Proposition of an Eco-Design Approach for an Easy Appropriation by Companies

Ahmed.Cherifi[1,2], Mickaël.Gardoni[1], Abdelaziz.Tairi[2]
[1]Ecole de Technologie Supérieure, Montreal, Canada
[2]Université de Boumerdès, Boumerdes. Algeria

Abstract--**Today, in the context of product innovation, the environmental dimension takes a special place of choice and cannot be separated from the other requirements of the product which make it competitive. Tools are available but unfortunately proficiency levels required for their use are at the level of an expert; moreover, the tool must be able to clearly identify the benefits arising from its use, with its strengths and weaknesses.**

We have adopted an approach that consists in proposing a qualitative evaluation matrix including no less important parameters related to the comfort factors of the product and organizational preparation for the appropriation of an eco-design approach, in addition to the standard factors of eco-efficiency. The operation will determine the environmental profile of a product. In order to help the designer to make a decision the TRIZ (theory of inventive problem solving) method was proposed. This way of proceeding can help the designer and encourage the company to choose an approach and attain a degree of eco-design at the level of the resources available to it.

I. INTRODUCTION

Ever more stringent standards and legal regulations as well as consumer awareness of environmental issues have transformed the daily activities of engineers and designers in order to think about design and eco-design at the same time. Moreover, the negative environmental impact of a product cannot be significantly reduced by mere consideration of environmental constraints added to the many existing design problems.

The preventive approach is, in most cases, preferred in industrial culture, but it remains nevertheless in the application aspect of the multitude of eco-design tools developed in recent years.

The use of the life cycle in the design of environmentally friendly products is common. However, this tool requires a lot of data, time and expertise. If it is today recognized that a lot of implementation and evaluation of impact software exists, it is however very often expensive to collect all the many data in cases containing relatively large margins of error and difficult to collect. All these difficulties have forced many businesses, especially those who do not have financial means, not to use the tool at this level of expertise. Constraint can be lifted by using more simplified tools requiring less data, in general of a recommendation nature, and the outcome which is in this case qualitative remains approximate and will serve as overall direction for the designer.

Karlsson and Luttropp[12]; Luttropp and Lagerstedt[13]; Dangelico and Pontrandolfo [5] have worked on eco-design tools that can assist engineers in the design of ecological products.

The work of Cheng [6] describes a new model to accelerate the preliminary design of an eco-innovative product by incorporating the benefits based upon reasoning and upon the TRIZ method.

Several examples of eco-design are given to illustrate the capabilities of such a method already from the work of Chih-Chen and Jahau Lewis[4].

Hsiang Tang Chang [11] proposed an eco-innovating method based on the design by approach by using TRIZ. Chakroun, Pradel [2], from a LCA, also offer a TRIZ approach, which is a design based on eco-innovation that enables designers to identify and resolve problems related to the environment in the case of a centrifugal spreader.

David Russo [15] describes a way to use concepts and tools of TRIZ to, at the same time, assess and innovate a technical system in such a way that some practical activities to ensure sustainable results can be easily incorporated into everyday design practices.

Vicenti Chulvi [8] compares the evolutionary trends of TRIZ with eco-design strategies presented under the name of *LiDS Wheel (Life Cycle Design Strategies)* in order to analyze the effects on environmental parameters.

D'Anna[9] provides a tool that faces this obstacle during the early phases of design by way of a new instrument: the sustainability card. It is based on two key elements of TRIZ: the existence of laws describing the evolution of engineering systems and network operations.

Cheng Jung[7] presents a new forecasting model to acquire innovative ideas that help to design environmentally friendly products while following the evaluation of the new design and see whether it is more efficient than those currently available.

From the literature review on evolutionary models Petrov [14] developed a panoply of laws in order to predict technological change easily and more thoroughly. Eco-compass Fussler and James [10] and the Brezet wheel [1] are among the standard tools used in eco-design and eco-innovation. These are tools that have this feature to condense environmental data in a simple and robust, potentially faster method adoptable by companies. The different axes proposed by the two tools seamlessly integrate the environmental dimension of the product, particularly around the central concept of the life cycle of the product. It does, on the other hand, not help at all in terms of a reflection on the social dimension of the product.

