

# A PRACTICAL AND USER FRIENDLY INTERFACE OF FUZZY LOGIC RULE-BASED SYSTEM FOR MAINTENANCE POLICY DECISION MAKING

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**Abstract:** This paper discusses the use of fuzzy logic rule based (FLRB) to improve and enhance maintenance policy decision making. Currently, the decision provided by maintenance engineers is referring to their expert's opinion based on experience. By using a practical and user friendly FLRB method, better opinion could be derived. There are mainly three basic features of FLRB namely fuzzification, FLRB evaluation and defuzzification. The decision making grid (DMG) is an added feature to classify for example the most important machines by their associated grid of maintenance policy. The grid is developed from the low, medium and high range, the prevention action information and the above mentioned three basic features of FLRB. A real world case study at Palm Oil Mill (POM) plant is used to test the practicality and user friendliness of the technique.

**Keywords:** Fuzzy Logic Rule-Based (FLRB), maintenance policy, decision making.

## 1. INTRODUCTION

The concept of fuzzy logic is a pragmatic idea of artificial intelligence (AI) that was first introduced by Lofti Zadeh [13] as a fuzzy set theory. Since then, the vast growth interest in fuzzy logic is underscored with the numerous researches being conducted in this area (see for example [4], [7]). In the case of maintenance policy decision making [5] the main issue is how good the user interface when interact with the users. Researches on user interface design have been conducted by many researchers, for example in [1], [2], [3]. To date, the graphical

user interface (GUI) has proved its success with the considerable number of successful systems being implemented using this kind of interface, see for example in [6], [9], [12].

The computer forms or screens and its associated keyboard are the interface elements that lets the user communicate with the computer. The computer forms are used primarily for data input, data updating, data deletion, and data inquiry. It is recognised the importance of a good screen design that reduces the interface complexity as perceived by the users. The features embodied in the form design [11] include:

- a) Meaningful title. Identifies the topic and avoid computer terminology.
- b) Comprehensible instruction. Describe the user's tasks in familiar terminology. Be brief; if more information is needed, make a set of help screens available to the novice user.
- c) Logical grouping and sequencing of fields. Related fields should be adjacent, and should be aligned with blank space for separation between groups. The sequencing should reflect common patterns. For example, city followed by state followed by zip code.
- d) Visually appealing layout of the form. Using a uniform distribution of fields is preferable to crowding one part of the screen and leaving other parts blank. Alignment creates a feeling of order and comprehensibility. For example, the field labels name, address, and city can be right justified so that the data-entry field are vertically aligned. This layout allows the frequent user to concentrate on the entry fields only. If users are working from hard copy, the screen should match the paper form.
- e) Familiar fields' level. Common terms should be used. If home address were replaced by domicile, many users would be uncertain or anxious about what to do.
- f) Consistent terminology and abbreviations. Prepare a list of terms and acceptable abbreviations and use the list diligently, making additions only after careful consideration.
- g) Visible space and boundaries for data-entry fields. Users should be able to see the size of the field and anticipate whether abbreviations or other trimming strategies will be needed. Underscores can indicate the number of the characters available on text-only displays, and an appropriate-sized box can show field length in GUIs.
- h) Convenient cursor movement. Use a simple and visible mechanism for moving the cursor, such as TAB key or cursor movement arrows.
- i) Error correction for individual characters and entire fields. Allow use of a backspace key and overtyping to enable the user to make easy repairs or changes to entire fields.

- j) Error prevention. Where possible, prevent users from entering incorrect values. For example, in a field requiring a positive integer, do not allow the user to enter letters, minus signs, or decimal points.
- k) Error messages for unacceptable values. If users enter unacceptable value, the error message should appear on completion of the field.
- l) Optional field clearly marked whenever appropriate, the word optional or other indicators should be visible.
- m) Explanatory messages for fields. If possible, explanatory information about a field or the permissible values should appear in a standard position, such as in a window on the bottom, whenever the cursor is in the field.
- n) Completion signal. It should be clear to the users what they must do when they have finished filling the fields.

