Analysis of Product Disassemblability Using the Disassembly Evaluation Chart Methodology

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Abstract

One aspect of product development which focuses on the recovery of resources at the end of the product lifecycle is Design for Disassembly (DFD). Disassembly evaluation chart methodology (DECM) is one of the various methods in DFD which can be used to evaluate the disassemblability of a product by using a spreadsheet-like chart with the respect to the disassembly difficultness for each task of the disassembly operation. The goal of DECM is to make products easier to disassemble. The evaluation result such as disassembly efficiency, disassembly time and disassembly cost estimation are calculated and evaluated to identify what should be improved. The design optimization is achieved by reviewing the evaluation results, making improvements on the design and re-evaluates it. Validation of DECM is done by using a product case study. Results obtained from the case study showed that the method is able to achieve objectives of the product disassemblability.

1. Introduction

In recent years of environmental awareness, the steadily increasing consumption of industrial product is facing with the environmental issue for both consumer and manufacturer. These products sooner or later have to be dumped in landfills after their life cycle are over. Product life cycle becomes short not only because they fail but also because they go out of style or become technologically obsolete. However, the biggest damage to the environment occurs when the product completes its useful life.

The disposal of this product by conventional means, such as landfill or incineration, represents an unsustainable loss of raw material resources and poses another problem because the product does not simply disappear after disposal. Since the value of preserving the environment and natural resources may soon predominate the cost of recycling, then it is expected to face a growing demand to dispose of old products in constructive way by removing hazardous materials, retrieving reusable components and recycling.

Although it is rarely possible to recycle a product completely, it would be noteworthy to maximize the recycled resources and to minimize the rubbish of the remaining product. Product recovery usually performed in two ways: recycling and remanufacturing [6]. Disassembly has proven its role in material and product recovery. However, in the process of disposing and recycling old product which include the cost of handling, sorting and disassembly will play an important role.

Some manufacturer now inlaid their take-back legislation on their product to make them responsible for the environmentally safe recycling or disposal of their end-of-life products. The legislation is designed to create an economic incentive for manufacturers to design more environmentally friendly products, and to reduce the environmental impact of waste by increasing the volume that is recovered and recycled.

Product disassembly is motivated to obtain the pure secondary material and to isolate environmentally relevant materials from other materials [18]. Disassembly a product into separate part or material is just one of may possible end-of-life treatment options for obsolete product. Even though the disassembly approach may seem to provide a way to minimizing the environmental problems, it should be mentioned that the cost of disassembly and the market process for recycled materials are less than the environmental benefits.

Product life cycle can be extended by good maintenance and servicing, these activities usually require partial disassembly in order to replace or repair parts that are embedded with other parts in the product structure. The main issue is how to redesign a product in such way to make it ease to disassemble with the minimum cost. It is due to the cost of handling, sorting and disassemble time which plays an important role in process of disposing and recycling old product.

2. Design for disassembly

Designing products in order to minimize the impact on the environment is becoming increasingly important. Many designers are beginning to recognize this fact and therefore demanding tools and techniques which enable them to design more responsible. One technique which can be used is design for disassembly (DFD). Product may be disassembled to enable maintenance, enhance serviceability and affect the product end of life objectives such as product reused, remanufactured and recycled.

The main principle of DFD is the same as DFA which is to reduce the number of parts in a product. The fewer is the parts, the faster the disassembly operations. There are 2 basic methods of disassembly which usually used: (1) non-destructive disassembly or reverse assembly and (2) destructive disassembly or brute force approach. For reverse-assembly, if a fastener is screwed in, then it is screwed out; if two parts are snap fit together, then they are snap out. In the case of destructive disassembly part are just pulled or cut [15].

It is important to remember when designing for disassembly that the product which needs to be designed is not only for ease of disassembly but also to ensure that the product's parts and materials can easily be recycled. There are 3 main areas of the design which need to be closely examined for DFD [4] : (1) fastening methods should be reversible and easy to undo (i.e. cheap to disassemble); (2) materials must be compatible if they are to be easily recyclable as subassemblies, (i.e. without exhaustive disassembly); and (3) parts should have their fate determined at an early stage of design in order that they can be targeted for removal.