The work of Chen and Liu focused on the contradiction matrix of TRIZ. The authors sought at first to establish a correlation table between the 7 principles of eco-efficiency by the WBCSD (World Business Council for Sustainable

Development) described below and the parameters of the TRIZ matrix.

A. reduced demand for the materials for products and services;
B. reduction of the energy intensity of goods and services;
C. reduction of the dispersion of toxic substances;
D. improvement of the recyclability of materials;
E. optimization of the sustainable use of renewable resources;
F. the extension of the durability of products;
G. the increase of the operating intensity of goods and services.

The present work aims at finding the best approach to provide to designers and companies, through an easy to use tool, and for greater ownership.

The environmental effects of product design all throughout its life cycle can be assessed and prioritized according to a new approach to eco-efficiency parameters: the parameters A, B, C are maintained, the parameters D, F and G are taken into account in the new matrix by issues relating to the end-of-life of the product. The parameter E is part and parcel of A and B. Therefore, the new principles that we propose will take into account:

1. Comfort factors that are related to the service provided by the product during its life cycle (Ergonomics, sensory status through the noise and odours generated, the perception of beauty and utility).
2. From adaptation to eco-design is related to the measures taken by the company to support all environmental impacts (training and staff awareness, compliance with the standards in force, strict systematic application of eco-design tools in launching new products, aspects of organizational set-up etc...).

In a first step, the use of the matrix which is based on a response to questions formulated in a sufficiently general manner globally and according to multi-criteria to apply itself to a wider range of products, derive from it maximum information and evaluate the influence of a product on the environment during its design. In order to verify, to complete and to strengthen the results obtained, we will test the TRIZ contradiction matrix. The inventive principles that can reduce the environmental impact will therefore be identified. The research work presented is structured as follows:

A description of the analysis of the life cycle of the product as well as the simplified matrix is given in section 2.

In Section 3, we will discuss the TRIZ evolution model by defining the rules that govern this tool.

In Section 4, we will introduce TRIZ as a complementary tool to support the simplified matrix through eco-innovation.

II. THE ANALYSIS OF THE LIFE CYCLE OF THE PRODUCT AND ITS SIMPLIFIED METHOD

A. Methodological framework

Many eco-design tools or “eco-design” are found in the literature. Examples of applications on specific cases or a summary of work and tools available are often reported by the authors. Each research has a specificity and is based on the analysis of the life cycle of the product, when the objective is to consider a multi-criteria approach to evaluate the impacts thereof. Commonly called Life Cycle Analysis (LCA), this assessment tool takes into account the evolution of the product from the raw materials used in its manufacture, at this same stage, its use and its end of life, not to mention all the intermediate steps (transport, packaging, storage, etc ...), all generating negative impacts on the environment.

B. Proposal for a simplified assessment process

The environmental effects of the design of a product all throughout its life cycle can be evaluated by use of a matrix that is based on a written response to questions that have been put together in a sufficiently general manner to apply to a wider range of products.

The advantage of such a matrix is the ease of use and appropriation as well as the taking into account of all the environmental concerns (multi-criteria) and the length of the product life cycle (global) and does not require data because the evaluation is qualitative.

1. Global Matrix

It is a square matrix (5x5) which encompasses vertically the stages of the life cycle of the product (prefabrication, manufacturing, transportation and packaging, use, end of life) and horizontally the sources of environmental impacts. Each element of the matrix is presented as a score (from 0 to 5, with 5 being the best location, perfect for reducing impact). This assessment can be made after the answer given to each question in the box. The first line of the matrix is in the form of an inquiry in relation to organizational situations of the company with respect to environmental issues.

Issues of line1 of matrix, relatives to prefabrication are not mandatory and may be considered by designers of firms whose prefabrication phase of product depends on the upstream phase.

The questions are related to environmental management policy environmental practices of the company that provides materials, energy conservation, farm program compliance discharges, compliance with the conditions of comfort and eco-design policy (Figure 2).