The main purpose of this paper is to discuss the practical and user friendly of fuzzy logic rule-based interface for maintenance policy decision making. The paper is organized as follows: Section 2 presents the design of FLRB interface. Section 3 on the other hand, discusses the testing and the result on practicality and user friendliness of FLRB interface. Finally our conclusions and future work directions are summarized in Section 5.

## 2. THE DESIGN OF FLRB INTERFACE

This section discusses on the interfaces that interact with the FLRB modules as shown in Figure 1 and Figure 2. Figure 1 shows the fuzzification, FLRB evaluation and defuzzification process. Fuzzification process aims to identify the fuzzy set in low, medium and high range. Trapezium membership value is used and each of the criteria is chosen by their associated range of low, medium and high value. This process acts as an input from crisp (normal) value to fuzzy set value. FLRB evaluation aims to identify the rules associated with the prevention action or policy taken. For example, *IF* Frequency is *Low* *AND* Downtime is *High* *THEN* *DM* (Detection-based Maintenance) is adopted. The sets of nine rules must be inserted because the DMG value grid is nine. This tool used maximum-minimum (*OR & AND* Zadeh) as fuzzy inference computations.

Defuzzification aims to provide a reference to defuzzify (crisp) the fuzzy value (input) into a meaningful manner (output). If in FLRB process has already chosen Frequency and Downtime as their rules, it could not be used again in defuzzification process. This defuzzification interface provides a selection of criteria with their associated reference or weight to defuzzify the given fuzzy set. The centroid (centre of gravity) under the curve of the function is used to defuzzify the fuzzy input. Given the chosen criteria for example cost function of each prevention action, one can arrange the prevention actions, the fuzzy output,

and the cost scale function. The feedback mechanism offered by DMG (see Figure 2) will show the machines condition and their associated prevention action.

