

# A TRIZ APPROACH TO DESIGN FOR ENVIRONMENT

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**Abstract:** The purpose of the research carried out was to identify ways in which tools and methodologies from Theory of Inventive Problem-Solving (TRIZ) might be used in Design for Environment (DFE) approaches. The aim was to develop an integrated methodology for environmentally superior product design at the conceptual stage of the product design phase. The paper commences with a review of the TRIZ methodology itself, followed by a discussion of the DFE strategies. A TRIZ approach to DFE is proposed as a new methodology and the paper concludes with a case study using the new TRIZ to DFE approach.

**Key words:** design Process, theory of inventive problem-solving (TRIZ), design for environment (DFE)

## 1. BACKGROUND

In recent times, increasing attention has been given to the design process, both in industry and in research. A number of reasons can be identified for this trend. First, it is recognized that, even if the design process itself had only a minor contribution to the cost of product, a considerable portion of the cost to be made in later product life cycle phases is committed at the design stage. Furthermore, the earlier in the design process the decisions are made the higher the impact is on the final design. Secondly, manufacturers are faced with increasing demands from their customers to increase variety in their product types, reduce costs, increase quality, environmentally superior and compliant products (ESCPs) in reduced time-to-market. Compounding this, the complexity of products has increased and the typical life cycle has reduced, focusing specifically on the environmental aspects of product design.

With the emergence of new global policies (e.g. Integrated Product Policy), emerging legislation (e.g. WEEE and EEE) and environmental standards (e.g. ISO 14000) manufacturers are forced to move towards the development of ESCPs. According to WEEE and EOLV manufacturers are obliged to take responsibility for their waste management by implementing reuse, recycling and recovery for their products. The design of ESCPs (through DFE practices) is a strategy to support compliance with these environmental drivers [1].

Figure 1 shows the interaction between the design process and the life cycle of the product. Life cycle information is acquired through a set of life cycle design information loops, i.e. design for use, design for end of life. The design process transforms this information into product design characteristics, which are in turn embedded in the product.

Four generic and interrelated strategies for the development of ESCPs can be derived from the model as follows [2]:

- a) Select low impact materials and processes over all life cycle phases.
- b) Reduce life cycle resource consumption (Material and Energy).
- c) Reduce life cycle waste stream (Material and Energy).

- d) Resource sustainment by facilitating first life extension and post first life extension, i.e. reuse, remanufacture and recycling.

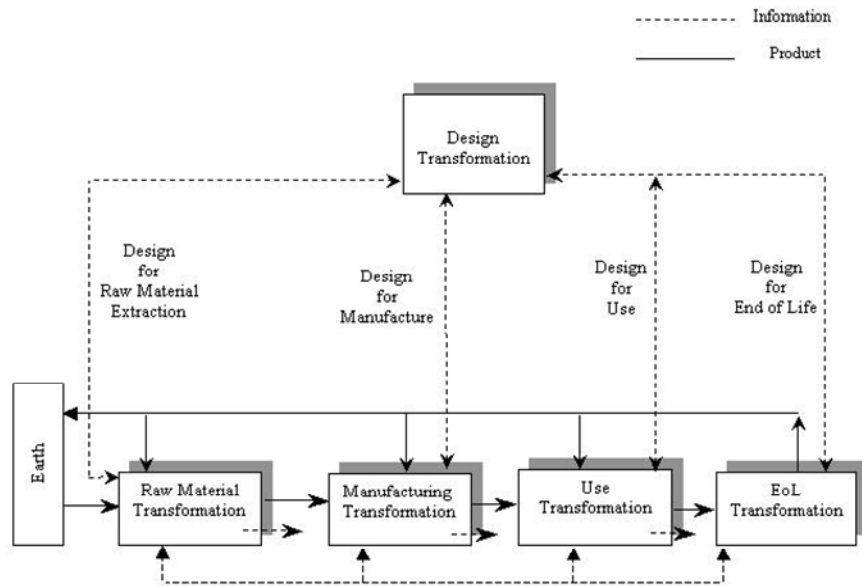


Figure 1. Life Cycle model [2]

There is a need for a new design model to support the development of new methodologies and tools to assist the designer in the creation of ESCPs.