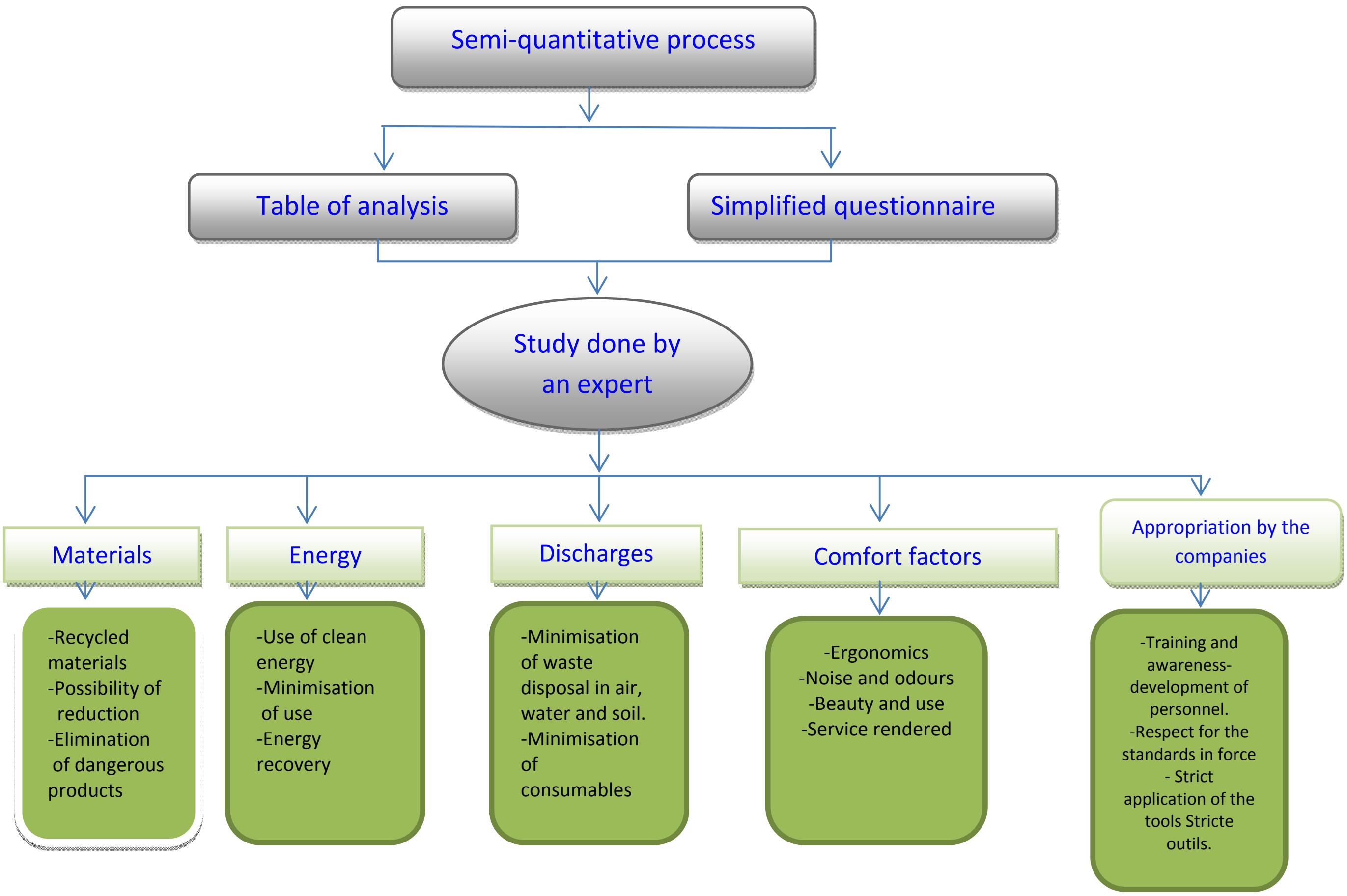

Figure 1. Questions of the matrix

2. Analysis of the product

The results of the prioritization of environmental issues will be expressed as a histogram on a scale of 0 to 5. This hierarchy corresponds with the environmental assessment of the product.

