

Product Characteristics and their Relationship to End-of-Life Strategies

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Abstract: End-of-Life treatment of products is a growing concern as legislation requires industry to share responsibility for costs associated with recycling, reuse, remanufacture and disposal. Case studies on office automation and information technology equipment indicate a relationship between product characteristics and end-of-life strategies. This practical approach has led to the development of a web based End-of-Life Design Advisor (ELDA) tool. The goals of the ELDA are increasing designer environmental awareness, predicting end-of-life strategies from product characteristics and assisting in decision making. This paper highlights technical product characteristics that affect end-of-life strategies such as wear-out life, number of modules, functional complexity and technology cycle. Designers typically have strong influence over these factors. Other characteristics such as legislation, infrastructure, supplier and secondary material recycling are not included since they are more difficult for producers to control. Recycling technology developers should anticipate end-of-life needs and innovate based on product characteristics. Authorities must consider technical aspects of products when developing policy, for example, when setting recycling targets.

1. INTRODUCTION

Increased environmental awareness and legislative developments enhance the need for manufacturers to address the product end-of-life phase in addition to material extraction, manufacturing, packaging, transportation and usage phases. End-of-life is typically defined as any processing of a product after the initial user discards the product. This processing includes steps taken to collect, reuse, remanufacture, recycle, incinerate or dispose of a product. Estimating the environmental gain and costs, or eco-efficiency, of these processes is essential to determine the best life cycle strategy. Every manufactured product unique in functions, materials, parts, technology and intended consumer. It is necessary to determine on a product level if an intended end-of-life system is technically and economically feasible (Stevens and van der Horst, 1997). Current product designs, recycling technologies and legislative decisions heavily influence end-of-life strategies.

The European Union's proposed legislation established targets for collection and recycling for various consumer products. The draft legislation for requiring take back and recycling of products are societal concerns about resource, landfill or incineration and lack of control of hazardous substances at the end-of-life phase as things stand now. The proposal is not yet based on a rationale for balancing ecology and economy although it is becoming apparent that, for example, recycling percentages to be realized are highly dependent upon end-of-life technology, industrial infrastructure and outlets for secondary materials.

This paper shows how an End-of-Life Design Advisor (ELDA) can aid in influencing decisions made by product designers, recycling technology developers and policy makers. ELDA focuses on technical characteristics that can be controlled by industry. The follow sections show the proposed approach leads to a better categorization of product end-of-life strategies based on product characteristics.

2. OVERVIEW OF END-OF-LIFE DESIGN ADVISOR

The End-of-Life Design Advisor (ELDA) tool is a web-based tool for product end-of-life strategy assessment. Case studies have shown that there is a preferred end-of-life strategy that depends on product characteristics. Our initial set of case studies highlighted characteristics related to external, material, disassembly and inverse supply chain (Rose, 1998a). The progress thus far focuses on key characteristics (Table 1). The list does not include product price, since it is hidden in other characteristics, and is not usually controlled by designers. A more detailed summary of the questions asked in ELDA are given in the Appendix.

Table 1. Product characteristics

Key Characteristics	Explanation
functional complexity	addresses the relationship between modules and the functions the modules perform; a functional complex product has highly dependent modules that support a variety of functions while a product with low functional complexity has modules that independently support the functions
number of materials	number of different materials
number of modules	number of subassemblies that are physically detachable and still preserve function

number of parts	approximate number of parts in the product
cleanliness of product	as a product is used, different amounts of dirt or filth build up; the more dirt or filth, the more work that has to be done prepare the product for reuse or remanufacture
hazards	hazardous or unwanted materials that contaminate components that need to be removed before further recycling because of hazards to humans, the environment or contamination of other components
size	approximate dimensions of the product
design cycle	the length of time between successive generations of a product or the frequency that a design team redesigns the product or designs a new product that makes the original product obsolete
technology cycle	the length of time that the product will be on the leading edge of technology before new technology makes the original product obsolete or less desirable
replacement life	the length of time that elapses before the average user decided to upgrade their product to one with increased functionality
reason for obsolescence	reason that the product is no longer able to perform its intended function; a product reaches its end-of-life because it is either worn-out or outmoded
wear-out life	the length of time form product purchase until the product no longer meets the original functions

2.1 Goals and Structure of ELDA

The goals of the End-of-Life Design Advisor are:

- to increase designers' environmental awareness.
- to predict end-of-life strategies.
- to assist in decision making.

The current ELDA software increases the environmental awareness of designers. Our current research seeks predictive models for the end-of-life strategies that will be incorporated into ELDA in the fall. We are now in the initial stages of planning for the decision making modules.

