IMPLEMENTATION OF RELIABILITY CENTER MAINTENANCE (RCM) PROGRAM USING FUZZY LOGIC ON THE STEAM TURBINE GENERATOR

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ABSTRACT

The Increasing complexity of Geothermal Power Plants (GPPs) installations and operations, along with growing public awareness to ensure higher levels of reliability, has put great pressure on the designers and operators to find innovative solutions to ensure reliability as well as economically viable operation. Reliability Centered Maintenance helps in finding such solutions and thus in gaining more importance in the industries, especially on Power Plants. A wide range of methodologies currently in use for RCM includes commercial and in-house software packages (specific to individual plants). The techniques with software produce very different results, raising serious concerns. Here, we present a simple and structured RCM methodology that can bridge this gap. The proposed methodology uses fuzzy logic to estimate risk by combining (fuzzy) likelihood of occurrence, (fuzzy) severity and its (fuzzy) detection.

Keywords: FMEA, fuzzy logic, RCM, steam turbine, geothermal power plants, RCM, strategies maintenance

INTRODUCTION

Renewable energy plays an important role in the provision of the secure supply of energy. Geothermal energy is one of the renewable energy forms that meet popular demand, especially in Indonesia. Geothermal becomes the important source for electricity needs in Indonesia. In order to generate stabile electricity, every equipment in the geothermal power plants must be maintained appropriately. Somehow, not every equipment needs excessive treatment, because it will need high cost and high amount of source. Some Critical Analysis Methods have been proposed to fix this problem. Failure Mode and Effect Analysis (FMEA) has been applied in some power plants to decrease potential failure modes in some power plants. The utilization of Failure Mode and Effect Analysis (FMEA) as a convenient technique for determining, classifying and analyzing common failures in typical GPPs in considered (Feili, 2013). As a result, an appropriate risk scoring of occurrence, detection and severity of failure modes and computing the Risk Priority Number (RPN) for detecting high potential failure is achieved. RPN (Risk Priority Number) is determined to rank the failure modes, however, the methods have been criticized for having some weakness (M Giardina, 2014). Fuzzy rule based assessment model has been applied to evaluate the RPN index to rank component failure (M Rafie F, 2015). The fuzzy assessment model is applied due to difficulty for the experts to give precise numerical inputs for the three risk factors and due to important factor for severity, occurrence, and detection, which never considered for rank the equipment criticality in geothermal power plants (M Giardina, 2014). The proposed methodology is applied to Geothermal Power Plants equipment) using MATLAB software, which never done before. Due to the complexity of geothermal power plants equipment, the proposed methodology can make the right decision to determine appropriate treatment for every equipment in geothermal power plants based on FMEA priority categorization. The obtained results allow the identification of the component faults that need to be known to achieve a better understanding. Those fuzzy logic approaches on FMEA application is applied on RCM (Reliability Centered Maintenance) program, In order to develop an appropriate maintenance task and build a living program.

FMEA

FMEA is a systematic method of identifying and preventing product or process problems before they occur (Mychael R. Beauregard, 1996).Thus, applying FMEA to Geothermal Power Plants to evaluate all the possible consequences of failure modes can be a useful technique to present a recommended action. Some of the experts give the score for every failure modes of each equipment. The risk ranking is based on the result of calculation among severity, occurrence, and detection.

$$RPN = S \times O \times D \tag{1}$$

The result of this calculation is RPN (Risk Priority Number). RPN is used to compare criticality of all equipment in the system. This method that the traditional FMEA employs to achieve a risk ranking is critically debated (M Rafie F, 2015). Various sets of O, S and D may produce an identical value of 3, 5, 2 and 2, 3, 5 for O, S, D respectively. For example, we consider two different events having values of 3, 5, 2 and 2, 3, 5 for O, S and D, respectively. Both this event will have 30 in RPN value, however, the risk implications of these two events may not necessarily be the same. In order to solute this problem, a fuzzy logic approach is used. Using expert knowledge and decision for input calculation in FMEA, a fuzzy logic approach could be used to improve the quality of the results and be applied especially in Geothermal Steam turbine system.

