Integration of design for modularity and design for assembly to enhance product maintainability

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ABSTRACT

This paper discussed the relationship between design for modularity and maintenance in order to extend product life. Modularization can be described as an engineering approach to simplify component or product configuration as functional independence it creates. This loose interaction characteristic makes the maintenance process easier. In this preliminary study, experiment is conducted to measure the maintainability in term of maintenance time. A case study of drum brake is carried out to clarify this work. At this stage, a survey and time study have been conducted and the result is presented.

Keywords: Maintainability, modularity, assembly digraph, assembly type, accessibility

1. INTRODUCTION

Product design and assembly type will affect the maintainability efficiency; this is why companies are struggling to achieved not only the best design but also provide a maintenance-friendly features that could increase their product performance. Proper and simpler maintenances can extend product life-cycle. There are many approach have been taken such as Design for Maintainability, Life-Cycle Cost (LCC), Design for Serviceability and many more. In maintenance time to repair (TTR) is very crucial and it depends mainly on the product/system configurations. By simplifying the product configuration, repair and maintenance can be accomplish in shorter time Modularity is believed capable to makes maintenance simpler due to functional independence created in the product configuration [1].

The paper is organized as the following steps. It begins with introduction and then the result of the customer survey result is tabulated. Furthermore the methodology used is presented. A time study is also conducted. Result is then discussed and the paper ends with conclusion.

2. DESIGN FOR MODULARITY AND DESIGN FOR ASSEMBLE

Design for Assembly have similar characteristic in nature to Design for Modularity, where they try to achieve the highest level of simplification and standardization in product design. There several similarity features that DFA and DFMo have as summarized in Table 1.

Table 1 Similarity between DFA and DFMo

Characteristic	Design For Assembly (DFA)	Design For Modularity (DFMo)
1- Standardize Part	Standardize to reduce part variety.	Standardize and use common parts and materials.
2- Reduce Part	Simplify the design and reduce the number of part.	Modularize multiple parts into single subassemblies.
3- Insertion Part	Insert new part into an assembly from above.	Design for ease of assembly.
4- Orientation	Analyze each part for ease of handling.	Design for parts orientation and handling.
5- Assembly	Provide alignment features.	Building in self-fastening features.

3. RELATED WORKS

In maintainability analysis, disassembly and reassembly is the most critical factor [3]. Balanchard et al. [4] and Cunningham and Cox [5] include time taken in disassembly, assembly, localization and isolation of least replacement of components. There are several quantitative measure used in determining maintenance efficiency. Maintainability can be measured based on time consume in completing the task or mean time to repair (MTTR) and maintenance activity time as claimed by Utez [2]. Ehud et al. [6] measure disassembly using difficulty rating, where accessibility, position, force, additional time and special problems is interpreted based on difficulty of disassembly task. Cost of assembly/disassembly is critical only in selection of appropriate tools [7]. Meanwhile Tsai et al. [8] introduce modularity operations and considering reliability and maintenance cost as a measure. They also list five problems that should be considered in maintainability analysis, which are disassembly sequence, selection of tools, time required for disassembly and human factor issues such as accessibility and visibility. Clark and Parsch [9] and Parsch and Ruff [10] taken diagnosability aspect as main consideration in determining maintainability, while Wani and Gandhi [11] consider tribology aspect. Maintainability also should consider optimal resources such as personnel and support equipment [12]. A maintainability software named Relex, use the same approach where measured time is the major output.

4. METHODOLOGY

This study involves development of Maintainability Index Template (MIT) based on several established formulas. By implementing the characteristics and guideline given by the developed approach named Design for Assembly (DFA) and Design for Modularity (DFMo), the formulas are developed.

5. CASE STUDY

For this work, a case study of rear motorcycle brake system is used. For that purpose, several experiments have been conducted to determine mean time by involving operator with different background from beginner with no experience to expert whom dealing with the job daily. From the observations, indicates that time needed is between 1 to 5 minutes as shown in Table 3. The objective of the experiment is to establish a standard time for maintaining the targeted parts for this case, brake shoe. Figure 4 show the model that been used for the experiment.

Table 3 Experimental Result

Operator Level	Average Time, t_{avg}
Beginner	5 min 6 sec.
Intermediate	2 min 22 sec.
Expert	1 min 15 sec.

