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DEVELOPMENT OF A NEW ECO-DESIGN TOOL

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Abstract : EcoDesign software tool ATROiD (Assessment Tool for Recycling Oriented Design) has been developed to support design engineers to evaluate and improve products on environmental aspects. The tool mainly consists of three levels including assessment, analysis and improvement. ATROiD shows various variables to assess and analyze the grade of recyclability of the product. Results of this process give a direction to improve the design towards least end-of-life costs and highest end-of-life performance. The tool has been applied to LG Electronics home appliances such as refrigerators, air conditioners and washing machines, and its usefulness was clarified.

Key Words : ATROiD, DFE, Disassembly, EcoDesign, End-of-Life, LCA, Recycling

INTRODUCTION

The concept of EcoDesign or DFE (design for environment) has recently been introduced, largely through the efforts of some electronics firms that were attempting to build environmental awareness into their product development efforts.[1] The practice of EcoDesign is becoming essential in today's industrial environment because leading companies recognize the importance of environmental responsibility to their long term success. Their experiences reveal that EcoDesign provides competitive advantage by reducing the costs of production and waste managements, encouraging innovation in product simplification, and attracting new customers.

Furthermore, the electronics industry will increasingly be forced by laws and regulations to implement product responsibility especially focused on the 'end-of-life' of a product because of its rapid technological rate of change and subsequent high rates of product obsolescence and growing problems from waste products throughout the world. EU (european union) directives that focus on 'end-of-life' issues which have major implications for ecodesign, such as the WEEE (waste from electrical and electronic equipment) Directive and the RoHS (restriction on the use of hazardous substances in electrical and electronic equipment) directive, are the examples presenting the trends.[2]

Those intensified legislations will oblige electronics companies to secure a certain degree of recycling rates and avoidance of the listed hazardous substances at the design phase of a product. Consequently these regulations may impose additional costs to electronics sectors. This may pose a threat to electronics companies.[3]

Nevertheless research into this area has been sparse in industrial sectors of Korea. Just a few large companies have begun to get concerned about this matter.

However, proactive companies can take a leading edge by transforming threats into opportunities. Since, in general, the end-of-life costs

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of products are determined at their design stage, it is essential that designers should identify ideal 'end-of-life' strategies prior to determining the specifications of the product.[4] In addition, pollution problems can be solved according to the "end-of-pipe" principle but more efficiently if they are considered from the starting point of the process.[5] But designers have usually not had enough experience to recognize the new demands, and to give suitable solutions. For these reasons design engineers need a supporting tool with which they evaluate environmental aspects of their proposed design and which guide them to improve its environmental performance. The software tool ATROiD (assessment tool for recycling oriented design) has thus been developed to meet these requirements, and been applied to LG Electronics home appliances and other competitor' products for benchmarking.

In particular, ATROiD provides more than 500 ecodesign examples/practices and guidelines for improvement based on environmentally weak point analysis of a product. On the other hand, existing DFE tools over the world such as "design for environment" of BDI and REM of Hitachi show deficiency in these points.[6] In addition, LCA (life cycle assessment) tools such as Simapro, Gabi and Team focus on estimation of environmental burden of a product or material/part during its whole life cycle without giving end-of- life strategy, recycling performance, design guides and so on.[7]

END-OF-LIFE ORIENTED ECODESIGN TOOL : ATROiD

Principle and Algorithm

EcoDesign software, ATROiD, is a tool which supports a designer to consider the end-of-life of a product at design phase. ATROiD is composed of four main modules including 'input', 'assessment', 'analysis' and 'improvement' (see Figure 1).

In the 'input module', a designer inputs product-related information which is classified into three sub-modules: 'part information', 'connection information' and 'disassembly priority information' (see Table 1).

