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Utilization of Design for Assembly Guideline to Enhance Product Maintainability

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Abstract: This study discussed the relationship between design for assembly and maintainability in order to remain product/system performance and at the same time to extend their life. The maintenance efficiency is measure based on maintainability index, which is derived based on several assembly criteria such as disassembly, assembly direction and tools used. To increase the maintainability, redesign of the potential components based on design for assembly guideline have been made. A case study of drum brake is carried out to clarify the work.

Key words: Maintainability, design for assembly, assembly criteria

INTRODUCTION

Maintainability is a design attribute of a product or system and plays significant role during their usage. Product or system with maintenance-friendly features will resulting in ease of maintenance, hence contributes to the life extension and cost reduction. Maintainability can be described as the ease of maintenance and resources at retaining equipment in or restoring it to a specified operational condition (Rosenberg, 1990). Anonymous (1990) defines maintainability as the ease and speed with which any maintenance can be carried out on an item of equipment. It's a function of equipment design and maintenance task design (including use of appropriate tools, jigs and work platforms). In maintenance, time to repair (MTTR) is very crucial and it depends mainly on the product/system configurations (Utez, 1983). By simplifying the product configuration, repair and maintenance can be accomplished in shorter time. The time is also including the disassembly, reassembly, localization and isolation of least replacement of components (Cunningham and Cox, 1972; Vujesovic *et al*., 1995; Balanchard, 1995). There are two aspects of maintainability i.e., serviceability which can be described as the probability of returning the item to normal service and repairability or in other words the probability of repairing the actual or impending fault. But the problem of inconsistency will occurred if time become the only quantitative measures of the maintainability, because time depends on personnel skill and support equipment (Wani and Gandhi, 1999). Tsai *et al*. (2003) find out that 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 and they introduce modularity approach to the system and claimed for cost reduction. Rather than that other aspect such as diagnosability (Clark and Paasch, 1996; Paasch and Ruff, 1997) and tribology (Wani and Gandhi, 2002) also been considered. Less effort on effect of assembly criteria to maintainability have been studied elsewhere, but its influence should not be neglected.

In this study, several assembly criteria have been considered in determining maintainability index and it begins with introduction and then the result of the customer survey result is tabulated. Furthermore, the methodology used is presented. Result is then discussed and the several redesigns solution to enhance the maintainability is suggested and the paper ends with conclusion.

DESIGN FOR ASSEMBLY GUIDELINE

Design for assembly is an approach to designing products with ease of assembly in mind. The aim of Design For Assembly (DFA) is to simplify the product so that the assembly process become faster and cost of assembly is reduced. This results in higher profit to the

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manufacturer and can also add value for the customer. There are some basic guidelines for DFA (Boothroyd and Dewhurst, 1989).

- Minimize part count by incorporating multiple functions into single parts.
- Modularize multiple parts into single subassemblies.
- Assemble in open space, not in confined spaces or preferred stacked assemblies.
- Use standard parts to reduce part.
- Maximize part symmetry to provide orienting features.
- Insert new parts into an assembly from above (z-axis)
- Eliminate fasteners, if not, placed fasteners away from obstructions.
- Ensure sufficient space between fasteners and other features for a fastening tool.

MATERIALS AND METHODS

For this research, the maintainability is investigated based on assembly criteria. After the components in the product or system are listed, several maintenance parameters such as maintenance rate, critical path and selected assembly criteria need to be identified. After that the maintainability index of the product or system can be calculate (Fig. 1).

The motorcycle braking assembly is used a case study and it consists of several components such as drum brake, brake lining, paddle and brake shoe. One of the parameter considered in the maintainability index is maintenance rate or identification of the component, which required the most frequent maintenance. In order to identify the components, a survey has been conducted.

Customer survey: In this study, three categories of respondent have been selected, beginner, intermediate and expert. The first category is the user who directly used the product but have no experience of maintenance works, the second category is similar but the user have experience before and the third category the mechanics who dealing with repair, replace or maintain the product everyday. Note that tires and rubber tube are not taking into consideration in the maintenance. 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 used to decelerate the drum brake rotation by providing restraint to the inner brake drum surface. And the most interesting thing is that most of the user claimed that assembly method and component location plays the most important role in maintenance process. About 43% out or 35 customer recommended that for future design of the drum brake, the configuration need to be simplified and maintenance task should only be carried out by a skillful or experience mechanic.