III.TRIZ

For designers, the problems arising from two or more conflicting settings are often complex. The TRIZ method, called the inventive problem theory, was developed by Altshuller. Five key concepts characterize the method:

- the management of contradictions, that is to say that any problem must be formulated in such a way that it establishes a contradiction and instead of accepting compromises resulting from taking into account certain constraints.
- The identification of resources (energy, materials, information, time and space) necessary to achieve a technical system and the final ideal reasoning system and considering the laws of evolution of technical systems.

A. Usual diagram of problem solving by TRIZ

Here, a method of application of the TRIZ contradiction matrix is proposed. TRIZ consists of various tools, including the popular contradiction matrix module that consists of the contradiction matrix and invention principles [8]. The contradiction matrix is a square matrix in which 39 standard technical features are listed on both the vertical and horizontal axes. In each element of the matrix, the identifying numbers for the corresponding principles of invention are described. These principles of invention are aimed at solving technical contradictions (there are 40 such principles in TRIZ). Here, the technical contradictions refer to engineering trade-offs where when something improves, something else becomes worse. In other words, the desired state can not be reached because something else in the system prevents it. The improvement of one parameter results in the degradation of another one: the solution is to gather generic principles that allow to eliminate the conflict rather than compromise.

The important point in the utilization of the TRIZ contradiction matrix is the identification of pairs of contradictory characteristics and their conversion into the standard terms in TRIZ.

The method is based on the exploitation of the matrix, on the guidelines selected, the 39 design parameters (table 1) and the 40 inventive TRIZ principles.

TABLE 1. MATRIX OF RESOLUTION OF TECHNICAL CONTRADICTIONS

Parameters to be improved ↓ — Parameters degraded by improvement →

Design parameters			Design parameters: 1	2	3 to 38	39
			Mass of a moving object	Mass of an inert object	, , ,	Productivity
Design parameters	1	Mass of a moving object				35,3,24,37
	2	Mass of an inert object				1,28,15,35
	3 to 38	, , ,				
	39	Productivity	35,26			

35,26 → Numbers of principles helping to eliminate the conflict

B. Analogy with inventive matrix parameters: Eco-efficiency as a contradictory parameter in the matrix of design parameters

So that the company can consider an eco-efficiency of its products and so that it may consider that it develops environmentally friendly products or participates in the reduction process of these environmental impacts we selected the same factors considered in the previous matrix.

A- The reduction in the intensity of the materials.
B- The reduction of the energy intensity.
C- The reduction of toxic releases and others.
D- The improvement of comfort factors (ergonomics, sensory effect, etc ...)
E- The predisposition to adapt to eco-design

The model is based on the effect induced by a design parameter on the environmental impact of the product.

Therefore, the method leads to propose the designer to select a principle of eco-efficiency to be improved and a corresponding parameter, using the matrix in Table 2.

A high eco-efficiency is dependent on the improvement of one or more elements simultaneously. Therefore, and in order to improve the eco-efficiency, the problem will be managed by TRIZ.

At first we are selected eco-efficiency parameters. Their relation to the TRIZ parameters is giving in Table 3.

TABLE 2. CORRESPONDING MATRIX IN RELATION TO THE ECO-EFFICIENCY PARAMETERS

Engineering parameter ↓ — Eco-efficiency parameter → Design parameters

			A	B	C	D	E
			Intensity of materials	Energy intensity	Toxic discharges	Comfort factors	Learning to eco-design
Design parameters	1	Mass of a moving object				35,3,24,37	
	2	Mass of an inert object				1,28,15,35	
	3 to 38	, , ,					
	39	Productivity					

35,26 → Numbers of the principles helping to improve the product

TABLE 3. CORRESPONDENCE BETWEEN ECOEFFICIENCY PARAMETERS AND ENGINEERING PARAMETERS

Ecoefficiency parameters	(Number) TRIZ parameter Engineering
Intensity of materials	(23) Waste of substance
Intensity of energy	(19) Energy spent by moving object
Toxic discharges	(31) Harmful side effects
Comfort Factors users	(33) Convenience of use
Predisposition of to adapt to eco-design	(24,25) Loss of information,waste of time

We established a relationship between the elements of eco-efficiency and the 39 TRIZ matrix elements.