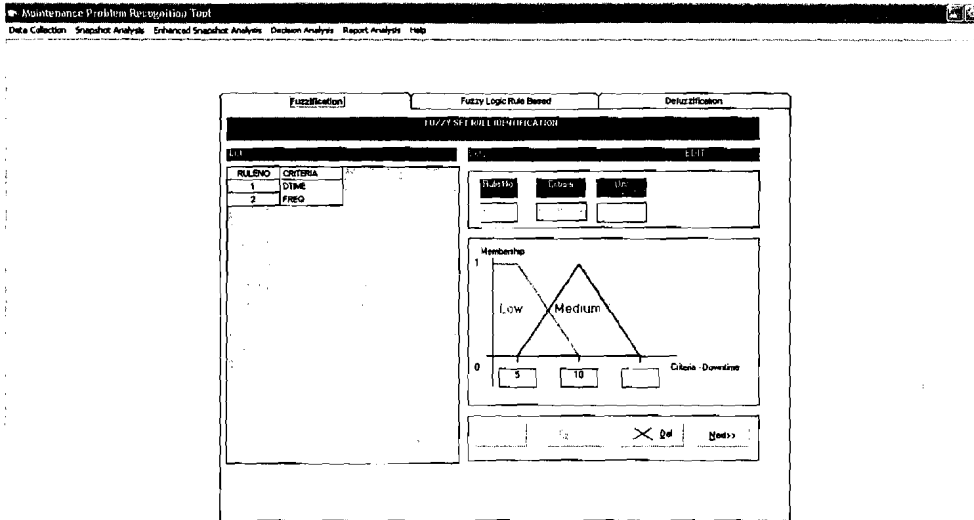


Figure 1. Interface of FLRB

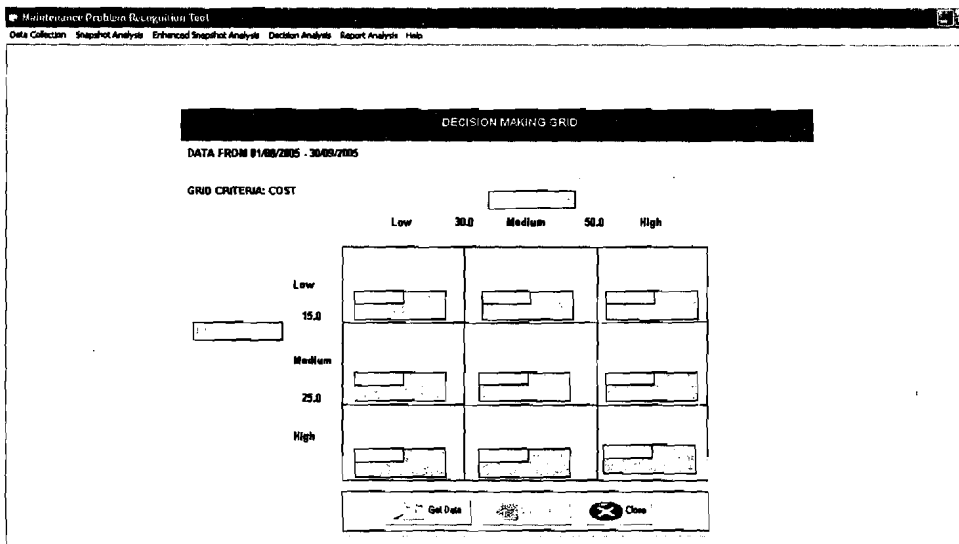


Figure 2. Interface of DMG

### 3. TESTING OF THE FLRB INTERFACE

This section aim at evaluating the FLRB interface whether its main purpose to assist maintenance engineers made decision is acceptable. The agreement between the behaviour of the model and that of the real tools is validated. In this study, the validation of this tool is focused on two characteristics namely user interface and tool usability. The procedure to carry out the validation is as follows:

- a) Present a complete introduction of the purposes, functions and interfaces of the tool to users.
- b) Demonstrate the tool to users.
- c) Let users work on the tool to solve their real-world problems.
- d) Complete the evaluation questionnaires.
- e) Review the suggestions and comments from the users.
- f) Analyse the data to obtain the final results of the tool evaluation.

#### 3.1 User Interface Evaluation

The user interface evaluation in Table 1 contains eleven items to evaluate level of the effectiveness and efficiency of the interfaces of the tool.

Table 1. User Interface Evaluation Results

Item	Description	1	2	3	4	5	6
1	This tool provides enough information for the user to learn how to use it.	0%	60%	25%	15%	0%	0%
2	The terminology in this tool is easy to understand.	5%	40%	35%	15%	5%	0%
3	This tool provides an effective means for the user to understand the problem recognition techniques.	10%	50%	30%	10%	0%	0%
4	This tool provides an effective means for the user to collect and analyse the fault data.	15%	50%	25%	10%	0%	0%
5	The "Editors" in the tool provide easy ways for the user to utilise the tool ability	10%	35%	35%	15%	5%	0%
6	The tool provides an effective means for the user to assist them make decision	15%	15%	45%	25%	0%	0%

Table 1. User Interface Evaluation Results (Cont.)

Item	Description	1	2	3	4	5	6
7	The menu and "Help" function provides enough information for the user to learn and use the tool.	15%	25%	50%	10%	0%	0%
8	The dialog function in the tool is brief and informative	0%	40%	35%	15%	10%	0%
9	The graphical input and output interfaces is user friendly.	10%	15%	45%	20%	10%	0%
10	The reports of this tool are satisfactory	15%	30%	50%	5%	0%	0%
11	The speed of processing during using the tool is satisfactory.	10%	30%	30%	15%	15%	0%

Evaluation scale level reference:

Strongly Agree	Agree	Sort of Agree	Sort of Disagree	Disagree	Strongly Disagree
1	2	3	4	5	6

Twenty theoretical engineers (lecturers) in Engineering Faculties of the Universiti Teknikal Malaysia Melaka (UTeM) and twenty experts from several POM companies participated in this survey. The results as shown in Table 1 are generally satisfactory. Most of the items received good scores except item 9 and 11 had a relatively low score due to the lack of chart and graphical output displays and the speed of processing when calling other applications respectively.

