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EFFECT OF DESIGN FOR MODULARITY ON PRODUCT MAINTAINABILITY – A PRELIMINARY STUDY

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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, time

INTRODUCTION
Proper maintenances can extend product life-cycle. 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].

This study is split into three phases. Phase 1 involve determination of maintainability index based existing quantitative measure such as time, accessibility and assemblability. Phase 2 consist of construction of new index of maintainability by taking into consideration every aspect and parameter that could affect the maintenance including frequency of maintenance and repair. In Phase 3, the modularity effect to the maintainability index is measured by conducting several case studies. This paper is part of phase 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.

RELATED WORKS
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]. 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. 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].

CUSTOMER SURVEY
A survey has been conducted to identify the most frequent part that requires routine maintenance or repair. There are two types of customer have been shortlisted, i.e. the customer who directly used the

product and the mechanic who dealing with repair, replace or maintain the product. Note that tires and tube are not taken into consideration. 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 1. This component is used to stop drum brake rotation by providing restraint to the inner brake drum surface. From mechanic point of view, 72% of the brake shoe needs to be change and only 14% each requires cleaning or adding oil as shown in Figure 1. As shown in Figure 2 most of the user claimed that assembly method and component location plays an important role in disassembly process.

Table 1

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%

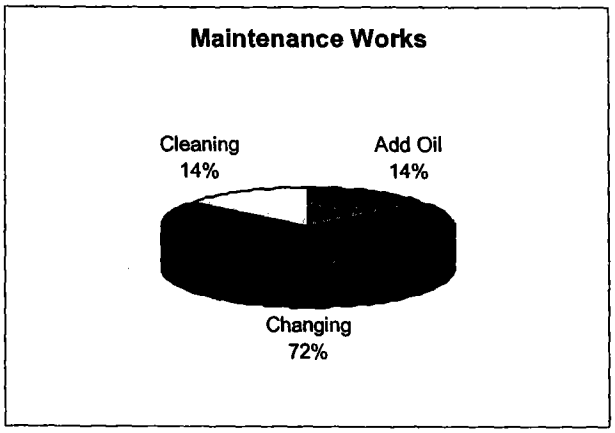


Fig. 1 The most frequent maintenance works for drum brake.

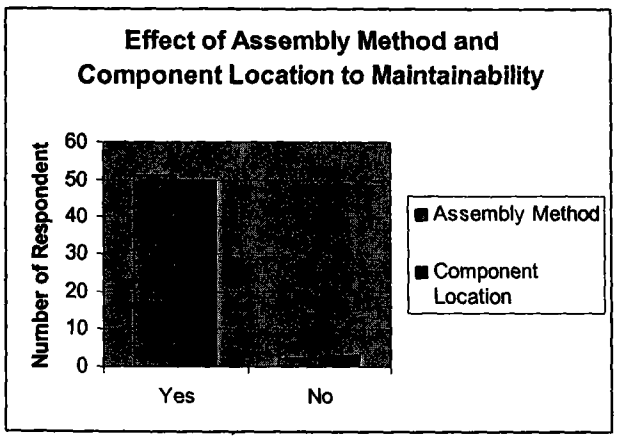


Fig. 2 Customer responds on effect of assembly method and component location to maintenance.

From the survey, the customer recommended that for future design of the drum brake, the configuration need to be simplified and should be handled by a skillful and experience mechanic.

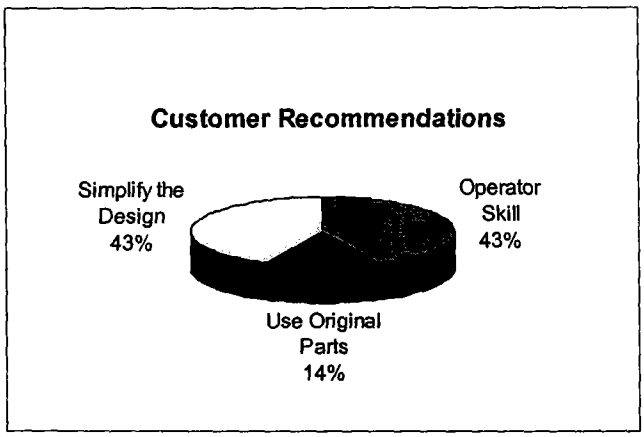


Fig. 3 Customer recommendation

METHODOLOGY

For this work, the maintainability is studied based on maintenance time. Experiment will be conducted by involving operator with different background from beginner with no experience to expert whom dealing with the job daily. The overall methodology used in this project is as shown in Figure 4.

