Proposition of new recoverability indicators as support for the product design process: the electr(on)ic sector experience

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Abstract
This papers focuses on Recovery Conscious Design for electr(on)ic products. It presents a new tool that has been developed following requirements from industrial partners. The tool is made of quantitative Recoverability Indicators calculated on the Bill of Materials of the sub-assemblies of the product. The indicators can be used to track recoverability problems in the product. It is shown through the simulation of the application of the new tool on a case-study that it could be very beneficial at various stages of the product design in order to drive the product design process from a recoverability perspective.

Keywords:
WEEE conformity, product recyclability/recoverability indicators; ecodesign; electr(on)ic equipment; software.

1 INTRODUCTION

1.1 WEEE Directive implementation

With the implementation of **WEEE (Waste Electric and Electronic Equipment) Directive** [1] in European countries, recovery technologies and networks for end-of-life (EoL) products are developing fast, both with specific organisational and financial systems.

1.2 Product ecodesign

Moreover, as requested by WEEE Directive in its Article 4, product manufacturers are currently adopting **design practices** that take into account the management at the end-of-life of products and components. As defined by ISO [2], this requests that EoL issues are considered at all stages of the product development process (and as early as possible) as any other design criterion, e.g. quality, cost, security, other environmental criterion. Indeed, to put in practice the requested Recovery-Conscious Design (RCD), companies need not only to review the **organization** of their design practices, but also to use relevant and **standardised indicators** and user friendly assessment tools. This paper will specifically focus on these two issues.

1.3 A project to define a collective and sector-relevant strategy for recovery-conscious design

This paper reports initial results of a current research project funded by ADEME, the French EPA and called ECO'DEEE, that aims at defining collectively (i.e. several electr(on)ic sectors companies) some tools and methods to better integrate end-of-life recovery during the design of new products. Electr(on)ic design companies indeed share the same constraints (WEEE compliance, costs, similar suppliers, etc.) and opportunities (recovery networks and technologies are similar, product compositions are close, etc.). In order to ensure the best technical and scientific output as well as relevance for design teams, the following consortium has been set-up to lead the project:

- Leader: CODDE, a consulting company on environmental assessment and ecodesign in the electr(on)ic sector; CODDE also develops EIME, an ecodesign software very much used in the electr(on)ic sector;
- 5 French electr(on)ic equipment manufacturers: Fagor Brandt, Neopost Technologies; Sagem, Schneider Electric, SEB; 4 product categories are therefore considered in this study: large household appliances, small household appliances; white goods, telecommunications equipment; professional electric equipment;
- One academic partner, G-SCOP Laboratory at the University of Grenoble: this partner has been developing in recent years a strong expertise on Recovery Conscious Design (RCD) (in particular on: Dismantlability / Remanufacturability / Recyclability Conscious Design) and on its integration within the design process

The project aims in particular at:

1. Consolidating information on performances of the recovery currently applied to WEEE in Europe;
2. Developing a simple analysis tool of recoverability of the product that could be used during the design of products;
3. Developing training modules giving more knowledge of end-of-life treatments to the product designers.

The paper reports initial results specifically concerning the second objectives. Section 2 summarizes the current RCD practices in the electr(on)ic sector and demonstates the need for new RCD tools. Section 3 analyses current design and ecodesign practices of one electronic manufacturer and presents more in details why new tools are needed. In Section 4, a new RCD tool currently under development is presented; moreover, its possible benefits in the industry is discussed. Section 5 concludes the paper.

2 CURRENT RECOVERY-CONSCIOUS DESIGN PRACTICES IN THE ELECT(ON)IC SECTOR AND FUTURE REQUIREMENTS

2.1 EIME: an ecodesign tool with RCD functionalities currently used in the electr(on)ic industry

Since the first draft of the WEEE Directive, in the early nineties, the Electr(on)ic industry has been very active in developing innovative methods and tools for better ecodesign. In particular, in the mid nineties, a consortium of manufacturers developed the EIME (Environmental Information Management Explorer) methodology and tool [3, 4]. Today, EIME is widely used in the electr(on)ic sector for ecodesign, in particular by industrial partners of the project.

Since the first version of EIME software tool in 1996, some indicators that can be used for recovery-conscious design were implemented [5]. During the modelling of the product with EIME, it is possible to associate to the product one of the two following recovery scenarios:

- either a manual dismantling scenario,
- or a shredding scenario.