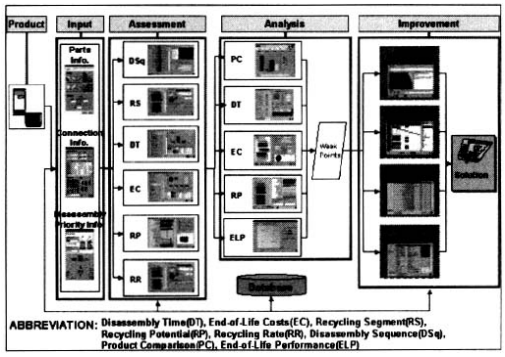

Figure 1. ATROiD process.

Table 1. Input information in ATROiD

Sub-module	Contents
Parts information	part name, shape, size, accessibility, material type, weight, serviceability of parts
Connection information	types of joining techniques, number of joining techniques, types of disassembly tools
Disassembly priority information	disassembly priority

Given the product information from the 'input module', ATROiD determines optimal 'disassembly sequence' of parts minimizing the number of exchange of tools as the first stage of the 'disassembly time' calculation.

After determination of 'disassembly sequence', ATROiD determines the EoL destination of all the parts using the decision algorithm for disassembly and recycling (see Figure 2). In

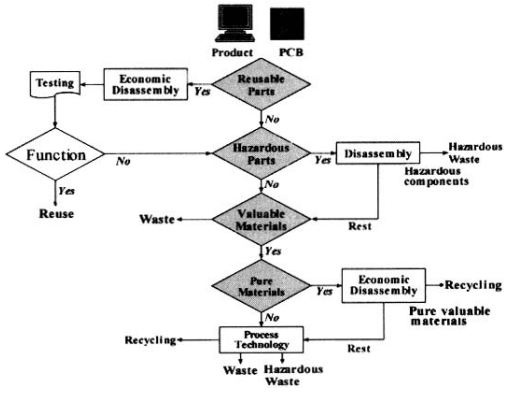

Figure 2. Decision algorithm for disassembly and recycling.

ATROiD there are three EoL destinations such as reuse, recycling, waste / hazardous waste. Each EoL destination has their own database where reuse profits, recycling profits and waste disposal costs are registered. The original database has default values, which were surveyed, for several countries. A user has to choose the proper country mode before ATROiD evaluation.

One of the unique functions of ATROiD is to group several parts into a 'recycling segment' which minimizes 'end-of-life cost (EoL cost)' of a product. It is not necessary to disassemble all the components since it causes cost rising due to the disassembly of even valueless parts. To avoid this unnecessary action, it is essential to determine 'disassembly segment' according to the minimization algorithm of 'EoL cost'.

To find the minimum 'EoL cost', ATROiD determines the optimal degree of disassembly considering reuse and material profit, disposal costs and labor costs. these values increase (reuse and material profit, disposal cost) or decrease (labor cost) as the degree of disassembly of a product increases. ATROiD plots the 'added value' summing up the values. The point having the highest 'added value' is the point for the lowest 'EoL cost' (see Figure 3).

ATROiD determines 'recycling segment' by checking all the parts with 'added value'. 'recycling segment' can thus reflect the economic efficiency in view of the current recycling demand. ATROiD presents all evaluated results in both segment and part basis.

Once 'disassembly sequence' and 'recycling segment' are determined, ATROiD calculates 'recycling rate' (see Figure 4).

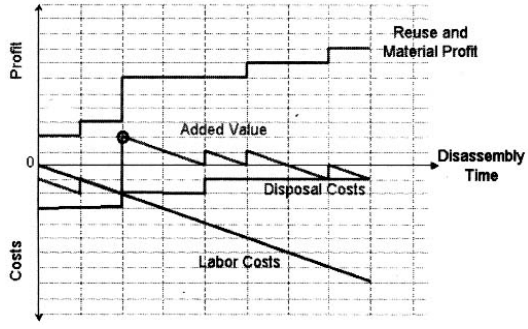

Figure 3. Recycling segment with maximum added value.

