Faculty of Manufacturing Engineering

APPLICATION OF DFA AND AHP IN DESIGN EVALUATION PROCESS FOR ENVIRONMENTAL PERFORMANCE IN THE CONCEPTUAL DESIGN STAGE – A CASE STUDY

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2015

DECLARATION

I declare that this thesis entitled "Application of DFA and AHP in design evaluation process for environmental performance in the conceptual design stage – a case study" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

Signature : ……………………………………

Name : ……………………………………

Date : ………………………………….…

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Manufacturing System Engineering).

Signature : ……………………………………

Supervisor Name : ……………………………………

Date : …………………………………....

DEDICATION

I dedicate my dissertation work to my beloved family. A special feeling of gratitude to my loving parents, Jamaliah bte Hj Saibot and Hasan bin Sirun, and my siblings, for their continuously support and endless loves that give me strength to complete this work.

ABSTRACT

This thesis basically discusses on the application of design for assembly (DFA) method and multi criteria decision making (MCDM) tool namely analytic hierarchy process (AHP). The main objective of this study is to apply both DFA and AHP in conceptual design stage to evaluate the environmental performance of a product. Conceptual design stage is a stage where no final decision has yet been made, therefore giving more flexibility to designer to focus on environmental aspect in their design. This study was conducted by using mechanical pencil design as case study. 5 conceptual designs were developed and 3 type analysis based on Lucas DFA method were done to evaluate the design functional efficiency, feeding ratio, and fitting ratio. 10 selection criteria for AHP were considered based on literature studies which are recyclable material, renewable material, number of parts, durability, modularity, ease of maintenance, ease of disassembly, functional efficiency, feeding ratio, and fitting ratio. Through the literature study, judgements through pairwise comparison were done to the selection criteria with respect to the goal. This is to select the optimum design that has the highest environmental performance. Functional efficiency has the highest priority vector as much as 33.4% while the least important criteria is shared by feeding ratio and fitting ratio with priority vector of 1.97%. At the final stage of AHP, each alternative were sorted based on their priority vector. Conceptual design 5 was ranked 1st with priority vector of 30.41%, followed by conceptual design 2 with priority vector of 21.2%. Conceptual design 4 and conceptual design 1 followed on 3rd and 4th in ranking with priority vector of 19.49% and 15% respectively. The least preferred alternative is conceptual design 3 with priority vector of 14.02%. Then, several sets of sensitivity analysis were carried out by using Expert Choice software to study whether any changes on the selection criteria's priority vector will affect the conceptual design ranking that were obtained on previous AHP analysis.

ABSTRAK

Tesis ini membincangkan penggunaan kaedah reka bentuk untuk pemasangan (*DFA*) dan *analytic hierarchy process* (*AHP*). Objektif utama kajian ini adalah untuk menggunakan *DFA* dan *AHP* dalam peringkat konsep reka bentuk untuk menilai prestasi alam sekitar sebuah produk. Peringkat konsep reka bentuk adalah peringkat di mana tiada lagi keputusan muktamad dibuat, oleh itu memberi lebih fleksibiliti kepada pereka untuk memberi tumpuan kepada aspek-aspek alam sekitar dalam reka bentuk mereka. Dalam kajian ini juga, reka bentuk pensil mekanikal telah digunakan untuk kajian kes. 5 konsep reka bentuk telah dihasilkan dan 3 jenis analisa telah dijalankan untuk menilai kecekapan fungsi, nisbah pengendalian, dan nisbah lekapan reka bentuk tersebut. Melalui pembelajaran literasi, 10 kriteria pemilihan telah digariskan iaitu bahan yang boleh dikitar semula, bahan yang boleh dihasilkan semula secara semula jadi, bilangan bahagian, ketahanan, modulariti, kemudahan penyelengaraan, kemudahan pengasingan, kecekapan fungsi, nisbah pengendalian, dan nisbah lekapan. Melalui pembelajaran literasi juga, perbandingan antara kriteria pemilihan telah dijalankan dengan matlamat untuk memilih reka bentuk optimum yang mempunyai prestasi alam sekitar yang terbaik. Kriteria yang terpenting ialah kecekapan fungsi yang mempunyai kadar keutamaan sebanyak 33.4% dan kriteria yang paling kurang kadar kepentingan adalah nisbah pengendalian dan nisbah lekapan di mana kedua-dua kriteria tersebut mempunyai kadar kepentingan yang sama, iaitu sebanyak 19.7%. Di penghujung peringkat *AHP*, konsep reka bentuk 5 telah dipilih sebagai alternatif terpenting dengan kadar kepentingan sebanyak 30.41%, diikuti konsep reka bentuk 2 dengan kadar kepentingan sebanyak 21.2%. Kedudukan ketiga dan keempat diisi oleh konsep reka bentuk 4 dan konsep reka bentuk 1 dimana masing-masing mempunyai kadar kepentingan sebanyak 19.49% dan 15%. Alternatif di kedudukan terakhir ialah konsep reka bentuk 3 dengan kadar kepentingan 14.02%. Beberapa set analisis sensitiviti juga telah dijalankan dengan menggunakan perisian *Expert Choice* untuk mengkaji sama ada perubahan pada kadar kepentingan kriteria pemilihan akan memberi kesan kepada kedudukan reka bentuk konsep yang telah diperolehi pada analisa awal *AHP*.