3. Disassembly evaluation chart methodology

Disassembly Evaluation Chart Method aims to make products easier to disassemble through a disassemblability evaluation in the early stages of design. This methodology was developed by Kroll, et, al. This evaluation will identify what should be improved, estimate quantitatively the effects of improvement and facilitate design improvement. The aim of DECM can be achieved in the product design stage.

3.1. Procedure of disassembly evaluation chart methodology

The procedure of DECM can be carried out earlier in design stage by evaluating the sample or product prototype. The product disassemblability can be evaluated through this stage and the product improvement can be done continuously by comparing the product with the alternatives or comparing with the competitor's.

The design improvement can be performed by reviewing the evaluation results. The improved design is subjected to the disassemblability evaluation process in order to quantitatively evaluate the effects of the improvements. These steps facilitate the design improvement activities. Figure 1 explains about the procedure for evaluating the ease of disassembly of a product using DECM in flowchart.

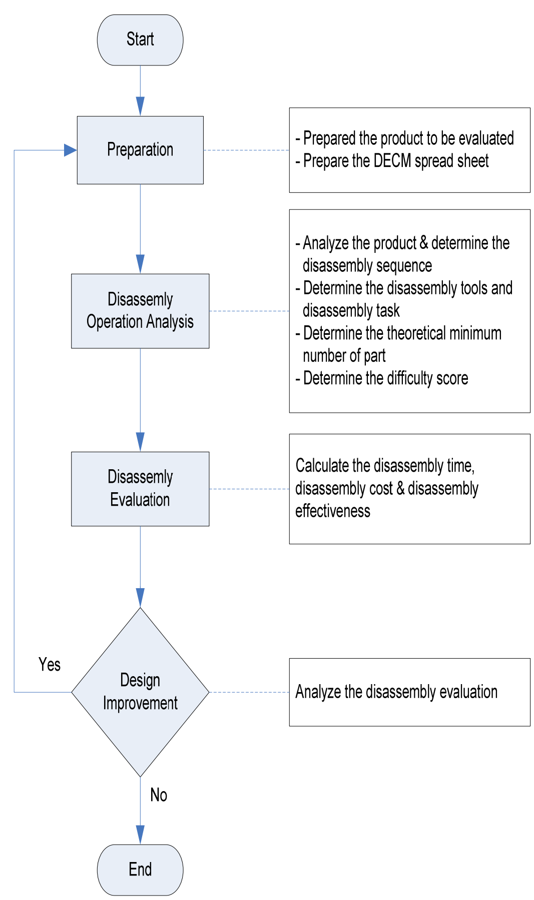

Figure 1: Disassembly evaluation chart procedure

3.2. The evaluation method

The disassembly evaluation method is done by using the disassembly evaluation chart which is formed in a spreadsheet-like chart. The chart entails the disassembly operation sequences of the product and recording each task on separate row of the chart. The information about the disassembly operation, disassembly tools, disassembly rating difficultness and the disassembly time are also included in the chart. The structure of DEC is shown in table 1.

Table 1: Structure of disassembly evaluation chart

Disassembly Evaluation Chart

Product : Date :
Prepared by : Sheet :

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							DIFFICULTY RATING 1 (EASY) ....10 (DIFFICULT)										
PART NO.	PART NAME	QUANTITY	MIN. NO. OF PARTS	TASK TYPE	No. OF TASK REPETITIONS	REQUIRED TOOL	ACCESSIBILITY	POSITIONING	FORCE	BASE TIME	SPECIAL	SUB TOTAL	TOTAL (column 13 x column 6)	COMMENTS	No. OF TOOL MANIPULATION	No. OF HAND MANIPULATION	ESTIMATION TIME (sec) (column 14 - 5 x column 6) x 1.04 + (no. of tool & hand manipulation) x 0.9

3.3. Difficulty rating

Difficulty rating is a quantitative difficulty scores which is assigned for five categories of task performance [3], [8], [13]. The scores are based on scale of 1 (easy) to 10 (difficult). The five categories of task performance are:

1. Accessibility
   Accessibility is a measure of the ease with which a part can be accessed or reached by the tool or hand. It is indicated whether adequate clearance exists and how easily the part can be maneuvered during disassembly.
2. Positioning
   Positioning is a measure of how precisely the tool or hand needs to be positioned and oriented in order to perform the task.
3. Force
   Force is a measure of the amount of force required to do a task.
4. Base Time
   Base time is the time required to do the basic task movements without difficulty. The basic ease of doing a task is indicated by this task.
5. Special
   This category was added to account for special circumstances which are not considered in the standard task model. For example, if the standard task model includes removal of screws with only six to nine threads and a screw with 12 threads is encountered, then a score greater than ‘1’ would be appeared in the special category. In most cases, disassembly tasks follow the standard task models and a ‘1’ is entered in this column.

