INVESTIGATING THE REQUIREMENTS NEEDED TO MAKE APPROPRIATE END OF LIFE DECISIONS

Kirsty Doyle, Winifred L. Ijomah and Jiju Antony
University of Strathclyde, UK

ABSTRACT
The purpose of this paper is to present the key findings on End of Life (EoL) decision making during product design, followed by a summation of the further research needed within the field. The methodology includes a literature review and preliminary case study findings. Literature suggests that the EoL of a product should be determined in the early stages of design, based on the product characteristics. However, preliminary findings suggest that additional external factors, such as legislation, financial implications, market trends and the return logistics should also be taken into consideration. The originality of this work is that it studies the potential external and internal factors that should be incorporated into designing for End of Life.

Keywords: End of Life, Product Design, Ecodesign, Remanufacture, and Decision Making

1. INTRODUCTION
As it is estimated that consumer waste will increase by 40% by 2010 [1] and landfill sites are near their full capacity [2], there is need to reroute EoL products back into a new lifecycle. Recent European Extended Producer Responsibility (EPR) ensures that the Original Equipment Manufacturer (OEM) endures full responsibility of the product throughout its entire life-cycle[1]. It is also estimated that more than 90% of WEEE will be sent to landfills and incinerators without prior inspection or treatment [3]

Leading EoL author Rose's definition of EoL is used within this paper, as it allow for the maximum amount of EoL to be analyzed. The author defines a product's EoL as "the point in time when the product no longer satisfies the initial purchaser or first user"[4]. Successful EoL management has the potential of reducing landfill waste and converting that waste into a profitable product, by retaining the product value, using less virgin materials and resources. Consequently, OEMs have to implement take-back requirements into their strategic planning processes and product design strategies into the design process. Product design has been identified as the vital stage to determine the EoL route for a product as the product's characteristics can be designed to match the EoL requirements.

EoL decision making models have been integrated into the design process at various stages such as conceptual design and detail design. However there are several problems associated with EoL decision models. Ultimately there is conflict regarding when to integrate into the design process, the type of criteria that is used to analyze EoL decisions and who is responsible for making EoL decisions. Finally, EoL determination tools are often difficult for designers to understand and utilize.

The aim of the research is to develop an understanding of the optimum design stage in which End of Life decisions should be made. Additional research is needed to identify and understand the attributes/factors/criteria needed to make EoL decisions. The paper includes the following sections. Section 2 focuses on approaches to determine a product's EoL. Section 3 discusses the current EoL determination models and the limits of those approaches. Section 4 highlights preliminary findings from designers involved with End of Life. Section 5 focuses on the gaps in research and future work. Section 6 will conclude the paper.

2. APPROACHES TO DETERMINE A PRODUCT'S EOL
From the literature, there are four different approaches to determine a product's EOL:

1. Using Ecodesign tools
2. Using LCA
3. OEM/3rd party "recoverers" determine the strategy once the product has been returned to them
4. Using Design for EOL (DfEoL) models

It is suggested by literature that the use of EOL decision-making models in the early stages of design is the optimum method of determining a product's end of life strategy/route [5-7].

2.1 Selecting the appropriate EoL using Ecodesign Tools

The objective of Ecodesign is to improve the environmental impact of the product, throughout its lifecycle [8]. Although end of life issues plays a influential role in many ecodesign approaches, it is not considered a complimentary approach for selecting a product's end of life route during the design process [9, 10] for the following reasons:

- This approach requests a lot of information from the designers, which is often unknown at the point of Ecodesign integration [4, 11].
- The integration of Ecodesign often happens at the later stages of design, to analyse the environmental impact of the design. Consequently, due to the late integration, large redesigns are frequently overlooked as it would not be economically viable. As an alternative a simple redesign of an existing idea happens [11, 12].
- The third problem with Ecodesign is that there is emphasis on the designer's perceptive to make EoL choices. This is a subjective form of analysis resulting in different outcomes, depending on the user's experiences/knowledge.
- Finally, Ecodesign is an approach which does not exclusively determine a product's EOL. Rather, it analyses each aspect of the product's lifecycle. As a result the Ecodesign approach is often too general and not specific to types of product, environments or markets [11]

2.2. Selecting the appropriate EoL using LCA

LCA is a method for evaluating the environmental impact of a product's lifecycle using environmental indicators. Although LCA is beneficial in terms of evaluating the environmental impact of a product, it is not necessarily the best approach for determining the product's EoL because:

- The use of LCA requires extensive training [12]. Furthermore, due to the nature of LCA, it contradicts designers' preferences for quick and easy design methodologies to use [13].
- LCA's environmental outputs do not educate the designer on how to make improved design choices regards products' EoL. Instead, it relies on the designers' experiences to make the right changes to either the product's manufacturing process or the product itself.
- Another disadvantage of using LCA is that it does not show whether it is environmentally advantageous to prolong the life of a product which is an essential indicator in EoL decision making.