Table 1: Result of survey

Component	No. of 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

Table 2: Time study result

Operator level	Average time (t_{avg})
Beginner	5 min 6 sec
Intermediate	2 min 22 sec
Expert	1 min 15 sec

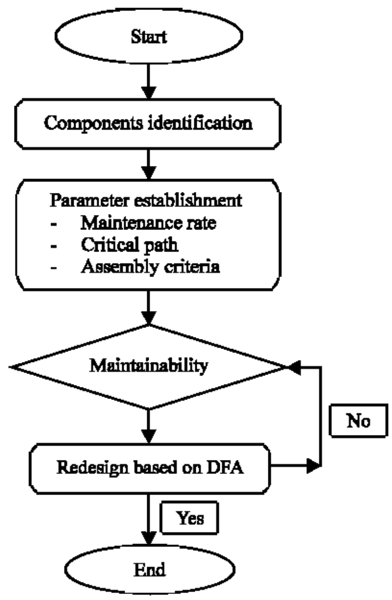


Fig. 1: The overall methodology of the study

Before the maintainability of the products is measure, a time study has been conducted. The objective of the experiment is to investigate the effect of skill level to the disassembly time of the brake shoe as the most frequent component to be maintained. To implement the study, a model of rear motorcycle brake assembly has been fabricated. Figure 2 shows the rear braking system to represent the real rear braking system of a motorcycle. The components used are standard part and commonly used by most of the motorcycle model including wheel, drum brake, brake pad and paddle. The result shows that the longer time needed by the most of the motorcycle user as they can be categorized as the beginner (Table 2).

Table 3: Result of maintainability index of the rear brake assembly

Ref. No.	Names of components	Maintenance frequency (M_f)	Critical path (C_p)	Assembly score (A_s)	Maintainability degree (M_d)
1	Axle rear wheel	1	1	14	0.071
2	Rear brake panel side collar	1	2	18	0.056
3	Rear brake panel component	1	3	22	0.045
4	Shoe brake component	4	4	26	0.154
5	Spring brake shoe	3	5	30	0.100
6	Rear brake cam	1	3	12	0.083
7	Dust seal brake cam	2	2	8	0.250
8	Rear brake indicator	1	1	4	0.250
15	Rear brake arm	1	1	14	0.071
18	Rubber stopper arm cushion	2	1	4	0.500
19	Bolt brake stopper	2	1	14	0.143
20	Rear brake rod	1	4	18	0.038
21	Nut brake rod adjusting	2	2	28	0.091
22	Joint brake arm	1	2	22	0.056
23	Spring brake rod	2	2	26	0.091
			Maintainability Index =		1.999

Fig. 2: Experiment set-up for time study

Determination of maintainability index: Figure 3 shows the exploded view of the rear brake system of the motorcycle and its component name. As indicated in the survey, the brake shoe is the most frequent parts that required maintenance either for replacement or for repair. So that it become the main focus or targeted parts in this study.

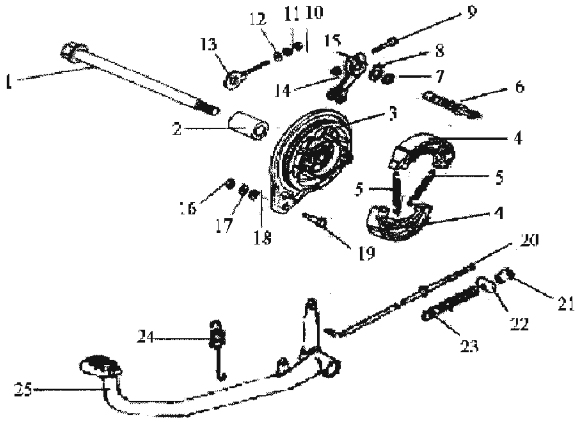
During the decomposition process, information in each steps involve in disassembly process especially the fastener used and sequence of assembly are recorded. Figure 4 shows the disassembly steps. All information is then demonstrated in the form of disassembly digraph as shown in Fig. 5. The arrows demonstrate direction of disassembly process and sequence of disassembly till the end. By using the developed equations (Abdullah and Ripin, 2005), the maintainability index is then calculated and the result is as shown in Table 3.