The ELDA tool asks designers to evaluate product characteristics and gives examples to guide the designer. Users input the data within their internet browser and the data is reported back to Stanford using a Java applet. Students from Stanford's Design for Manufacturability Course (ME 217) tested and provided feedback on the data collection portion of ELDA. This trial involved more case studies addressing aircraft engines, portable phones, lead battery, bubblejet printer, line-matrix printer, portable projector, car, computer and net server. The interactive nature of ELDA, along with direct focus on designer and specific products, provides an excellent medium to educate designers on environmental implications of their decisions. Figures 1 and 2 are examples of current input and output screens. ELDA currently displays the output in a spider graph with each axis representing a different characteristic.

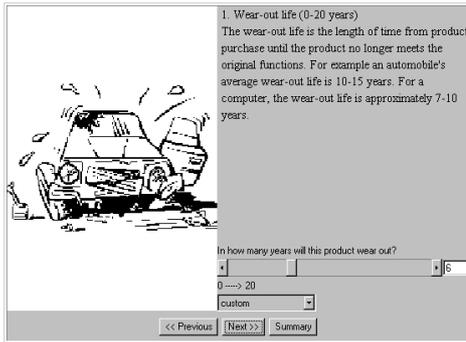


Figure 1. Example Input Screen of Product Characteristics

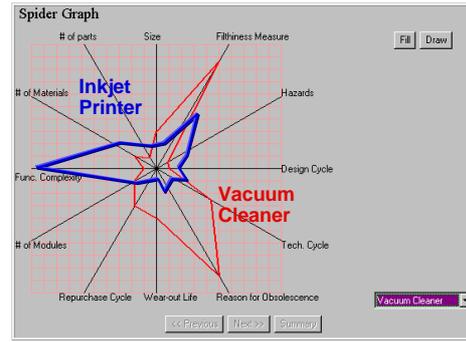


Figure 2. ELDA Spider Graph for Inkjet Printer and Vacuum Cleaner

The spider graph can be used to compare one set of product characteristics to other products' characteristics. On the output screen, the user can compare and contrast the product with other products such as vacuum cleaner, digital copier, washing machine, deskjet printer, single use camera and television.

2.2 Increase Awareness

The first goal of ELDA is to make designers aware of the impact of their decisions on end-of-life strategies. In our ME217 course trial, over eighty product designers and manufacturing engineers used ELDA to improve their product designs. Questions related to technology cycle, reason for obsolescence and number of materials force designers to integrate end-of-life issues in their decisions.

2.3 Predict End-of-life Strategies

The second goal of ELDA is end-of-life strategy prediction, as will be implemented in the coming months. ELDA will initially use product characteristics to predict the following end-of-life strategies: reuse, remanufacture, recycle and disposal. The case studies drive the correlation between product characteristics and the appropriate end-of-life strategies.

The Classification and Regression Trees (CART) map the characteristics to decision trees. Classification analysis produces an accurate classifier or uncovers predictive structure of data to predict medical conditions, consumer behaviors and other complex patterns (Breiman et al, 1984). Preliminary CART analysis results in a decision tree based on technology cycle, number of materials and number of parts (figure 3). The numbers inside the circles of the decision tree represent the node numbers. The notation below each node indicates the observations while the numbers outside the nodes are the breakpoints. Running various simulations combining and deleting characteristics will lead to improved decision trees.

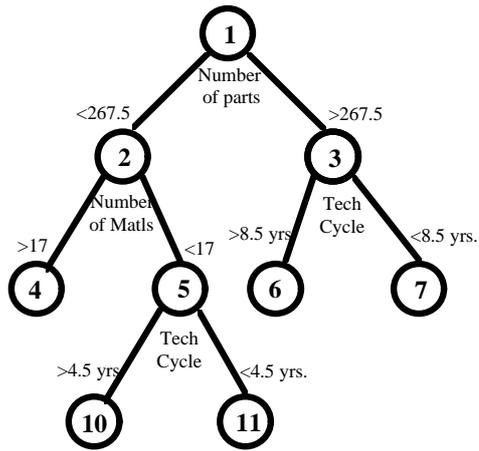


Figure 3. Preliminary CART Results

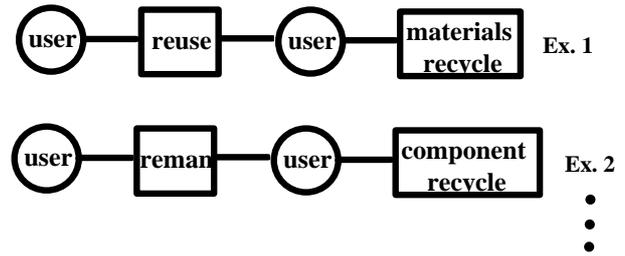


Figure 4. Example Output showing predicted end-of-life strategies.

