

Improving Environmental Design Using TRIZ Inventive Principles

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Abstract

This paper describes design principles that were extracted from the profiles of products redesigned to be more environmentally benign. These extracted principles will be used to support the work of creating a Design for Environment (DfE) methodology called ENVRIZ that provides product designers with a procedure for creating more environmentally benign products and overcoming environmental contradictions. The framework for ENVRIZ exists in the Theory of Inventive Problem Solving (TRIZ). ENVRIZ will provide designers with a method for overcoming conflicts between improving environmental objectives and increasing product usefulness.

Keywords:

Design Methodologies, Design for Environment, TRIZ

1 INTRODUCTION

Today, product development organizations are facing pressures to become more environmentally responsible. Issues such as “the fossil fuel supply, global warming, depletion of the ozone layer, misdistribution of water use, and the loss of forest have been described by some as ‘extinction-level’ crises” [1]. Up to this point, environmental concerns within most organizations have been monitored using typical “manufacturing” metrics such as air emissions metrics, water emission metrics, and total land-filled waste. Consequently, much of the work to improve these end-of-the-production-line metrics are “patch jobs” such as adding filters to smokestacks. This is like inspecting quality into a product, an inefficient strategy that produces favorable results in the short-term but does not discover and fix root causes that compromise product quality. Instead, engineers should be designing products and processes whose manufacturing or operation naturally reduces air emissions.

As responsible members of society, product development organizations must incorporate the idea of sustainability into both engineering and manufacturing processes. When the benefits of being socially responsible are not enough to shape behavior, countries impose restrictions on materials

and processes to limit the amount of environmental damage an organization can commit. The current regulatory situation reflects the need to influence manufacturers through penalties. Developing the first generation of products contributing to a sustainable world requires identifying a new set of business strategies and design and manufacturing tactics. Products for a sustainable way of life may be an unrealistic objective for green engineering practice today, but there exist many benefits to moving in this direction. Studies demonstrate the greatest opportunity for Environmentally Responsible Product Development occurs during the product design phases, specifically the early design phases [2-6]. Therefore, designers need to learn design principles and practices focused on the early design phases that will ultimately lead to sustainable products.

The Theory of Solving Inventive Problems (TRIZ) [7-10] was developed by Genrich Altshuller, a Russian-born patent examiner. During his experience in the Soviet Navy, he helped many inventors not only apply for patents but also solve problems as well. His line of work led to him to question the accepted fact that inventing was a random act and ideas just came easier to some people. Altshuller believed there had to be a systematic process for inventing that could be documented and taught to inventors. Instead

of randomly searching the design space for a solution to a problem, inventors needed a methodology that directed them to the solution. Altshuller and his associates studied over 1.5 million patents and determined that over 90% of engineering problems they addressed had been previously solved. By studying the patents that represented original solutions to problems, Altshuller's team was able to define inventive principles and processes used within different industries. The results of their study yielded foundations and tools for solving technical problems of varying complexities, which is known as TRIZ.

Section 2 of this paper explains a conceptual law that designers can use to create more environmentally benign products. Section 3 provides examples of TRIZ design principles extracted from the profiles of products redesigned to be more environmentally benign. Section 4 explains how this work will be incorporated into creating a DfE methodology titled ENVRIZ. Section 5 concludes the paper.

2 CREATING MORE ENVIRONMENTALLY BENIGN PRODUCTS

A major goal of many organizations is increasing their market share of a particular product or family of products. In order to achieve this goal, organizations are constantly redesigning their products to keep up with their competitors. During the redesigns, organizations are interested in increasing the "usefulness" of their products. The term usefulness includes all valuable results of the product's function such as specific features, ergonomics, and capacity. Within these redesigns it is also desirable to reduce the harmful effects of a product. Examples of harmful effects include cost, energy use, safety hazards, and pollution. Within TRIZ, the idea of increasing useful effects and decreasing harmful effects is captured within the law of ideality. The law of ideality states that "technical systems evolve toward increasing degrees of ideality, where ideality is defined as the quotient of the sum of the system's useful effects, U_i , divided by the sum of its harmful effects, H_j " [7].

$$Ideality = \frac{\sum U_i}{\sum H_j} \quad (1)$$

Typically, an improvement in the usefulness of a product results in an increase in the harmful effects, and the design team is forced to make a trade-off. When a trade-off is made, the ideality does not increase, and the technical system does not evolve. Using techniques found in TRIZ helps increase the ideality of a technical system by resolving design contradictions. The ideal final result would be a product that provides the useful benefit but does not exist itself.