FUZZY LOGIC APPROACH

Generally the fuzzy logic approach proceed in the following steps (M Giardina, 2014):

- Fuzzification
- Fuzzy inference (apply implication method)
- Aggregation of all outputs.
- Defuzzification

The input parameter of the fuzzy logic approach is used gaussmf and gauss2mf membership function, such in works (Tay KM, 2008) in order to gap between practical realities and mathematical modeling. While the output parameter is used trapezoidal and triangular membership function.

Gaussmf membership function

$$f\ (x;\sigma.c)\ =\ e^{\frac{-(x-c)^2}{2\sigma^2}} \qquad (1)$$

The symmetric Gaussian function depends on two parameters σ and c factors.

Gauss2mf membership function

$$f\ (x;\sigma.c)\ =\ e^{\frac{-(x-c)^2}{2\sigma^2}} \qquad (2)$$

The first part of the function of the *gauss2mf membership function* is specified by σ_1 and c_1, which determine the shape of the left-most curve. The second part of the *gauss2mf membership function*, specified by σ_2 and c_2, determines the shape of the right-most curve. Whenever $c_1 \leq c_2$, the gauss2mf function reaches a maximum value of 1. Otherwise, the maximum value is less than one. The order of the parameters follows: $[\sigma_1\ ,\ c_1, \sigma_2\ , c_2]$ (Ratnayake, 2017).

Triangular membership function.

$$\mu_A(x) = \begin{cases} \frac{x-x_1}{x_2-x_1} & \text{for } x_1 \leq x \leq x_2 \\ \frac{x-x_1}{x_2-x_1} & \text{for } x_2 \leq x \leq x_3 \\ 0 & \text{For others} \end{cases} \qquad (3)$$

Where $x_1 \leq x_2 \leq x_3$

Trapezodial membership function.

$$\mu_A(x) = \begin{cases} \frac{x-x_1}{x_2-x_1} & \text{for } x_1 \leq x \leq x_2 \\ 1 & \text{for } x_2 \leq x \leq x_3 \\ \frac{x-x_4}{x_3-x_4} & \text{for } x_3 \leq x \leq x_4 \\ 0 & \text{For others} \end{cases} \qquad (4)$$

Where $x_1 \leq x_2 \leq x_3 \leq x_4$

Moreover, the other parameters of the fuzzy logic based expert system that has been selected for the current analysis are as follows: "AND" operator with "minimum", "OR", operator with "maximum", "Implication" with "minimum", "Aggregation" with "maximum" and "Defuzzification" with "centroid" algorithm. A fuzzy rule base has been developed using weighing factor as showm in Table 5 (Ratnayake, 2017). The toolbox simulator tool of MATLAB (R2015a) has been utilized to execute the suggested fuzzy inference process.

FMEA FUZZY LOGIC APPROACH

The input parameter are using gaussmf and gauss2mf membership functions, while The output risk is using triangular and trapezoidal membership functions. The input and output parameter have been decomposed into fuzzy sets as shown in figures 2-5. The values are based on ranking scales as shown in Tables 1-4, which describe some consequences explanation of each value (M Giardina, 2014).