### 3.2 Usability Evaluation

Tool usability evaluation measures the tool functionality and users' satisfaction. In this study, a method proposed by [8] has been used for quantifying tool usability. In this method, the tool performance variables and user perception variables need to be specified. The method is briefly described as follows:

Let  $S_j$  - user perception variable and

$Q_k$  - tool performance variable.

Then the usability variable ( $U$ ) can be expressed as

$$U = \sum_{j=1}^m a_j S_j + \sum_{k=1}^n b_k Q_k \quad (1.1)$$

Where  $m$  and  $a_j$  are the number and coefficient of user perception variables respectively,  $n$  and  $b_k$  are the number and coefficient of tool performance variables respectively, and

$$\left. \begin{aligned} 0 \leq S_j, O_k \leq 1, \\ 0 \leq a_j, b_k \leq 1, \\ \sum_{j=1}^m a_j + \sum_{k=1}^n b_k = 1 \end{aligned} \right\} \quad (1.2)$$

Three variables  $S_1$ ,  $S_2$  and  $S_3$  regarding the user perception are defined as follows:

- $S_1$  : Variable of user confidence,
- $S_2$  : Variable of user perception of the tool advantage as maintenance problem recognition tool,
- $S_3$  : Variable of user perception of ease of use of the tool.

Similarly, three variables  $O_1$ ,  $O_2$  and  $O_3$  associated with the tool performance are defined as follows:

- $O_1$  : Variable of accuracy of tool performance,
- $O_2$  : Variable of completeness of the tool,
- $O_3$  : Variable of interface performance.

Saaty and Kearns [10] proposed a method of Analytic Hierarchy Process (AHP) which can determine the coefficients  $a_k$  and  $b_k$  of the usability function. In Saaty's method, parity checking is used to express the relative importance of the function variables. The same participants as in Section 3.1 are involved in the evaluation because of they have engineering or decision support background and experienced in using expert system. Tables 2 and Table 3 show the results using geometric and arithmetic mean respectively of the pair wise comparison between the tool usability variables.

Based on these two tables the coefficient of function variables are calculated and the results are

$$\left( \begin{array}{l} S_1 \\ S_2 \\ S_3 \\ O_1 \\ O_2 \\ O_3 \end{array} \right) \left( \begin{array}{l} 0.1317 \\ 0.2370 \\ 0.1561 \\ 0.2147 \\ 0.1982 \\ 0.0932 \end{array} \right)$$

Table 2. Results of Pair Wise Comparison using Geometric Mean

		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	O <sub>1</sub>	O <sub>2</sub>	O <sub>3</sub>
User confidence	S <sub>1</sub>	1	2.8471	0.4480	0.4155	0.4302	1.1722
Tool advantages	S <sub>2</sub>	0.3512	1	3.1488	3.0078	1.1487	2.2914
Perception of ease of use	S <sub>3</sub>	2.2321	0.3176	1	1.1487	0.4215	2.8064
Accuracy of results	O <sub>1</sub>	2.4067	0.3325	0.8705	1	2.8230	2.9054
Completeness of tool	O <sub>2</sub>	2.3245	0.8705	2.3725	0.3542	1	2.8471
Interface performance	O <sub>3</sub>	0.8531	0.4364	0.3563	0.3442	0.3512	1

