Multi-criteria decision aid for product end of life options selection

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Abstract

This paper presents research objectives, accomplished work and results associated with the research project AEOLOS (An End-of-Life of Product Systems), a project of the 5th framework programme "Competitive and Sustainable Growth" of the Europena Union. The emphasis of the overview is on the multicriteria decision aid aspects of the project. The goal of the AEOLOS project is the development of an integrated methodology and sofware tool to aid in evaluating product end-of-life (EOL) treatment options with regard to environmental, economic and social criteria. The main scientific innovation is in using multi-criteria decision aid methods to select product EOL options under several often conflicting criteria which are not necessarily quantitatively defined. The case studies treated in the AEOLOS project are for electro-mechanical and electronic products with a goal in assisting in the implementation of the WEEE (Waste of Electrical and Electronic Eequipment) Eeuropean directive. However, the methods employed in the project are general and can be applied to other product types and possible directives such as the end-of-life of vehicles (ELV) directive.

Keywords

Multi-criteria decision aid, EOL management, WEEE.

INTRODUCTION

The discussion about the end-of-life phase of products becomes more and more interesting and intensive in our industrialised societies and involves more and more social actors such as producers, consumers and public authorities. The reason is that the amount of worn-out products generated each year is increasing and the landfills are saturated and their expansion is not always possible. In addition to the problem of finding landfills to dispose the huge volume of retired products, the problem of the hazardous nature of some of their components is becoming also a subject of investigation.

Waste from Electronic and Electric Equipment was identified as a major component of the generic stream which could be easily diverted to alternative processes other than landfill [7]. This has lead the European Union commission to realize a draft directive on waste from electronic and electric equipment (WEEE) to investigate regulations concerning the treatment of these products at their end-of-life. This draft is still being discussed in the European parliament and the council of ministers. When this directive will be finalised, it will be implemented in national legislations before end of 2004 [8].

In a near future, the original equipment manufacturers (OEMs) in many countries will be financially and organisationally responsible for the take-back of their products when they reach the end of their life-cycle [11]. This follows the principle of extended producer responsibility according to which producers should be responsible for the entire life cycle of their products and especially for the take-back, the recycling and the final disposal of their products. Hence, the choice of the most appropriate scenario for treating products at their end-of-life should not only be based on economic considerations but should also take into account environmental and social aspects in order to ensure compliance with legislation and satisfaction of customers.

The problem of selecting a good scenario for treating products at their end-of-life concerns different types of users such as authorities, recycling companies, remanufacturers and original equipment manufacturers. Each user has its own objectives and priorities and it is possible that a good scenario for a user is not necessarily good for another user. Even for the same set of EOL scenarios and the same family of criteria, the weight of a criterion may be different from one user to another. Moreover, within a criterion, the same score of an EOL scenario has not necessarily the same importance for all users. Hence, the type of user will play a key role in the proposed approach.

Once a product moves from the drawing board to the production line, its environmental attributes are largely fixed [4]. However, the economic, environmental and social impacts of a product during its life cycle depend also on the way the product is treated. Especially, at the end-of-life phase where the choice of an appropriate scenario for treating the product can reduce largely the negative impacts on the environment and society. To achieve this goal, the most important EOL scenarios should be considered, compared and evaluated on the basis of their performances with respect to relevant environmental, social and economic indicators and the preferences of the user. Usually, the indicators are conflicting and not equally important. To deal with such decision situations, a multicriteria decision-aid (MCDA) approach is suitable.

Multicriteria decision-aid aims to give the decision-maker some tools in order to enable him to advance in solving a decision problem where several-often contradictory-points of view must be taken into account.

AEOLOS User Groups and Toolset

The AEOLOS methodology and sofware aims at satisfying the needs of two user groups (Figure 1): (i) the decision makers at the public authority level that formulate policy on product EOL selection and treatment at the local, regional, national or EU levels and (ii) the decision makers at the level of resource recovery/recycling companies and original equipment manufacturers (OEM) who must implement the policy directives issued by the public authorities [2]. Both user groups must consider the product EOL selection and treatment from an integrated viewpoint i.e. by simultaneously taking into account environmental, economic and social criteria. Furthermore their actions must be compatible i.e. the implementation must be according to the public policy and public policy must take into account the realities and constraints of the possible practical implementations.