2.3 OEM/3rd party recoverers determine EOL once the product has been returned to them

Many different models exist in determining a product's EoL once it has been returned by the user to the OEM or 3rd party recoverers. However, by delaying the EoL decision until this stage, the optimum EoL may not be selected, but rather the best compromise, thus EoL decisions must be made when the design characteristics are still flexible, i.e. the design stage. What's more, EPR schemes are now putting pressure on organizations to design products responsibly, including the disposal of products. For these reasons, determining the EoL of a product at the EoL Stage is not advisable.

2.4 Determine the EOL using design for EOL models

As previously indicated, the EoL of a product should be determined in the Product Development Process [4, 17, and 18]. EoL decision making models, rather than Ecodesign and LCA, are a viable method to select the optimum end of life for a product during the design stage. Section Three will further discuss EoL decision making models in the design process and problems related to the criteria used.

3. PROBLEMS WITH EXISTING EOL APPROACHES

Literature highlights that many existing EoL decision making models fail as they are not aimed at designers, although they are the ones directly involved with the decisions that influence a products EOL manipulation. Alternatively, many are focused on economical or environmental goals. The main issues acknowledged are presented below within the following categories:

- *When*: when should EoL decisions be agreed
- *Who*: who should be involved in the decision making process and what skills do they need
- *How*: what criteria/attributes should be analysed in order to make EoL decisions.

Table 1 outlines the EoL decisions making models and highlights the differences between when decisions are made, who makes decisions and which criteria is involved. Of the issues mentioned this paper will concentrate on the 'how' issues by investigating which criteria should be integrated into the design process to determining appropriate EoL strategies.

Table 1 Table depicting when, who and how EoL models make decisions

Author	**When**	**Who**	**How: Type of criteria analyzed**
Rose [4]	Early Stage	Designer/project manager	Internal factors that the designer can control : Product characteristics
Brissaud [11]	Conceptual	Team Based Negotiation	Environmental, Product characteristics
Gehin [19]	Conceptual	Designer	Environmental
Gonzalez [6]	Detailed	Not Clear	Economical, limited environmental aspects
Staikos and Rahimifard [20]	Not stated	Not clear	Environmental, economical
Kwak[7]	Not Stated	Not Clear	Environmental, economical, Product characteristics

3.1 Problem with the type of criteria included in the decisions

Literature shows that there is distinctive lack of EoL models which simultaneously analyze economical, environmental, social (including customers' needs), technical and legislative factors during the design process. Many EoL determination models commonly analysis economical, environmental and technical aspects. However, many fail to include social and legislative factors. It is detrimental to neglect legislative factors as OEMS (in EU) must comply with EPR schemes such as WEEE, RoHs and EUP. More importantly, social considerations such as fashion/technology preferences must be considered to determine the product's expected life span and hence when the product is returned and enters its second life.

The ELDA approach (End of Life Design Advisor) bases its decision making criteria solely on product characteristics, as this is the only aspect the designer has control over during the early stages of design. The output strategy is determined by six inputs; reason for redesign, wear out life, design cycle, technology cycle, design cycle and number of parts. The suggested outputted EoL is compared to company's actual EoL, then any necessary improvements to either design or strategies are made (see Figure 1). Furthermore, an advantage of ELDA is that it provides design guidelines for the suggest strategy.

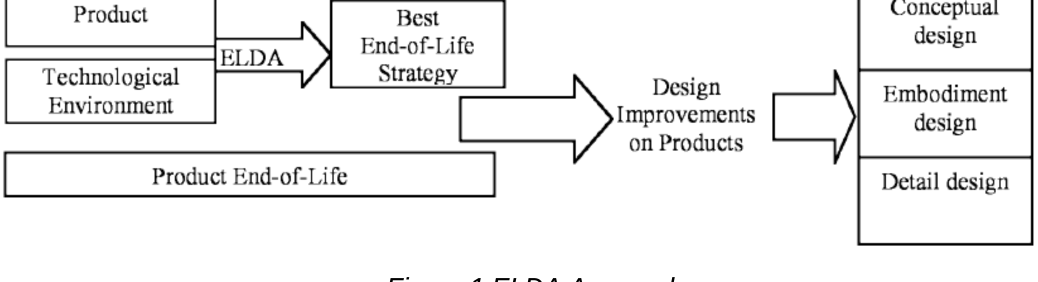

Figure 1 ELDA Approach

ELDA is a sound approach for integrating end of life thinking into the design process, as it relies on the information available at during the design stage. However, the main limit in this approach is the type of criteria evaluated. By analyzing only the product characteristics, it fail to consider external factors (external factors to the design process) which are central to distinguishing one EoL strategy from another, such as returns logistics in place and rate of technology changes in the market. The implication of this leads to the step of comparing the designer's suggested strategy to the company's actual strategy. The consequence means that in some instances the strategy between to the two can alter, as the designer only considers internal factors (internal to the design stage) rather than integrating information regarding the company's external factors into the decision making process.

