Using Cost Analysis as a Tool for Combining Design for Assembly and Design for Disassembly at the Early Stage of Sustainable Product Development Process

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Abstract

A model for Integration of Assembly and Disassembly in Lifecycle Management is proposed and its efficiency is evaluated using case studies. The feasibility of considering assembly and disassembly together in the way that End of Life Option gives the highest profit and promotes recycling profitability is investigated.

Keywords; Design for Sustainability, Design for Assembly, Design for Disassembly, Life Cycle Management

1 Introduction

Today, Environment is dealing with high amounts of solid waste added to the earth. These wastes are making severe problems for earth. For instance, in 2001 Japan calculated that it was soon to run out of space for landfill so government passed a law which added the cost of recycling home appliances to the retail price.

Product design is a critical determinant of a manufacturer's competitiveness. It has been claimed that as much as 80% of the costs of product development, manufacture and use are determined during the initial design stages. The needs in incorporating environmental consciousness into the design for a product or production process lead to the emerging of design for environment (DFE).

Currently, product designers consider design for assembly and design for manufacturing during product design and development early stages. These considerations are necessary to reduce production

costs. But, those methods that facilitate manufacturing, usually makes environmental problems. As a case in point difficulties in disassembly and using toxic materials are sizeable. In order to solve this problem, whole product life cycle should be considered during product development process.

2 Literature Review

2.1 Design for Assembly

Design for Assembly is considering and resolving the possible problems in the assembly process at the early stage of the design which can make sure the part will be assembled with high speed, low cost and productivity.

DFA is a kind of design method that can be used in two ways. First a tool for assembly analysis and second a guide for assembly design.

There are different Quantitative evaluation procedures design that mostly concentrates on evaluating the design and improving it using quantitative methods. Between them three popular ones which are mostly used in the industry are:

1. Boothroyd-Dewhurst Design for Assembly Method [1]
2. Hitachi Assemblability Evaluation Method [2]
3. Lucas Design for Assembly Methodology

Geoffrey Boothroyd and Peter Dewhurst who founded the Boothroyd-Dewhurst, Inc. (BDI) in 1982 are the first persons doing the research job in this new technology at the beginning in the early 1970's [1]. Actually, the "DFMA" is a trademark of their

company. They created and developed the DFMA concept which is used in developing the products of their company (DFMA software system).

The Boothroyd-Dewhurst methods provide a quantitative measure called the design efficiency based on analysis of a product.

The Hitachi [2] AEM analyses the motions and operations, called 'assembly operations', necessary to insert and secure each component of the product.

2.2 Design for Disassembly

Suga et al. (1996) [3] presented the quantitative method to evaluate the disassembly evaluation by introducing two parameters, energy for disassembly and entropy for disassembly.

Mok et al. (1997) [4] published a paper that defined the parameters of disassemblability to propose design rules for easy disassembly. The authors divided the disassembly process into 3 categories; pre-process, in process and after process. For each process the authors defined the determining factors for disassembly.

Gungor and Gupta (1997) [5] proposed the evaluation method for different disassembly strategies, so that the best one could be chosen. The authors use Total Time for Disassembly (TTD) as the parameter to measure a given disassembly sequence of a product.

Kroll and Hanft (1998) [6] presented a method for evaluating the ease of disassembly of a product, proposed a catalogue of task difficulty scores, and explained the derivation of the difficulty scores. The method presented uses the spreadsheet chart, and uses the catalogue of task difficulty scores.

Hesselbach and Kln (1998) [7] presented the disassembly evaluation of electronic and electrical products. The evaluation tool was translated to the computer software that was developed by Institute of Production Automation and Handling Technology, Germany.

Kroll and Carver (1999) [8] presented a method for estimating disassembly time to allow the designer to identify weakness in the design and improve it accordingly.

Yi et al. (2003) [9] proposed the method for evaluating the disassembly time. The aim of the study is to obtain approximate disassembly time for the product to be disassembled by using the formula derived from the information on the product's connecting parts and working environment without disassembling the product directly.

