MODULARIZATION OF DELTA 8AH EMERGENCY LAMP PRODUCT BASED ON DESIGN FOR REMANUFACTURING (DFR) AND DESIGN FOR ENVIRONMENT (DFE) CRITERIA

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Abstract

A modular product is made up from various different modules that can be easily attached / detached. These modules can be manufactured, assembled and repaired separately. Modular product concept enables end-of-life product to be reused, recycled or even remanufactured as each component of the product has been defined according to its functions into different modules.

The product components are split into a number of modules based on certain criteria. In this research, there are two criteria used, which are Design for Remanufacturing (DFR) and Design for Environment (DFE). The Hierarchical Clustering Algorithm (HCA) method also applied to devide product components into a number of modules.

The Delta 8Ah emergency lamp product, which is used as research object in this paper, consists of 18 different components. Preliminary research shows that there are 5 modules which can be used as recommendation for product design. However, further research concludes that the final recommendation for product design suggests only 4 modules.

As proposed improvements, there will be reductions in the total number of screw FSC 11, screw FSC 13 and cord holder components; changes in the material used for battery holder component; addition of features on housing component and a new component called elastic cover; simplification of reflector and housing components; and a reduction in the additional tools required for disassembly and assembly processes. These recommendations are based on considerations for improving the remanufacturing process as well as creating environmental-friendly product.

Keywords: product modularization, design for remanufacturing (DFR), design for environment (DFE), hierarchical clustering algorithm (HCA)

1. INTRODUCTION

Rapid growth of technology significantly affects every aspect of life, especially in manufacturing industries. In such environment, manufacturers have to be able to maintain their product existence in order to compete with their competitors. One way that can be used to do such is by developing products modularly. A modular product is made up from various different modules that can be easily attached / detached. These modules can be manufactured, assembled and repaired separately (Gu & Sosale, 1999). Modular product concept enables end-of-life product to be reused, recycled or even remanufactured as each component of the product has been defined according to its functions into different modules. Therefore, the application of product modularization will facilitate remanufacturing process of a product.

Remanufacturing is disassembly process of an end-of-life product, which its components are cleaned, repaired or replaced through certain manufacturing processes, then reassembled so that it results in a better or new-like product (Bras & Hammond, 1996). In this paper, product modularization concept will be implemented by using Design for Remanufacturing (DFR) criterion. The other criterion that will be used in this research is Design for Environment (DFE). DFE is a product design approach for reducing the impact of products on the environment. By using DFE criterion, the products produced are expected to be environmental-friendly, since products can have negative impact on the environment during their manufacture through the use of highly polluting processes and the consumption of large quantities of raw materials. They can also have adverse impact through the consumption of large amounts of energy and long half-lives during disposal (Otto & Wood, 2001).

Accordingly, the objective of this research is to implement product modularization concept based on DFR and DFE criteria such that the design of modular product that can be remanufactured and has less environmental impact can be obtained.

2. PROBLEM IDENTIFICATION AND FORMULATION

This research will be focused on emergency lamp product, i.e. lamp that will be turned on automatically if the main power source is cut off. Delta 8Ah emergency lamp product, which has lighting capacity for 8 hours, will be used as research object. The problems can be formulated as follows: (1) What DFR and DFE criteria will be used for redesigning Delta 8Ah emergency lamp product based on modularization concept?, (2) What is the modules of Delta 8Ah emergency lamp product based on DFR and DFE criteria?, (3) What is the design of modular Delta 8Ah emergency lamp product based on DFR and DFE criteria?

3. DESCRIPTION OF DELTA 8AH EMERGENCY LAMP PRODUCT

Delta 8Ah emergency lamp product consists of 18 separated components with simple assembly. Description and details of components of this product are shown in Figure 1 and Table 1.