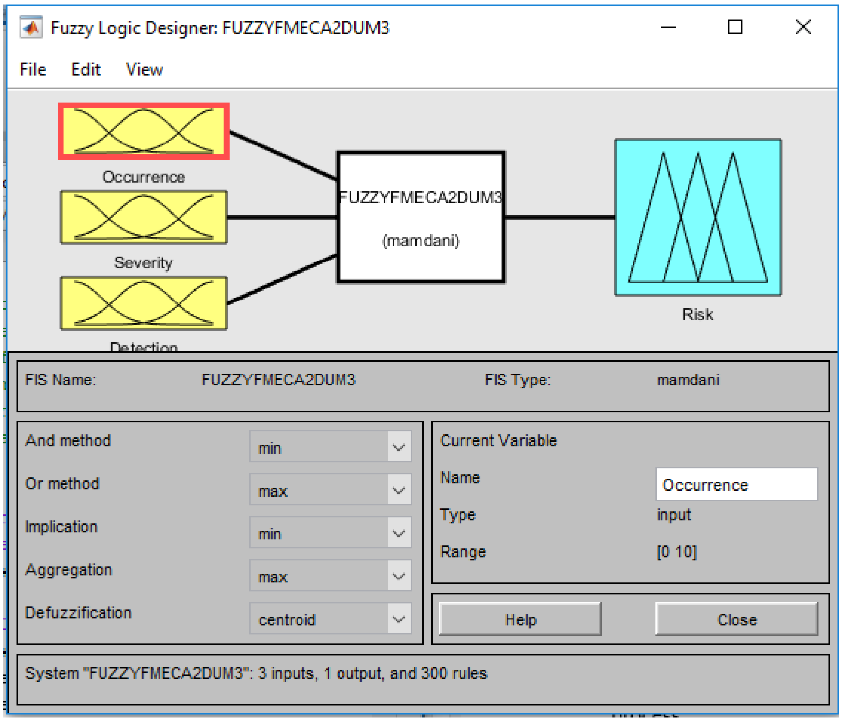

Figure 1 : Toolbox simulator tool of MATLAB (R2015B)

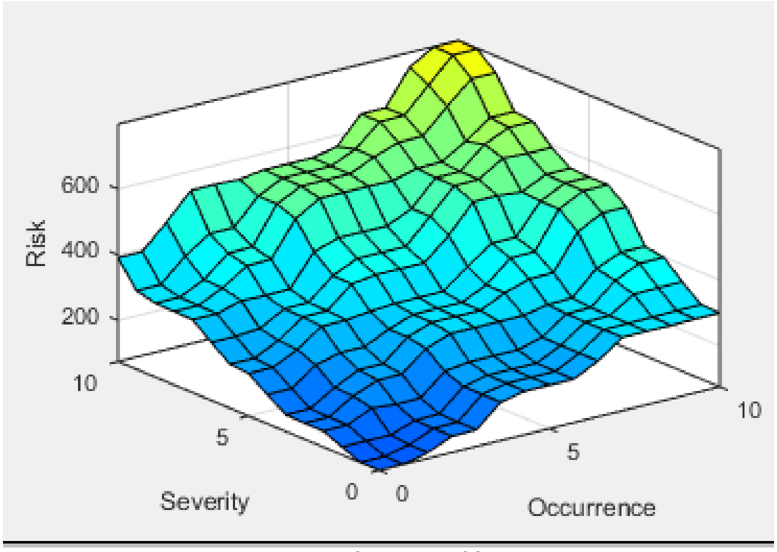

Figure 2 : Surface view of fuzzy logic

Table 1 : Occurrence ranking scale.

Rank of Occurence	Rating	Description	Linguistic Fuzzy	Weight (W)
1	Very Low (VL)	Failure unlikely,	[0.008493 0 0.3397 1]	0.2
2	Low (L)	Few Failures,	[0.34 2 0.34 3]	0.4
3,4,5	Moderate (M)	Occasional failures,	[0.3397 4 0.3397 6]	0.6
6,7,8	High (H)	Repeated failures,	[0.3397 4 0.3397 6]	0.8
9,10	Very High (VH)	Inevitable failure,	[0.3397 9 0.008493 10]	1

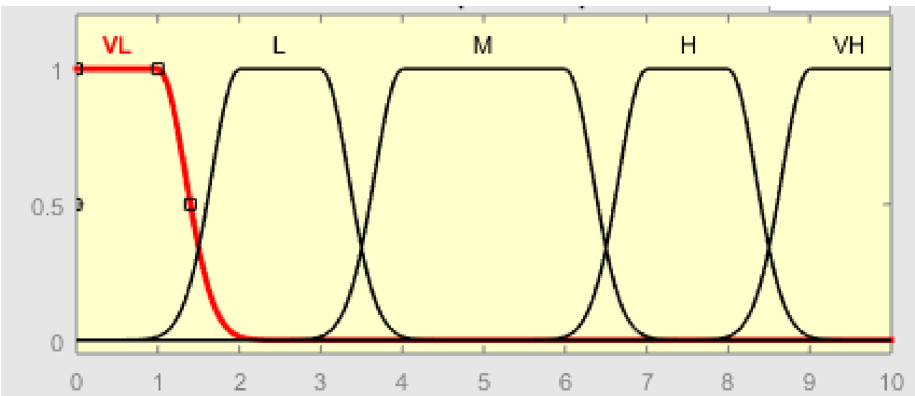

Figure 3 linguistic fuzzy value on Occurrence

Table 2 : Severity ranking scale.

