pressure Vessels, Surface Treatment and Automation). Its Mechanical Engineering department works in the areas of machine design, CIM, CAD/CAM and manufacturing technologies.

WTCM designs together with IAT the methodology and is responsible for the software development with support from SNI.

Siemens-Nixdorf Belgium is a software development center, of the Belgian subsidiary of Siemens-Nixdorf Informationssysteme, a major European information technology. As a vendor of CAD-products SNI participates in the development of the software prototype and exploit it on the market.



recycling companies	*universities & research centers*	*system developers*	*end-users*
MANN	*IAT*	*WTCM*	*ELCO*
GEP	*WTCM*	*SNI*	*GEP*

Figure 2: Partners' role in the TOPROCC project

The partnership is highly complementary and multi-disciplinary, combining the effort of the material recycling company MANN Organisation with consulting companies in the area of [illegible] knowledge acquisition side, IAT and WTCM as R&D centers and system developers with the support of one of the biggest European system developers SNI. The system will be validated and tested in the design environment of the end-user company ELCO and by the DFR consultants in the'ir role as end-user.

4. RECYCLING SCOPE

Recycling is a general term used for a broad scope of the processes ranging from incineration of household waste with heath recovery until the second hand market for e.g. cars.

The Design For Recycling methodology in TOPROCO is limited in the recycling scope as far as it concerns the recycling processes as the product range. TOPROCO evaluates a product design with respect to material recycling as far as this material can be reused in equivalent applications and products. This is only a limited scope compared to the total recycling scope as defined by the VDI 2243 (VDI 1993) (See Figure 7) creating levels of recycling going from reuse to (material) dew-n-cycling. Also as far as the type of products TOPROCO limits itself to the assessment of electromechanical and electronic products and equipment. This implies the most important material category is plastics. Concerning the product choice it is not really a constraint if you know that the whole European Union is producing about 6 million tons of plastics a year and 4 million tons electromechanical and electronic waste a year (ENEA 1994). The demonstration products in TOPROCO are a keyboard, a vacuum cleaner, a boiler, an oven door, a pump control unit and a monitor.

5. PRODUCT DI3SCR1PTION

Development of an assessment system for end-of life costs during conceptual design is for the designer a valuable complement to the widely available commercial "Design for X" tools. These tools like e.g. Design for Manufacturing, Design for Assembly. Design for Serviceability take into account other life-cycle phases as production processes. assembly, maintenance while up to now the fast increasing end-of-life cost of conventional disposa l land filling, incineration) were never. taken into account. During the detailed design phase, usually performed with help of a CAD system, it is generally to late to design the product for recycling. The TOPROCO system is therefore aimed at the "functional parts list" design stage and cannot make use of the product model described in the CAD system.