Beside other indicators in particular LCA-based impact indicators, EIME contains a so-called “Design Indicators” category that is made of the following sub-categories:

- In the “Physical characteristics” category: Special handling substances in composition (expressed in % of weight); Number of parts (expressed in units),
- In the “End-of-life characteristics” category:
  - Weight ratios (expressed in % of total weight) of: special handling Components; re-usable components; recyclable components; residual waste and energy recovery (EIME currently does not distinguish both type of waste);
  - Number (expressed in units) of: special handling components; extractible reusable components; problematic links; distinct materials.

Moreover, the EIME’s functionality Bill of Materials (BoM) gives the detailed composition of the studied product and is therefore complementary to the indicators presented above: the information is useful to identify the presence of high value metals or the presence of regulated substances which, should be extracted at the product EoL.

Figure 1 illustrates this with a screen copy of the EIME “End-of-life characteristics” indicators sub-category.

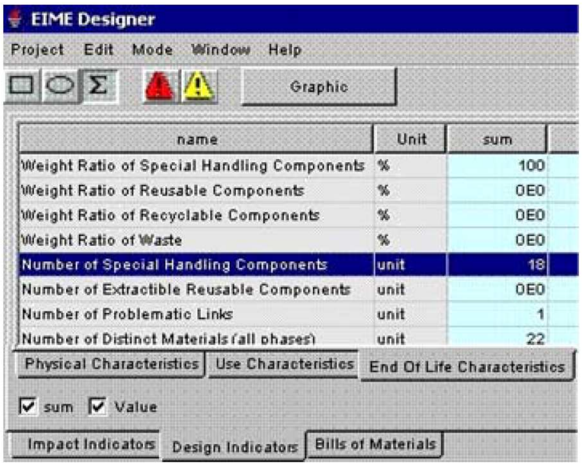

Figure 1. Screen copy of “End-of-life characteristics” indicators currently contained in EIME for a sub-assembly made of special handling components.

In order to calculate the various weight ratios of the product expressed in % of total weight, EIME database contains data related to each material, component and links of the database, such as:

- The recycling potential (in % of weight) of a material after dismantling or after grinding;
- The ability of a component to be re-used;
- The ability of a physical link to be easily dismantled;
- The compatibility of materials.

These data are then aggregated to form the recovery indicators described earlier.

2.2 Requirements for further developments

A literature review of many recovery conscious design tools has been presented elsewhere [6]. It was in particular demonstrated that a recovery-conscious tool should as far as possible fulfil the **following specifications** [6]:

- It should be based on **quantitative assessment** of the recoverability: the design team will only be able to integrate efficiently recovery issues during the design if these criteria can be quantitatively balanced to other design criteria such as cost, quality, manufacturability, etc.;
- The assessment should be **multicriteria**, at least per weight, costs and if possible the environmental impact;
- It should consider as much as possible the **reality and the complexity of products recovery systems**, that are made today of several processes (e.g. collection, storage, dismantling, depollution, shredding, sorting, cf. Fig. 2);
- It should consider **multiple attributes of a product**, in particular materials, architecture and links, and not only links as Dismantling-Recovery conscious design usually does;
- Results should be **usable by design team** for improvement, i.e. they should lead to concrete direction for improvement.

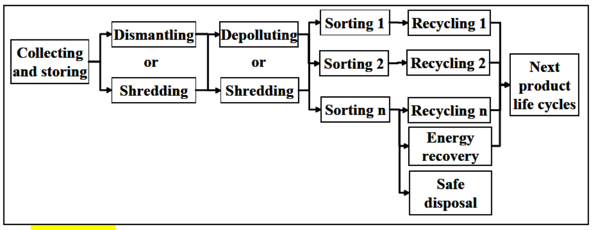

Figure 2. Product recovery scenario as a mix of different processes.

Considering this, it seems that EIME current RCD performances are insufficient because:

- Today, because of limited economic viability of manual dismantling [7], recovery networks are not anymore either dismantling-based or shredding-based but more often a mix of these processes (cf. Fig. 3);
- Values used by EIME database were set in the mid-nineties and do not consider technology progress achieved since then;
- Assessment give aggregated values for the whole product that can allow comparison of two design options but that are hardly exploitable (e.g. when tracking design weak points) in real-time design

Further requirements for the new method came from the industrial partners, in particular:

- It should be life-cycle based, i.e. so that EoL-centred design evolutions do not impact other life cycle stages;
- It should fully be integrated into EIME that partners widely use.

3 ANALYSIS OF DESIGN PRACTICES OF AN ELECTRONIC MANUFACTURER

3.1 General presentation of Neopost

Neopost offers mail management through various solutions for document inserting and mailing systems as well as traceability of internal mail. It designs and manufactures several types and categories of mailing machines such as the one presented on Figure 3. Its customers are public and private sectors including large and small companies (industrial, services) and administration.