Another proposed output of ELDA is a flow chart of the predicted end-of-life strategy (figure 4). From the predicted strategy, ELDA should provide design recommendations and guidelines based on the end-of-life strategy.

Since ELDA targets early stages of design, we may need to change some characteristics to better address designer knowledge and more reliably predict the end-of-life strategies. Finding the balance between designer knowledge and reliable prediction is an iterative process. The first phase of ELDA data collection in ME217 revealed that some characteristics required excessively specific information (number of parts), information not available to designers (reason for obsolescence) and additional interpretation (functional complexity). Requesting more generic information, information accessible by designers and clarifying characteristics will improve ELDA.

2.4 Aid in decision making

The final goal of ELDA is to contribute technical and technological aspects to decision making process. Decisions concerning environmental policy have considered various factors as a part of a total decision matrix. Decisions depend on the following aspects:

- the goals set for end-of-life systems.
- the eco-efficiency requirements.
- the external factors such as infrastructure, consumer behavior, and legislation.
- the product characteristics.

Goal setting for end-of-life systems is complex and should be an appropriate mix of minimizing landfill space, maximizing recycling and controlling hazards. However, few understand that these goals are sometimes mutually exclusive and may not work in parallel. Similarly, depending on how eco-efficiency principles are implemented, the decision could be different. Decisions relating to end-of-life policy are also influenced by the infrastructure available, consumer behavior and legislative situation. While product characteristics are not a decision element, they strongly determine what can be reasonably expected at end-of-life. Lastly, ELDA's innovation focuses on incorporating product characteristics to end-of-life policy. ELDA will categorize products based on technical characteristics, leading to more meaningful criteria for reuse and recycling.

3. IMPLICATIONS ON DECISION MAKERS

Designers, recycling technology developers and policy makers must recognize the importance of product characteristics when making decisions about end-of-life strategies. Frequently, designers make arbitrary assumptions about an end-of-life strategy and should pay more attention to product and sector differences. Recycling technology developers advance the associated technologies to address certain products and ignore product diversity based primarily on product characteristics. More detailed understanding of product characteristics would enhance enormously the eco-efficiency of take back systems. Examining the needs from a product point of view is necessary because designing and manufacturing of a product is controlled by companies. It is important for all of these groups to understand and base decisions on individual products and sectors.

3.1 Product designers

While Life Cycle Analysis is an effective tool for determining the environmental impact of the different phases of a product's life, the method does not lead designers to direct improvements to current or future designs. Product designers require green options starting from a product point of view and methods to prioritize environmental improvement areas from a life cycle perspective. Current tools give ample improvement options but fail to set priorities for implementing.

ELDA can aid designers in both of these tasks: new idea generation and priority setting. The ME217 teams who used ELDA in their projects were more aware of novel design improvements and issues associated with incorporating environmental concerns. Noticing the comparison between their product and an example product, one team incorporated improved end-of-life assessment early in conceptual design. Another team changed materials and reduced the material content of their product for increased recyclability. The statistically based prediction of end-of-life strategies feature of ELDA will help designers to prioritize their efforts further. The knowledge of appropriate end-of-life strategy of a product helps designers to focus their efforts on the most pertinent areas.

The process depicted above, finding green options, distinguishes our approach from typical Life Cycle Analysis. Identifying green design opportunities focuses on environmental efforts that can be directly influenced by companies. LCA proposes improvements from a general environmental perspective, including in the analysis of, for example, electricity generation, infrastructure and other items which and not be directly influenced by the designer or industry.

3.2 Recycling technology developers

Recycling technology aims at extracting value from end-of-life products through cascading material streams. The specifications of these materials determine to a large extent the basic eco-efficiency of recycling systems. Technology can contribute substantially to increase this basic eco-efficiency. By focusing on product characteristics and four main technologies, improvement areas are as follows:

- Disassembly of valuable parts and components and/or hazardous parts and components
- Mechanical treatment and separation of metal dominated products
- Mechanical treatment and separation of precious metal dominated products
- Mechanical treatment and separation of plastic dominated products

Assessing product characteristics upfront and understanding the relationship between end-of-life strategies will help focus the technology improvement effort. A proposed module of ELDA will give guidelines similar to those shown in table 2 (Rose, 1998b).