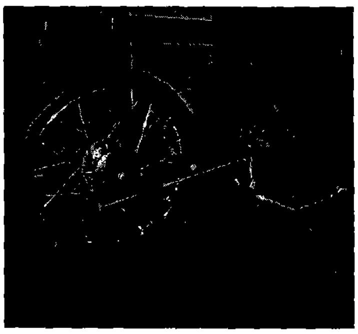

Figure 4 Rear brake assembly

Each steps involve in disassembly process are recorded. Figure 5 shows the disassembly steps. After that, the disassembly digraph is constructed to demonstrate the disassembly process. Figure 8 depicts the disassembly digraph. The disassembly process starts by unscrewing the nut from the shaft (Part no. 2). The numbers represent the components as listed in Figure 5 and the arrows demonstrate the sequence of disassembly process till the targeted parts is achieved. Time is taken after the brake shoes are disassembled. As a result from the simulation, the average time is about 2 to 5 minutes for disassembling the parts till accessing the brake shoe as simplified in Table 2.

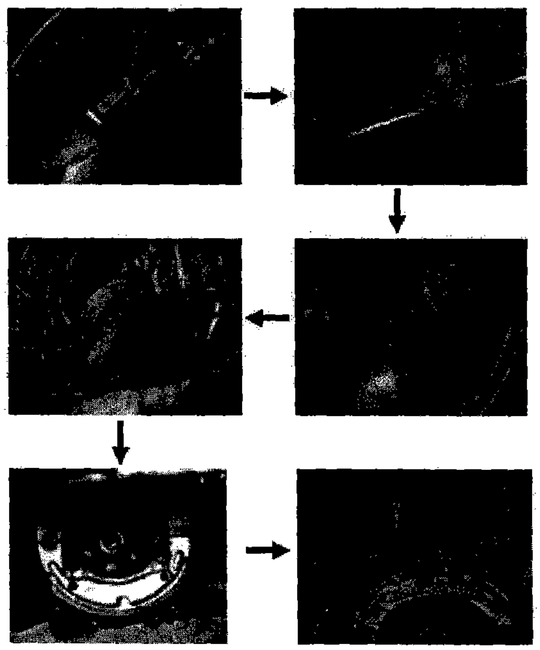

Figure 5 Brake shoes disassembly process

5.1 Maintainability Index Calculation

The maintainability index is calculated based on the assembly characteristics and the components features. For example the harder component to be access whether the component is located inside other components or it is blocked by other components, the lower maintainability index. Here the most important factor are the assembly type and location of the components. So that formula have been derived as shown in Figure 6 [13].

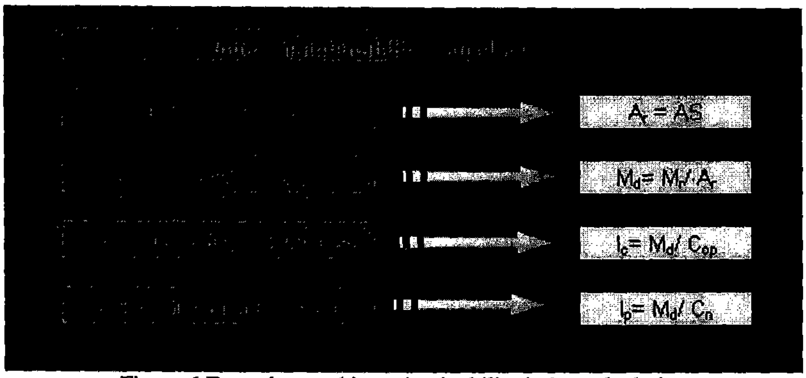

Figure 6 Formulas used in maintainability index calculation

Where;

M_T = Maintenance Frequency (Rare = 1, Seldom = 2, Frequent = 3, Most Frequent = 4)
CP = Critical Path, (i = 1, 2 ......n)
AS, = Assembly Score for assembly n=i
AN = Assembly Number
C_n = Total Number of Components in the Product
C_{cp} = Total Number of Components in the Path

In determining the component maintenance frequency, as survey have been conducted and as a result, most of the customer claimed that the most frequent (every 4-6 months) is the brake shoe which is about 71.5% as shown in Table 4. From here, quantitative weightage is given as 1 to 4.

Table 4

Component	# Respondent	Percentage
Brake Shoe	25	71.5%
Brake Lining	1	2.8%
Spring	5	14.3%
Paddle	2	5.7%
Brake Rod	2	5.7%

After that, based on the formula, the maintainability index of the selected case study is determined. Table 5 shows the result of the rear drum brake assembly maintainability index.