Rank of Severity	Categorization	Description	W_S
1	No Effect (N)	No reason to expect failure. Slight annoyance-no injury to people.	0.1
2	Very Minor (VMR)	Very minor effect on product or system performance. The product does not require. Slight danger-no injury to people.	0.2
3	Minor (MR)	Minor effect on product or system performance. The product does not require repair. Very minor or no injury to people.	0.3
4	Very Low (VL)	Very low effect on system performance. The system does not require repair. Minor or no injury to people.	0.4
5	Low (L)	Moderate effect on system performance. The product requires repair. Very moderate danger-minor injury to people.	0.5
6	Moderate (M)	System performance is degraded. Some safety functions may not operate. The product requires repair. Moderate danger-minor to moderate injury to people.	0.6
7	High (H)	System performance is severely affected but functions (reduced level of performance). The system may not operate. The product requires repair. Very moderate danger-minor injury to people.	0.7
8	Very High (VH)	System is inoperable with loss of primary function. Failure can involve hazardous outcomes. Dangerous-may result in major injury to people.	0.8
9	Hazardous with Warning (HWW)	Failure involves hazardous outcomes. Very dangerous-may result in major injury or death of people.	0.9
10	Hazardous without Warning (HWOW)	Failure is hazardous and occurs without warning. It suspends operation of the system. Extremely dangerous-may cause death of people.	1

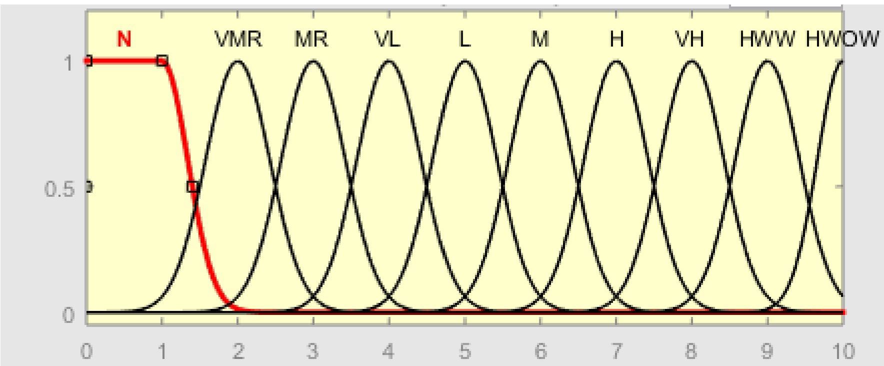

Figure 4 : llinguistic fuzzy value on Occurrence

Table 3 : Detection ranking scale.

Rank	Detection (%)	Description	Linguistic Fuzzy	W_D
1,2	0-15	Design control will almost certainly detect a potential failure mode/task error.	[0.008493 0 0.3397 2]	0.17
3,4	16-35	High chance that the design control will almost certainly detect a potential failure mode/ task error	[0.3397 3 0.3397 4]	0.33
5,6	36-65	Moderate chance that the design control will detect a potential failure mode/ task error (e.g. the defect will remain undetected until the system performance is affected).	[0.34 5 0.34 6]	0.5
7,8	66-85	Remote chance that the design control will detect a potential failure mode/task error (e.g. the defect will remain undetected until an inspection or test is carried out).	[0.3397 7 0.3397 8]	0.67

9	86-100	Defect most likely remains undetected (e.g. the design control cannot detect potential cause or the task will be performed in the presence of the defect).	[0.4247 9]	0.83
Rank	**Detection (%)**	**Description**	**Linguistik Fuzzy**	**WD**
10	90-100	System failures are not detect (e.g. there is no design verification or the task will certainly be performed in the presence of the defect). System failures are not detect (e.g. there is no design verification or the task will certainly be performed in the presence of the defect).	[0.3397 10 0.008493 10]	1