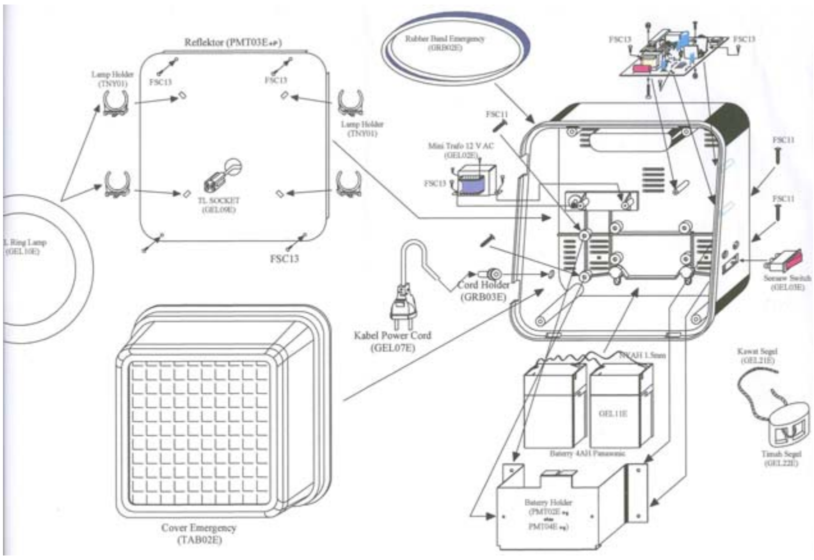

Figure 1. Components of Delta 8Ah emergency lamp product

Table 1. Components of Delta 8Ah emergency lamp product

No	Part Name	No	Part Name	No	Part Name
1	Cover	7	Screw FSC 11	13	Battery 4Ah
2	Housing Delta 8Ah	8	Screw FSC 13	14	Battery Holder
3	Rubber Band	9	Power Cord	15	Battery Cable
4	TL Ring Lamp	10	Cord Holder	16	Seal String
5	Lamp Holder	11	Mini Trafo 12V AC	17	Tin Seal
6	Reflector	12	Printed Circuit Board (PCB) DT-07	18	SISO Switch

4. METHODS

4.1 Identification of DFR and DFE Criteria

The first step in modularization process is identification of DFR and DFE criteria as the base for grouping components into modules. Each of those criteria will be given certain weight and then divided into several levels of sub-criteria. The criteria and their sub-criteria will be used in component scoring process. The DFR and DFE criteria, sub-criteria, and their weights are as follows (Magrab, 1997; Otto & Wood, 2001; Malta, 2004; Hundal, 2000; Fiksel 1996):

1. The use of assembling and fastening methods that can be easily disassembled. Weight = 0.20
    - The use of assembling and fastening methods that can be easily disassembled, such as snap-fits [high].
    - The use of assembling and fastening methods that is difficult to disassembly, such as bolt, nut and screw [medium].
    - The use of assembling and fastening methods that cannot be disassembled, such as adhesives, welding [low].

2. Minimizing the use of tools in disassembly processes. Weight = 0.20
   - Disassembly process requires no tools [high].
   - Disassembly process requires 1 tool [medium].
   - Disassembly process requires 2 or more tools [low].
3. Part design has corners or holes that can be easily accessed / avoiding corners or holes at all. Weight = 0.20
   - Part design has no corners or holes at all [high].
   - Part design has corners or holes that can be easily accessed [medium].
   - Part design has corners or holes that are difficult to access [low].
4. Minimizing the use of different materials. Weight = 0.15
   - Component is made of one type of material [high].
   - Component is made of two different types of materials [medium].
   - Component is made of more than two different types of materials [low].
5. Wear and tear / damage of components can be easily checked or known. Weight = 0.10
   - Wear and tear of component can be directly identified by looking at the physical form of the component [high].
   - Wear and tear of component can be identified after testing by using tools [medium].
   - Wear and tear of component can be identified by disassembling the component [low].
6. Reducing reworks on components. Weight = 0.05
   - Component does not require reworking [high].
   - Component requires some reworking [medium].
   - Component requires reworking totally [low].
7. The use of standard components to reduce component variation. Weight = 0.10
   - Component is categorized as common component [high].
   - Component is categorized as special component [low].