IV. IMPLEMENTATION OF THE TRIZ METHOD FOR INVENTIVE DESIGN WITHOUT CONTRADICTION

The method for the design without contradiction is based on the use of engineering parameters to improve performance. It is not useful to know if there is a parameter of contradiction and this has no influence on the methodology. It consists of matching each parameter to improve one or more of the 40 innovative principles on which Altshuller founded TRIZ. Thus we obtain through Table 7 all possible solutions associated with eco-efficiency parameters that we have chosen to reinforce our matrix. As a result, for some inventive principles that appear more frequently, it is clear that their taking into consideration produces a high success rate for solving innovative design problems.

For each theme of eco-efficiency, one puts to notice the most frequent figure and one gives the number of occurrences along the column.

The stages of the eco-design process are shown schematically in Figure 2.

V. APPLICATION

As an application of the TRIZ-matrix combination tool we tested it while monitoring students working to solve an eco-design problem of a product presented by a company.

The combined tool was used as a methodological framework to help the team to move towards an eco-innovative product.

The grading system at the base of the matrix allows the design team to:

- have an idea about the eco-design of the product under evaluation.
- compare the designs of the products of substitution and identify areas where design changes are more required from an environmental point of view.

The score of this matrix should be part of the overall assessment of the product and be used as an input in the choice right from the beginning of the design of the product.

The most favorable case is one for which the sum of all the cells is equal to 100 (the first line is considered as a preliminary step for the company).

VI. RESULTS

A. Step 1 The qualitative assessment matrix

From the results of the survey in response to the questionnaire that was made available, we obtained the results shown in Table 4.

B. Step 2 Prioritization of environmental issues

The results obtained are given in the following histogram (figure 3) and with representation on a 3D surface (figure 4)

Figure 2. Flowchart of the eco-innovative design process

TABLE 4. EVALUATION SCALE OBTAINED

Life cycle	Materials	Energy	Discharges	Comfort factors	Adaptation to eco-design	Total
Manufacturing	2	2	3	5	4	16
Transport and packaging	3	2	2	4	3	14
Use	4	3	4	5	4	20
End of life	3	4	3	3	4	17
Total						∑67