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CHAPTER 1

INTRODUCTION

This chapter includes the project background, problem statement, the aim and objectives, scope and limitations, and the significance of study.

1.1 Project Background

Nowadays, people started to concern more about protecting the environment. The fact that we only have one earth make people realize how important for us to work together to reduce any negative impacts towards environment in every aspects in our life. Mahatma Gandhi once said "Earth provides enough to satisfy every man's needs, but not every man's greed" (Nayyar, 1958), which means we already have enough for what we need, not what we want. Any action or decision that only made based on our greediness will let to the damaging of our earth.

The environmental factors or requirement can be taken into count as early as at the conceptual design stage. One of approaches that can be introduced during this stage is DFA (design for assembly). By implementing Lucas DFA method during the conceptual design stage, numbers of conceptual design can be developed based on three analysis which is through functional, feeding, and fitting analysis which designer can evaluate the design's ease of assembly. With application of AHP (analytic hierarchy process), the most beneficial design can be selected based on environmental requirements. The implementation of AHP will help designer to sort the alternatives based on priority rank with respect to the goal, which in this study, to select the optimum conceptual design which have the highest environmental performance.

1.2 Problem Statement

With the raising trend for sustainable product demand, people have started to take environmental requirement into count when designing a product. Product designer needs to focus more on the designing process as he or she needs to put the environmental requirement in the process at the early stage of design process. Conceptual design stage, which is the early stage in the designing process, is the most suitable platform to perform the environmental requirement into the design stage. . In conceptual design stage, product designer can apply the design for assembly method such as Lucas DFA method in their design process in order to develop number of designs that are easy to be assemble during the manufacturing stage. To determine which design that have the highest performance in terms of environmental aspect, a multi criteria decision making (MCDM) tool namely analytic hierarchy process (AHP) can be applied. With respect to the goal which is to select the optimum conceptual design that have the highest environmental performance, the selection criteria for the AHP should be based on environmental aspect such as types of material used, number of parts, percentage of recyclable material used, and many more. Therefore, DFA and AHP can be performed together during the conceptual design stage to evaluate the environmental performance of the developed designs and also to select the optimum design that have the highest environmental performance.

1.3 Aim and Objectives

The aim of this study is to apply the design for assembly (DFA) and analytic hierarchy process (AHP) approach during the conceptual design stage in evaluating the environmental performance of a product.

The objectives of the project are:

i. To apply the design for assembly (DFA) approach and analytic hierarchy process (AHP).
ii. To identify the selection criterion based on environment requirements.
iii. To perform sensitivity analysis to verify the results.

1.4 Scope and Limitations

The study was carried out within the following limits:

i. Mechanical pencil design was used to conduct the case study.
ii. Focus on conceptual design stage.
iii. DFA based on Lucas Method.
iv. Environmental factors in AHP.
v. Software such as AutoCAD and Expert Choice 11.5 were used during the study.

1.5 Significance of Study

The study can benefit product designer as one of selection process or tools for selecting the optimum conceptual design by the application of design for assembly (DFA) and analytic hierarchy process (AHP) in terms of environmental requirement or performance.

CHAPTER 2

LITERATURE REVIEW

This chapter focused on issues related with the project. The focus will be on the application of design for assembly with analytic hierarchy process during the conceptual design in evaluating the environmental requirements on the product's early design stage.