Figure 3: Example of mailing machine equipment designed and produced by Neopost Technologies.

Although Neopost has got its own specificities, it is considered in this paper as representative of the electr(on)ic sector and of the industrial partners.

3.2 Ecodesign drivers at Neopost

During recent years, ecodesign has been developing strongly at Neopost not only due to legislative developments (e.g. WEEE, RoHS and EuP Directives) but also due to customer requirements (e.g. Energy Star eco-labelling program; specific criteria in large call for tenders) and to Corporate Social Responsibility developments.

So far, in order to comply with the principle of continuous improvement for ecodesign implementation (cf. [2]), Neopost has first focused on end-of-life issues through the development of its own Design for Recycling (DfR) guidelines, largely based on Design for disassembly (DfD) guidelines. The guidelines are today used by designers. Then, it has enlarged its focus on other life cycle stages. Together with current WEEE Directive implementation, Neopost is willing to explore further the end-of-life issues, when developing new DfR guidelines (less DfD-based; more specific to different type of its products) and other tools usable during the design process. Neopost products are covered by the WEEE Directive, under product category 3 and should therefore comply with the following recovery rates: 75% per weight of recovery, 65% per weight of re-use/recycling. The mailing machine market being a professional one, Neopost is also responsible for setting-up its own take-back and recovery system for its products from its customers. Therefore, good recovery-conscious design of products should directly impact Neopost's economical balance (decrease costs of increase benefits) of the products recovery.

3.3 Current and future (eco)design practices at Neopost

Neopost designs its various types of products in several locations in France and in The Netherlands. For the product type considered in this paper, the design is mainly carried out in Bagneux, France. Neopost uses a classical Pahl & Beitz's-type development process [8] for its new products, with the following steps: Clarifying the tasks and product planning; Conceptual Design; Embodiment Design; Detailed Design; Industrialisation. This product development process should also be considered within an integrated design framework as defined for example in [9]: the product development process is considered as a collaborative process where all expertises (i.e. marketing, mechanical, electronic, aesthetics, … and EoL recycling) are being considered concurrently by various actors in the design team.

Today, the EoL Recycling expert - who is also a mechanical engineer well aware of design constraints and practices - is a member of the mechanical design department. He is being **regularly integrated** into product design review meetings, mainly to ensure conformity to regulations during the whole product development process. The design department is currently willing to improve this situation so that the Recycling expert is consulted **at each design review meeting**, and is consulted by other experts to discuss design options and to pro-actively "negotiate" the design parameters such as material, joining techniques or global architecture with the rest of the design team. Doing so, the design department hopes to turn the end-of-life recycling issue from a constraint into a driver for innovation. The designers would then need some quantitative assessment of the recyclability of the product and its sub-assemblies so that it could be compared to quantified objectives, and can be balanced with other quantitative design criteria, e.g. manufacturing cost.

4 PROPOSITION OF A NEW RCD TOOL

4.1 Features of the new tool

Partners of the project are now developing a new RCD tool based on recoverability indicators to be integrated into EIME in the future. The indicators are inspired from the ReSICLED method presented in [6] as well as the ISO standard [10] for EoL vehicles. However, they are largely adapted to respect electr(on)ic industry requirements. The features of the tool are the following:

- The tool is made of **three** recoverability **indicators**:
    - RI: re-usability and recyclability indicators per weight, in %;
    - ReI: re-usability, recyclability, energy recoverability per weight, in %;
    - WI: residual waste indicator per weight, in %,

  where

  $$ReI + WI = 100\% \quad (1)$$

  and $ReI \geq RI$ (2)

- The recoverability indicators are calculated based on the weight and the potential of each material / component contained to be re-used / recycled or energetically recovered, whether the part is either manually dismantled or mechanically shredded;
- Although the indicators are only recoverability **per weight**-orientated, and not fully multicriteria, **they partially include economical aspects** as only Best Available Technologies (BAT) are considered in the project: BAT are defined as technologies that achieve the best recoverability yield, and that are economically viable today in 2007, i.e. there are at least two industrial plants using the technologies in operation in Europe;
- The complexity of recovery networks is considered: for any product, it is supposed to be a mix of manual dismantling (for depollution and extraction of specific part for re-use / recycling) and of shredding / automatic sorting.

The indicators can be used by the recycling expert integrated into the design team at any stage of the design in order to track possible recoverability problems, and to validate / optimize design options.

4.2 Data associated to the tool

In order to serve the calculation, a large quantity of data on the "potentials" of materials and components to be re-used / recycled and/or energetically recovered is needed. The project also aims at collecting this data, combining analysis and homogenization of available data and, if necessary, collection of specific data at recycling plants.