Table 3. Results of Pair Wise Comparison using Arithmetic Mean

		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	O <sub>1</sub>	O <sub>2</sub>	O <sub>3</sub>
User confidence	S <sub>1</sub>	1	2.9000	0.4583	0.4292	0.4417	1.2500
Tool advantages	S <sub>2</sub>	0.3448	1	3.2000	3.0500	1.2000	2.3500
Perception of ease of use	S <sub>3</sub>	2.1820	0.3125	1	1.2000	0.4333	2.8500
Accuracy of results	O <sub>1</sub>	2.3299	0.3279	0.8333	1	2.8500	2.9500
Completeness of tool	O <sub>2</sub>	2.2640	0.8333	2.3079	0.3509	1	2.9000
Interface performance	O <sub>3</sub>	0.8000	2.3079	0.3509	0.3390	0.3448	1

The values of the six variables are determined by means of a questionnaire and the same participants are participated in the survey. The items and results of the survey are shown in Table 4.



Table 4. Results of Function Variables Measurements

Item	Description	Excellent	Good	Acceptable	Fair	Poor
1	User confidence	10%	60%	30%	0%	0%
2	Tool advantages	0%	65%	35%	0%	0%
3	Perception of ease of use	15%	50%	25%	10%	0%
4	Accuracy of results	15%	55%	30%	0%	0%
5	Completeness of tool	10%	50%	40%	0%	0%
6	Interface performance	15%	50%	35%	0%	0%

Evaluation scale level reference:

Excellent	Good	Acceptable	Fair	Poor
5	4	3	2	1

The usability function can be written as

$$\begin{aligned}
 U &= \sum_{j=1}^m a_j S_j + \sum_{k=1}^n b_k O_k \\
 &= 0.1317x S_1 + 0.2370x S_2 + 0.1561x S_3 + \\
 &\quad 0.2147x O_1 + 0.1982x O_2 + 0.0932x O_3 \\
 &= 0.1317x 0.76 + 0.2370x 0.73 + 0.1561x 0.74 + \\
 &\quad 0.2147x 0.77 + 0.1982x 0.74 + 0.0932x 0.76 \\
 &= 0.7714
 \end{aligned}$$

This result verifies that the tool behaviour is satisfactory to the user. But the validation result reveals that the tool contains limitations.

### 3.3 Statistical Test

Once the tool is validated, the next step is to determine whether the tool is capable of achieving its purpose. As FLRB tool success was predefined as facilitating the maintenance policy decision making, the general hypothesis is initiated by the dependent variables of the

number of the features investigated (Hypothesis One) and the time to reach a decision (Hypothesis Two). The general and test hypotheses are:

- General Hypothesis. The proposed prototype FLRB tool will significantly facilitate maintenance engineers' decisions during the maintenance policy decision making.
  - Hypothesis One. FLRB tool-assisted users will consider a greater number of features than non-FLRB tool-assisted users.
  - Hypothesis Two. FLRB tool-assisted users will take less time to make decision than non-FLRB tool-assisted users.

The testing was conducted in KSUB office. The FLRB tool program was installed and tested on 4 computer tools on 1 June 2007. The experimenting tool setups were equipped at least with a 1.73-gigahertz *Intel's Celeron processor* with a 512-megabytes memory. An introductory session was conducted on 2 June 2007. The testing process started with a hands-on demonstration of the tool, using a data collected from 1 August 2005 to 30 September 2005. The evaluation experiment was conducted during the same session (2 June 2007). Sixteen participants from the department of maintenance participated in the study by completing two data collected from 1 August 2006 to 30 September 2006 (case A) and 1 November 2006 to 31 December 2006 (case B). These participants varied from engineers to general workers who are involved in maintenance.

Although the two period of data collection selected for the experiment are equally compatible in work amount because the production operated for 24 hours daily, there might be some differences in the nature of the cases. This is due to the uncontrolled and unpredicted of the machine behaviour during the production process. The sixteen participants were randomly divided into two groups, the control and the experiment groups. Half of the participants in each group were randomly assigned to the case A-then-B experiment scheme, while the other half of each group was assigned to the case B-then-A experiment scheme in order to minimise impacts caused by differences on the case studies' nature. Due to lack of computers, the session will be divided into four sessions where each session consists of two participants for each group.