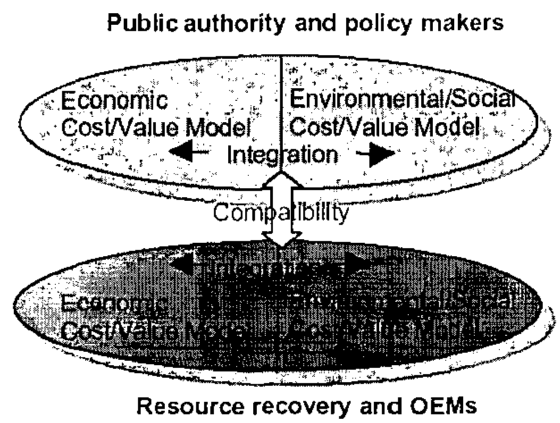

Figure 1. AEOLOS methodology user groups

Product Life Cycles and Associated Environmental Issues

The basic assumption made behind the AEOLOS methodology is that the product in question has arrived at its end of life i.e. it is assumed that the product is already retired from its functional environment. The decision for the retirement of a product is based on a number of reasons which will influence its EOL treatment decision. The selection of an EOL treatment process is then based on the evaluation of a number of feasible EOL scenarios.

The end-of-life of a product can be defined in technical, economic, social or legal terms:

- **Technical life**: The product reaches its EOL when it cannot function properly with normal service and maintenance.
- **Economic life**: The product reaches its EOL when repairing the product is not cost-effective.
- **Social life**: The product reaches its EOL when it is out of fashion.
- **Legal life**: The product reaches its EOL because it does not satisfy the safety regulations.

Here we may say that, if the product reaches its EOL because it is perceived as being out of fashion then the possible EOL scenarios could include the recuperation of valuable parts or components. This may not be the case if the product reaches its EOL due to technological reasons.

AEOLOS Lifecycle Functional Model

The overall objective of the product life cycle and retirement process is to close the material loop and minimise landfill and pollution to air and water. In order this to be achieved, a lot of questions are generated and have to be answered and a lot of decisions have to be made by different users.

In order to evaluate environmental, social and economic values and make good decisions, knowledge, experience and information at all levels are needed. Sharing knowledge between different users is a critical factor to success. To disassemble a product is easier, faster and safer when correct information is available about the product structure, materials, hazardous components etc. To make products prepared for a given EOL scenario, a lot of knowledge is required about how to meet environmental challenges and EEE directives and legislation.

Figure 2 below gives the highest level of the AEOLOS solution activity that is to evaluate an EOL scenario of a product [10].

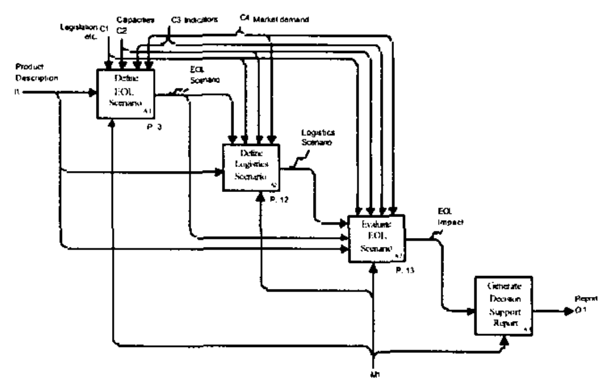

Figure 2. AEOLOS Functional model

The functions described in this model show "what" functionality is implemented in AEOLOS:

Evaluate EOL of products
- Define EOL Scenario
  - Treat without disassembly
  - Define material separation scenario
  - Treat with disassembly
  - Separate for Functional Reclamation
  - Separate for Material Reclamation
  - Separate for Disposal
  - Separate for Incineration

Define Logistics Scenario
 Define collection strategy
 Define storage strategy
 Define transport strategy