## 2. DESIGN PROCESS METHODOLOGIES FOR DESIGN FOR ENVIRONMENT

Extensive research has been carried out in the Design Process field in the attempt to map DFE tools and methodologies into existing design process models trying to develop new approaches to DFE that are more appropriate for the design engineer.

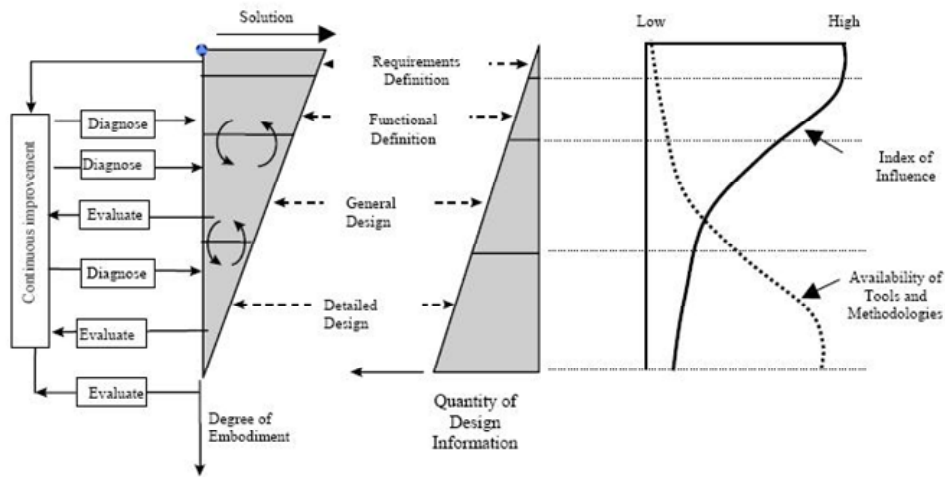


Figure 2. The degree of embodiment of design versus quantity of environmental information [2]

There are many models and classifications of the tasks included in the design stage, but most of the experts agree that the design process must start with collecting information and defining requirements of the product and finishes with a complete and detailed description of the product, as shown in the model presented in figure 1 [2].

The design process can be described by (a) the degree of embodiment and (b) the solution space. The degree of embodiment is described on the vertical axis, i.e. representing the transformation of information through four generic stages of design (requirement definition, functional definition, general design and detailed design) from qualitative to quantitative environmental information. In the early stages of design, the solution space is very large, however as the design evolves this solution space becomes narrower until there is one specific solution, as shown in figure 2. Decisions made in the earlier phases of the design process have the largest influence on the final design.

Compounding this there are few tools and methodologies available and the amount of information on which to make decisions is limited in these early design stages. Therefore the development of powerful methodologies for early stages of design is critical. The development of DFE tools and methodologies that apply to early stages of the design process are likely to be highly effective in supporting the development of ESCPs. The authors perceive that the TRIZ methodology is likely to be highly supportive in the early phases of the design process.

### 3. THEORY OF INVENTIVE PROBLEM-SOLVING (TRIZ)

Theory of Inventive Problem-Solving (TRIZ) is a unique knowledge-based methodology, for accelerated development of design concepts. TRIZ is a creative problem-solving methodology especially tailored for scientific and engineering problems.

The TRIZ philosophy is based on the fact that the evolution of a design is not a random process. It correlates with the evolution of customer needs. Every field of engineering influences the evolution of other fields. Therefore, the process of the design evolution can and has to be studied.

The TRIZ's major discovery was revealing the origin of an inventive problem, which is defined as a "contradiction". A contradiction arises when two mutually exclusive design requirements are put on the same object or system. When a designer faces a contradiction that cannot be solved by redesigning a technical system in a known way, this means that he faces the inventive problem, and its solution principle resides outside the domain the technical system belongs to. There are two ways to solve problems that contain contradictions: by finding a compromise between two conflicting parameters or by eliminating the contradiction. TRIZ is aimed at solving problems by eliminating the contradictions.

