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AN ECO-INNOVATIVE DESIGN METHOD BY GREEN QFD AND TRIZ TOOLS

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Abstract

This paper presents an eco-innovative design method of products by constructing the relationship among the elements of eco-efficiency, the elements of green QFD table, and the TRIZ engineering parameters. This new method can be used as a supporting tool for designers to invent novel, useful, and environmentally friendly products.

Keywords: Sustainable Design, Eco Design, Eco-Innovation, Quality Function Deployment (QFD), TRIZ

1 Introduction

The development of technology plays a crucial role in modern economic growth, but it also is the key factor of environmental crisis. It usually emphasizes the novelty and economic usefulness of an innovation product but neglects its environmental impact. Currently, many green design methods [1-2] have been developed to support the designer for reducing the environmental impact of the product throughout its life cycle. However, those methods are focused on the redesign or optimization of existing products. Therefore, there is a need to develop a product green innovation design method for this situation. The ideas of using TRIZ method [3-4], which was developed in the former Soviet Union by Altshuller, who had analysis over 400,000 patents to build 40 inventive principles and contradiction matrix tool, for eco-innovative design tasks have been proposed [5-7].

The green quality function deployment (QFD) [8] approach was selected in this new method to acquire the voice of customer in sustainable products. By combing the green QFD table, seven elements of eco-efficiency, and TRIZ parameters, a design table for finding suitable TRIZ parameter from the voice of customer is constructed. Details of framework of this new method are presented. An eco-design case is demonstrated in this paper to show the effectiveness of the eco-innovative design method.

2 Design tools

For developing an eco-innovative design method to design environmentally and customer friendly products, several design tools, such as eco-efficiency, green QFD, and TRIZ, are chosen and integrated together in developing this new method, and it can be explained by the Table 1. The vertical axis of Table 1 shows TRIZ 39 engineering parameters. The horizontal axis represents the elements of eco-efficiency and green QFD. Details of each design tool will be illustrated in the following sections.

Table 1. The relationship table of green QFD, eco-efficiency, and engineering parameters.

Green QFD Elements / TRIZ Engineering Parameters		Elements of Eco-efficiency								Customer Requirement\Quality\Function										Importance
		A	B	C	D	E	F	G		a	b	c	d	e	f					
Geometry	3 Length of M	◎	◎							◎										
	4 Length of non-M	◎								◎										
	5 Area of M	◎	◎							◎										
	6 Area of non-M	◎								◎										
	7 Volume of M	◎	◎							◎										
	8 Volume of non-M	◎								◎										
	12 Shape	◎								◎										
Physics	1 Weight of M	◎	◎								◎									
	2 Weight of non-M	◎									◎									
	9 Speed				◎			◎			◎									
	10 Force				◎						◎									
	11 Tension/pressure				◎						◎									
	17 Temperature		◎								◎									
	18 Brightness		◎								◎									
	21 Power		◎								◎									
Resources	19 Energy spent by M		◎									◎								
	20 Energy spent by non-M		◎									◎								
	22 Waste of energy		◎									◎								
	23 Waste of substance	◎		◎								◎								
	24 Loss of information							◎				◎								
	25 Waste of time							◎				◎								
	26 Amount of substance	◎		◎								◎								
Capabilities	13 Stability of object			◎			◎						◎							
	14 Strength	◎				◎	◎						◎							
	15 Durability of M						◎						◎							
	16 Durability of non-M						◎						◎							
	27 Reliability							◎					◎							
	32 Manufacturability	◎	◎		◎								◎							
	34 Repairability												◎							
	35 Adaptability							◎					◎							
	39 Productivity	◎	◎					◎					◎							
Harm	30 Harmful factors acting on object					◎	◎							◎						
	31 Harmful side effects			◎										◎						
Control	28 Accuracy of measurement			◎	◎										◎					
	29 Accuracy of manufacture				◎										◎					
	33 Convenience of use							◎							◎					
	36 Complexity of device				◎										◎					
	37 Complexity of control							◎							◎					
	38 Level of automation				◎			◎							◎					
Importance																				

Note：M=moving object

2.1 Green design and eco-efficiency

WBCSD has pointed out seven major elements for a company in considering the eco-efficiency of developing environmental friendly products or processes to reduce environmental impacts.