Evaluate EOL Scenario
 Calculate Economic Impact
 Calculate Environmental Impact
 Calculate Social Impact
 Calculate Integrated Impact

Generate Decision Support Report

AEOLOS Integrated Methodology

The AEOLOS methodology consists of five steps [1]:

i. EOL Scenario Definition

This is done by the user and it consists of product data and EOL option description.

ii. Scoping of Scenario

This step involves the consideration of known legal, technological or marketing aspects that allow the elimination of non-conforming scenarios.

iii. Assessment of Scenario

This step involves the selection of relevant environmental, economic and social indicators and the assessment of the associated impacts of each scenario.

iv. Analysis and evaluation of scenarios

This step involves the ranking of the EOL scenarios according to the selected environmental, economic and social indicators using multi-criteria decision aid methods.

v. Refinement of Scenarios and Final Evaluation

This step involves the checking of the selected EOL scenarios with regard to predefined checklists.

Along the activities to perform the assessment, the user is provided with information to take into account constraints (such as due to legislation, new technologies and marketplace requirements) in the feasibility of the EOL scenarios. The AEOLOS methodology also considers methods of communicating the results of EOL scenario analysis in the particular context of the user.

Definition of EOL Scenarios

The first step that the user of the AEOLOS methodology and toolset has to do is to select a product and associated EOL option(s), which together make up an EOL scenario. [1]. A product is selected from a list of product types, based on the WEEE hierarchy. The definition of the scenarios is unlimited by any constraints, such as local availability of facilities at this stage. A refinement of scenarios occurs later in the iterations "loop". The EOL options included in the AEOLOS methodology and software are re-manufacturing, component reclamation, material recycling, incineration with energy recovery, incineration without energy recovery, and landfill. The minimum amount of information required for a product definition is the weight of that product.
A product can be structured like in Figure 3. This figure shows the different levels of detail that can be defined for any pro duct.

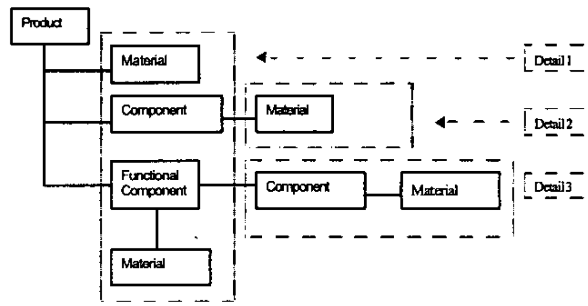

Figure 3: Product Structure

Analysis of EOL Scenarios

The implementation of an EOL scenario for treating a product at its end-of-life has environmental, social and economic impacts. These impacts are measured by means of appropriate indicators [5]. In this paper, we deal with the problem of selecting the best compromise EOL scenario among a finite set of EOL scenarios on the basis of their scores on relevant environmental, social and economic indicators and preferences of the user (decision-maker). Hence, the EOL scenarios constitute the objects of comparison in the multicriteria decision-aid problem we are considering. In the literature of multicriteria decision-aid, the objects of comparison are generally called actions or alternatives [12].
The definition of EOL scenarios will be based on the description of the product and the EOL options. As it was mentioned before, according to the WEEE directive, the EOL options considered are product re-manufacturing, part/components reclamation, material recycling, incineration with energy recovery, incineration without energy recovery and disposal to landfill.
Some EOL scenarios necessitate a partial or complete disassembly of the product. Disassembly consists of separating a product into its constituent subassemblies, parts or components. Generally, only partial disassembly is applied.
In this paper, we call an element a result of a disassembly operation. Hence, an element can be the whole product, a part, a subassembly or a component. A basic element is an element that cannot undergo any disassembly operation.
We define an EOL scenario as a set of pairs (element, EOL option). Since the number of basic elements in a product is necessarily finite, say n, then a scenario has the following form: ((element 1, EOL option 1), (element 2, EOL option 2), ..., (element n, EOL option n)) where $m \leq n$. In case of a complete disassembly $m = n$. Different elements may the same EOL option.
If all elements of a product or a part or a subassembly have the same EOL option (only if the application of the EOL

option does not necessitate the separation between these elements), it (product, part or subassembly) will undergo the same EOL option without resorting to disassemble it into these elements. For example if a product has m elements: element 1, element 2, ..., element m, then the scenario: ((element 1, disposal to landfill), (element 2, disposal to landfill), ..., (element m, disposal to landfill)) is the same as the whole product is disposed to landfill. The formulation in (element, EOL option) is used to have a common structure for all EOL scenarios.