So far, data collected and homogenized came from various sources, such as material producers European associations, scientific publications (e.g. [6, 11]), Environmental Protection Agency. As an illustration, some –not definitive, still under verification- recovery potentials of some materials / components are presented in Table 1 below.

Table 1: Values of recovery potential after dismantling and after shredding for several materials and components (expressed in % of the weight).

Material / component	AD: after dismantling			AS: after shredding		
	RP_{AD}	ReP_{AD}	WP_{AD}	RP_{AS}	ReP_{AS}	WP_{AS}
Aluminium	93,5	0	6,5	91	0	0
ABS	95	0	5	74	0	26
LCD screen	0	0	100	NR	NR	NR

Where:

- *$RP_{AD/AS}$: Recycling Potential of a material / a component After Dismantling / Shredding (in % (in % of weight)*
- *$ReP_{AD/AS}$: energy REcovery Potential of a material / a component After Dismantling / Shredding (in % of weight)*
- *$WP_{AD/AS}$: residual Weight Potential of a material / a component After Dismantling / Shredding(in % of weight)*
- *And* $RP_{AD} + ReP_{AD} + WP_{AD} = 100\%$ for any material / component

According to Annex 2 of [1], some components, such as LCD screen, electronic card or external cables, should be always extracted: therefore they could not be shredded and their xP_{AS} values is assigned to "NR", i.e. Not Relevant.

4.3 Relevance of the new tool for product design in real industrial conditions

The use of the new tool during a product design process has been simulated with the recycling expert and the head of the mechanical engineering department of Neopost Technologies. This was done in order to find at which stage of the design process the tool should be used, and for which benefits.

The studied product is a Neopost mailing machine that was recently designed. It is a typical EEE of around 10Kg made of a mix of mechanical parts and electronic components. Its global architecture is represented on Figure 4. It should be noted that this product was developed using Neopost internal guidelines that are largely DfD based and has indeed been optimised for EoL disassembly. This has mainly imposed to many constraints on designers, especially for parts and assembly that would not be disassembled manually but rather shredded and automatically sorted.

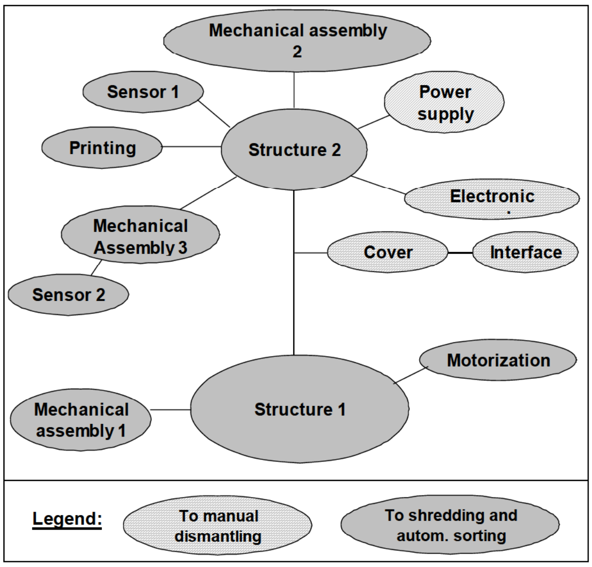

Figure 4. Global architecture of the mailing equipment. Planned destinations at EoL are also represented.

Figure 5 represents the product development process that leads to the industrialisation of the product. Arrows represent the time for possible application of the Recoverability Indicators. Our research together with the product design team shows that the new Recoverability Indicators could be applied at various stages, as shown by arrows on Fig. 6, in particular:

- at initial stage, when it can be applied to past generation product and when recoverability objectives can be set to the new product: these objectives should be at least the WEEE directives ones but could also overcome them if some customers are especially sensitive to the EoL issue;
- at conceptual/embodiment stage, when it can be applied to on approximate Bill of Materials of the product layout, and when recoverability routes and objectives for each assembly can be set;
- at detailed design stage when the BoM is almost definitive; and when final design decision should allow to reach the objectives for each assembly and the product;
- at industrialization stage when the BoM is definitive and the recoverability assessment can be used for commercial purpose.