The main difference between the TRIZ methodology and all other innovative or creative methods is the reduction of ineffective solutions by using a purposeful and systematic procedure and by passing over the psychological inertia barrier. The method of TRIZ is to break the psychological barrier, to abstract the initial problem (see figure 3). This means, generalisation of a specific problem to an analogous problem, comparison of this standard problem with analogous standard solutions well known in other scientific branches and industries and back transfer of this analogous standard solution to a specific solution [3]. As the earlier stages are the most important in the design process and as the TRIZ methodology is focusing on the conceptual design stage, this is the way how TRIZ might provide a systematic support for the following phases of conceptual design [4]:

- Analysis of ill-defined design problems by describing functions between the system components and identification of core problems by formulating contradictions;
- Generation of new solution concepts by using TRIZ problem-solving techniques: inventive principles, inventive standards and pointers to physical effects ;
- Producing a technological forecast (prediction) of a particular design product using TRIZ technology evolution trends (see figure 3).

The most important tools and methods of TRIZ methodology are Contradiction Matrix, 40, Inventive Principles, 39 TRIZ Parameters, ARIZ Algorithm, 76 Standard Solutions, Su-Field analysis, laws and trends of the technology evolution, Separation Principles – to solve physical contradictions, System of Operators, Effects and Anticipatory Failure Determination (AFD) [5].

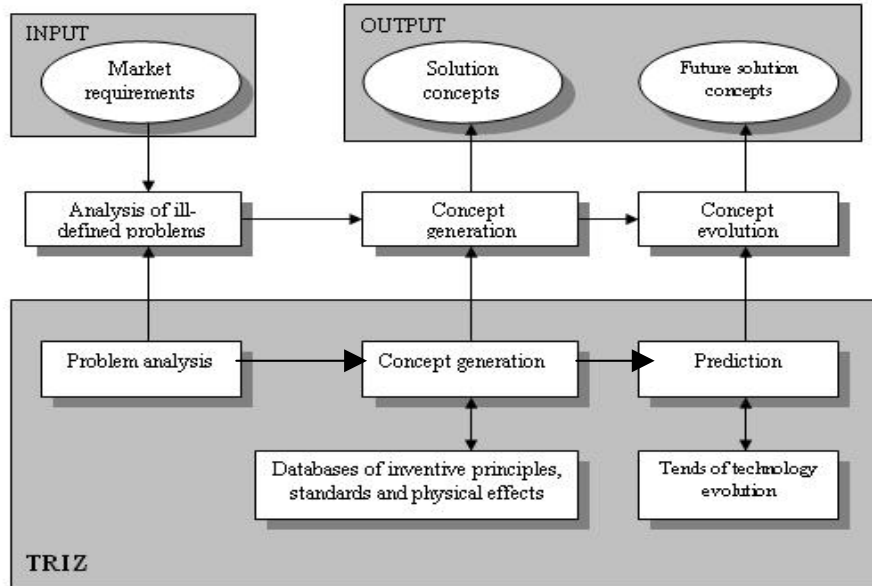


Figure 3. Conceptual design with TRIZ [4]

#### 4. THE NEW METHODOLOGY FOR EARLY STAGES OF THE DESIGN PROCESS APPLYING TRIZ FOR DESIGN FOR ENVIRONMENT

Analysing and applying the TRIZ approach to problem-solving for Design for Environment, TRIZ principles for DFE were obtained, and the authors considered they could be implemented successfully in the early stages of the design process. There were two steps as follows: first, the TRIZ methodology was analysed in an attempt to identify how it can be implemented or adapted to fulfil the DFE strategies, especially focusing on the Inventive Principles of TRIZ.