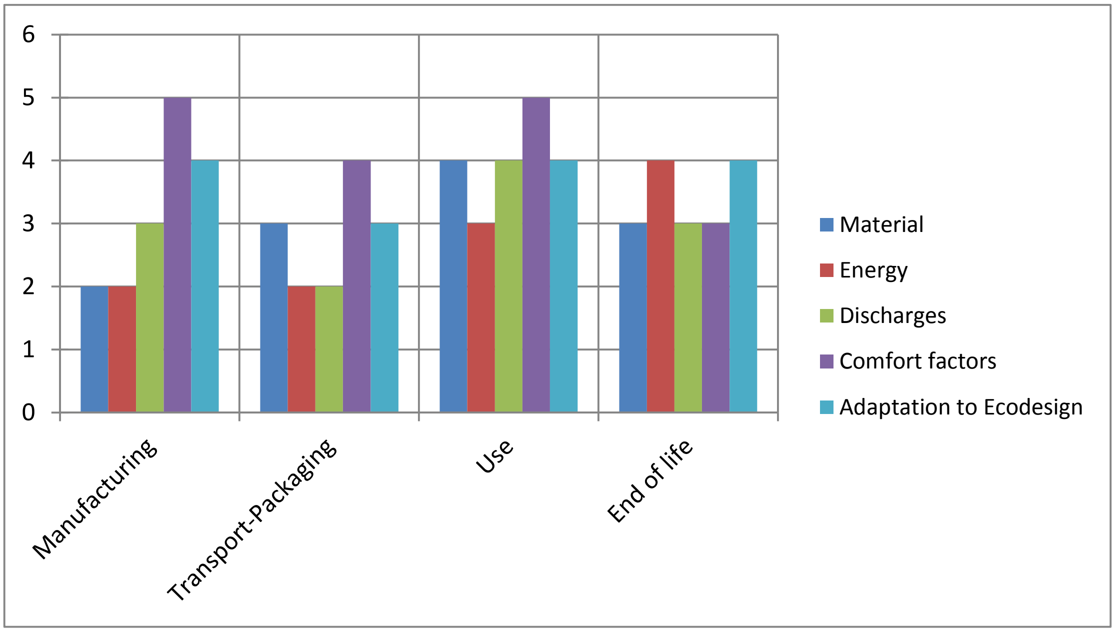

Figure 3. Results of the prioritization of environmental issues

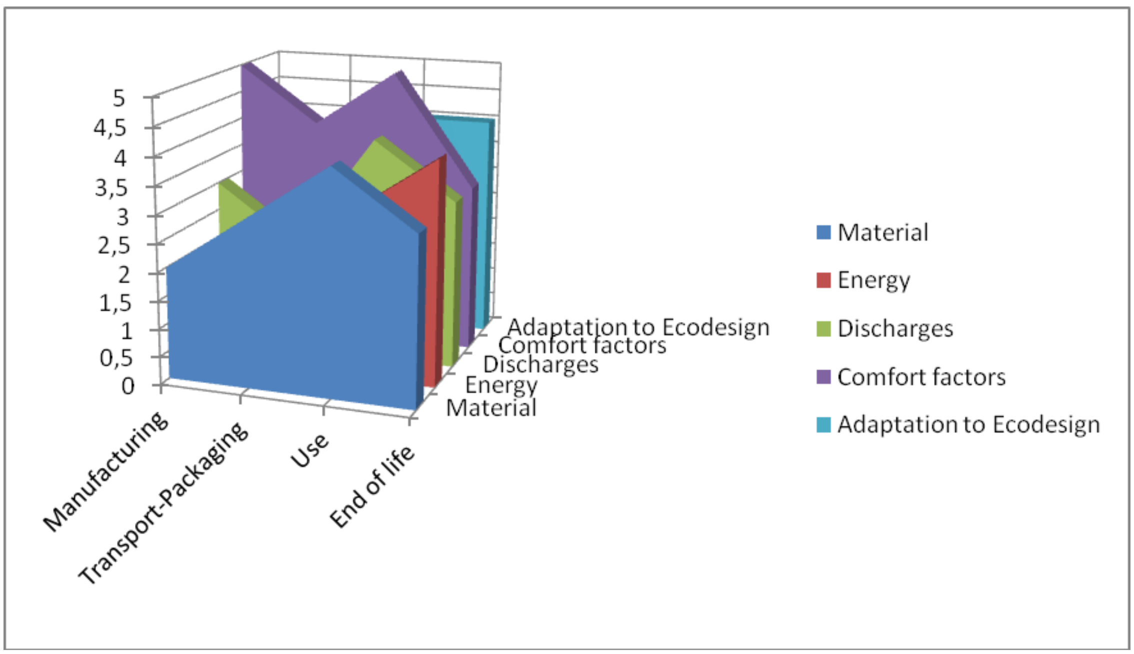

Figure 4. Representation of the results on a 3D surface

Following the results given on the matrix the eco-designer will pay attention to all efficiency parameters, it will guided to opere at the stage that has the most impact. According to the terminology used in table 5 and in order to guide the ecodesigner, we built the matrix given in table 6.

TABLE 5 . TERMINOLOGY USED FOR ECODESIGNER

Position	Abreviation	Level of intervention
Strongly positive	++	Very low
Positive	+	Low
Negative	_	High
Strongly negative	_ _	Very high

TABLE 6 . MATRIX

Ecoefficiency Parameter	Materials	Energy	Discharges	Comfort factors	Adaptation to Ecodesign
Manufacturing	_ _	_ _	_	++	+
Packaging and Transport	_	_ _	_ _	+	_
Use	+	_	+	++	+
End of life	_	+	_	_	+

C. Step 3

According to the steps described in Table 2, the designer will make the choice of the most relevant eco-efficiency parameters, consistent with the frequency of occurrence of each parameter. The choice of the corresponding inventive principles will be made from the engineering parameters.