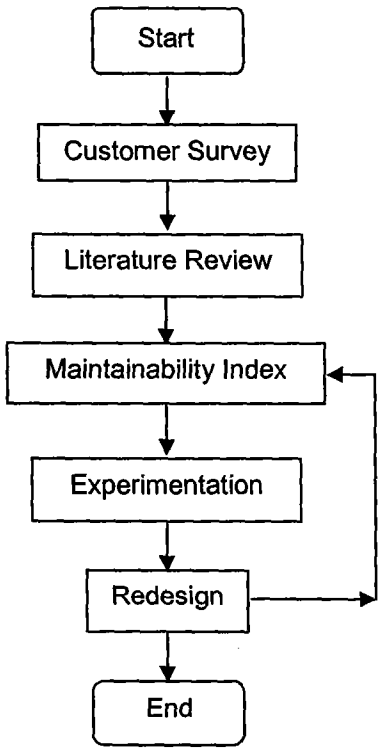
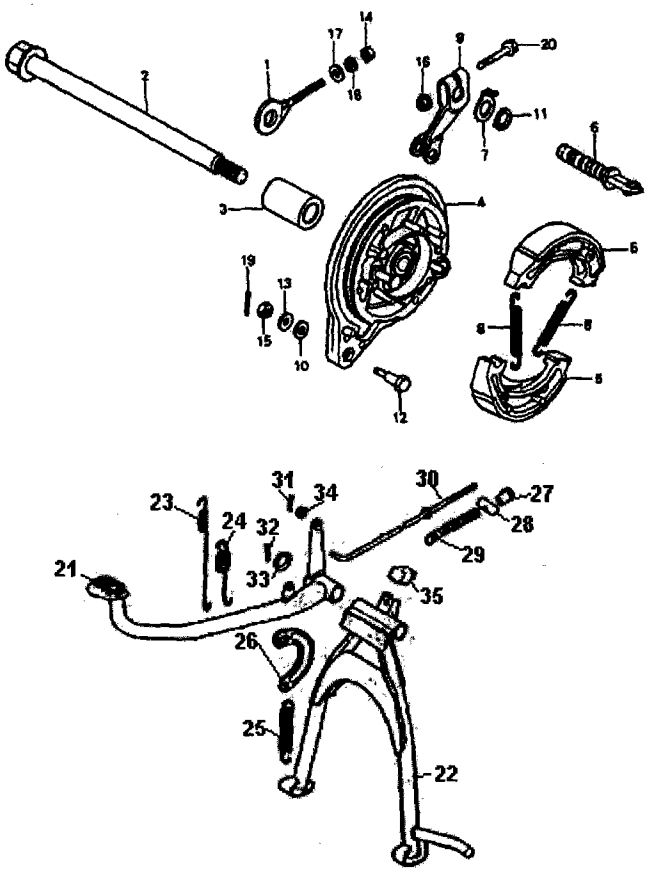


Fig. 4 The overall methodology of the study

Motorcycle braking system consists of several components such as drum brake, brake lining, paddle and brake shoe. As a result form survey, brake shoe is the most frequent. In order to access this part, the operator requires disassembling several other parts such as motor cycle wheel, shaft, brake cam lever and etc. Figure 5 show the brake system of the motorcycle and its component label. This will prolong in time to repair (TTR) or maintain (TTM) of the desired parts. Moreover the multi-type of assembly methods used also contributing to the complexity of the process. For that reason, an experiment regarding to the motor cycle brake system maintenance need to be studied.



Part Name	# Part	Quantity
Chain Adjuster	1	1
Rear Axle Bolt	2	1
Rear Wheel Spacer	3	1
Rear Backing Plate	4	1
Brake Shoe	5	2
Brake Shaft	6	1
Rear Brake Indicator	7	1
Brake Shoe Spring	8	2
Brake Cam Lever Rear	9	1
Washer 1	10	1
Seal	11	1
Rear Backing Plate Bolt	12	1
Washer 2	13	1
Chain Adjuster Nut	14	1
Rear Backing Plate Nut	15	1
Side Stand Bolt	16	1
Washer 3	17	1
Washer 4	18	1
Split Pin	19	1
Brake Lever Nut	20	1
Paddle	21	1
Stand	22	1
Spring, Stop Switch	23	1
Spring, Paddle	24	1
Spring, Stand	25	1
Hook	26	1
Nut	27	1
Pin	28	1
Spring	29	1
Rod	30	1
Pin M2x16	31	1
Pin M2x16	32	1
Washer, M17x22	33	1
Washer, 5mm	34	1
Rubber Cushion	35	1

Fig. 5 An exploded view and component listing of motorcycle drum brake assembly

EXPERIMENTAL SETUP

The objective of the experiment is to investigate the disassembly time for the brake shoe for repairing or replacement. Figure 6 demonstrate the rear braking system to represent the rear braking system of the motorcycle.