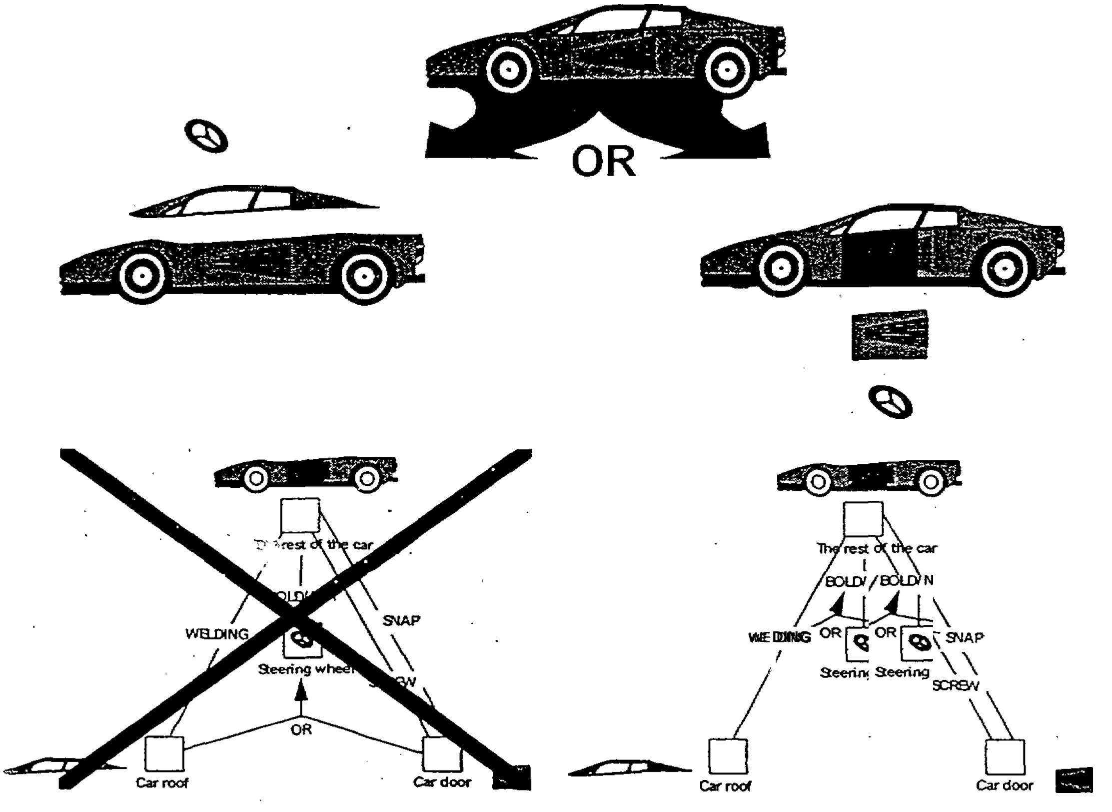


Figure 3: The recycling precedence graph

The product description used in TOPROCO is the so-called "recycling graph", a graph which connects the components with physical relations (the fasteners) and the logical relations with respect to dismantling. These logical or blocking relations between the components indicate a component or a fastener has to be dismantled before a second one can be reached or disassembled. This recycling path is not always unique, so that sometimes an "OR" operation has to be included in the blocking relations. So can the steering weel of a car be removed by taking of the roof or by removing the door. But even that is not correct: The door doesn't have to be removed. Opening the door is sufficient to remove the steering weel. (See Figure 3) This is an indication that the "relation blocks relation approach" is more general than the "component blocks component" approach. This-was at least the conclusion of a more in depth research done as part of the TOPROCO 'project.

6. RECYCLING STRATEGY

Once the product is described, the different recycling alternatives can be assessed. These recycling alternatives are restricted by the processes used in the recycling companies Mann Organisation and GEP participating in the TO PROCO project. Only those processes used in the companies are modeled in the calculation logic of the software prototype. Care has been taken however that when the prototype will be used in another environment the recycling processes can easily be added or updated in order to be able to incorporate the processing of new material streams. These processes are documented, using the IDEF0 modeling technique (See Figure 4).

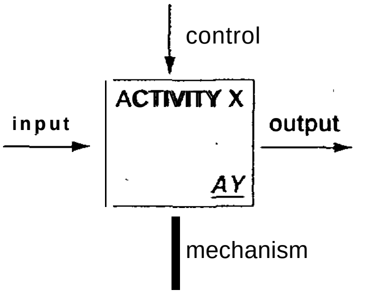


Figure 4: IDEF0 modeling technique

For the whole set of IDEF0 activities documented in "TOPROCO's virtual recycling company" chart a cost formula has been generated based on the Activity Based Costing paradigm. Four important criteria have been kept in mind when selecting and detailing these formulas. First, what are the cost drivers for this activity. Second, because we don't want to overload the user with a huge number of questions (especially not when the overall contribution of this activity is ...ble) we [illegible] many cost drivers [illegible] this activity So the third question was how important this activity was compared to the total recycling cost. And fourth and most important question checks whether the designer can i influence the cost or revenue of this Activity. Our research 'pointed out that the actual disassembly activity accounted for only between 6 and 20 % of the total recycling cost but can certainly be influenced by the designer. On the 'other hand a non neglectable part of the recycling cost is consumed by the unpacking of product brought to the recycling company because the product is taken out of the market being outdated by a newer version. But the packaging is hardly being influenced by the product designer.

The recycling strategy is in fact a search for the optimal disassembly depth. It is clear that when a product at its end. of life is not disassembled at all no disassembly costs are incurred but no material revenue will be created. In the majority of cases the product will end up on a landfill for which has to be payed. The other extreme is when a product is disassembled until all components are separated so that the material revenues are maximized. But the disassembly cost will be skyrocketing in this case. Somewhere' in between the optimal disassembly depth can be found. The cost calculation of the recycling of the product is a semi-autcmated process. On one hand we are well aware of the fact that the average designer is not aware of the recycling processes available now.

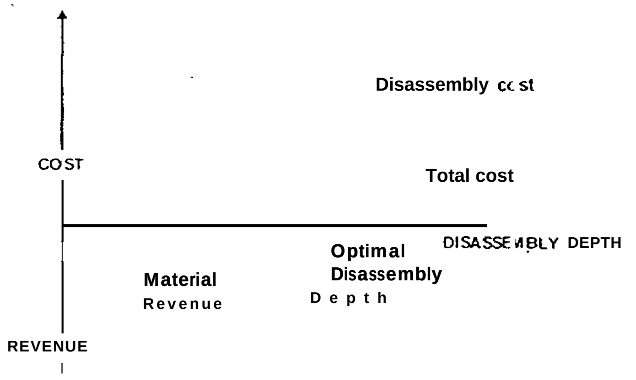


Figure 5: The Optimal Disassembly Depth.