Table 1. The 40 Inventive Principles TRIZ for DFE [Ser02]

The 40 Inventive Principles of TRIZ for DFE			
1. Segmentation	Adopt	21. Skipping	Eliminate
2. Taking back	Adapt	22. "Blessing in disguise"	Adopt
3. Local quality	Adapt	23. Feed-back	Adopt
4. Asymmetry	Eliminate	24. "Intermediary"	Adopt
5. Merging	Adopt	25. Self-service	Adopt
6. Universality	Adopt	26. Copying	Adapt
7. "Nested doll"	Adopt	27. Cheap short-living objects	Adopt
8. Anti-weight	Adopt	28. Mechanical substitution	Adopt
9. Preliminary anti-action	Adopt	29. Pneumatics and hydraulics	Adopt
10. Preliminary action	Adopt	30. Flexible shells and thin films	Adapt
11. Beforehand cushioning	Eliminate	31. Porous materials	Adopt
12. Equipotentiality	Eliminate	32. Colour changes	Eliminate
13. "The other way round"	Adapt	33. Homogeneity	Adopt
14. Spheroidality	Adopt	34. Discharging and recovering	Adapt
15. Dynamicity	Adopt	35. Parameter changes	Adapt
16. Partial or excessive action	Eliminate	36. Phase transition	Adopt
17. Another dimension	Eliminate	37. Thermal expansion	Adapt
18. Mechanical vibration	Adopt	38. Strong oxidants	Adapt
19. Periodic action	Adopt	39. Inert atmosphere	Adopt
20. Continuity of useful action	Adopt	40. Composite materials	Adapt

A systematic approach for obtaining the TRIZ principles for DFE is presented in Figure 3:

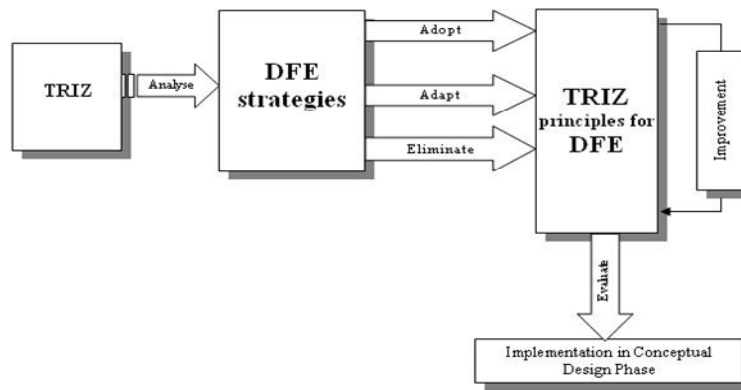


Figure 4. Systematic approach for obtaining the TRIZ principles for DFE[6]

The schematic representation of the proposed methodology for early stages of the design process applying TRIZ for DFE is presented in Figure 4, which shows the schematic way of using the TRIZ methodology for the DFE proposed for this study.

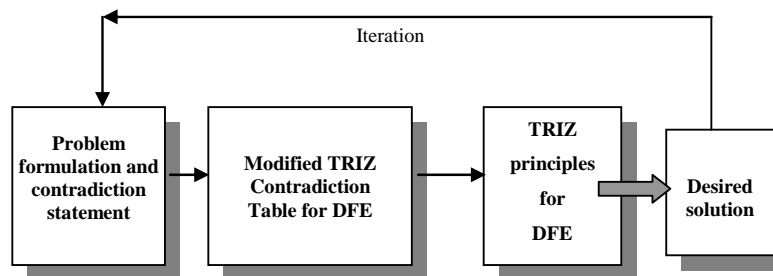


Figure 5. Schematic representation of using the proposed methodology [6]

The algorithm of the new methodology (figure 4) is presented in four steps as follows:

Step 1. Problem formulation and establish contradictions: At this stage an analysis of the problem was made in order to identify the basic functions of the system, the sub-systems, super-systems, the environment, useful, unuseful and harmful systems. The technical contradiction (the conflict) ought to be solved when the analysed problem has been established.

Step 2. Establish specific DFE-TRIZ principles using the contradiction TRIZ matrix for DFE: Based on the technical contradiction established in step 1, product characteristics that should be improved are identified. Coupled product characteristics are also identified. The row of the Contradiction Matrix is entered with a product characteristic that it is desired to be improved, and this is intersected with the column of the coupled product characteristic that is producing an undesired result.

Step 3. Establishing generic solutions using TRIZ principles for DFE: The cell in the intersection gives the number of the inventive principles that are suggested as being able to resolve the contradiction.

Step 4. Establishing specific solutions: By obtaining the inventive principles needed, the designer applied them to the product for obtaining the desired solution. Data was then re-synthesised from the (new) model and the process begins again. This continuous improvement process continued by iteration until the best solution was found.