Desai and Mital (2005) [10] present a methodology to design products for disassembly. This would facilitate end-of-life product disassembly with a view to maximizing material usage in the supply chain at a

low cost to the environment. The disassemblability of the product is the function of several factors, such as, effective tools placement, weight, size, material and shape of component being disassembled. The authors stated that the previous research concerned on the theoretical part of disassembly process, such as optimization algorithm, and algorithm based on economic analysis but they failed to consider several factors, such as, the magnitude manual force required, the need of specialized manual tools, accessibility, and the need for assumption of irregular working postures for a prolonged period of time. The proposed method consists of two elements, a numeric disassemblability evaluation scores and the systematic application of design for disassembly. In their scoring system each difficulty score is equal to one TMU and is equal to 0.36 seconds.

2.3 Life Cycle Assessment

According to Alting and Legarth, 1995 [11] life cycle engineering/design is the discipline which incorporates environmental issues and parameters across the life cycle of a product into product development.

By using the LCA tool, the weaknesses of a product in term of environmental consequences can be detected. According to Wenzel et al. (1994) [12], improvement potentials in order to improve the environment performance may vary among product types, but they generally correspond to one or more of five overall improvement strategies: better material handling, chemical savings or substitutions, thermal energy savings, electricity savings and overhead reduction.

3 New Framework

Proposed framework for integrating the assembly and disassembly in life cycle management consists of two steps. First step is cost analysis for finding the best end of life option. Next step is improving the assembly and disassembly design based on end of life option and design weaknesses. Cost analysis which is proposed in this research is an optimistic method. Consequently, if there is any obligation such as health requirements and environmental problems that need special end of life option; first step is just for cost analysis.

In the proposed framework, Boothroyd-Dewhurst design evaluation worksheet is applied to find the assembly cost and Anoop-Mital method is used to get the disassembly cost.

Based on desired end of life option a new algorithm is suggested for improving the design of each part in the product. In the suggested algorithm, design features in assembly and disassembly are considered concurrently. Figure 1 shows the process of improving the design of products. First step is to identify each part features. Next step is finding the end of life option of part. Based on the end of life option, three integrated design improvement guidelines are introduced. Table 2 shows guidelines which can be used to improve product design with reuse and remanufacturing end of life option.

Figure 1 Design improvement algorithm

Table 2 Reuse and remanufacturing design guidelines

REUSE DESIGN AND REMANUFACTURING GUIDELINES	Avoid corrosive materials
	avoid snap fits or use easily removable snap fits
	take advantage of snap fit and slot combination to reduce snap fits
	facilitate tool access
	increase fastener head size
	fastener head size close to surface
	use standard fasteners
	make part easily separable from other parts
	Increase component rigidity
	consider part disassembly while doing the assembly design
	use wide tolerances
	reduce friction using suitable materials
	avoid wedging
	use less screws or screws with fine threads
	avoid tight clearance
	use standard size
	increase symmetry
	use non toxic and hazardous materials
	minimize fastener
	use single direction disassembly and assembly
	avoid inserting parts to plastic
	Take advantage of spring characteristics of materials

Regarding the recycling, design guidelines are almost same as reuse and remanufacturing, but in recycling it is rational to combine parts with the same

material into one or at least make them a subassembly that can be easily disassembled. Guidelines for improving a part design with recycling end of life are shown in Table 3.

Table 3 Recycling design guidelines

RECYCLING DESIGN GUIDELINES	combine parts with same material into one subassembly
	avoid snap fits or use easily removable snap fits between subassemblies, but easily use them inside subassemblies with same materials
	take advantage of snap fit and slot combination to reduce snap fits
	facilitate tool access
	increase fastener head size
	fastener head size close to surface
	use standard fasteners
	avoid parts which consist same material with different colors
	Use wide tolerances between subassemblies.
	reduce friction using suitable materials
	avoid wedgings between subassemblies
	use less screws or screws with fine threads
	avoid tight clearances between different recycling groups
	use standard size
	increase symmetry
	use non toxic and hazardous materials
	minimize fastener
	use single direction disassembly and assembly
	avoid inserting parts to plastic
	Take advantage of spring characteristics of materials to reduce springs

4 Framework Evaluation

Selected case study is an electric pot that has high rate of production in Malaysia.

First step is Identify Parts, Functions, Materials and Joints in case study. Next, End of life Options are considered.