A. Reduce the material intensity of its goods and services
B. Reduce the energy intensity of its goods and services
C. Reduce the dispersion of any toxic materials
D. Enhance the recyclability of its materials
E. Maximize the sustainable use of renewable resources
F. Extend the durability of its products
G. Increase the service intensity of its goods and service.

As each element improves or more elements improve simultaneously, it produces high eco-efficiency products or services.

First of all, the relationship of each element of eco-efficiency with the 39 engineering parameters of TRIZ method is examined. For example, reducing a product's "material intensity", that can be achieved by changing it's properties, such as weight, dimensions, shape or the amount of material used. Next, reflecting these properties to closely related engineering parameters of TRIZ. Therefore, the problem of improving eco-efficiency is transferred to TRIZ problem. Part of Table 1 illustrates the relationship between all elements of eco-efficiency and 39 engineering parameters of TRIZ method. For designers convenience, the 39 engineering parameters are put into Table 1 and categorized into six groups: geometry, physics, resources, capabilities, harm and control. The left part of horizontal axis (eco-efficiency) in Table 1 is divided into the seven major elements of eco-efficiency as mention in previous paragraph. In Table 1 there is a symbol "◎" which shows there is an interrelationship between the elements of eco-efficiency, customer requirements, quality, or function and the corresponding engineering parameter.

2.2 Green QFD

When designers try to improve product quality or develop new products, if they understand beforehand the customers' requirements then they can improve efficiency or develop products suitable for the market. Normally a customer expresses his requirements abstractly, which must then be changed into technical or design language in order for the designers to design and produce market-friendly products. Quality Function Deployment (QFD) method can transform customers' requirements into product quality, and consequently the function of each product, by calculating the most necessary improvements to quality or product functions. Green QFD method integrated environmental factors with customer requirements into QFD table. In this method, the elements of eco-efficiency are chosen as environmental factors to form green QFD.

The right part of horizontal axis (customer requirements/quality/function) in Table 1 shows customer requirements from QFD table to quality and product functions and also categorized into six groups each corresponding with appropriate 39 engineering parameters.

2.3 TRIZ

When a design engineer tries to solve an innovative design problem, it is usually a system incompatibility or conflict design problem. As the designer changes certain parameters of the system in his design problem, it might affect other parameters badly. Traditionally, the design engineer compromises with this kind of contradiction situations and restricts him on performing innovative design tasks. The TRIZ method [3-4] is an available tool for the designer to handle these conflict conditions during the innovative design problem solving process. The TRIZ method was developed in the former Soviet Union by Altshuller, who had analysis over 400,000 patents to build the contradiction table and 40 inventive principles [3-4]. For using TRIZ method in the innovative design problem solving, the designer needs to first find the corresponding contradictions for his problem at hand. Next, the designer matches the meaning of each contradiction with two appropriate parameters from 39 engineering parameters that have been defined in the TRIZ contradiction table. The designer can find the 3-4 most frequently used principles for solving engineering innovative design problem from the contradiction table when he confirms the parameters of contradiction for an engineering system.