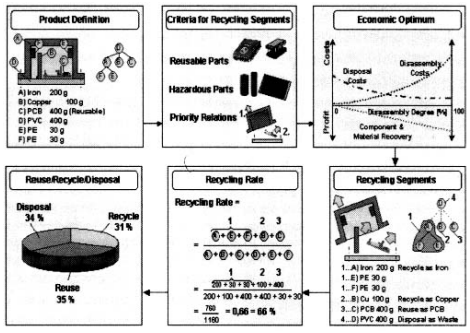

Figure 4. Algorithm calculating economical recycling rate.

ATROiD provides a designer with improving opportunities in several perspectives such as 'disassembly time', 'EoL cost' and 'recycling potential' from 'assessment module' through 'analysis module' to 'improvement module'. The evaluating criteria are further described in detail as follows.

Disassembly Time

'Disassembly time' of a product takes a great influence on its 'EoL cost'. However it is difficult for a designer to identify which parts are bottlenecks regarding 'disassembly time' because of the following two substantial problems.

1. no data related to disassembly of each joining technique.
2. disassembly process is not just the reverse of assembly process

ATROiD resolves the problems by building up comprehensive database for joining techniques and providing 'recycling segment' function.

In the 'assessment module', ATROiD calculates 'disassembly time' of a product as well as its parts based on an optimal disassembly sequence by using database. In the 'analysis module', parts are classified into four levels based on its relative contribution to total disassembly time. The designer can thus recognize whether the part shall be redesigned or not. Finally, ATROiD gives some guidance to solve the bottlenecks (see Figure 5).

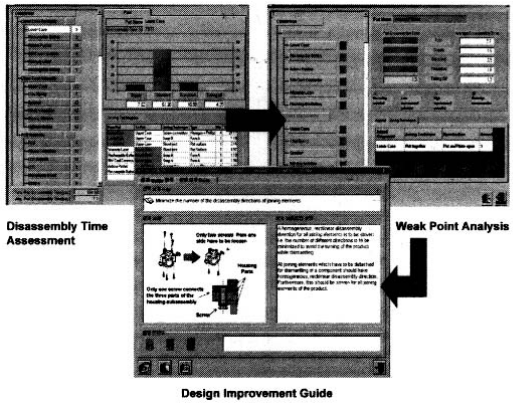

Figure 5. Design improvement through the minimization of 'disassembly time'.

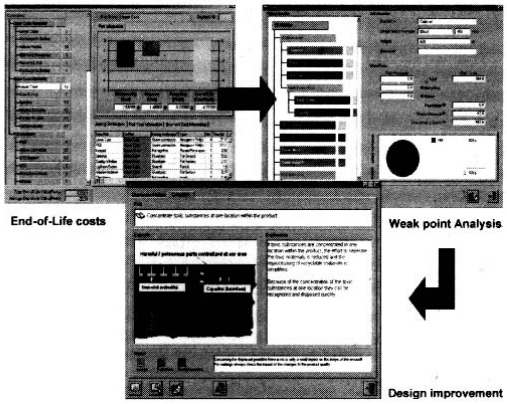

Figure 6. Design improvement through the minimization of 'end-of-life cost'.

End-of-Life Cost

As mentioned in the earlier part, many of legislations related to recycling of a product force a company to secure certain degrees of recycling. In this situation the reduction of 'EoL cost' can be a competitive factor.

To estimate accurate 'EoL cost', ATROiD includes the database for the disposal cost of waste or hazardous substances, the disassembly cost which depends on disassembly time and the recycling profit from valuable materials. 'EoL cost' is thus equal to the net sum of these three factors.

ATROiD estimates 'EoL cost' for both a product and its parts. It is also presented according to 'recycling segment'. Similar to 'disassembly time' criteria, ATROiD classifies the parts or segments into four levels depending on relative contribution to the total 'EoL cost' in order to find key issues for the improvement of 'EoL cost'. ATROiD provides the information with which a designer can make cost-effective design by reducing 'EoL costs' (see Figure 6).

Recycling Potential

Both of 'disassembly time' and 'EoL cost' are the quantitative results based on MTM II method and the cost data, respectively. Those factors are useful to identify the environmental status of a product. Those thus can be used to estimate the degree of improvement of a newly developing product and to benchmark the advanced products. Furthermore it will be useful for a company to set up an environmental roadmap for further development by considering those factors.