Maintainability index template: To assist in determining the product maintainability a Maintainability Index Template (MIT) is developed. The MIT is a template used to calculate the maintainability index of the product or system automatically. By using this template the user can determine product assembly score, product maintainability degree and product maintainability index in short time without having difficulty and this will advantages to the product design as it's introduce at early design stage. Figure 6 shows the front pages of the MIT, where user can directly key-in the information regarding to the product or system and those results are obtained. The system allow user to add and delete components as required. The result can be present in the form of standard chart as shown in Table 3.

Maintainability improvement: The safety, strength and stability factors namely the 3S effects are going to be considered in the redesign process. All these factors are related to the function of the product or system. The definition of each factor is discussed afterwards with the aids of few examples for ease of understanding the concepts.

Strength: Strength in product or system can be described as a level of loading which produces a significant change in the state of the assembled structure, e.g., collapse. For example, usually cup and basement of electrical blender are attach each other using screw, but it can be replace by using snap fit as shown in Fig. 7. These changes will affect neither the strength nor function of the electrical blender. The strength factor can be categorized into three;

- No effect to strength or function.
- Effect to strength and not to function.
- Effect to function but not to strength.



Reference No.	Component name
1	Axle rear wheel
2	Rear brake panel side collar
3	Rear brake panel component
4	Shoe brake component
5	Spring brake shoe
6	Rear brake cam
7	Dust seal brake cam
8	Rear brake indicator
15	Rear brake arm
18	Rubber stopper arm cushion
19	Bolt brake stopper
20	Rear brake rod
21	Nut brake rod adjusting
22	Joint brake arm
23	Spring brake rod