However, in using QFD table or green QFD table, the designer only knows how to improve one parameter of his design problem, but doesn't know or can't predict the corresponding contradiction parameters of this system. In this case, the contradiction matrix is useless in helping the designer find suitable inventive principles to solve their innovative design problem. Therefore, a method [6-7, 9] that uses one parameter to improve system performance is chosen in this paper for the designer to solve innovative design problems without the use of contradiction matrix in TRIZ method. By combining the principles that appear in both the favorable and undesirable parameters in the contradiction matrix, a table for single engineering parameters and inventive principles is constructed, as shown in Table 2. The TRIZ 39 parameters that the designer wanted to improve are placed in rows, and the frequency of appearances of each parameter's corresponding principles are placed in columns. Table 2 classifies inventive principles into different ranks, according to their number of appearances in the contradiction matrix for each parameter, such as A (appearing more than 19 times), B (between 16 to 18 times), C (13 to 15 times), D (10 to 12 times), E (7 to 9 times), F (4 to 6 times) and G (1 to 3 times). Those principles appearing most frequently (ranked at A, B, or C in Table 2) will have a better chance of success in solving inventive design problems. Therefore, the designer can solve innovative design problems without requiring contradiction analysis by choosing those most commonly occurring TRIZ inventive principles based on information in Table 2. The detail of 40 inventive principles can be found in References 3 and 4.

3 Eco-innovative design method

An eco-innovative design method based on green QFD, guidelines of eco-efficiency, the 39 engineering parameters of TRIZ and 40 inventive principles of TRIZ are proposed and presented in this section. The design processes of eco- innovative design method are shown in Figure 1.

As illustrated in Figure 1, the designer can first fill in customer (or quality/function) requirements from the QFD table or green QFD table, depending on properties, across the horizontal axis of Table 1 and find possible corresponding engineering parameters on the vertical axis. The designer can fill in the score of importance weighting. Next, one can add each engineering parameters' score and record in the far right "importance" column. The engineering parameters with higher score are chosen as key parameters. Moreover, the designer can use Table 2 with key parameters to get some TRIZ inventive principles with high priority. These inventive principles may be used as the innovative design problem solving methods. As the designer innovates new green products, inventive principles become very important reference information for him while performing eco-innovative design tasks.

Table 2. Table for single engineering parameter and inventive principles.

Parameters \ Level of Principles		A (more than 19 times)	B (16~18 times)	C (13~15 times)	D (10~12 times)	E (7~9 times)
1	Weight of M	35		28	26.18.02.08.10.15.40.29.31	27.34.01.36.19.06.37.38
2	Weight of non-M	35	28.10.19.01.26	26	27.13.02.18	06.15.22.29
3	Length of M	01.29	15	35.04.17	10.28.08.14	19.24.13.26
4	Length of non-M			35	28.14.26.01.10	07.15
5	Area of M		15	17.26.13.02	10.29.30.04	01.14.19.32.34.28.03
6	Area of non-M			18.35	39.30.17.04.36	39.30.17.04.36
7	Volume of M		35	02.10.29	01.15.34.04.06.07	13.40
8	Volume of non-M	35		02		18.14.34
9	Speed	28.35	13	34	10.38.15	08.02.18.19
10	Force	35.10.36	37.18	28.19	15.01.02	03.21.13.40
11	Tension/pressure	35.10	36.37		02.14	19.03.18.40.01
12	Shape	01	10.14.15.35	29.34	32.13.40.04	02.28.22
13	Stability of object	35	39.02	01	40.13.18.32.30	27.15.03.22.28
14	Strength	03.35.10.28	40.15	14.27		26.09.18.02.32.01.29
15	Durability of M	35.19	03.10	27	28	02.06.18
16	Durability of non-M			16	35.10	01.40
17	Temperature	35.19	02		03.10.39.18.22	21.32.27.17.16.28.36.26.38
18	Brightness	19.32.01	13		15.35.02.26	06
19	Energy spent by M	35.19			18.28.02.06	15.24.01.13.27.32
20	Energy spent by non-M					01.35.19
21	Power	35.19.10.02			32.06.38.18	34.31.26.28.17
22	Waste of energy	35	02	19.07	15.10	18.06.38.32.
23	Waste of substance	10.35.28	18	31.24	02.27.39.03	34.40.29.05.13
24	Loss of information	10			35	24.26.22
25	Waste of time	10.35.28.18		04.32	34.20.26	29.24.05
26	Amount of substance	35.03.29	18	10		14.27.40.31.28.15.02
27	Reliability	35.10.11	40	28.27.03	01	13.24.08.02.32.29
28	Accuracy of measurement	32.28.26		03.10	24.06.34.01.13	35.02.
29	Accuracy of manufacture	32	28.10	18	02.26.35	03
30	Harmful factors acting on object	22.35.02	01	33.28	18.19.24.27.40	39.10.37
31	Harmful side effects	35.22.02.39		01.18	40	21.24.17.19
32	Manufacturability	01.35	28	27.13	26	24.15.16.29.
33	Convenience of use	01.	13	02.28.35.32	12.15.34.25	16.26.17.27
34	Repairability	01.10.02	11.	35.13	32.15.16.27	25.28.
35	Adaptability	35.15.01		29	16.02.13	
36	Complexity of device	01	26.28.10.13	35	02.29.19.24	34.27.15.17
37	Complexity of control	35	28	27.26	02.19.29.15.16.01.03	18.24.13.32.39.10
38	Level of automation	35.		02.28.26	01.13.10.34	18.24
39	Productivity	35.10.28		01		18.02.37.26.34.14.15.38.29.17