However the above two factors are not sufficient for identifying detailed end-of-life problems. Thus, ATROiD introduces 'recycling potential' to support a designer with detailed information. 'recycling potential' is composed of 29 criteria which are classified into 4 groups such as 'material', 'product structure', 'joining techniques' and 'PCB (printed circuit boards)'.

This shows quantitative results for each criterion and gives an averaged value of 29 criteria assessment results. 29 criteria can be linked with product attributes. Each criterion is evaluated based on the criterion evaluation plot regarding characteristic values which are associated with product attributes (see Figure 7).

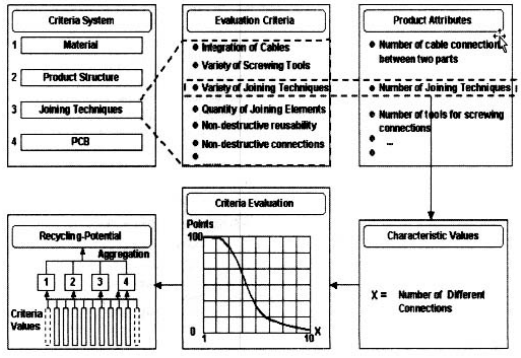

Figure 7. Assessment flow for recycling potential calculation.

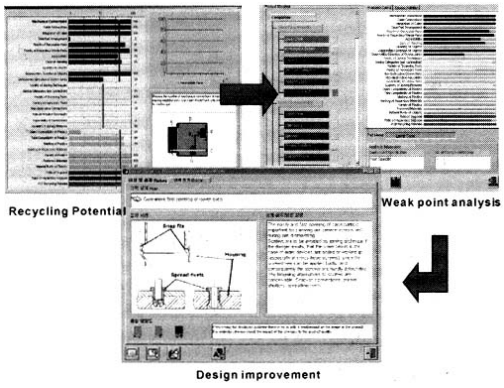

Figure 8. Design improvement based on 29 criteria for 'recycling potential'

Based on the results of 'recycling potential', a designer can find the weak points on ecodesign aspects and determine improvement opportunities by using the subdivided information (see Figure 8).

APPLICATIONS

ATROiD has been applied to LG electronics products such as air conditioner, washing machine and refrigerator for improving their environmental performance. It has thus been identified that ATROiD is specifically useful for the cases written below.

Identifying Improvement Opportunities

At the recent project, 23 different models have been evaluated to improve the environmental performance of products by using ATROiD and 5 models of them were redesigned focused on the key issues which ATROiD has defined.

The opportunities for improvement were determined by doing assessment/analysis of the product itself, using the design guide provided in ATROiD, and by benchmarking the competitors (see Figures 9 and 10).

After improvement opportunities are identified, a cross-functional team checks the feasibilities of the options. The options that satisfy all the requirements such as functional, technical, legislative feasibility and so on are selected as the promising ones. Finally designers redesign the

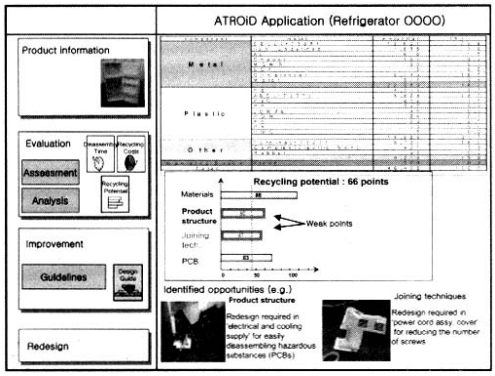

Figure 9. Environmental improvement opportunities based on the DFE tool ATROiD.