Some organizations have also adopted this idea of ideality as a way of measuring environmental improvements in their products. Two examples of organizations that have done this are Matsushita and Toshiba [11,12]. Both of these organizations have adopted a version of Factor X, which was developed using terms coined by both the Wuppertal Institute for Climate, Environment and Energy (Factor) and

The World Business Council for Sustainable Development (Eco-Efficiency). "Factor X indicates the levels of affluence and environmental impact using the improvement scale of the Eco-efficiency" [11]. It was first advocated in the late 1990s and "has been drawing public attention as a reliable tool for evaluating the technical progress of products and services from an environmental perspective" [11].

Matsushita uses an equation where Factor X is equal to the improvement in "Quality of Life" divided by the reduction in "Environmental Impact." Toshiba calculates the eco-efficiency of a product as its value divided by its environment impact. They then calculate a product's Factor T as its eco-efficiency divided by the eco-efficiency of the benchmark product. While the specific values they use for calculations are different, these two firms have both adopted the idea that a product can be made more environmentally benign by increasing its usefulness, decreasing its harmful effects, or both. Since most decisions to redesign a product are based on increasing the usefulness of a product, it would be beneficial for designers to have a tool to help them reduce or at the very least maintain the environmental impact level. This tool would assist in resolving the typical contradiction of harmful effects increasing as product usefulness increases. In the next section, we will examine the TRIZ principles used to create more environmentally benign products.

3 TRIZ PRINCIPLES USED IN CREATING MORE ENVIRONMENTALLY BENIGN PRODUCTS

Many organizations showcase environmentally benign advancements in products to show that they are responsible members of society. In this section, we will examine products designed by Matsushita and Toshiba and extract TRIZ principles they have unknowingly used to increase product usefulness and decrease environmental impact.

3.1 Toshiba's GR-NF415GX Refrigerator

The Toshiba GR-NF415GX is an excellent example of a more environmentally benign product because it won the 2003 Grand Prize for Energy Conservation. In addition, this product example provides more insight than most because Takehisa Okamoto, an engineer who designed the refrigerator, participated in an interview discussing the design of the product [13]. Takeshisa describes the problem with previous refrigerators in this excerpt:

To review the mechanics of earlier refrigerators, previously both the refrigerator and freezer sections were cooled by a single cooling unit. Since the refrigerator section didn't require as much cooling as the freezer section, it tended to be over-cooled. To prevent this, a damper was attached to open and close vents automatically. This would close the vents when it got too cold and open them when it got too warm. However, in the area near the vents where the cold air came out, eggs would sometimes get too cold or tofu would sometimes freeze.

Takeshisa then describes the solution to the problem and advantages of the new refrigerator in these excerpts:

Then the twin cooling unit refrigerator was developed. This involved two cooling units—one in the refrigerator section and one in the freezer section—using a single compressor. This system alternates between cooling the refrigerator and cooling the freezer, which allows each section to be cooled to a more suitable temperature. While the freezer's being cooled, the frost that accumulates on the cooling unit in the refrigerator section, where coolant isn't flowing, is melted once again and returned to the refrigerator section using a fan for humidification. This prevented drying, so that cheese and ham wouldn't lose all their moisture.

The technology makes it possible to cool the refrigerator and freezer sections simultaneously and to maintain two temperatures, with a major difference in temperatures between the temperatures of the refrigerator cooling unit (-3.5°C) and the freezer cooling unit (-24°C). Now, the refrigerator section is cooled by -2°C air to maintain a temperature of 1°C. This technology uses an ultra-low-energy freeze cycle that makes it possible to cool using cold air at temperatures close to the ideal temperature for the food.

Since this is the first technology of this kind in the industry, some aspects were definitely difficult. At the same time, I think this innovation was really the key point of this development. The two-stage compressor distributes coolant compressed in two stages in two directions: to the refrigerator side and to the freezer side. For this reason, the flows of coolant to each cooling unit must be adjusted to ensure optimal flow. We achieved efficient simultaneous cooling using a pulse motor valve (PMV).