The same thing is also carried out for DFE criteria, sub-criteria and their weights (Otto & Wood, 2001):

1. The impact of material extraction and processing step on the environment based on eco-indicator 95. Weight = 0.15
2. The impact of manufacturing step on the environment based on eco-indicator 95. Weight = 0.15
3. The impact of waste management step on the environment based on eco-indicator 95. Weight = 0.25
   Sub-criteria for criteria 1, 2 and 3 are the same, which are:
   - Indicator value is low [high].
   - Indicator value is medium [medium].
   - Indicator value is high [low].
4. Materials / components can be easily recycled, remanufactured or reused. Weight = 0.30
   - Material / component can be recycled, remanufactured or reused by using available technology and infrastructure [high].
   - Material / component is technically feasible to recycle, remanufacture or reuse – supporting infrastructure is not available [high-medium].
   - Material / component is technically feasible to recycle, remanufacture or reuse with further process or material development required [medium].
   - Material / component is organic – can be used for energy recovery but cannot be recycled [medium-low].
   - Material / component is inorganic with no known technology for recycling [low].
5. Minimizing the use of materials that are in restricted supply. Weight = 0.15
   - Material is available in unlimited supply [high].
   - Material is available in a large amount [high-medium].
   - Material is available in a medium amount [medium].
   - Material available is potentially restricted [medium-low].
   - Material available is very restricted in supply [low].

4.2 Components Interrelationship Criteria

In grouping product components into modules, interaction among components must be identified so that each component that includes in certain module has strong relationship with other components in the same module. Therefore, components interrelationship matrix will be created by using two criteria, which are component attachment (weight = 0.6) and component alignment (weight = 0.4). Table 2 shows attachment and alignment evaluation criteria that will be used as a reference.

4.3 Interaction Matrix

In creating interaction matrix, Table 3 and 4 are used to determine interaction score between components. From DFR, DFE and component interrelationship criteria, three interaction matrices will be obtained. Final interaction matrix is established by summation between DFR - component interrelationship interaction matrix and DFE - component interrelationship interaction matrix. In this calculation, the weight of each criterion is multiplied by 0.5 so that the total weight is still equal to 1. Table 5 is an example for calculation of DFE interaction value between component 1 and 2.

Table 2. Evaluation criteria for component attachment and alignment

Relationship	Component Attachment	Component Alignment	Interaction value
Very strong	Permanent attachment	More than 2 components have to be aligned with more than 1 component	10
Strong	Attachment cannot be easily disassembled	More than 2 components have to be aligned with 1 component	8
Medium strong	Key and spline attachment	Two components have to be aligned each other	6
Medium weak	Attachment with thread	One component has to be aligned with fixed component	4
Weak	Attachment can be easily disassembled	Alignment that avoids a component from obstructing other components	2
No relationship	No contact between components	No alignment required	0

Source: Gu & Sosale (1999)

Table 3. Component interrelationship score for criteria with 2 or 3 sub-criteria

Interaction	*High*	*Medium*	*Low*
High	10	3	0
Medium	3	7	0
Low	0	0	4

Table 4. Component interrelationship score for criteria with 5 sub-criteria

Interaction	*High*	*High-Medium*	*Medium*	*Medium-Low*	*Low*
High	10	7	0	0	0
High-Medium	7	8	5	0	0
Medium	0	5	6	3	0
Medium-Low	0	0	3	4	1
Low	0	0	0	1	2

Table 5. Calculation of DFE interaction score for component 1 and 2

DFE criteria	Component		Interaction score	Weight	Weighted score
	1	2			
1	*Medium*	*Low*	0	0.075	0
2	*Medium*	*Medium*	6	0.075	0.45
3	*High*	*High*	10	0.125	1.25
4	*High-Medium*	*High-Medium*	8	0.15	1.20
5	*High-Medium*	*High-Medium*	8	0.075	0.60
Attachment	*Weak*		2	0.30	0.60
Alignment	*Medium Strong*		6	0.20	1.20
Total					**5.30**

5. RESULTS

5.1 Components Grouping by Using Hierarchical Clustering Algorithm (HCA)

Components grouping using HCA are performed by searching the highest interaction value between components. Components with the highest interaction value will be gathered in one group. This iteration then continued until all of the components have been included and results in one big group of components. The outcome of HCA is a dendogram (see Figure 2) that will be cut at a certain threshold value based on the predetermined number of modules so that components grouping into each module can be known.