Note：M=moving object

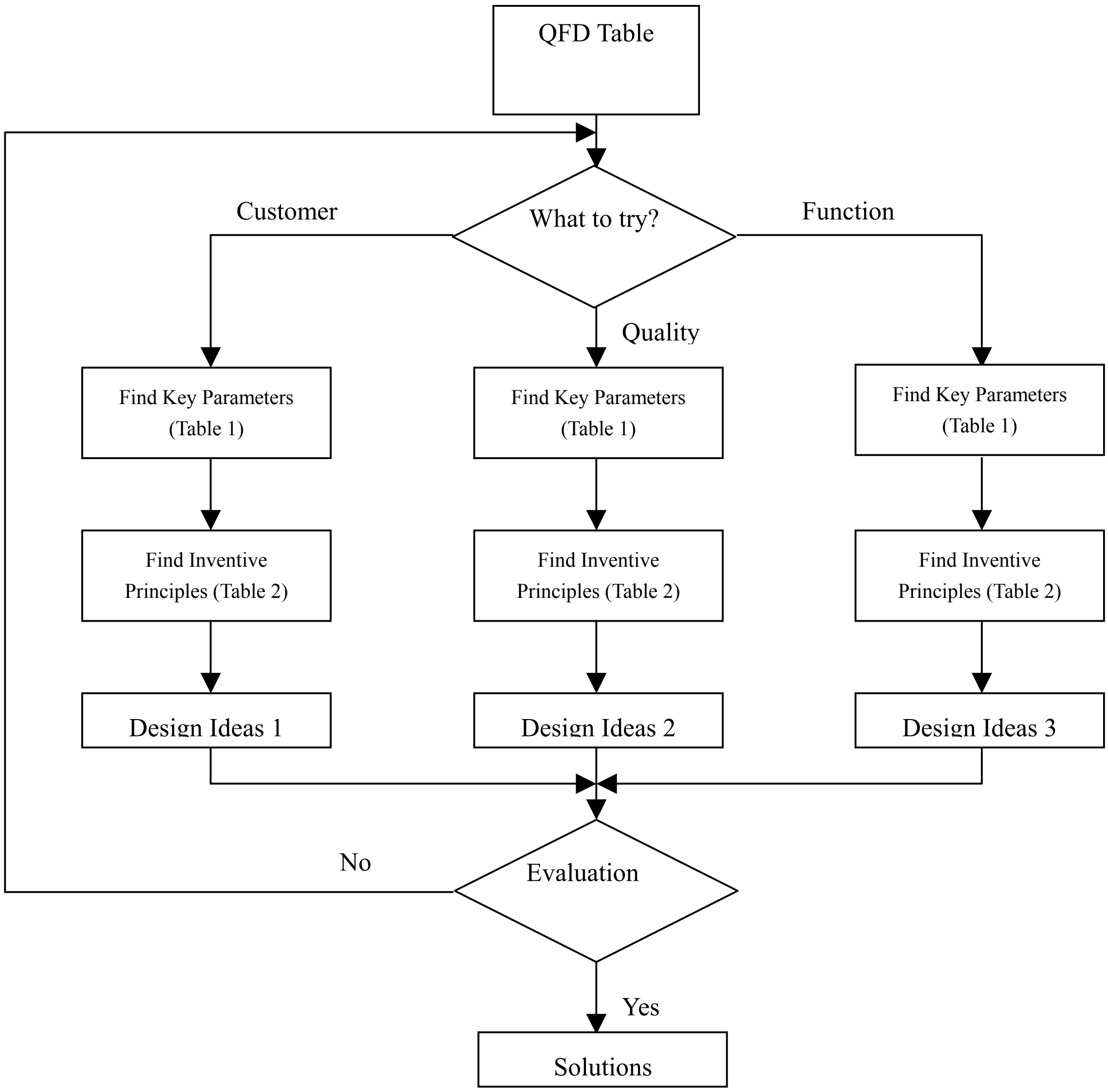

Figure 1. The design processes of eco- innovative design method.

4 Example

A vacuum cleaner innovative design case is chosen as case study. Table 3 shows the QFD table for the current product illustrating the current customer and technical (quality) requirements and their importance weighting.

First step, customer requirements in Table 3 are divided according to properties into low weight, easy handling/cleaning, quiet operation, etc. According to its attributes, fill in across top of Table 1. For example, put “low weight” in the customer requirements’ “a” column and find out which engineering parameter might correspond to it. In this case, the appropriate engineering parameter is “weight of moving object”. Next enter importance to customer grade “3” into the importance column. Enter “saving energy” in the eco-efficiency’s “B” column and find out corresponding engineering parameter. The “energy of moving object” or “ energy of non-moving object” is the appropriate engineering parameters. Next enter importance to customer grade “2” into the importance column. Follow steps to fulfill all the customer requirements and again add up each engineering parameters' score and record in the far right "importance" column, as shown in Table 4. Finally from the Table 4, the highest engineering parameter was found to clearly point to the necessity to improve "productivity" and "harmful side effects". These two will use to improve customer requirements "good dirt pickup" and "quiet operation". Then continue to use Table 2 to find most frequently occurring corresponding inventive principles.

By using Table 2, the designer can locate most frequently occurring inventive principles, such as 35, 10, 28, 01, etc. and 35, 22, 02, 39, etc. for "productivity" and "harmful side effects", respectively. Using inventive principle 35 (Parameter changes) to improve the physical or chemical status of dust, i.e. changing the dust density or adherence, can reduce the dust. The sub-rule A of inventive principle 10 (Preliminary action) is to be done before completion, i.e. try to pick up dust adherence from a carpet first then use suction to collect dust. The sub-rule A of inventive principle 22 (Blessing in disguise) is to transfer environmental harmful factors into positive effects, i.e. leading released exhaust air into suction to pick up dust. From US patent 6345411, 6237188, and 6324722, one can find the above inventive principles are used as innovation concepts.

Table 3. QFD table of vacuum cleaner [10].