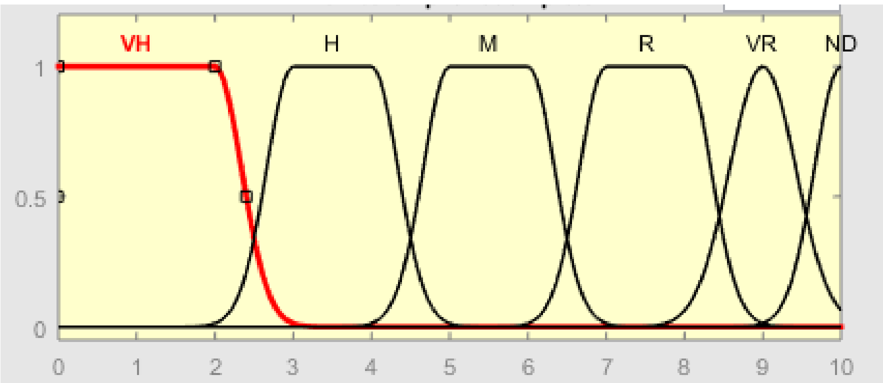

Figure 5 : linguistic fuzzy value on Detection

The linguistic term of the RPN fuzzy output and the pertinent weight W_{RPN} used within the proposed fuzzy if-then rules are identified using the value of the summation of the product of the relative importance factor and weight for each fuzzy input term (M Giardina, 2014):

$$W_{RPN} = R_O W_O + R_S W_S + R_D W_D \quad (5)$$

This W_{RPN} value allows for the identification of the output of the RPN linguistic terms as explained in the following examples (M Giardina, 2014):
Rule: If the occurrence is Moderate (with W_O=0.6) and the severity is No effect (with W_S = 0.1) and the detection is High (with W_D = 0.33), then the consequent part is obtained using equation (5), namely 0.4.0.6+0.4.0.1+0.2.0.33 = 0.346. This number is placed between W_{RPN} =0.3 of risk Very Low and W_{RPN} =0.4 of risk Low, but being closer to risk Very Low, therefore the result is Very Low with W_{RPN}=0.35
The rules have 300 combinations and Table 5 shows the fuzzy inference rules obtained by setting the linguistic terms of occurrence O as Moderate M and varying the linguistic terms of severity S and detection D. The W_{RPN} for each fuzzy rule are also reported.

Table 4 : Risk RPN ranking scale.

Linguistic value for RPN	**Rank**	**Linguistic**	**Fuzzy lingustik**	**W_{RPN}**
Almost unnecessary to take the follow-up actions	1-50	Unnecessary (U)	[0 0 25 75]	0.1
Minor priority to take the follow-up actions	50-100	Minor (MI)	[25 75 125]	0.2
Very Low priority to take the follow-up actions.	100-150	Very Low (VL)	[75 125 175]	0.3
Low priority to take the follow-up actions.	150-250	Low (L)	[125 200 300]	0.4
Moderate priority to take the follow-up actions.	250-350	Moderate (M)	[200 300 400]	0.5
High priority to take the follow-up actions.	350-450	High (H)	[300 400 500]	0.6
Very High priority to take the follow-up actions.	450-600	Very High (VH)	[400 550 700]	0.7
Extremely High priority to take the follow-up actions	600-800	Extremely High (EH)	[500 650 800]	0.8
Necessary to take the follow-up actions.	800-900	Necessary (N)	[700 800 900]	0.9
Absolutely Necessary to take the follow-up actions.	900-1000	Absolutely Necessary (AN)	[800 900 1000 1000]	1