The number of modules is determined by looking at the functional characteristic of components of emergency lamp product, which are modules that consists of components functioning as product main frame, electronics, output element, appendage and activator (on-off). Modules that are obtained from the above processes are as follows:

1. Module 1 (Main Frame): Housing Delta 8Ah, Battery Holder, Screw FSC 13, Reflector, Screw FSC 11, Cover, Rubber Band, Seal String and Tin Seal.
2. Module 2 (Output Element): TL Ring Lamp and Lamp Holder.
3. Module 3 (Electronics): Battery 4Ah, Battery Cable, Power Cord, Mini Trafo 12V AC and PCB DT-07.
4. Module 4 (Appendage): Cord Holder.
5. Module 5 (Activator): SISO Switch.

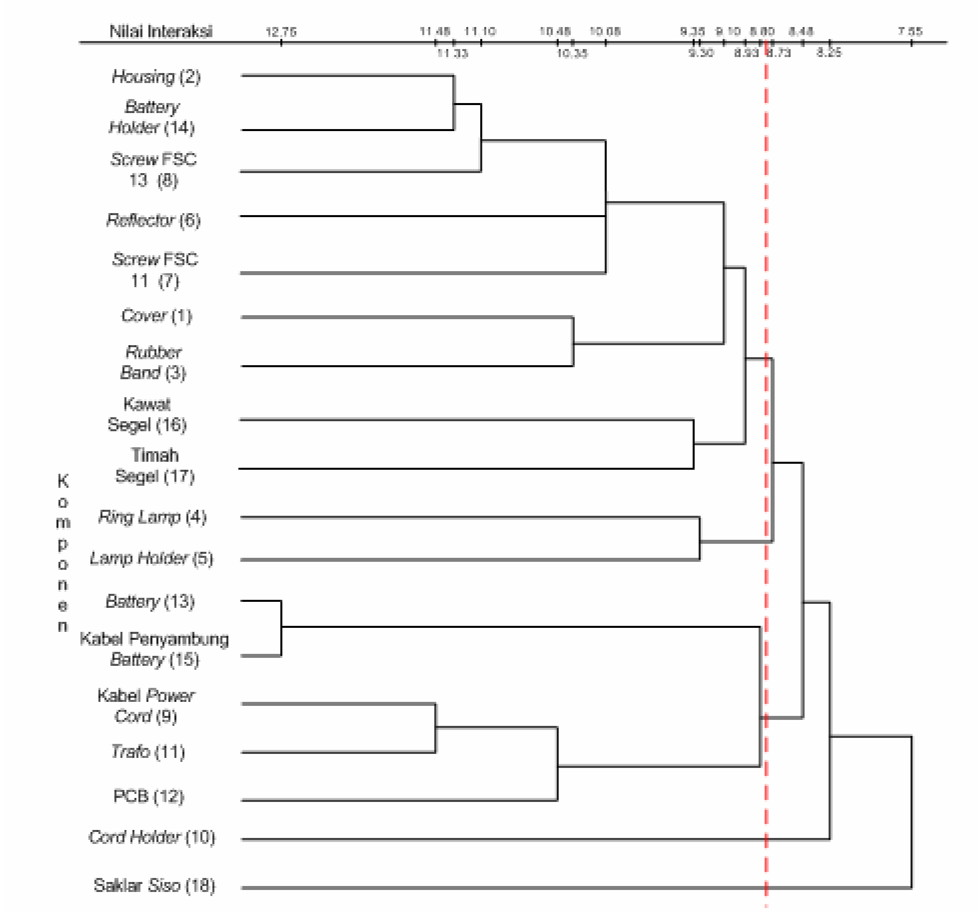

Figure 2. Dendogram from HCA and its cutting location

5.2 Product Redesign

After modularization process, redesign are performed on some components/modules to further support in creating product that is easy to remanufacture and gives less adverse impact on the environment. Table 6 shows comparison between current condition and after redesign process of Delta 8Ah emergency lamp product. Figure 3 illustrates several redesigned components.