To determine the difficulty score, the standard disassembly task should be identified which could be determined through the observation of manual disassembly experiments. The MOST (Maynard Operation Sequence Technique) method can be used to performing a task under average conditions to designate the standard task [13]. MOST is a predetermined time system which provides standard time data for performance of precisely defined motions [24].

Factors such as obstructions, handling difficulties and resistance were considered as the parameters of each task. The effects of these conditions on performance time were assessed by assigning the appropriate MOST parameter indices. The factors which complicated the disassembly received higher parameter indices and increased overall task performance. The sequence parameters in each task were then categorized according to the task performance. The parameter indices in each category were summed to obtain the component of the total task time consumed by each category.

All task component times were converted to difficulty score by using the following linear relationship and rounded to the nearest integer [13]:

$$\text{Difficulty score} = \frac{1 + 9 \text{ x (component time in TMU)}}{260}$$

In the physical term, the difficulty of 1 is associated with the basic hand motion required to pick up, move and place an object. A difficulty score of 10 is associated with the movements of the hand and forearm to twist a screwdriver against heavy resistance. Due to the score which were derived from estimation of task performance time, an estimate of disassembly time can be obtained from the difficulty score by reversing the process of deriving scores from time.

3.4. Disassembly estimation time

The disassembly time estimation is amount of time required to do the disassembly task for a certain product. The disassembly time can be estimated from the disassembly tasks data which entered in disassembly evaluation chart.

The disassembly time was calculated by using equation [13]:

Disassembly Time = (Total difficulty score - 5 x Total number of task repetitions) x 1.04 + (No. of tool and hand manipulation) x 0.9

= (∑Column 14 – 5 x ∑Column 6) x 1.04 + (No. of tool and hand manipulation) x 0.9

3.5. Disassembly effectiveness

Design effectiveness is a percentage rating which compares the ideal product to the actual product in terms of the disassembly time. The ideal product would contain only those parts which are theoretically necessary. The ideal disassembly time is 5 second per part, where the ideal part is considered as 1 inch cube that requires 5 second to handle and disassemble [1]. Design efficiency derived as follows:

$$DE = \frac{\text{5 sec x (Total minimum number of}}{\text{Total difficulty rating x No. of task repetition}} \text{ x } 100\%$$

3.6. Disassembly cost

The disassembly cost is referring to the cost required during the disassembly process which is usually referred to the labor cost. It is assumed that the cost for disassembly operator is RM 800 per month, and then the labor cost per second can be calculated as follows:

$$\text{Labor Cost} = \frac{\text{Labor cost per month}}{\text{Number of work-seconds per month}}$$

4. Product case study

In order to evaluate the design efficiency based on the disassembly evaluation chart, a case study on a Central Processing Unit (CPU) is conducted. The computer components were fairly standardized and easily to upgraded or replaced, thus the possibility of recovery and resale of used or refurbished parts of computer became an important factor to design for disassembly. CPU consists of several electronic components which were fastening to the housing by using screws, and wires with various types of plugs to interconnecting the components. Some critiques to evaluate the weaknesses of each component were done to make improvement in the redesign product.

5. Design modifications and improvement

The improvements and modifications are based on the evaluation of the original design of product case study. According to Boothroyd, the improvement is focused on a few aspects such as reducing the part count and part types, considering the access and visibility for each operation, and elimination of reorientation during disassembly. The disassembly evaluation chart worksheet from the previous work is contained with the information about the evaluation of the original design. The improvement can be made based on the theoretical minimum number of part and the difficulty score.