On the other hand would the automatic generation of the optimal disassembly strategy, although from research point of view very interesting and challenging, cause the calculation of too much. recycling alternatives, most of them being obviously sub-optima! for the overal design. Therefore we will support the designer when he determines the "clu reps". A clump is a group of components in a product which will be processed in a recycling company in the same way (i.e. in one fraction).. When the designer is putting several components in one clump, the TOPROCO system indicates in which material stream or fraction this c ump can be processed, if any. Otherwise this clump be threated as waste.

In the next phase the designer decides which clumps are actually worth to be disassembled. Therefore the TOPROCO system lists the clumps in decreasing, recycling value. This value ... called "original estimated revenue" indicates what the additional reve... would be if the ... decide to recycle this clump as ... This value includes the material revenue or resale value (of a spare part, if the designer knows this value) minus the disassembly 'cost of this clump and the disassembly cost of clumps that prevent the actual interesting clump to be recycled immediately. What also is taken into account is the fact that by removing a hazardous material clump the rest of the product, the so-called "remaining clump", could possibly go into a cheaper landfill.

Once the designer has decided to disassemble a particular clump the exact revenue is calculated taking into account which other clumps have also been recycled up to that moment. So the disassembly' cost of breaking fasteners between two clumps both to be disassembled is split between both. This exact revenue includes not only the disassembly costs and material revenues but also e.g. the cost for storage of the (plastic) material and overhead costs. Now the first clump is disassembled it is possible that the effort to be done to recycle other clump drastically has been decreased, in an extreme case a clump can even be disassembled for free because he was blocking the first clump. This change in additional effort is indicated by the "updated estimated value". This update estimated value gives an indication of the v due (or cost) when recycling this clump, taking into account the clumps which are already disassembled, whereas the original estimated value irrespective of the other clumps (recycled or net). The output of the TOPROCO system will give the designer an overview of costs and revenues per clump and per activity in the recycling company and a comparison with previous designs or recycling alternatives in a bar chart. This will help in the determination of those components and relations that are subject to considerable improvements in the design from recycling point o f view.

7. DESIGN SUPPORT SYSTEM

Guidelines will give the designer a set of rules for design for recycling. The Design Support System is accessible in two different ways. After having selected the menu item ' Design Support' the Design Support System is activated. Individual rule access is provided by an hierarchical structure. Design Support System access is possible also context-sensitively from various interaction windows and from the system output" screens. By means of the detailed system output the user is given information on which clumps are responsible for which amount of the total cost, and on how much cost is contributed due to each processing activity. The design engineer will be shown a list of all relevant rules for the desired context. Each rule is elaborated in more detail by explanations, graphical" examples, information on the impact and applicability of the rule, as well as further support tools such as material compatibility matrices. For all processing activities generating cost within the recycling company the formula is given according to which the cost is calculated. The formulas give the design engineer an indication on how to design cost-efficient products.

This way the designer will be guided in both the original and the redesign of his product with the overall objective of designing a product with a positive end-of- life value.

S. SOFTWARE DEVELOPMENT

The software prototype based on this assessment method is a stand-alone PC based tool written in Visual C++ and using a MS Access database. This database not only 'stores the product model but also all the cost information of the processes in the recycling company. Since recycling is due at the end of the product-life many factors, which should be considered within the selection of the appropriate recycling concept, will change. Therefore it is very important to take general cost ..... of mat[illegible] [illegible] ration to get a realistic detailed picture of the real life-cycle cost. The integration of these trends in a scenario modeler will allow additional evaluations in an easy way within the software. Therefore cost trends for each variable in the cost formulas of the virtual recycling company have to be established.

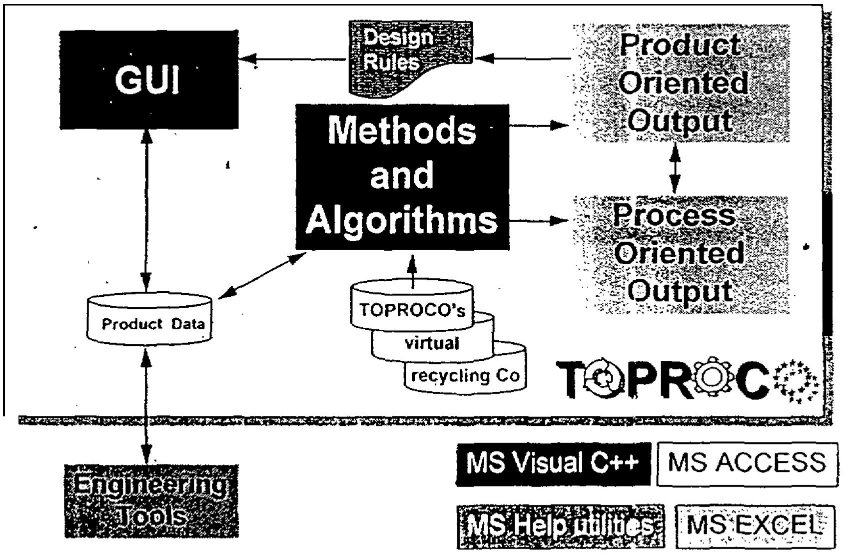


Figure 6: System Overview

9. TOPROCO'S SHORTCOMINGS & FUTURE DEVELOPMENTS

The partners in the TOPROCO project have understood a number of drawback of their development that are too complex to be tackled by this relatively small project. On the other hand these problems are fundamental and need to be solved to come to DFR tools relevant for and successful in industry.