## 5. CASE STUDY

The automotive industry is among the most resource intensive of all major economic system: for example, in USA it represents at least one-third of the consumption of iron, lead, platinum and synthetic and natural rubber.

Resource depletion for automobile includes product component (all the replacement parts: tires, hoses, lights, belts, filters, batteries, etc), process component (fuel, fluids and associated packaging, highway infrastructure), distribution components (packaging associated with replacements parts). But the most serious environmental issue facing the automobile is surely its enormous consumption of non-renewable energy. The most significant impacts on vehicle maintenance are the too often not environmentally friendly. In this last field the principles tier manufacturers are involved in improving the reutilisation of used tires [7].

From all the subassemblies composing a car, the authors decided to apply the proposed methodology on the car rear view mirror. The authors were focusing only on the improvement of the case and the back-can subassemblies of the car-mirror assembly, using the proposed methodology of applying TRIZ for DFE.

The improvement was referred to the virtual prototype design model of the car-mirror assembly, as seen in the figures 6, 7, 8 and 9. The advantage of using virtual prototyping included three dimensional visualisation, as well as the opportunity to extract information from the model for the purposes of evaluation and the use of information to manipulate the model prior to manufacture

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Figure 6. Car-mirror assembly (front view)



Figure 7. Car-mirror assembly (back view)



Figure 8. Case subassembly



Figure 9. Back-can subassembly

In the case of the car-mirror assembly, the fundamental design trade-off may be seen to be one of compromise between a requirement for a performant rear mirror, in order to achieve the best visibility for driver and a recyclable mirror in order to fulfil the environmental requirements, from the manufacturer point of view.

Seeking out the best compromise between the two extremes was not solving the “right” problem. From TRIZ point of view, a physical contradiction results when a physical attribute should be increased to improve one function of the system, and decreased to improve another. Traditionally, trade-offs are used to handle contradictions. But TRIZ always seeks a solution without compromise. The right problem is more likely to be how to achieve a performant mirror and a recyclable one in the same time.

Regarding just the back-can and case subassemblies, it has been identified that they are stuck together using adhesive, which makes them hard to separate for recycling, and a solution must be found to join them without using a adhesive. And it has also been identified that they are made from plastic or different polymers. Degradation of plastics is more critical than that of the metals, since it is often difficult to ensure that different types of polymers were not mixed together. Only thermoplastic polymers can be recycled. And often, recycled material is used for a less critical application than its original use. Thermosets, which are degraded by high temperature, cannot be recycled. Composite materials consisting of mixtures of glass and polymer represent a problem in recycling.

In the case of redesigning the car mirror, the problems that should be solved must contain the improvement of the parameters to solve the technical contradiction, therefore two of the TRIZ instruments were selected: the Contradiction Matrix and the 40 inventive principles.

Thinking from the final product point of view, expressed in the terms of the Contradiction Matrix, the authors thought that the parameters to be improved for the car-mirror assembly are:

- a) “Stability of the object composition” (parameter 13 from the Contradiction Matrix)
- b) “Quantity of substance/matter” (parameter 26)
- c) “Ease of manufacture” (parameter 32)
- d) “Ease of operation” (parameter 33)

And the parameters that are getting worse when trying to improve the ones above are:

- “Shape” (parameter 12)
- “Strength” (parameter 14).
- “Device complexity” (parameter 36)

The principles extracted from the Contradiction Matrix are presented in table 2. Based on those principles that are actually generic solutions, 28 specific solutions of conceptual design were established among them new ideas for designing for environmental compliance .

All these specific solutions to improve the car mirror assembly can be applied to the virtual prototype design models, without any large cost, just the designer’s knowledge experience and ability to make the changes, when the product is still in conceptual phase.