For a product with m elements: element 1, element 2, ..., element m, each scenario: ((element 1, EOL option 1), (element 2, EOL option 2), ..., (element m, EOL option m)) is a potential scenario. A potential scenario is a possible candidate for evaluation and comparison during the decision process. The relevant EOL scenarios that will be used as alternatives for the multicriteria decision-aid problem should be selected from the set of the potential EOL scenarios.

The number of potential EOL scenarios increases exponentially with respect to the number of elements in the product. For a product with m elements, there are 6^m potential EOL scenarios (for a product composed of 4 elements, there are 1296 potential EOL scenarios!). Consequently, it is not practical to consider all the potential EOL scenarios in the multicriteria decision-aid problem. It is necessary to overcome this difficulty in order to progress in structuring and solving the problem. In general the users consider only the main parts on the basis of their functionality or the materials composing them. This can reduce largely the number of potential EOL scenarios to consider for further investigations.

Among potential EOL scenarios, the user should select the feasible ones according to the information available concerning technological, market and legislative constraints. By imposing these constraints to potential EOL scenarios, the number of potential EOL scenarios to consider for the remaining of the decision process may be reduced significantly. Nevertheless, this number can still be too big to be used in practice.

The EOL scenarios should satisfy the following conditions. Some of them are practical and some others are technical.

- **Feasibility**: The implementation of the EOL scenario should be possible. There should exist technologies and infrastructures which are necessary for the implementation of the EOL scenario.
- **Legality**: The implementation of the EOL scenario should be compliant with legislation on the treatment of products at their end of life.
- **Objectivity**: The implementation of the EOL scenario should be driven by realization of benefit, satisfaction of legislative requirements or achievement of environmental or social goals.
- **Relevance**: Only EOL scenarios relevant to the activity of the user can be considered. A recycler will focus on EOL scenarios based on elements composed of the most important materials to recycle.
- **Completeness**: All relevant EOL scenarios should be considered.
- **Non-redundancy**: Only EOL scenarios that are different should be considered. If two EOL scenarios are too similar, only one of the two should be retained.

These selection criteria are mainly qualitative. Their satisfaction by the potential EOL scenarios should be based on the available information on subjects related to the criteria, the experience of the user and the objectives of the problem.

Application of an MCDA Method for the Evaluation of EOL Scenarios

A major difficulty encountered by potential MCDA users is the wide range of different MCDA techniques that have been proposed, each having its own strengths and weaknesses. None of these techniques has been proven to be the most suitable to every multicriteria decision making situation. Hence, the choice of an appropriate multicriteria decision aid method to deal with a given multicriteria decision situation should be given a great attention. Especially, when it is known that two different multicriteria decision aid methods may lead to different results.

The main parameter, which is used in almost all MCDA methods, is the criterion weight. The role of criteria weights in an MCDA method depends mainly on the aggregation rule used by the method.

According to Choo et al. [7], the true meaning and validity of criteria weights are crucial in order to avoid improper use of the MCDA methods. Hence, the choice of a procedure to define the criteria weights should be based on its compatibility with the meaning and the role of the criteria weights used in the MCDA method under consideration.

In the AEOLOS application we choosed the method ELECTRE III, where there are three parameters associated with each criterion. These are the indifference threshold, the preference threshold and the veto threshold. They are used to take into account the uncertainties related to the evaluation of alternatives on criteria.

Once an MCDA method is applied and a partial or total ranking of the EOL scenarios is obtained, the solution process is not finished, further analyses should be applied to the obtained results before taking a final decision. The decision-maker should be aware of the consequences of selecting one or another EOL scenario. A graphical presentation of the results makes their understanding much easier for the decision-maker than other forms of presentation.