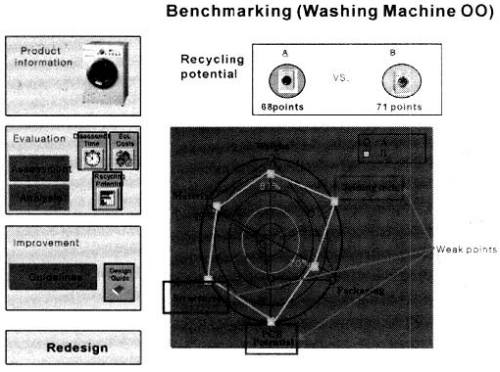

Figure 10. Environmental improvement opportunities by benchmarking.

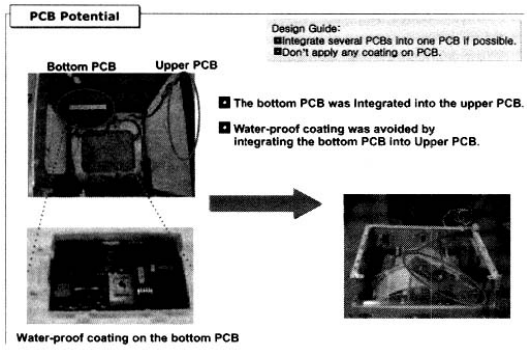

Figure 11. The case of redesign for environmental improvement in the washing machine.

product embedding those promising options (see Figure 11).

Setting up an Environmental Roadmap

In addition to identifying the options for

Table 2. Setting up mid & long term roadmap

Mid & Long Term Roadmap (e.g.)

		2001	2002	2003	2004
Compare with the reference product in 1999	Recycling rate		( )% improvement	( )% improvement	( )% improvement
	EoL cost		( )% improvement	( )% improvement	( )% improvement
	Recycling potential		( )% improvement	( )% improvement	( )% improvement
Compare with the best competitor	Recycling rate		( )% improvement	( )% improvement	( )% improvement
	EoL cost		( )% improvement	( )% improvement	( )% improvement
	Recycling potential		( )% improvement	( )% improvement	( )% improvement

improvement, ATROiD can be used to plan environmental roadmap especially when companies should reach certain goal in the defined due.

EU is going to establish an environmental milestone such as stipulated in the WEEE. For large household appliances such as refrigerator the rate of reuse and recycling shall be increased to a minimum of 75% by an average weight per appliance from the beginning of 2007. Then company should set up a roadmap to achieve the requirement. ATROiD has a function to estimate economically acceptable recycling rate. Thus the setup of environmental roadmap could be possible, for instance, by using several indicators such as 'disassembly time', 'EoL cost' and 'economically acceptable recycling rate' (see Table 2).

Comparative study between new model and a reference model lets the company recognize where they have reached and how far the goal is.

CONCLUSIONS

ATROiD is the EcoDesign tool which helps a designer develop an environmentally sound product at the design phase regarding its recyclability, disassemblability and environmental impact.

ATROiD does not simply evaluate the environmental aspects of the product, but improve its environmental weak points. 'disassembly time', 'EoL cost' and 'recycling potential' are the major factors which identify environmental improvement opportunities. For estimating those factors the logic to determine optimal disassembly sequence and recycling segment is embedded in the ATROiD system. A comprehensive database related to recycling process and costs is also included in the ATROiD.

The output generated by ATROiD has been used to identify improvement opportunities for the products of LG electronics and to guide designers to redesign them for environmental improvements. Furthermore ATROiD can be used as a tool to plan an environmental roadmap of a firm to achieve the mid & long-term goal.

Typical examples of the application of ATROiD such as the identification of environmental weak points and the setup of environmental roadmap were presented.

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NOMENCLATURE

ATROiD: assessment tool for recycling oriented design
DFE: design for environment
DS: disassembly segment
DSq: disassembly sequence
DT: disassembly time
EC: end-of-life cost
EoL: end of life
LCA: life cycle assessment
MTM: method of time measurement
PC: product comparison
PCB: printed circuiit board
RoHS: restriction on the use of hazardous substances in electrical and electronic equipment
RP: recycling potential

RR: recycling rate
WEEE: waste from electrical and electronic equipment

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