*Table 2.* Generic Solutions and Specific Solutions for car-mirror assembly

Principle No.	Freq. of appearance	TRIZ Principles	Specific Solutions
0	1	2	3
1	4	SEGMENTATION	1. Provide the mirror easy to disassemble and recycle 2. Avoid embedding and non-dismantling assemblies 3. Avoid adhesives, welding and soldering constructions
10	3	PRELIMINARY ACTION	4. Possibility of mirror adjusting from inner car
26	3	Copying	5. Using virtual prototypes to design the assembly
27	3	CHEAP SHORT-LIVING OBJECTS	#. No ideas;
28	3	MECHANICS SUBSTITUTION	6. Instead of painted labels use inscriptions 7. Replace manual adjustment system with electrical/electromagnetic system
35	3	PARAMETER CHANGES	8. Internal heating of the mirror against steaming to permit the hot air to enter through the acclimatization system of the car
13	2	THE OTHER WAY ROUND	#. No ideas;

0	1	2	3
14	2	SPHEROIDALITY - CURVATURE	9. Make aerodynamic shape of the back can; 10. Use spherical hinge for position's adjustment; 11. Use partially spherical shape glass in order to obtain a bigger image;
15	2	DYNAMICS	12. Make a position system easy to adjust from the inside of the car; 13. Make folding system to protect the mirror during the parking; 14. Make a system that "memories" the initial position after folding and brings it back to the "memorized" position;
22	2	"BLESSING IN DISGUISE" OR "TURN LEMONS INTO LEMONADE"	#. No ideas;
34	2	DISCARDING AND RECOVERING	15. The possibility of rapidly ejection of the glass for replacing without disassembling the entire mirror from the car; 16. Dismounting assembly between the housing and the back body using elastic elements;
2	1	TAKING OUT	17. Elimination of the screws for assembly and use snap fits and spring clips for easy disassembling; 18. Minimise the quantity of material used and the number of components; 19. Minimise the number of materials used to manufacture the product; 20. Elimination of the non-recyclable or non biodegradable materials; 21. Choose compatible materials that don't need separation before recycling (ex. Use on single type of plastic); 22. Elimination of the adhesives, paints, inks and labels that can harm the environment during recycling and increase recycling cost 23. Use integrated labels (material inscriptions made by molding injection) instead of painted labels 24. Avoid thermoset materials and use thermoplast materials that are recyclable
3	1	LOCAL QUALITY	25. Against steaming, the fixing system shape should allowed the access of the hot air through the acclimatization system inside the mirror during the cold seasons
9	1	PRELIMINARY ANTI- ACTION	26. Use pre-strained spring to self adjust the mirror in case of accidental disturbing
18	1	MECHANICAL VIBRATION	#. No ideas;
29	1	PNEUMATICS AND HYDRAULICS	27. Replace manual operation system with hydraulic or electrohydraulic operating system 28. Use hydraulic mini-damper to self adjust the mirror in case of accidental disturbing
40	1	COMPOSITE MATERIALS	#. No ideas;

## 6. CONCLUSIONS

TRIZ is a logical, knowledge-based methodology for early stages of the design process. Guided by TRIZ, users not only overcome the psychological barrier but they also have the opportunity to analyse the best direction for improvement of products. The integration of TRIZ methodology into Design for Environment help the designers to maximise the utilisation of the resources of a system to meet the objectives of a new product development with less cost and without any unwanted effects.

The application of traditional TRIZ accelerates the search for breakthrough solutions and gives users the ability to reach greater levels of product performance. This is expected also from TRIZ methodology for DFE, in order the products to fulfil the environmental requirements even from conceptual design stage, because TRIZ users have demonstrated a strategic advantage in **NEW** product development.

The results of the research carried out were materialized in the development of a new methodology for applying TRIZ for DFE, by adapting one of the most useful tools of TRIZ - the Inventive Principles, for Design for Environment. The results of the proposed methodology of TRIZ for DFE were also shown by the case study performed.

## **7. FURTHER WORK**

The proposed methodology does not represent a ready-to-use methodology by the designers. The aim of the research was to present a proposal and to prove the viability of the idea. The proposal for the methodology has been done in a simple manner, graphically, to facilitate the understanding of the TRIZ methodology for Design for Environment. But high-level performance methodologies applying TRIZ for Design for Environment can be developed using Computer-aided TRIZ and CAD/CAM software. As further work, the aspect of integrating the TRIZ for DFE methodology with the DFE Workbench may be looked at.

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