From this dialogue, one can see that there is an improvement in freshness of the food due to the accuracy of the air temperature being output into the refrigeration section. This innovation also conserves electricity because of the ultra-low-energy freeze cycle. In addition, a typical engineering solution to this problem would require two compressors to achieve the final result, while this product only required one. TRIZ principles that can be found in the design of this product are Principle #1: Segmentation and Principle #19: Periodic Action. Segmentation can be achieved by (a) dividing an object into independent parts, (b) making an object sectional, or (c) increasing the degree of the object's segmentation [10]. Segmentation was accomplished in this product by segmenting the cooling units; one in the refrigerator section and one in the freezer section. Periodic Action can be achieved by (a) replacing a continuous action with a periodic one, (b) if the action is already periodic, changing the frequency, or (c) use pauses between impulses to provide additional action [10]. Periodic

Action was accomplished in this product by using a pulse motor valve.

3.2 Matsushita Alkaline Ion Water Purifier

The Matsushita PJ-A40MRA Alkaline ion water purifier [14] has increased functionality and decreased environmental impact compared to the TK7505 Alkaline ion water purifier. The new water purifier increases functionality by allowing the user to select seven kinds of water quality as opposed to five. The new purifier also decreases environmental impact by reducing standby power from 6 Watts to 0.7 Watts through division of the integrated power source into two separate power sources for operation and standby. TRIZ principles that can be found in the design of this product are Principle #15: Dynamicity and Principle #1: Segmentation. Dynamicity can be achieved by (a) altering characteristics of an object or outside environment to provide optimal performance at each stage of an operation, (b) making an object mobile if it is immobile, or (c) dividing an object into elements capable of changing their position relative to each other [10]. Dynamicity was accomplished in this product by allowing seven different kinds of water quality based on what the user needs in a particular situation. Segmentation was accomplished through the division of the integrated power supply into two separate power sources for operation and standby.

4 APPLICABILITY TO THE DFE METHODOLOGY ENVRIZ

Many researchers acknowledge the strengths of the TRIZ approach to improving design and have experimented with adaptations of TRIZ [15-17]. Liu and Chen [15] developed a green innovation design method using the established TRIZ inventive principles and parameters. Chang and Chen [16] present an eco-innovative example product for each of the 40 TRIZ inventive principles. This research can be taken further to determine the contradictions that needed to be resolved before applying the TRIZ principle. Low *et al.* [17] explore the applicability and adaptation of TRIZ to an eco-centered service solution.

Extracting TRIZ principles from examples of more environmentally benign products will be beneficial in helping to create a contradiction table for ENVRIZ. Within TRIZ, the contradiction table is the most popular tool. The contradiction table consists of engineering parameters and design principles. An engineering parameter is a feature of a problem that can worsen or improve such as weight of a moving object, temperature, or reliability. A design principle such as segmentation or dynamicity is a technique that has been used for solving a contradiction between certain parameters. There are 39 engineering parameters, and they are the headings on the top and left side of the table. The intersection of two parameters within the matrix lists one or more numbers corresponding to the 40 TRIZ principles. The list of principles, which was created by Altshuller and his associates, has an explanation of each principle and examples of how the principle was implemented in other

inventions. They also created the table by studying numerous patents and determining the design principles that were frequently used in overcoming the specific contradictions.

ENVRIZ will use a contradiction table that has useful effects designers are looking to achieve on the top side of the table and environment impacts designers are looking to reduce on the left side. Examples of useful effects and harmful effects can be found in our products from section 3. The useful effect being improved from the refrigerator example would be increasing the accuracy of the output and the harmful effect being decreased would be energy use. For the water purifier, the useful effect being improved is the adaptability of the product and the harmful effect being decreased is energy use. The center of the table will consist of the TRIZ principles found to overcome these contradictions. A future task will be identifying more useful effects and environment impacts in terms general enough to apply to a variety of products, but specific enough to provide useful insight for designers. As more products are examined, a database will be maintained to track which principles assist in overcoming which contradictions. The principles that appear the most in solving a particular contradiction will be used within the ENVRIZ contradiction table. Also, a new principle list will be created containing environmental examples. The final result will be a useful tool that designers can use to help them create more environmentally benign products.

5 CONCLUSION

As responsible members of society, product development organizations must incorporate the idea of sustainability into not only their manufacturing processes but also their design process. Organizations such as Matsushita and Toshiba have taken the first step by incorporating an environmental metric into their product development process. The idea of increasing eco-efficiency by improving useful effects and decreasing environmental impact is an excellent idea that corresponds to the Law of Ideality contained within TRIZ. Through researching products that have become more environmentally benign and extracting the TRIZ principles used to overcome the design contradictions, it is possible to create a tool that can assist engineers in creating more environmentally benign products in the future.

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