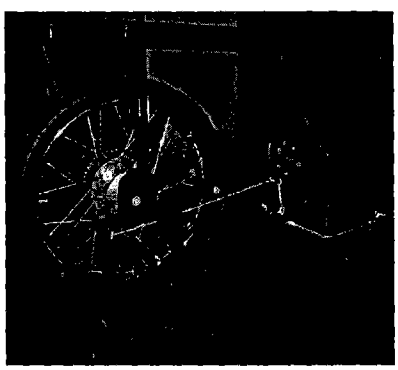


Fig. 6 Rear brake assembly for experimentation

Each steps involve in disassembly process are recorded. Figure 7 show the disassembly steps.

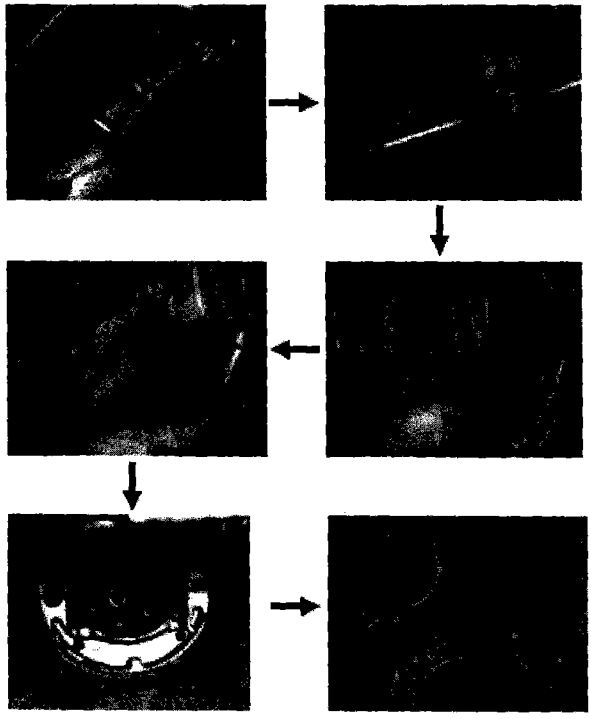


Fig. 7 Brake shoes disassembly process

After that, the disassembly digraph is constructed to demonstrate the disassembly process. Figure 8 depicts the disassembly digraph. The disassembly process start by unscrewing the nut from the shaft (Part no. 2)

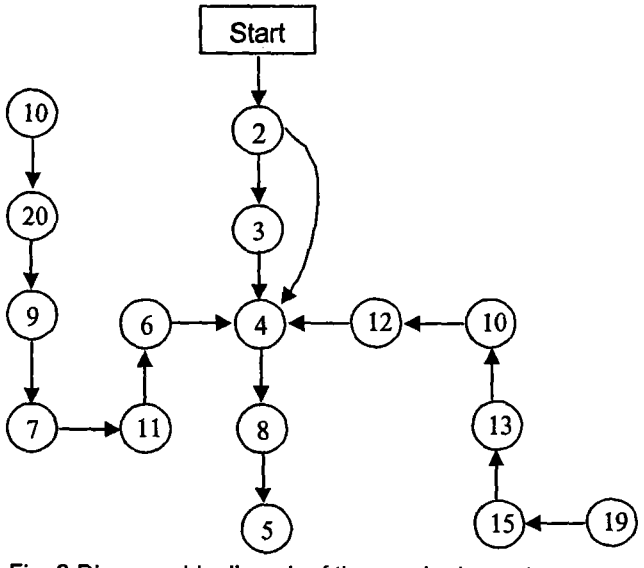


Fig. 8 Disassembly digraph of the rear brake system assembly

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.

SIMULATION RESULT

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.

Table 2. Experimental Result

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

CONCLUSION AND FUTURE WORKS

The study indicated that maintainability can be measured on time basis and it 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.

For the future work, other aspect such as frequency of component to be maintained and effect of assembly type for maintainability will be studied.

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