In the pre-test observation, participants in the control group had access to FLRB tool, while those in the experiment group had access to the existing Matlab Fuzzy Logic Toolbox (non-FLRB tool). All participants had access to FLRB tool during the post-test observation.

The data set comprises eight survey responses from the control group and eight survey responses from the experiment group. These qualified participants along with their corresponding pre-organised case sequences and required tools are summarised in Table 5.

Table 5. Qualified Participants' Surveys and their Corresponding Case Studies and Tool

Groups	Participant ID	Case Studies: Tools	
		Pre-Test	Post-Test
Control	111	B: FLRB tool	A: FLRB tool
	112	B: FLRB tool	A: FLRB tool
	113	B: FLRB tool	A: FLRB tool
	114	B: FLRB tool	A: FLRB tool
	115	A: FLRB tool	B: FLRB tool
	116	A: FLRB tool	B: FLRB tool
	117	A: FLRB tool	B: FLRB tool
	118	A: FLRB tool	B: FLRB tool
Experiments	AAA	B: Non-FLRB tool	B: FLRB tool
	AAB	B: Non-FLRB tool	B: FLRB tool
	AAC	B: Non-FLRB tool	B: FLRB tool
	AAD	B: Non-FLRB tool	B: FLRB tool
	AAE	A: Non-FLRB tool	A: FLRB tool
	AAF	A: Non-FLRB tool	A: FLRB tool
	AAG	A: Non-FLRB tool	A: FLRB tool
	AAH	A: Non-FLRB tool	A: FLRB tool

Legend

Case-A-then-B Group
Case-B-then-A Group

The test was run to find out whether the null hypothesis ( $\mu_{\text{control}} - \mu_{\text{experiment}} \geq D_0$ ) could be rejected. The hypothesis is

$H_0$ : Changes in the mean number of features examined in the experiment group are not more than those in the control group.

$H_A$ : Changes in the mean number of features examined in the experiment group are more than those in the control group.

The null hypothesis would be rejected if the  $t$ -statistic value is equal to or smaller than the negative  $t$ -critical value of ( $t\text{-statistic} \leq -t_{\alpha, 0.05}$ ). Table 6 presents a summary table of the pool  $t$ -test. It indicates a  $t$ -statistic of -7.1049, which is less than the negative  $t$ -critical value of 1.761 for a 95% confidence level. The level of significance  $p$ -value is reported at 0.0000. Therefore, the null hypothesis was rejected. This indicates a significant difference in number of features examined.

Table 6. Changes in Mean Number of Features Examined – All Participants

Pool <i>t</i> -Test ( $\alpha = 0.05$ )		
	Control	Experiment
Mean	0.625	4.625
Variance	1.6964	0.8393
Observations	8	8
Pooled Variance	1.126	
Hypothesised Mean Differences	0	
Degree of freedom ( <i>df</i> )	14	
<i>t</i> -Statistic	-7.1049	
<i>P</i> ( $T \leq t$ ) one-tail	0.0000	
<i>t</i> -Critical one-tail	1.761	

A plausible reason for the control group's decreased mean time to reach decisions in the two experiments can be explained by a maturation effect resulting from increased efficiency. For these participants, the post-test experiment was the second analysis utilising the same tool. Although the case situation was different, participants were expected to be more familiar with the FLRB tool. To determine if the decrease is statistically significant, a pool *t*-test was conducted. The test was aimed to examine whether the null hypothesis ( $\mu_{\text{control}} - \mu_{\text{experiment}} \leq D_0$ ) could be rejected. The null hypothesis will be rejected if the *t*-statistic value is equal to or higher than the *t*-critical value of ( $t\text{-statistic} \geq t_{\alpha, 0.05}$ ). The hypothesis is

$H_0$ : Changes the mean time to reach decisions in the experiment group is not more than in the control group.