Fig. 3: An exploded view and component listing of motorcycle drum brake assembly

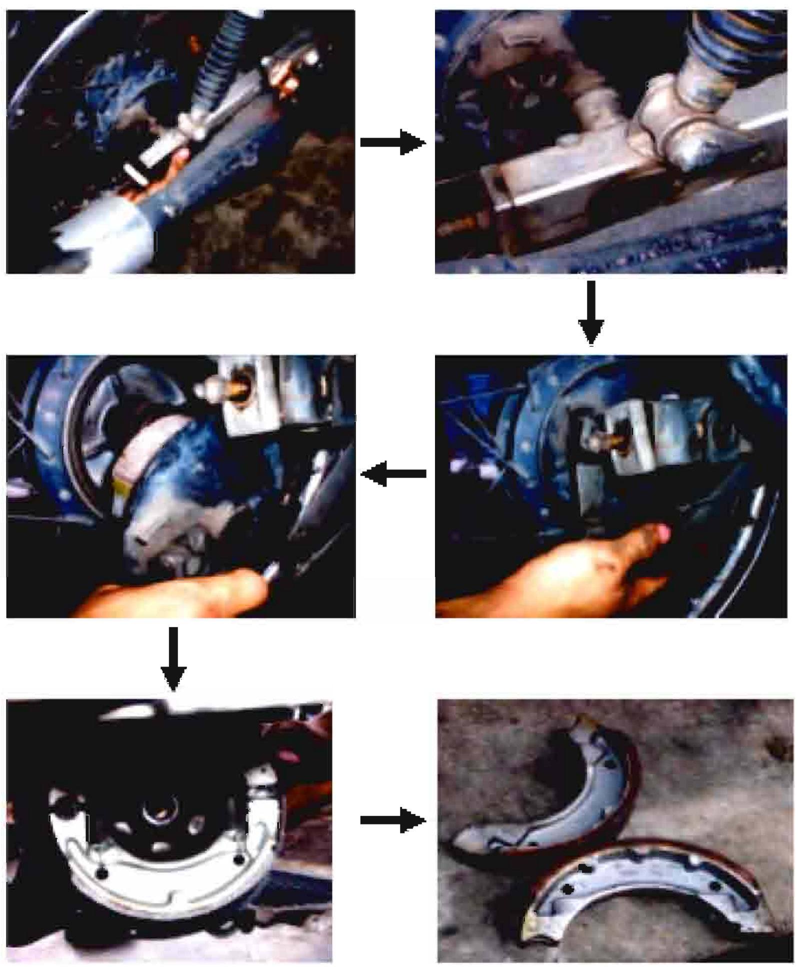


Fig. 4: Brake shoes disassembly process

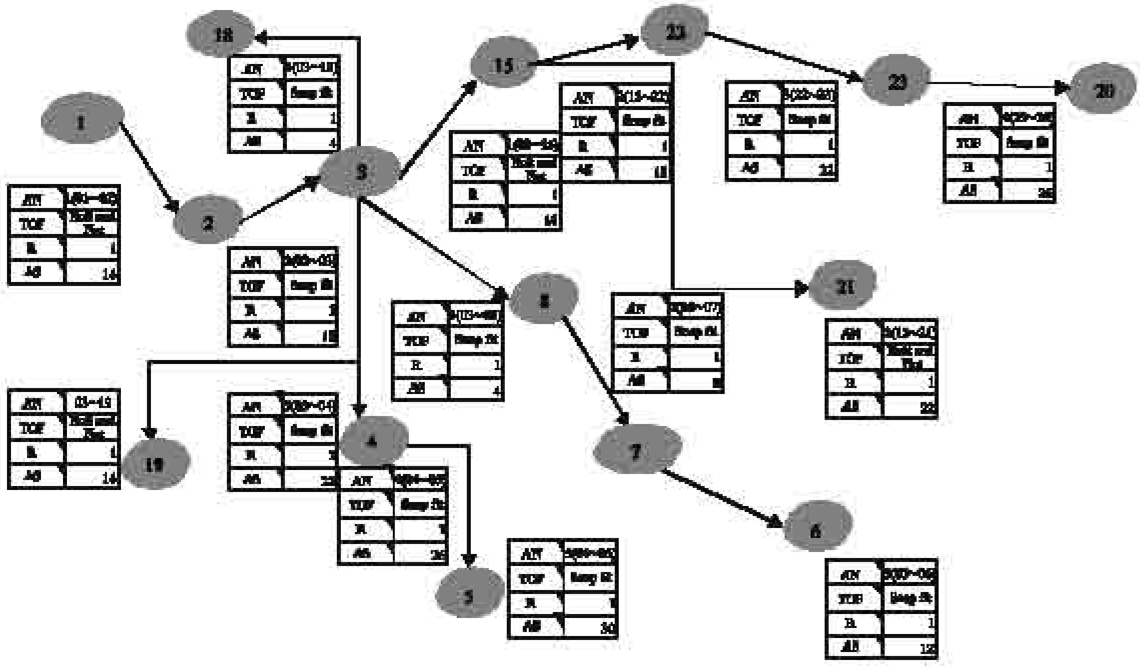


Fig. 5: Disassembly digraph of the rear brake system assembly

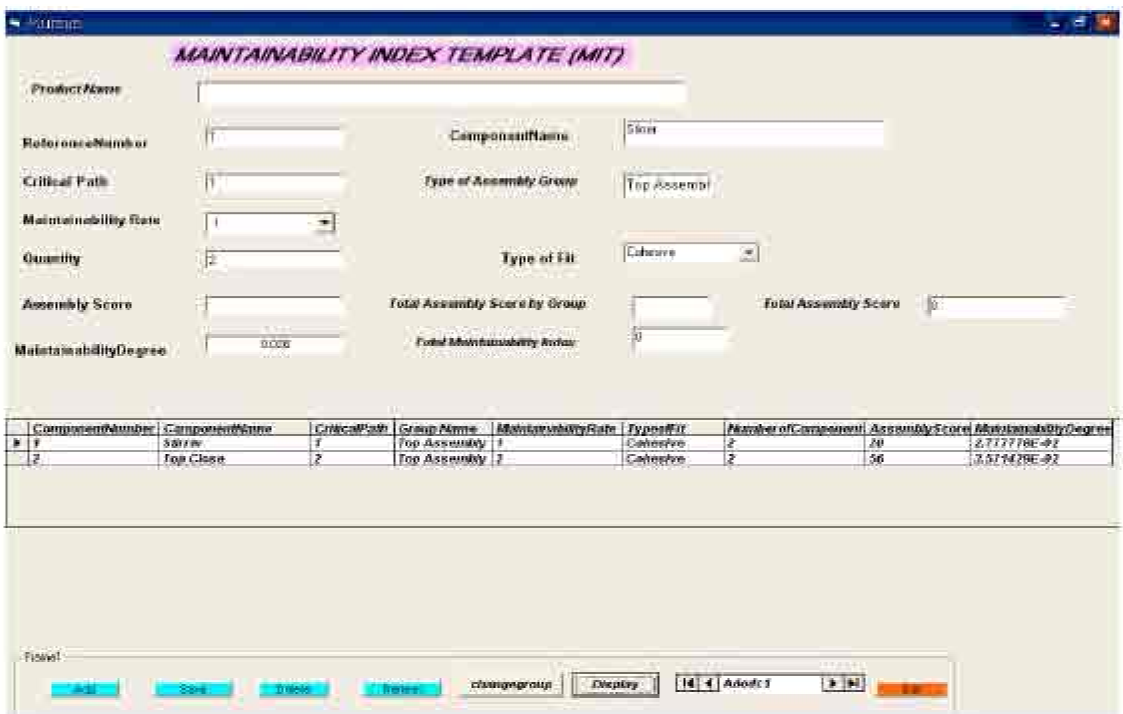


Fig. 6: Maintainability Index Template (MIT) front pages

Fig. 7: Cup and basement of electrical blender

Safety: Safety for product and system point of views can be defined as the state of being certain that adverse effects will not caused by some agent under defined condition. Safety nowadays is always become the major consideration of the manufacturer during product design and consumer before their purchasing. For example blade of electrical blender is attached to the basement by using nut, this is because this assembly requires strength and stiffness while at the same allow the blade to be replace due to wear or broken as shown in Fig. 8. If the fastener is replace by using snap fit, it may affect the safety and the function of the blade. The safety factor can be categorized into three;

- No effect to safety or function.
- Effect to safety but not to function.
- Effect to function but not to safety.

Fig. 8: Blade attachment of electrical blender

Fig. 9: Arm rest for car window

Stability: Stability factor is also an important factor especially for hanging parts. A product that has stability will operating in maximum performance and hence of that, will seldom need maintenance. For example arms rest for car window (Fig. 9) usually required at least three screws and if the numbers is reduce into one it may influence the stability and main function of the arm rest, but number of screw used is one but another two are replace by using clip, the stability and function may not be affected. The stability factor can be categorized into three;