2.1 Design for Assembly (DFA)

Design for assembly, as defined by Boothroyd & Alting (1992) is an approach used in order to design a product or part that make the assembly process easier to be executed. The importance of designing stage is such that the final cost of a product is highly contributed by its design stage. Therefore, the objective of DFA is to make the assembly process become easier and also to reduce the total parts cost. Apart from that, DFA aims are not only to reduce parts complexity and reduction in total part cost, but also reduction in time taken for assembly to be completed (Todić et al., 2012) and also to reduce the non-value added operations (Leaney & Wittenberg, 1992). Furthermore, Boothroyd & Alting (1992) has highlighted that the ease in assembly process are not depends on the product itself and its features, instead the ease in assembly process are based on the feeding or handling and the assembly process. Leaney & Wittenberg (1992) has highlighted few guidelines in order to achieve the DFA's goals. The guidelines are to reduce number of parts, product modularization, adjustment elimination, ease of feeding/handling design, able to self-aligned part design, appropriate fastening, handling and orientation minimization, gravity utilization, and part-symmetrical maximization.

The research of consideration for ease in assembly process actually have been done many years before and one of the example is back on year 1985, where Adachi et al. (1985) are working to develop a method to make the assembly process at the printed circuit board (PCB) easier (Boothroyd & Alting, 1992). The considerations or concerns that they put into the method's development are to complete the assembly process in simple steps and minimization of the parts and subassemblies' variety. In additional, Adachi et al. (1985) has presented a chart, filled with product design features which lead to easier assembly process as shown in Figure 2.1.

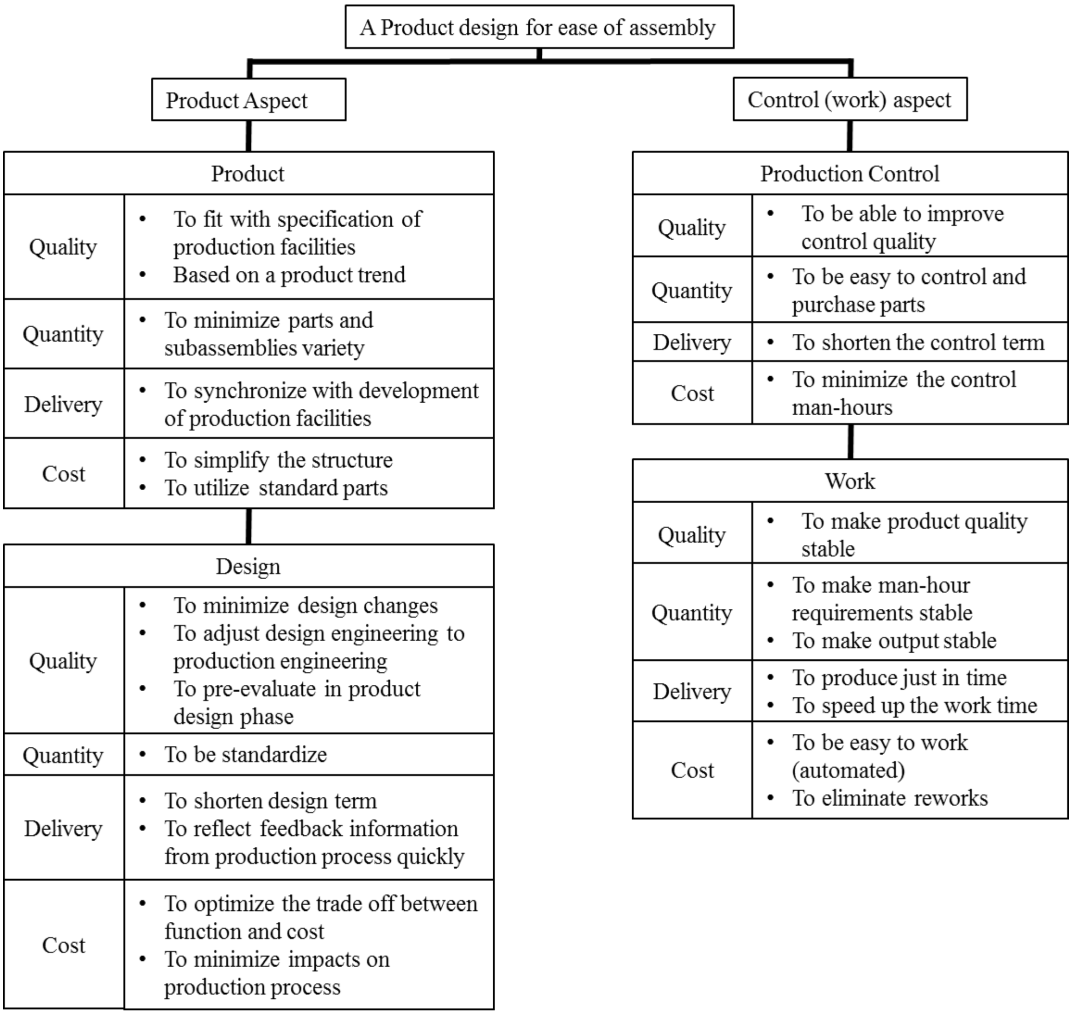

Figure 2.1: Product Design Features for Ease in Assembly Process (Adachi et al., 1985)