$H_A$ : Changes the mean time to reach decisions in the experiment group is more than in the control group.

Table 7 below presents a summary table of the pool *t*-test. It indicates a *t*-statistic of 5.1184, which is greater than the *t*-critical value of 1.761 for a 95% confidence level. The level of significance *p*-value is reported at 0.0001. Therefore, the null hypothesis was rejected. This indicates a significant difference in time to reach decisions.

Table 7 Changes in Mean Time to Reach Decisions – All Participants

Pool <i>t</i> -Test ( $\alpha = 0.05$ )		
	Control	Experiment
Mean	-5	-20.625
Variance	50	24.5536
Observations	8	8
Pooled Variance	37.2768	
Hypothesised Mean Differences	0	
Degree of freedom ( <i>df</i> )	14	
<i>t</i> -Statistic	5.1184	
<i>P</i> ( $T \leq t$ ) one-tail	0.0001	
<i>t</i> -Critical one-tail	1.761	

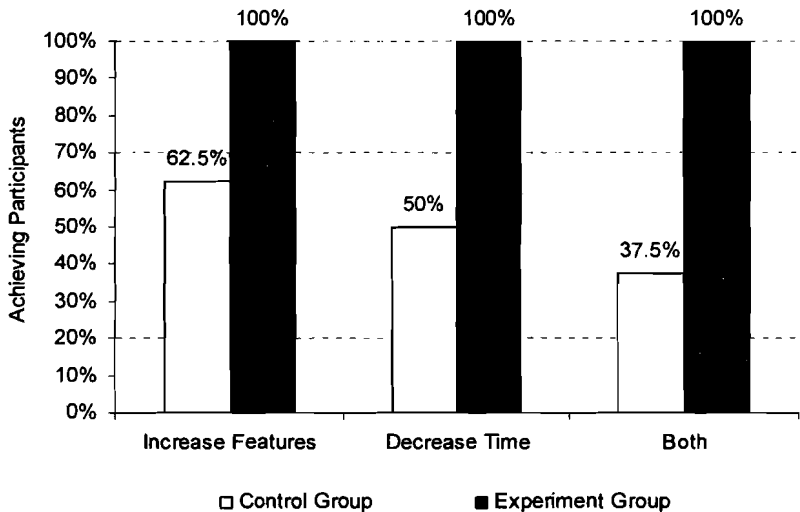


Figure 3. Result Summary – Hypothesis I and II – Graphic Comparisons

The hypothesis one aims to find whether FLRB tool has an impact on enhancing users' comprehensiveness of the decision context by increasing the number of features examined. According to Figure 3, the result indicates that all participants (100%) in the experiment group reported an increase in the number of features examined, as compared to a 62.5% of participants in the control group.

In other dimension, decreases in time to reach decisions are discovered in a 100% of participants in the experiment group versus a 50% of participants in the control group. Interestingly, in control group, both increase features and decrease time calculated about 37.5% while in experiment group shows a 100% participants.

#### 4. CONCLUSION AND FUTURE WORK

This paper proposed a practical and user friendly interface for fuzzy logic rule based (FLRB) system for maintenance policy decision making. According to the statistical result, the FLRB tool significantly enhances comprehensiveness of decision context by increasing the number of features examined, regardless of situations' difficulty. The FLRB tool also significantly contributes to the efficiency of decision-making process by reducing decision makers' time to reach decisions. However, the results also indicate that the decrease in time to reach decisions varies according to situations difficulty. A further study is needed to bridge the problems regarding to the situations difficulty. Users also indicate that the tool contains some limitations. The limitations include, the tool only offer facilitation based on one user for each analysis, while in the real world case, the decision making is made by more than one person. A group decision making interface should be considered in future works. The tools also offers only maximum nine rules whereas the fuzzy approach accuracy will offer better result when more rules provided. An extensive study should be conducted to determine the suitable rules for improving its accuracy.

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