If only economic, environmental or social indicators are considered for the evaluation of EOL scenarios, the MCDA technique provides the decision-maker with the best compromise EOL scenario from the corresponding point of view.

If the environmental, social and economic indicators are considered simultaneously in the evaluation of EOL scenarios, the MCDA technique provides the decision-maker with the best compromise EOL scenario from an integrated point of view.
The comparison of the profiles of these EOL scenarios allows the user to know more about the way concessions between various dimensions are made within the MCDA technique.
In case this EOL scenario is found to be unsatisfactory, the user has many options to consider in order to find a new solution. One possibility consists of considering the next EOL scenario in the ranking and test it in the same way as the previous EOL scenario.

CASE STUDY

To illustrate the application of the AEOLOS methodology a case study of a telephone is carried out (Figure 4) [8].

Figure 4: Test case telephone.

The telephone product is composed of the following main subassemblies: (i) handset, (ii) screws (iii) base, (iv) mainboard (PCB), (v) buzzer, (vi) keys, (vii) silicon contacts and (viii) cables.

Scenarios

Four EOL scenarios are defined in step 1 of the AEOLOS methodology. In step 2 (scoping of EOL scenarios) the first scenario is eliminated from the list because Swiss legislation prohibits the landfill of electronic and electric products at the end of their life.

Scenario 1:
the whole product is disposed to landfill.

Scenario 2:
recycling + disposal to landfill*Scenario 3:*
incineration with energy recovery + disposal to landfill

Scenario 4:
recycling + incineration with energy recovery

Indicators

In step 3 (first sub-step) of the AELOS methodology environmental, economic and social indicators are defined such as:

Environmental indicators
Name: CO_2 emissions.
Unit: Kg.
Goal: Minimizing CO_2 emissions.

Economic indicators
Name: Disassembly cost.
Unit: Euro.
Goal: Minimizing disassembly cost.

Social indicators
Name: Number of employees to perform the scenario.
Unit: Integer number.
Goal: Maximizing number of employees.

Matrix of Evaluations

In step 3 (second sub-step) of the AEOLOS methodology each scenario is evaluated according to the selected indicators. The values shown here (Table 1) are only for demonstration purposes.

Table 1. Costs of selected scenarios

	Logistics cost	Disassy cost	Product value	Product cost
Scenario2	0.34	0.42	0.21	0.25
Scenario 3	0.25	0.44	0.12	0.19
Scenario 4	0.28	0.43	0.16	0.23

Comparison of EOL scenarios from economic point of view

Rang	Action
1	A0002
2	A0004
3	A0003

Figure 5: Ranking from economic point of view

From an economic point of view, figure 5 shows that the scenario 2 is the best scenario.

Comparison of EOL scenarios from integrated point of view

Rang	Action
1	A0004
2	A0002
3	A0003

Figure 6: Ranking from integrated point of view

From an integrated point of view, figure 6 shows that the scenario 4 is the best scenario.

CONCLUSIONS

The AEOLOS methodology and toolset provides an instrument to evaluate and compare product routes utilising different treatment options in EOL management. It provides an integrated methodology, incorporating environmental, economic and social criteria into a comprehensive measurement tool for sustainability. The methodology and toolset is designed in a way to incorporate requirements from the WEEE directive of the European Commission. However, the methodology is open for other product types that can be described through a systematic product model. Results from the project indicate that there is still a major challenge for manufacturers to incorporate elements into products that makes EOL treatment activities easier to contribute to the removal of hazardous substances from the waste stream, and to contribute to closing material loops.

In this paper, we proposed a general multicriteria decision-aid approach to select the best compromise scenario for treating a product at its end of life. This selection is based on the comparison of EOL scenarios according to their performances with respect to relevant environmental, social and economic indicators and by taking into account the preferences of the decision-maker. This paper is a first attempt of applying an MCDA approach for the treatment of products at their end of life. We hope this will open the door for more applications of MCDA methods in the end-of-life phase of the life cycle of products.

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