2.2 Lucas Method

Chan & Salustri (2003), stated that Lucas DFA method was developed by the Lucas Corp. in the 1980s. Lucas method was developed based on the level of difficulties in the assembly process, a point scale. Lucas method is based on three separate and sequential analysis which are the functional analysis, feeding analysis, and fitting analysis (Chan & Salustri, 2003), and it helps the designer to reduce the number or components and also can identify assembly issues (Barnes et al., 1997). These three analysis are actually a part of assembly sequence flowchart (ASF). This assembly sequence flowchart can be represented as follows:

1. Specification
2. Design
3. Functional analysis (1st Lucas analysis)

   If problem are identified, return to step 2

4. Feeding analysis (2nd Lucas analysis)
5. Fitting analysis (3rd Lucas analysis)
6. Assessment

   If problems are identified by the analysis, return to step 2.

Barnes et al. (1997) has put an example for Lucas DFA methodology on assembly sequences which is depicted in Figure 2.2. The diagram shows the starting point for assembly process and the appropriate sequence and whether all undertaking shown are effective. Each of the boxes shown in Figure 2.2 also indicates the requiring substantial effort to complete each process. Another assembly sequence flowchart also can be represented as Figure 2.3.

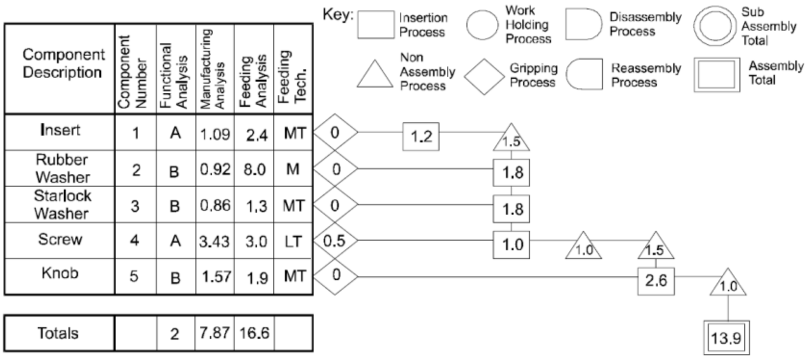

Figure 2.2: Example of Lucas DFA assembly sequence diagram (Barnes et al. 1997)

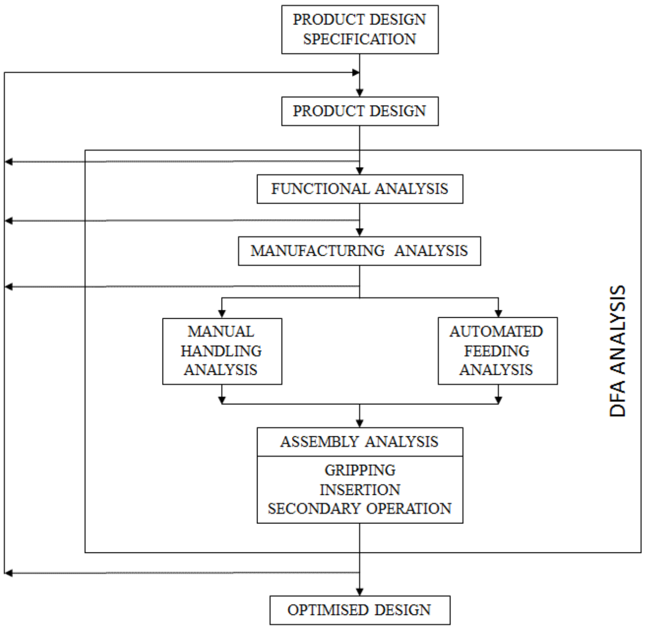

Figure2.3: Assembly sequence flowchart (Anonymous, 2015)

2.2.1 Functional Analysis

Chan & Salustri (2003) stated that in functional analysis, product's components are being monitored only for their functional purpose. The components then will be group into two group, one group which are very essential to the product's function, and another group that have less or not essential to the product's function. Let the first group named as "A" and the second as "B". Chan & Salustri (2003) in their writing has concluded the calculation for the functional efficiency. Equation 2.1 shows how to calculate the functional efficiency.

$$Functional\ efficiency\ = \left(\frac{A}{A+B}\right) x\ 100\% \qquad (2.1)$$

Functional analysis is carried out in order to reduce the number of parts in a product. Chan & Salustri (2003) added that a typical design efficiency for initial design will be 60%.