Table 5 Result from the calculation

Rear Brake Drum Assembly					
#	Component	Frequency, Mr	Critical Path, Cp	As. Score, Ar	Maint. Index
1	Axle Rear Wheel	1	1	14	0.07
2	Rear Brake Panel Side Collar	1	2	18	0.06
3	Rear Brake Panel Component	1	3	22	0.05
4	Shoe Brake Component	4	4	26	0.15
5	Spring Brake Shoe	3	5	30	0.10
6	Rear Brake Cam	1	6	34	0.03
7	Dust Seal Brake Cam	2	5	30	0.07
8	Rear Brake Indicator	1	3	22	0.05
9	Bolt Flange 6x28	2	3	22	0.09
10	Nut Hexagon 6mm	2	1	14	0.14
13	Bolt Flange 6x32	2	5	42	0.05
14	Nut Flange 6mm	2	1	14	0.14
15	Rear Brake Arms	1	2	18	0.06
16	Nut Hexagon 8mm	2	1	14	0.14
18	Rubber Stopper Arm Wheel	2	3	18	0.11
19	Bolt Brake Stopper	2	5	36	0.06
20	Rear Brake Rod	1	4	26	0.04
21	Nut Brake Road Adjustable	2	1	14	0.14
22	Joint Brake Arms	1	2	18	0.06
23	Spring Brake Rod	2	3	22	0.09
				Total =	1.68

6. MAINTAINABILITY INDEX TEMPLATE

To assist in the product maintainability calculation, a template using Microsoft Excel have been developed. The user could display the result after completing the steps involve. The steps are;

Step 1: Identify number of components
Step 2: Determine the type/number of assembly for each of the components
Step 3: Established the critical path
Step 4: Construct the assembly/disassembly digraph
Step 5: Calculate the maintainability index

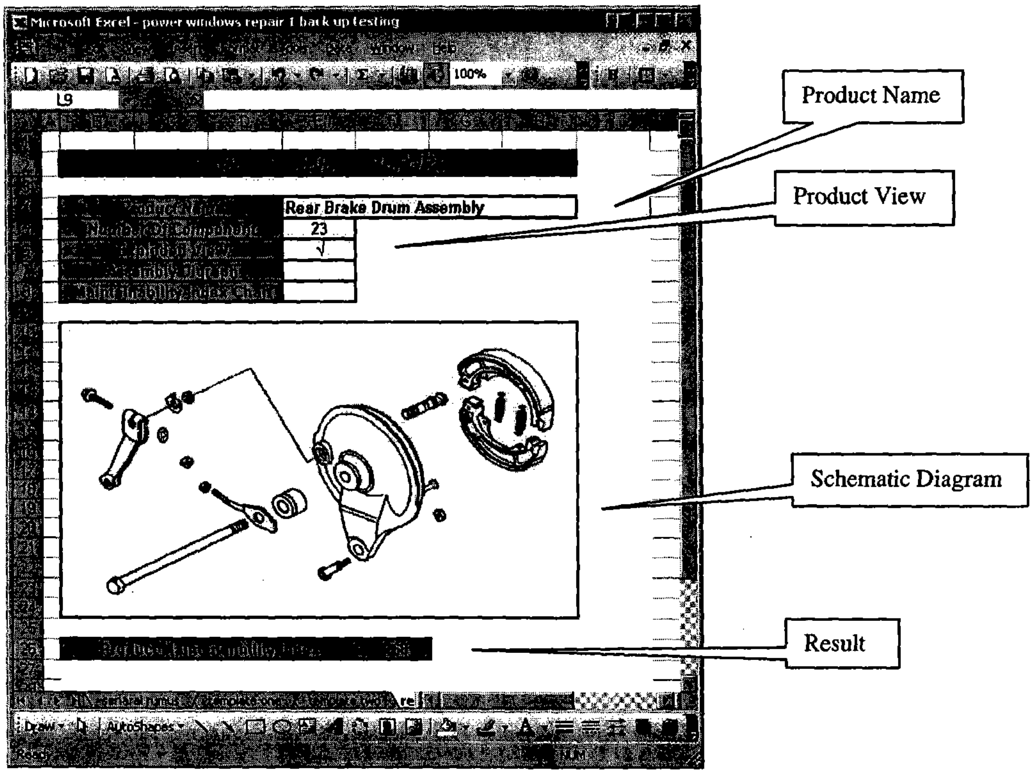

Figure 7 A template used in automating maintainability index calculation

7. CONCLUSION

The study indicated that maintainability depends on the component accessibility, location of the targeted components and the skill of the operator. The lesser workload requires in accessing the component, the better maintainability. Moreover the higher level of skill of the operator, the faster maintenance can be done. The development of the Maintainability Index Template could help in determining maintenance efficiency of the product.

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