Table 2. Initial Guidelines for Recycling Technology Developers

Product Category	Recycling Technology Developers
Type I	develop separation technologies accounting for different physical properties between materials that can not be sorted
Type II	develop efficient cleaning technologies to reduce remanufacturing cost
Type III	develop non-destructive techniques for removal of key components
Type IV	develop non-destructive techniques for maintenance and upgrading

3.3 Policy makers

Proposed European Union legislation sets targets for collection and recycling for a wide range of consumer products. The primary drivers in requiring take back and recycling of products are societal concerns about resources, landfill or incineration, and lack of control of hazardous substances at the end-of-life phase. Take back systems should be required to be eco-efficient as well as making sure that attaining environmental goals and the costs to achieve these are in proportion. Preliminary studies show that eco-efficiency is strongly dependent on product characteristics and recycling technology (Stevens, 1999). To optimize environmental gains and minimize costs, legislation of take back and recycling should be tailored to product sectors and types. Allenby suggests, “It is obviously desirable that policy development be based so far as possible on the scientific and technological characteristics of the system and understanding of implications on system performance in both short and long term” (Allenby, 1999).

ELDA will provide available technical information that is relevant for decision making on take back and recycling systems. In particular, it will assist in developing a sector based approach. ELDA will show how products from different branch organizations can display distinct end-of-life strategies and will contain different modules for geographical regions to account for diversity of take back schemes. Previous studies have compiled take back information on international regions such as Western Europe, US and Japan (Boks et al, 1998).

4. CONCLUSION

The End-of-Life Design Advisor (ELDA) tool is a web-based tool developed to increase designer awareness, predict end-of-life strategies, and aid in decision making. Classification and Regression Trees (CART) map product characteristics to end-of-life strategies through decision trees. Designers, recycling technology developers and policy makers must recognize the importance of product characteristics when making decisions concerning end-of-life strategies.

ELDA removes obstacles in decisions related to end-of-life efforts. By addressing concerns of product designers, recycling technology developers and policy makers, ELDA addresses varied perspectives in the analysis of end-of-life options. Focusing on product design changes addresses bottom-up perspective, recycling technology developers address an end-of-pipe perspective, and policy makers address a top-down perspective. Integration of these three sets of knowledge within ELDA leads to more informed decisions.

5. ACKNOWLEDGEMENTS

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7. APPENDIX: ADDITIONAL TEXT FROM END-OF-LIFE DESIGN ADVISOR (ELDA)

1. Wear-out Life: For example, an automobile's average wear-out life is 10-15 years. For a computer, the wear-out life is approximately 7-10 years.
2. Design Cycle: For an automobile, the design cycle is 2-4 years. For inkjet printers, the design cycle is 1 year.
3. Technology Cycle: Typically, the technology cycle is 10-20 years for automobiles. On the other hand, the technology cycle of computers is more like 6 months to 1 year.

4. Repurchase Cycle: The repurchase cycle is highly dependent on the type of user, but please try to estimate it for the “average” user. An example of repurchase cycle is automobiles, where an “average” user repurchases an automobile every 5 years.
5. Reason for Obsolescence: A product typically reaches its end-of-life because it is worn-out or because it is outmoded. A product is worn-out when crucial components supporting the key functions of the product fail. A product is outmoded when the user feels the functions are not the best on the market due to technology innovation.
6. Functional Complexity: Given the modularity of the product, a functionally complex product has highly dependent modules that support a variety of functions. On the other hand, a product with low functional complexity has modules that independently support separate functions.
7. Size: Please classify the products as either hand-held, arm-held or needs a forklift. A digital copier and washing machine require a forklift or hand truck to move them, thus they are considered large in size. An inkjet printer and television (standard) are medium-sized because they can be carried in the arms. A cellular phone or single use camera are hand-held and therefore small.
8. Number of parts: The number of parts is the approximate number of parts in the product.
9. Cleanliness Measure: The more dirt or filth, the more work that has to be done to prepare the product for reuse and recycling. The product may provide the function of cleaning dirty materials or may produce a dirty substance during use. For example, a washing machine is designed to remove dirt from clothes while the single use camera does not get dirty from normal use.
10. Number of Materials: A single use camera excluding the film has seven different materials, while an inkjet printer has forty different materials.
11. Number of Modules: The single use camera has 3 modules while the inkjet printer has 5 modules.
12. Hazards: Included in this penalty is the need to remove certain materials before further recycling, because of hazards to humans, the environment or contamination of parts. For example, the single use camera batteries are considered hazardous.