The following table gives the relationship between the elements of eco-efficiency and the parameters chosen in relation to the elements of the TRIZ matrix.

TABLE 7. SINGLE ENGINEERING PARAMETER AND INVENTIVE PRINCIPLES (IN ITALICS NUMBER OF INVENTIVE PRINCIPLES)

	Ecoefficiency parameters / Parameters Engineering	A (23)	B (19)	C (31)	D (33)	E (24,25)
1	Weight of moving object	5,35,3,31,18	35,12,34,31	22,35,31,39	35,3,2,24	10,24,35,20,28
2	Weight of non-moving object	5,8,13,30		35,22,1,39	6,13,1,32	10,15,35,26
3	Length of moving object	4,29,23,10	8,35,24	17,15	15,29,35,4	1,24,15,2,29
4	Lengh of no moving object	10,28,24,35			2,25	24,26,30,29,14
5	Area of moving object	10,35,2,39	19,32	17,2,18,39	15,17,13,16	30,26,4
6	Area of no moving object	10,14,18,39		22,1,40	16,4	30,16,10,35,4,18
7	Volume of moving object	36,39,34,10	35	17,2,40,1	15,13,30,12	2,22,34,10
8	Volume of no moving object	10,39,35,34		30,18,35,4		35,16,32,18
9	Speed	10,13,28,38	8,15,35,38	2,24,35,21	32,28,13,12	13,26
10	Force	8,35,40,5	19,17,10	13,3,36,24	1,28,3,25	10,37,36
11	Tension/Pressure	10,36,3,37	14,24,10,37	2,33,27,18		37,36,4
12	Schape	35,29,3,5	2,6,34,14	35,1	32,15,26	14,10,34,17
13	Stability of object	2,14,30,40	13,19	35,40,27,39	32,35,30	35,27
14	Strength	35,28,31,40	19,35,10	15,35,22,2	32,40,25,2	29,3,28,10
15	Durability of moving object	28,27,3,18	28,6,35,18	21,39,16,22	12,27	10,20,28,18
16	Durability of no moving object	27,16,18,38		22	1	10,28,16,20
17	Temperature	21,36,29,31	19,15,3,17	22,2,35,24	26,27	35,28,21,18
18	Brightness	13,1	32,1,19	35,19,32,39	28,26,19	1,6,19,28,17
19	Energy spent by moving object	35,28,18,5		2,35,6	19,35	35,38,19,18
20	Energy spent by no moving object	28,27,18,31		19,22,18		
21	Power	28,27,18,38	16,6,19,37	2,35,18	26,35,10	10,19,35,20,6
22	Waste of energy	35,27,2,37	35,18,24,5	21,35,2,22	35,32,1	19,10,18,32,7
23	Waste of substance			10,1,34,29	32,28,2,24	15,18,35,10
24	Loss of information			10,21,22	27,22	24,26,28,32
25	Waste of time	35,10,18,39	35,38,19,18	35,22,18,39	4,28,10,34	24,26,28,32
26	Amount of substance	6,3,10,24	34,29,16,18	3,35,40,39	35,29,27,10	24,28,35,38,18,16
27	Reliability	10,35,29,39	21,11,27,19	35,2,40,26	27,17,40	34,30,4
28	Accuracy of measurement	10,16,31,28	3,6,32	3,33,39,10	1,13,17,34	24,34,28,32
29	Accuracy of manufacture	35,31,10,24	32,2	4,17,34,26	1,32,35,23	32,26,28,18
30	Harmful factors acting on object	33,22,19,40	1,24,6,27		2,25,28,39	22,10,2,35,18,34
31	Harmful side effects	10,1,34	2,35,6			10,21,29,1,22
32	Manufacturability	15,34,33	28,26,27,1		2,5,13,16	32,24,18,16,35,28,4
33	Convenience of use	28,32,2,24	1,13,24			4,10,27,22,28,34
34	Repairability	2,35,34,27	15,1,28,16		1,12,26,15	32,1,10,25
35	Adaptability	15,10,2,13	19,35,29,13		15,34,1,16	35,28
36	Complexity of device	35,10,28,29	27,2,29,28	19,1	27,9,26,24	6,29
37	Complexity of control	1,18,10,24	35,38	2,21	2,5	35,33,27,22,18,28,32
38	Level of Automation	35,10,18,5	2,32,13	2	1,12,34,3	35,33,24,28,30
39	Productivity	28,10,35,23	35,10,38,19	35,22,18,39	1,28,7,10	13,15,23