4. PRELIMINARY FINDINGS FROM CASE STUDIES

Interviews with a focus group (consisting of remanufacturing experts, recyclers and designers), telephone interview of designers, and investigating a case study company involved in DfEoL help to shape the preliminary findings. The aim of the research is to create a list of factors which should be used during the design stage to help make better EoL decisions. Figure 3 outlines the data collected, which was collected as a respond to company's influential EoL decisive factors. The factors are split into common themes consisting of environmental, economical, technical (product charactistics), social and legislative.

Type of factor	Inputs
Environmental	Eco-balances, recycling costs, recyclability of materials, environmental characteristics of product, recycling targets, environmental indicators, LCA results, LCA type process,
Economical	Disassembly cost analysis, material processing costs, transportation costs, labour costs, subsidies, disassembly time, resell price, value of product/material/components
Technical	Clumping of products, material compatibility, product architecture, technology cycle, level of integration, number of parts, manufacturing processes, assembly techniques, disassembly operations, joining methods, purity and mass of material, hazardous content, assembly direction, relationship between components, estimated mass, number of subassemblies,
Social	Designer's intent, reason for redesign, expected degree of damage,
Legislation	Take back legislation, taxation, subsidies

Figure 2 Type of factors to consider when making EoL decisions

4.1 External Factors Play Pivotal Role

Findings from the pilot sessions indicate that there is a strong need to include external factors (external factors to the design process) into DfEoL. External factors include environmental and economical aspects, social implications and legislative pressures. When deciding on a retirement strategy, external factors play a significant role in the decision making process, e.g. the returns supply chain can effect an OEM's decision to remanufacture. Significantly, legislative factors, such as complying with the WEE Directive, also have to be brought into the equation. As such, preliminary findings have highlighted a need for information regarding these external factors to be integrated into the design stage to better enable the decision process. However, one significant problem is transferring the external factors into the design process in such a way that designer can fully understand and utilize the information.

4.2 The Important Factors

Preliminary findings have suggested that each factor has a varying degree of importance in the decision making process, whereby a few factors have paramount importance, such as cost implications of adopting a certain EoL strategy. Ultimately, economical factors have been identified as the most important criteria for EoL making in almost all instances. Similarly, of the designers interviews, they have also expressed the importance that legislative factors play in the decision making process, although many EPR schemes are not mandatory at this point in time. Notably, the findings have also expressed the importance for social factors, such as the needs of the customers in the decision making process. It is fair to argue that currently social factors are largely neglected in EoL decision making models. However, preliminary findings have suggested that there is a strong need to integrate them into DfEoL.

Finally, due to the extensive list of potential factors, there is a need to prioritize them into a comprehensive list which focuses on the most influential factors. The list will be devised in such a manner that it reflects that importance issues, as well guiding designers to select the most appropriate EoL strategy.

4.3 Making Research Useful

Finally, designers have criticized the effectiveness of current EoL models/tool. One common complaint is the extensive training procedures needed to use the tools. Designers have highlighted that the tools are not integrated into the design process and are instead seen as additional work that they do not have time to do. Currently, designers have indicated that EoL decisions are based on designers' experiences and preferences, rather than a formal decision making process. What they suggest they need was "quick and easy" tools, in the forms of checklists, guidelines or matrixes, which would steer them through DfEoL.

5. FUTURE WORK

Findings from the literature suggest that there are several gaps regarding the integration of EoL decision making models into the design process. These include that:

- Developing EOL models that deal consider factors out with product characteristics.
- Summarize the key internal and external factors into a comprehensive and easy to understand list
- Making the list of factors useful to designers; easy to use and understand.

Additionally, little attention is given to the role of the designer in making decisions that govern product's EOL route. Therefore, there is a need to establish and understand (i) the current process used by designers in making decisions that affect products' EoL route, (ii) whether designers normally consider product end of life in their work and (iii) whether the current tools are suited to their level of skills and knowledge?

6. CONCLUSION

This paper has described the preliminary work in research being undertaken to increase understanding and knowledge to further improve EoL decision making in design. EoL based models, integrated into the design stages are a more desirable approach, but there are problems regarding the factors used to analyze the optimum EoL strategy. More research is needed to improve the productivity of EoL models by integrating external factors into decision making process. Ultimately future work should include the amalgamation of environmental, economical, technical, social and legislative factors to create a holistic decisions framework for EoL of products during the design stage.

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Contact: Kirsty Doyle
University of Strathclyde
Department of Design, Manufacturing, and Engineering Management
G1 1XJ, Glasgow
UK
Tel: +44 (0) 141 548 3056
E-mail: kirsty.doyle@strath.ac.uk

Kirsty Doyle is a PhD candidate researching methods to integrate sustainable issues into the design process at the University of Strathclyde. Kirsty is part of research network consisting of PhD candidates and industry professionals researching remanufacturing issues. She is interested in better enabling designers to make sustainable design decisions.