- No effect to stability or function.
- Effect to stability but not to function.
- Effect to function but not to stability.

By giving them weightage (Table 4), the effect of redesign to the product or system can be determined. The

Table 4: Weightage of the three factors considered in the redesign

Effect	Level	Weightage
Strength	No effect	1
	Effect to strength	3
	Effect to strength and function	5
Safety	No effect	1
	Effect to safety	3
	Effect to safety and function	5
Stability	No effect	1
	Effect to stability	3
	Effect to stability and function	5

Table 5: Shaded block depicts the possible improvement of fastener changes

Assembly sequences	Fastener type Present	New	Strength	Stability	Safety	Total
1~2	Bolt and Nut	Wing Nut	5	1	5	11
2~3	Snap Fit	-	-	-	-	-
3~15	Bolt and Nut	Wing Nut	1	1	5	7
3~18	Snap Fit	-	-	-	-	-
15~22	Snap Fit	-	-	-	-	-
22~23	Snap Fit	-	-	-	-	-
23~20	Snap Fit	-	-	-	-	-
3~8	Snap Fit	-	-	-	-	-
3~4	Snap Fit	-	-	-	-	-
3~19	Bolt and Nut	Wing Nut	1	1	1	3
4~5	Snap Fit	-	-	-	-	-
8~7	Snap Fit	-	-	-	-	-
7~6	Snap Fit	-	-	-	-	-
15~21	Wing Nut	Snap Fit	5	1	1	7

Table 6: Modification before and after redesign for design one

Modifications	Original design	New design	Improvement (%)
Overall assembly score	240.000	184.000	30.43
Overall maintainability degree	0.071	0.250	252.11
Maintainability index score	1.999	2.467	23.41
Overall assembly number	15.000	14.000	7.14

lower weightage the better, this is because they exhibit the least effect upon any changes or redesign involve.