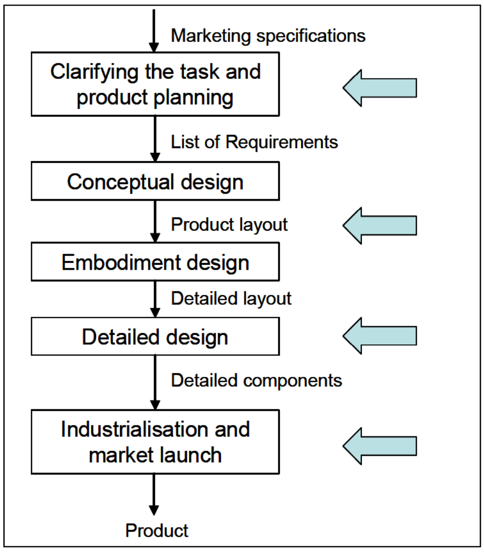

Figure 5. Possible uses of the recoverability indicators to drive the design of product at various stages of the development of Neopost products.

As an illustration, let's simulate the use of the recoverability Indicators during the design of the mailing equipment:

- After application of the indicators to past generation, the initial design objectives are to comply with WEEE, i.e. 75% of recovery (recycling + energy recovery) rates;
- At the end of conceptual design, when a product layout is available, the tool can be applied to a very approximate BoM; considering the results, some recovery routes (cf. Fig. 5) and recyclability targets (cf. column two of Table 2) can be allocated to each assembly considering their probable average material composition and weight; 5 levels can for example be considered: little (10%), a bit (25%), average (50%); well (75%), very well (90%) recyclable; each group in charge of the assembly should orientate the design to reach such targets; at this stage, the mechanical department chooses to turn the cover assembly (evaluated to around 2 kg), made mainly of plastic parts, well recyclable (around 90% of recyclability): to do so:
    - It is decided to orientate the cover assembly to advanced manual dismantling: this is possible as the cover should anyway be extracted for depollution purpose;
    - some design choices were made to prefer a limited number of heavy parts made of a single material, ABS, without any insert: these parts could be orientated to advanced manual dismantling for further high quality recycling;
    - it was also decided to concentrate sticks (inevitable for security reasons) on a limited number of plastic parts and to make all plastic parts of the assembly in ABS: these parts could be orientated to shredding and automatic sorting;
    - these choices should also be accompanied by a deal with the recycler so that he applies adequate processes to these few parts;
- at detailed design, the design and therefore the recoverability indicators can be refined considering real composition and weight (2.66kg for the cover) but also initial objectives and current performances;
- at industrialization stage, the planned recoverability performances of the product (here 74% of recyclability per weight and 4% of energy recovery per weight) can be publicized.

The tool **can indeed be applied at various stages of the design process, giving more precise results when BoM are turning more precise**. Results of this simulation are presented in Table 2.

Table 2: Results of the evaluation of Recoverability Indicators for assemblies and for the mailing equipment, as planned at conceptual design and as measured at detailed design (expressed in % of the weight); weight of parts is assemblies is also presented.

	Planned at conceptual design		Measured / Calculated at detailed design			
Assembly	Weight objectives (kg)	Recyclability indicators objectives	Weight (kg)	RI	Rel	WI
Cover	2	90%	2,66	80%	0%	18%
Interface	0,5	25%	0,69	39%	12%	49%
Structure 1	0,5	90%	0,90	93%	0%	7%
Motorization	2	75%	2,00	79%	79%	79%
Mech. Assembly 1	0,5	75%	0,85	65%	0%	35%
Structure 2	2,5	75%	1,99	77%	0%	23%
Power Supply	0,8	50%	0,89	54%	31%	15%
Electronic card	0,3	25%	0,26	38%	47%	16%
Mech. Assembly 2	0,25	75%	0,14	64%	0%	36%
Mech. Assembly 3	0,25	75%	0,13	58%	0%	42%
Sensor 1	0,1	75%	0,10	74%	0%	26%
Printing device	0,5	50%	0,39	38%	0%	62%
Sensor 2	0,1	10%	0,11	5%	0%	95%
Total	10,3	71%	11,11	74%	4%	22%

5 CONLUSIONS AND FURTHER WORK

This papers reports initial results of a project aiming at developing a new Recovery Conscious Design tool to be used during the design of electr(on)ic products. The tool has been developed following requirements from scientific studies of RCD methods and from industrial partners. The tool is made of quantitative Recoverability Indicators (% of the weight) calculated on the Bill of Materials of the sub-assemblies of the product. It was shown through the simulation of the application of the new tool on a real case study that, when implemented, it could be very beneficial at various stages of the product design in order to drive the product design from a recoverability perspective.

Current work focuses on the collection and the collation of data concerning recovery potential of materials and components, as well as the implementation of the indicators within an ecodesign software. Once this is done, it will be necessary to test the new tool ion real industrial design conditions.

6 ACKNOWLEDGMENTS

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