The proposed improvements parts are then classified into 2 classes which are major improvement and minor improvement. Both improvements, major and minor improvements give credits to the overall design. A part can be classified into major improvement if only the part can give substantial contribution to the whole design. It means that the part would give a value added to the design significantly. The major improvement changes the design by improving the weakness of the part and maintains its function; mostly it changes the design totally different from the original one. There are 4 major improvements which can be proposed to the product case study; the major improvements are the redesign of casing box, casing cover, CD-ROM rack and HDD rack.

The minor improvements give slightly modification to the original design. The modification was quite simple but it will make a better appearance compare to the original design. Based on the evaluation of the original design of product case study, there are 7 minor improvements which can be proposed to the product case study. The minor improvements are; protrude holes for screwing motherboard, the USB slot, the CPU cable speaker slot, the expansion slot, extra CD-ROM cover, power-reset button and rubber base.

5.1. Exploded view of redesign product

The exploded view of redesign product showed all the components which build the product. It would also determine how the product would be disassembled. The exploded view of redesign product is shown in figure 2.

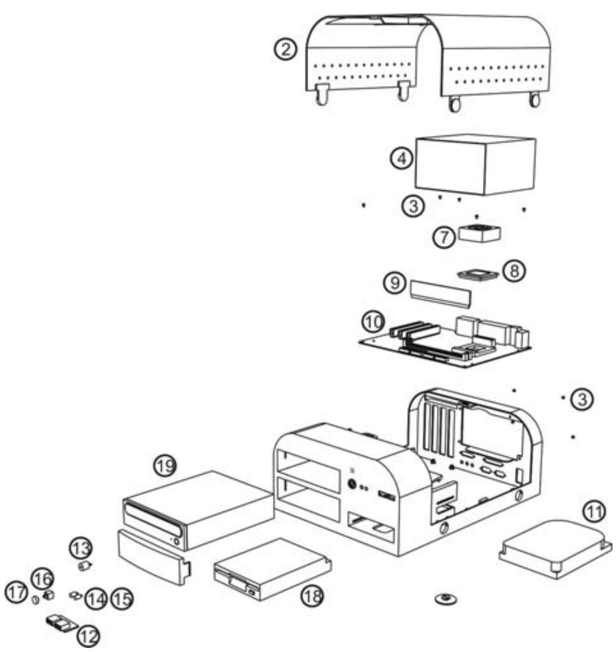

Figure 2: Exploded view of product case study

6. Conclusion

The implementation of the disassembly evaluation chart methodology was quite easier to evaluate the disassemblability of product case study. The DEC methodology has proved its ability to evaluate a product's disassemblability by determining the disassembly difficultness, disassembly efficiency, disassembly time, disassembly cost, and the number of required parts. The parts number sequences in the DEC represent the disassembly operation sequences. The important thing in this method is determining the difficulty scores because it would give high influence in overall. Due to that thing, redesigning the product should considering this score.

The original product case study and redesign product is compared in term of number of parts, disassembly time, disassembly cost, and design efficiency in order to see the result of design improvements. As an overall, evaluation result shown the significant improvement on the redesigned product compared to the original product. The overall achievement is summarized in table 2.

Table 2: Comparison result between original and redesign product

	Original Product	Redesign Product	Reduction/ Increment
Total Number of Parts	75	29	61.33 %
Total Number of Different Parts	42	22	47.62 %
Estimated Dis-assembly Time	420.72 s	154.76 s	63.22 %
Estimated Dis-assembly Cost	RM 0.589	RM 0.216	63.22 %
Disassembly Efficiency	20.20%	57.09%	36.89 %

7. Future Work

The DECM can be further improved by developing support system software to evaluate the product disassemblability by employing a knowledge-based approach into the system. The software should be developing as a smart system where it is not only evaluating the disassembly parameters but also evaluating the product design at once.

The support system can also be integrated with other design principles to allow the designer to apply the DFX principle in the product design process such as Design for Assembly (DFA), Design for Manufacturing (DFM), Design for Recycling (DFR) and Design for Environment (DFE). Therefore the prototype system can do the evaluation totally. The CAD system will allow the designer to see how the product will look alike with a certain parameter in 3D image. At the same time the evaluation can also be done with a certain design principles. The evaluation system should be equipped with the database of product information and its requirements.

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