TABLE 8. CORRESPONDING INVENTIVE PRINCIPLES

Elements of ecoefficiency	Number of the parameters	Engineering parameter	Inventive principles
A.Reduce Material Intensity	23	Waste of substance	*10,1,34,29,32,28,2,24,15,18,35*
B.Reduce Energy Intensity	19	Energy spent by moving object	*28,18,5,2,35,6,38,19*
C.Reduce Discharges	31	Harmful side effects	*34,2,35,6,10,21,29,1,22*
D.Comfort Factors	33	Convenience of use	*32,2,24,1,13,4,10,27,22,28,34*
E.Appropriation of ecodesign	24	Loss of information	21,27,22,24,28,32
	25	Waste of time	10,39,38,19 35,18,4,34,26

TABLE 9. NUMBER INVENTIVE PRINCIPLE RESULTS

Number inventive principle	Description (level 1)	Description (level 2)	Choosen principle
35	Modification of parameter	1. Modify the physical nature of an object (ex : in a gas, liquid or solid state) 2. Change the concentration or the consistency. 3. Modify the degree of flexibility. 4. Modify the temperature.	1.Modify the physical nature of an object (Ex: in washing machines design problem is to change the physical state of water. Therefore, the washing machines may fill with micro air bubble during washing clothes processes.
2	Extraction	Separate part of the object (or property) or disruptive, however, extract only a part (or property) required.	Ex:the noisy part of a washing machine can be removed and placed outside for better comfort canal of the user.
10	Preliminary action	1. Realise in advance (entirely or partially) a change required later-on. 2. Preposition ideally the objects in such a manner that they activate efficiently and without wasting time	Urgent implementation of ecodesign

To these factors of eco-efficiency will be associated engineering parameters that correspond to the inventive principles.

The designer can find corresponding inventive principles from Table 7**.** The inventive principles obtained by proposed method are shown in Table 8.

The inventive principles to remember arise from the frequency of repetition **35** (4 times), **2** (4 times) a **10** (4 times), **28** (3 times), **22** (3 times) and **34** (3 times) in this case. The choice of a section of the description depends on the case study (table 9).

VII. CONCLUSION

The idea of exploiting the results of the qualitative evaluation matrix taking into account the life cycle of the product and, in the case of a multi-criteria analysis, can provide us information on the most relevant eco-efficiency factors which will serve as an important benchmark to complete the study and then direct the user towards a design that respects the environment. In order to solve the problems of allocation of impact factors with respect to the eco-efficiency parameters and the resulting contradictions we have applied TRIZ.

This method is often wrongly considered as a tool allowing to invent new concepts. However, in our case, this tool was used to help the designer to choose among the cases of principles or ideas that best fit the design problem that presents itself to him. The idea of replacing the parameters of contradiction with parameters of eco-efficiency is an approach justified by the analogy that may arise from the numerous contradictions of environmental factors. Thus, the TRIZ-matrix method can be tested. It will, in many cases, allow to trigger a reflection on alternative solutions in situations of conflict, particularly unresolved situations and situations that are beyond the company's framework.

Moreover, it is worth noting that this tool which was developed to be a solving approach cannot explain some design problems which are only determined by a thorough and detailed analysis.

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