The end-of-life options are defined as follows

Reuse: Component is disassembled from the product structure and is used on an “as is” basis, without any technological up gradation/downgradation or being subject to any design modifications

Remanufacturing: Component is disassembled from the product structure and is subject to certain design changes which result in technological up-gradation/down gradation.

Recycling: Only the material of the component is used again to perform another function

Selected end of life option for all parts of this case study is recycling. This selection is for simplifying the analysis process.

Figure 2 shows the case study and some of its parts.

Figure 2 Electrical Pot and its Parts

Disassembly design evaluation for the hair clipper is done. Disassembly evaluation is shown in Table 1 and all digits are extracted from Desai, et al, (2005) [10] method which is explained in literature review.

As explained in Literature review section, Boothroyd-Dewhurst method is applied to evaluate the assembly design.

In order to find End of Life Value and Net Present value, all recurring costs are expressed as annual expenses incurred at the end of each year and one-time costs are incurred at the end of the year in which they occur. To determine the present value of future one-time costs the Equation 3 is used:

$$PV = At / (1 + d)^t \quad (1)$$

Where,

PV = Present Value

A t = Amount of one-time cost at a time t

d = Real Discount Rate

t = Time (expressed as number of years)

Disassembly cost is equal to Disassembly time multiply by Labor rate

Assembly cost is equal to Assembly time multiply by Labor rate

Table 4 shows the cost analysis worksheet which is used to identify improvement candidates.

Table 4 Cost analysis of Original Design

PART ID	PART NAME	END OF LIFE OPTION		RATE OF INTEREST			
		DISASSEMBLY COST	RECYCLING END OF LIFE REVENUE	ASSEMBLY COST(MYR)	ESTIMATED LIFE (YEARS)	RECYCLING NET PRESENT WORTH	RANK
						0.03	
1	stand body	0.003	0.030	0.004	2	0.0205	3
2	electricity plug	0.003	0.006	0.003	2	-0.001	7
3	screw	0.026	0.0002	0.033	2	-0.058	23
4	plug cover	0.004	0.013	0.006	2	0.0025	6
5	pot	0.004	0.13	0.004	2	0.1175	2
6	door	0.004	0.026	0.004	2	0.0160	4
7	door lock	0.010	0.001	0.022	2	-0.030	20

Final step is using design improvements guidelines for recycling.

As a case in point, one improvement in the design combines main body and handle through snap fits, furthermore gives easy access to electrical apparatus and element in order to be easily removed at the end of life.

Figure 3 shows modifications in main body structure. In comparison to original design as electrical apparatus and heat element can be easily disassembled after product life in modified design, while in original design first seven screws should be disassembled.

Figure 3 Modified main body structure (Left is new design)

Table 5 shows improvements in assemble and disassembly design costs. As shown assembly cost is decreased by 38 percent after applying the new frame work and disassembly cost is decreased 53 percent. Total profitability is increased by 146 percent in the new design.

Table 5 Improvements in costs

	Assembly cost (MYR)	Disassembly cost (MYR)	Net present Worth (MYR)
Original design	0.2837016	0.1858464	0.137031
Improved design	0.1761032	0.0879984	0.336861
Percent of Change	-38	-53	146

5 Conclusions

Decision making for conducting the assembly and disassembly design improvement should be combined together in order to get advantage of end of life value of products. Proposed methodology shows high improvements in assembly and disassembly cost decrease. Furthermore profitability of design recycling is enhanced. It is concluded that measuring design sustainability based on life cycle cost analysis and assembly and disassembly can be a good index for ecological design of products.

6 Guides for Further Research

In this research just one method is used to do the design for assembly evaluation and one method is used to do the design do disassembly evaluation. Consequently, investigating other methods in evaluating design for assembly such as Lucas design for assembly evaluation method and Hitachi assemblability evaluation method are recommended for more accurate results.

During the life cycle analysis, just recycling, reusing, and remanufacturing are considered in this research, so it is better to evaluate other end of life options to get more reliable results.

Assembly and disassembly sequences are important elements in design features. In fact sequence has dominant effect on both assembly and disassembly cost especially in disassembling the product for taking advantage of end of life has large effect on life cycle

cost. Consequently it is recommended to consider them in design improvements.

This research focused on electrical appliances however using other case studies with different design features will reveal more applicable design improvement guidelines.

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