Table 6. Comparison between current condition and redesign result of Delta 8Ah emergency lamp product

No	Component	Current Condition	Redesign Result
1	Reflector	4 screw holes	2 screw holes
		4 holes for lamp holder	3 holes for lamp holder
2	Lamp holder	4 pieces	3 pieces
3	Housing Delta 8Ah	3 screw holes for attaching PCB	2 screw holes for attaching PCB
		4 screw holes for attaching reflector	2 screw holes for attaching reflector
		4 screw holes for attaching battery holder	2 screw holes for attaching battery holder
		2 screw holes for attaching mini trafo	1 screw hole for attaching mini trafo, small feature for mini trafo holder, shifting the position of mini trafo 2 cm upward
		-	Feature for power cord opening
		-	Elastic cover for power cord opening
4	Cord holder (module 4)	Required	None
5	Battery holder	Height: 100 mm	Height: 40 mm
		Material: steel plate	Material: polypropylene plastic
6	Battery, Battery cable, Power cord, Mini trafo and PCB DT-07	Not integrated into a same module	Integrated as a module
6	Screw FSC 11	4 pieces	2 pieces
7	Screw FSC 13	9 pieces	5 pieces

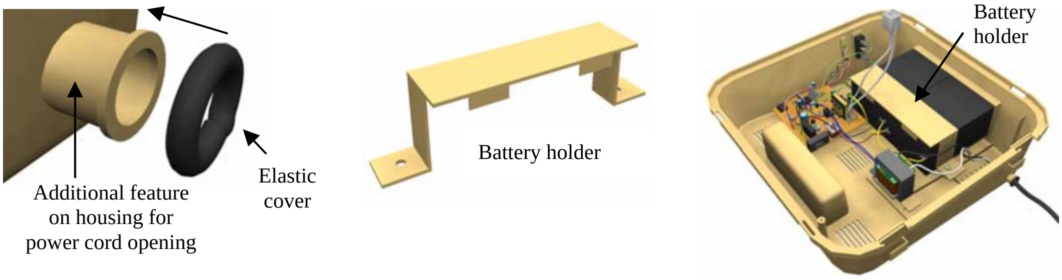

Figure 3. Illustration of several redesigned components

Advantages that can be gained from the product modularization and redesign process of Delta 8Ah emergency lamp product are as follows:

- In performing remanufacturing, components can be identified faster because they have been formed / integrated to certain module.
- Time required for disassembly and assembly steps is decreased because the number of fasteners and tools used are reduced.
- In the cleaning step, housing component can be cleaned easier because the number of holes and corners are minimized.
- In the sorting step, separation of components that can and cannot be reused can be directly known because they have been clearly divided into their modules.
- Reduction of several components and material change of battery holder component lessen negative impact on the environment.

6. CONCLUSION

Based on the above discussion and analysis, there are several conclusions that can be made:

1. As references for modularization process, there are 7 DFR criteria and 5 DFE criteria, which each of those criteria has certain weight and consists of several sub-criteria.
2. Based on DFR criteria, DFE criteria, component interrelationship criteria, final interaction matrix and HCA algorithm, Delta 8Ah emergency lamp product can be divided into 5 modules, i.e. main frame, electronics, output element, appendage and activator (on-off).
3. As the results of redesign, there are reductions in the total number of screw FSC 11, screw FSC 13 and cord holder components; changes in the material used for battery holder component; addition of features on housing component and a new component called elastic cover; simplification of reflector and housing components; and a reduction in the additional tools required for disassembly and assembly processes. In addition, after product redesign, the number of modules becomes 4.

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