Direction of Optimization		↑	↑	↓	↓	↑
Technical (Quality) requirements / Customer requirements	Importance to customer	Surface of nozzle	Power (depression)	Size of vacuum cleaner	Weight of vacuum cleaner	Filter bag volume
Low weight	3			△	⊙	
Easy handling/cleaning	3	○		○		○
Quiet operation	4					
Saving energy	2	○	⊙			
Good dirt pickup	4		⊙			
Fast cleaning	3	⊙	⊙			⊙
Small size	3			⊙	△	
Reliable product	3					○
Multi-functionality	0			○		
Importance weight		42	81	39	30	45

⊙ Factor 9 ○ Factor 3 △ Factor 1

Second step, following the same procedure of first step, technical (quality) requirements of Table 3 are fill in across top of Table 1 according to its attributes to form Table 5. The highest engineering parameter is found to improve "volume of moving object" and "power". These two will use to improve customer requirements "power", "size of vacuum cleaner" and "filter bag volume". The designer can find the corresponding inventive principles from Table 2, such as 35, 02, 10, 29, 01, 15, etc. and 35, 19, 10, 02, etc. for "volume of moving object" and "power", respectively. Among them, Inventive principle 15 (Dynamics) could be interpreted as utilizing the adjusable function to change the characteristics of object (adjustable nozzle) or modular design of vacuum cleaner to fit between portable and large vacuum cleaner (the innovation concept of US patent 4845793). Inventive principle 19 (Periodic action) is using periodic or pulse motion replacing continuum motion, such as inverter motor.

Table 4. The relationship between customer requirements and engineering parameters of vacuum cleaner.

Green QFD Elements / TRIZ Engineering Parameters		Elements of Eco-efficiency								Customer Requirement\Quality\Function										Importance
		A	B	C	D	E	F	G		a	b	c	d	e	f	b	d			
			Saving energy					Multi-function		Small size	Low weight		Good dirt pickup	Quiet operation	Easy handling	Fast cleaning	Reliable product			
Geometry	3 Length of M	◎	◎							◎										
	4 Length of non-M	◎								◎										
	5 Area of M	◎	◎							◎										
	6 Area of non-M	◎								◎										
	7 Volume of M	◎	◎							◎3										3
	8 Volume of non-M	◎								◎										
	12 Shape	◎								◎										
Physics	1 Weight of M	◎	◎								◎3									3
	2 Weight of non-M	◎									◎									
	9 Speed				◎			◎			◎					3				3
	10 Force				◎						◎									
	11 Tension/pressure				◎						◎									
	17 Temperature		◎								◎									
	18 Brightness		◎								◎									
	21 Power		◎2								◎									2
Resources	19 Energy spent by M		◎2									◎								2
	20 Energy spent by non-M		◎									◎								
	22 Waste of energy		◎2									◎								2
	23 Waste of substance	◎		◎								◎								
	24 Loss of information							◎				◎								
	25 Waste of time							◎				◎								
	26 Amount of substance	◎		◎								◎								
Capabilities	13 Stability of object			◎			◎						◎							
	14 Strength	◎				◎	◎						◎							
	15 Durability of M						◎						◎							
	16 Durability of non-M						◎						◎							
	27 Reliability							◎					◎				3			3
	32 Manufacturability	◎	◎		◎								◎							
	34 Repairability												◎							
	35 Adaptability							◎0					◎							0
	39 Productivity	◎	◎					◎					◎4							4
Harm	30 Harmful factors acting on object					◎	◎							◎						
	31 Harmful side effects			◎										◎4						4
Control	28 Accuracy of measurement			◎	◎										◎					
	29 Accuracy of manufacture				◎										◎					
	33 Convenience of use							◎							◎3					3
	36 Complexity of device				◎										◎					
	37 Complexity of control							◎							◎3					3
	38 Level of automation				◎			◎							◎3					3
Importance																				

Table 5. The relationship between quality and engineering parameters of vacuum cleaner.