Based on DFA guideline, there are two ways or possible approach for maintainability improvement, either by reducing part count or by changing the fastener used. The analysis based on the 3S effect for fastener changes is as summarized in the Table 5.

Fastener (Component No. 16) instead of using nut, wing nut is used. This will give advantages in terms of tools requirement. Previously spanner is required to detach the fastener, now it can disassemble using hand. Another possibility is that components No. 2 and 3 can be joined together as shown in Fig. 10. From the manufacturing point of view it may increase the complexity of the components but it still can be manufacture. Currently the rear brake panel side collar is placed between rear brake panel and main body of the motorcycle to give space for maintenance purposes. From Table 5 shows that, the changes only on bolt and nut since snap-fit already gives the lowest score among the fasteners. Figure 11 shows the new design of the rear brake panel side collar and rear brake panel, which have

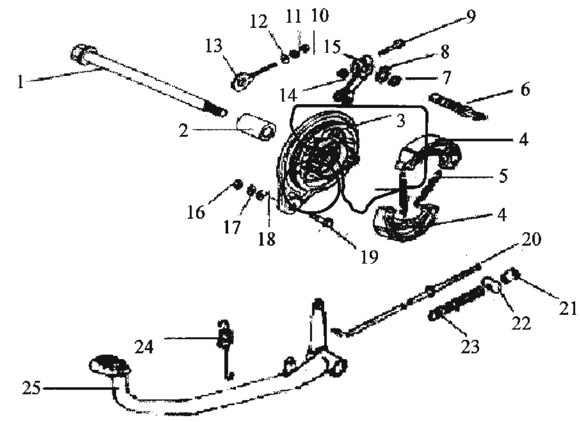


Fig. 10: Two possible modifications proposed to enhance maintainability shown in the circles

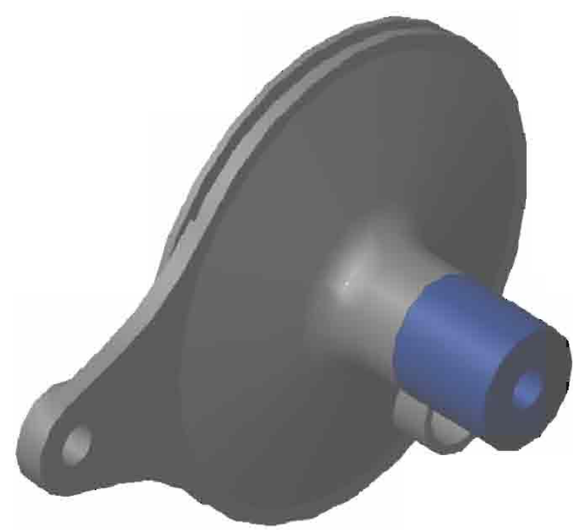


Fig. 11: Combination of rear brake panel side collar and rear brake panel become single part

been combined. As a result, compared to the original design, the new design of show the tremendous improvement as listed in the Table 6. For example, maintainability index itself shows more than 23% improvement, while in terms of assembly score, the new design is better than present design by 30.43%.

CONCLUSIONS

The study indicated that maintainability can be measured based on assembly criteria 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 is. Moreover the higher level of skill of the operator, the faster maintenance can be done. Throughout this study, other aspect such as frequency of component to be maintained and effect of assembly type to maintainability has been studied. Lowering assembly score and other assembly criteria will enhance the maintainability index or maintainability efficiency. Modifying the assembly type is also a way to lower the assembly score. Based on previous works, the maintainability concept has been understood and the maintainability index has been utilized. New design of the rear drum brake has been developed and shows some enhancement in terms of maintainability index. The new design can shorten the disassembly task and definitely will make the maintenance activity easier.

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