First, TOPROCO is mainly based on the present cost of the current material *recycling* processes and technology. Also the DEMROP (Design and evaluation method for recyclability of electromechanical products) project, another Brite-EuRam III reject (BE-7073) evaluates the value of the recycled electromechanical products at their end of life. This project focuses more on the automated dismantling. The whole product is put in a shredder and the material fractions are separated afterwards. This approach is especially valuable for a smaller type of product with a high mixture of materials for which it is economically unfeasible to dismantle the components manually. But since automated material separation methods are not yet so sophisticated to separate especially plastics into fractions which can be reused in the same high tech applications as e.g. electronical products, one should speak about material down-cycling instead of re-cycling in this case.

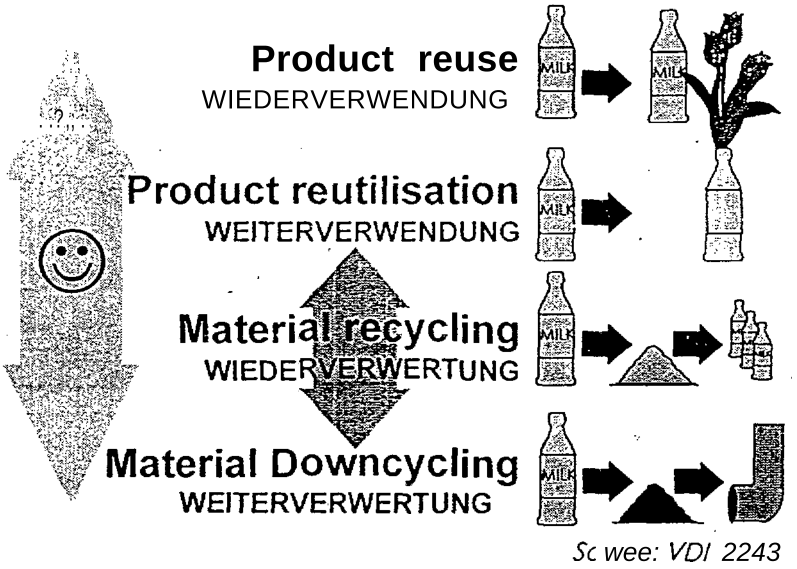


Figure 7: The Recycling Scope.

The major drawback with both projects mentioned above is that they do not return the real EOL value because they don't consider the complete range of options for revenue generation (See Figure 7), but only a specific recycling technology Especially component reuse, although an important potential source of revenue (Sun Microsystems is earning 6 MECU (app. $ 4.5 million) per year by reselling used computer parts) is not considered..

Secondly these projects hardly take into account the future revenues and costs nor future recycling technology. An important influence in the valuation of a product at its end-of-life is in fact the evolution over time of the material and component prices and costs. Classical approaches to model these price evolution have not given the expected results. Evolutionary algorithms, used in genetic programming show be useful techniques when other classical techniques are not possible.

Third, to gain acceptance in an industrial environment any engineering tool like the DFX tools need to be completely integrated in the current design process. The mostly used and generally recognized tool for product design applications today is CAD. Although effective in meeting the needs of the designer in the area of drafting the product as such, it has no ability to give sight of either the value or financial liability of the product at EOL. Product data technology has been topic of various national and international research activities over the last years.

One of the most important developments in this area is the product model specification ISO 10303 (Product Data Representation and Exchange) that is also known under the acronym STEP (STandard for the Exchange of Product model data). The goal of this international standard is, to define a product model specifying all product related informs! ion necessary to describe the product over its whole life cycle in a formal and non-redundant way. Product related information also comprises (static) information about the processes performed STEP, however does not (yet) include recycling or environmental information in the data model. The integration of the DFR tool in the design process through STEP based data modeling. A DFR product model. based on the current available STEP product model, which guarantees the integration of the system in practical] y all design environments, will be expanded where needed to fulfill the needs of the recycling environment. Via the STEP interface the necessary characterics of pre-designed components used in the product can be imported in the TOPROCO tool and on the other hand the structure of the product can "be re-used as e.g. BOM in the CAD or Product Data Management system.

ACKNOWLEDGMENT'

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