Green QFD Elements / TRIZ Engineering Parameters		Elements of Eco-efficiency								Customer Requirement\Quality\Function										Importance
		A	B	C	D	E	F	G		a	b	c	d	e	f	a	a			
			Power							Surface of nozzle	Weight of cleaner					Size of cleaner	Filter bag volume			
Geometry	3 Length of M	◎	◎							◎										
	4 Length of non-M	◎								◎										
	5 Area of M	◎	◎							◎42										42
	6 Area of non-M	◎								◎										
	7 Volume of M	◎	◎							◎						39	45			84
	8 Volume of non-M	◎								◎										
	12 Shape	◎								◎										
Physics	1 Weight of M	◎	◎								◎30									30
	2 Weight of non-M	◎									◎									
	9 Speed				◎			◎			◎									
	10 Force				◎						◎									
	11 Tension/pressure				◎						◎									
	17 Temperature		◎								◎									
	18 Brightness		◎								◎									
	21 Power		◎81								◎									81
Resources	19 Energy spent by M		◎									◎								
	20 Energy spent by non-M		◎									◎								
	22 Waste of energy		◎									◎								
	23 Waste of substance	◎		◎								◎								
	24 Loss of information							◎				◎								
	25 Waste of time							◎				◎								
	26 Amount of substance	◎		◎								◎								
Capabilities	13 Stability of object			◎			◎						◎							
	14 Strength	◎				◎	◎						◎							
	15 Durability of M						◎						◎							
	16 Durability of non-M						◎						◎							
	27 Reliability							◎					◎							
	32 Manufacturability	◎	◎		◎								◎							
	34 Repairability												◎							
	35 Adaptability							◎					◎							
	39 Productivity	◎	◎					◎					◎							
Harm	30 Harmful factors acting on object					◎	◎							◎						
	31 Harmful side effects			◎										◎						
Control	28 Accuracy of measurement			◎	◎										◎					
	29 Accuracy of manufacture				◎										◎					
	33 Convenience of use							◎							◎					
	36 Complexity of device				◎										◎					
	37 Complexity of control							◎							◎					
	38 Level of automation				◎			◎							◎					
Importance																				

5 Conclusions

This paper developed an eco-innovative design method for a product based on the concepts of eco-efficiency, the green QFD table, and the TRIZ method. The framework of this method was illustrated. Example demonstrated the feasibility of the proposed new method for eco-innovative design tasks. This method provides the designer a supporting tool to develop new products with less environmental impact.

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References

[1] Fiksel, J., "Design for Environment", McGraw-Hill, New York, 1996.

[2] Behrendt, S., Jasch, C., Peneda, M.C., and Van Weenen, H. (Eds.), "Life Cycle Design", Springer-Verlag, 1997.

[3] Ahshuller, G., "And Suddenly the Inventor Appeared-TRIZ, The Theory of Inventive Problem Solving", Technical Innovation Center, Worcester, MA, 1996.

[4] Savransky, S.D., "Engineering of Creativity", CRC Press, Boca Raton, 2000.

[5] Jones, E. and Harrison, D., "Investigating the use of TRIZ in eco-innovation", The TRIZ Journal, September 2000. (http://www.triz-journal.com).

[6] Liu, C.-C. and Chen, J.L., "Development of product green innovation design method", Proceedings of EcoDesign 2001: Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing, Tokyo, Japan,11-15 December, 2001, pp. 168-173.

[7] Chen, J.L. and Liu, C.-C., "An eco-innovation design approach incorporating the TRIZ method without contradiction analysis", to appear in The Journal of Sustainable Product Design, 2003.

[8] Masui, K., Sakao, T., Aizawa, S., and Inaba, A., "Design for environment in early stage of product development using quality function deployment", Joint International Congress Exhibition Electronics Goes Green 2000+, Berlin, Germany, 11-13 September, 2000, pp. 197-202.

[9] Liu, C.-C. and Chen, J.L., "A TRIZ inventive product design method without contradiction information", The TRIZ Journal, September 2001.

[10] Bassler, E., Breuer, T., and Grawatsch, M., "Combining the scenario technique with QFD and TRIZ to a product innovation methodology", The TRIZ Journal, January 2002.

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