2.2.2 Feeding and Fitting Analysis

In feeding analysis, the analysis of part handling and insertion times are being done in this stage. The result of feeding analysis is the feeding ratio, which is the ratio of total feeding index over number of essential components and it shows on equation 2.2. An ideal feeding ratio is 2.5. (Chan & Salustri, 2003; Leaney & Wittenberg, 1992).

$$Feeding\ Ratio = \frac{Total\ Feeding\ Index}{Number\ of\ essential\ components} \tag{2.2}$$

The total feeding index can be calculated by referring to Table 2.1. The term "feeding" and "handling" have same meaning, where "feeding" is use for component that being handled by machine or equipment, and "handling" term refers to the manual handling mechanism (Leaney & Wittenberg, 1992).

Table 2.1: Lucas DFA method – Manual Handling Analysis (Chan & Salustri, 2003)

Handling Index = A+B+C+D			
A. Size and Weight of Part One of the following		**B. Handling difficulties All that apply**	
Very small – requires tools	1.5	Delicate	0.4
		Flexible	0.6
Convenient – hands only	1.0	Sticky	0.5
		Tangible	0.8
Large and/or heavy requires more than 1 hand	1.5	Severely nest	0.7
		Sharp/Abrasive	0.3
Large and/or heavy requires hoist or 2 people	3.0	Untouchable	0.5
		Gripping problem /Slippery	0.2
		No Handling Difficulties	0
C. Orientation of Part One of the following		**D. Rotational Orientation of Part One of the following**	
Symmetrical, no orientation required	0.0	Rotational Symmetry	0.0
End to end, easy to see	0.1	Rotational Orientation, easy to see	0.2
End to end, not visible	0.5	Rotational Orientation, hard to see	0.4

For fitting analysis, it have same method with feeding analysis, but have small difference where the value of total feeding index is change to total fitting index, thus by the ratio of total fitting index and the number of essential components will resulted to the fitting ratio which shows by equation 2.3. The ideal ratio value is 2.5 (Chan & Salustri, 2003; Leaney & Wittenberg, 1992).

$$Fitting\ Ratio = \frac{Total\ Fitting\ Index}{Number\ of\ essential\ components}$$

The total fitting index can be calculated by based on information on Table 2.2.

Table 2.2: Lucas DFA method – Manual Fitting Analysis (Chan & Salustri, 2003)

Fitting Index = A+B+C+D+E+F			
A. Part Placing and Fastening One of the following		**D. Access and/or Vision One of the following**	
Self-holding orientation	1.0	Direct	0.0
Requires holding (Plus 1 of the following)	2.0		
Self-securing (i.e. snaps)	1.3	Restricted	1.5
Screwing	4.0		
Riveting	4.0		
Bending	4.0		
B. Process Direction One of the following		**E. Alignment One of the following**	
Straight line from above	0.0	Easy to align	0.0
Straight line not from above	0.1	Difficult to align	0.7
Not a straight line	1.6		
C. Insertion One of the following		**F. Insertion Force One of the following**	
Single	0.0	No resistance to insertion	0.0
Multiple insertions	0.7	Resistance to insertion	0.6
Simultaneous multiple insertions	1.2		

2.3 Analytic Hierarchy Process (AHP)

Analytic hierarchy process is an evaluation theory where discrete and continuous paired comparison ratio scales are derive by it (Saaty, 1987).

2.3.1 The functions of analytic hierarchy process

Analytic hierarchy process offers three main functions which are the structuring complexity, measurement, and synthesis (Forman & Gass, 2001). Forman & Gass (2001) stated that Thomas L. Saaty, who develop AHP, has found an easier way to handle complexity and based on the way people treat the complexity, he found that it is common to structure the complexity based on homogenous cluster or factors.

Scale measurement have four types which are nominal, ordinal, interval, and ratio. Ratio measurement can be used to show proportional value and also as a basic for physical measurement. Based on this acknowledgement, Saaty has derived the ratio-scale measures which can be explicated as the final ranking priorities by use paired comparison of the hierarchical factors. Forman & Gass (2001) has highlighted the necessary uses of ratio-scale priorities for any hierarchical-based methodology for components over the lowest level of the hierarchy. The reason is due to the priorities of the component at any level of the hierarchy are adamant by the result from multiplication of the priorities of the components and priorities of the parent component.

Forman & Gass (2001) added that analytic hierarchy process offer the synthesis function where the large numbers of aspects in the hierarchy can be measured and synthesize while facilitate the analysis.