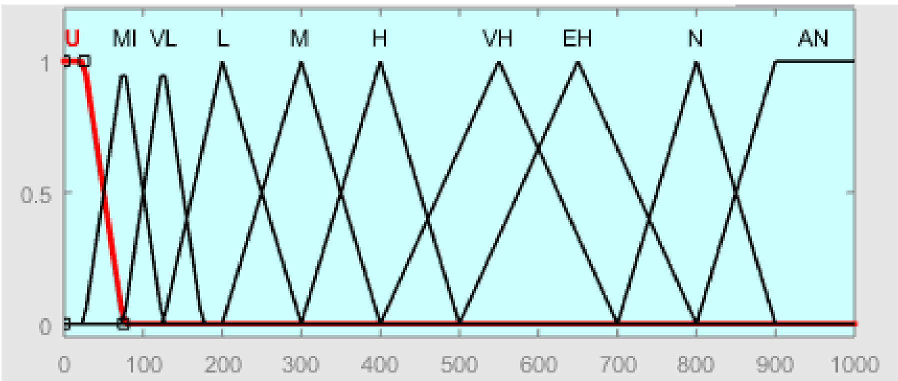

Figure 6 : linguistic fuzzy value on RPN (Risk Priority Number)

Table 5 RPN fuzzy inference rules.

				Occurrence (M)									
				R_o			0.4						
				W_O			0.4						
				Severity									
				R_D			0.4						
				N	VMR	MR	VL	L	M	H	VH	HWW	HWOW
				0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Detection	0.2	VH	0.17	0.23 MI	0.27 VL	0.31 VL	0.35 VL	0.39 L	0.43 L	0.47 M	0.51 M	0.55 M	0.59 H
		H	0.33	0.27 VL	0.31 VL	0.35 VL	0.39 L	0.43 L	0.47 M	0.51 M	0.55 M	0.59 H	0.63 H
		M	0.5	0.30 VL	0.34 VL	0.38 L	0.42 L	0.46 M	0.50 M	0.54 M	0.58 H	0.62 H	0.66 EH
		R	0.67	0.33 VL	0.37 L	0.41 L	0.45 L	0.49 M	0.53 M	0.57 M	0.61 H	0.65 H	0.69 EH
		VR	0.83	0.37 L	0.41 L	0.45 L	0.49 M	0.53 M	0.57 H	0.61 H	0.65 H	0.69 EH	0.73 EH
		ND	1	0.40 L	0.44 L	0.48 M	0.52 M	0.56 H	0.60 H	0.64 H	0.68 EH	0.72 EH	0.76 AN

RCM APPLICATION

Reliability Centered Maintenance is a process used to determine the maintenance requirements of any physical asset in its operating context (Moubrey, 1992). RCM application is used to determine the appropriate task and interval of maintenance scheduling.

RCM consists of 8 main process, which are listed below.

- **Prepare the Operating Context**
  Collect and identify all related data, in order to create an identification process comprehensive.

- ***Function***,
  Record what the asset does not what it is. Include desired standards of performance in its operating context.

- ***Functional Failure,***
  Document the ways in which the asset can fail to fulfill its function.
- ***Failure Modes,***
  Determine what causes each functional failure.

- ***Failure Effects***,
  Detail what happen if nothing were done to predict or prevent each failure mode.

- ***Failure Consequences***
  Determine how each failure mode matters.

Based on RCM book (Moubrey, 1992), there are several types of failure consequences.

1. Hidden failure consequences: Hidden failures have no impact, but they expose the organization to multiple failures with serious, often catastrophic, consequences.
2. Safety and environmental consequences: A failure has safety consequences if it could hurt or kill someone.
3. Operational consequences: A failure has operational consequences if it affects production (output, product quality, costumer service or operating cost in addition to the direct cost of repair).
4. Non-operational consequences: Evident failures which fall into this category affect neither safety nor production, so they involve only the direct cost of repair.

- ***Proactive Maintenance & Intervals***
  Determine if On-Condition or Preventive Maintenance is technically appropriate and worth doing. These are a task undertaken before a failure occurs, in order to prevent the item from getting a failed state. They embrace what is traditionally known as 'predictive' and 'preventive maintenance' although we will see later that RCM uses the terms *scheduled restoration, scheduled discard* and *on-condition maintenance* (Moubrey, 1992).

- ***Default Strategies***
  Determine if there are any other actions that are appropriate. RCM recognizes three major categories of default actions, as follows (Moubrey, 1992):
  1. Failure-finding: Failure-finding tasks entail checking hidden functions periodically to determine whether they have failed (whereas condition-based tasks entail checking if something is failing).
  2. Redesign: redesign entails making any one-off change to the built-in capability of a system.
  3. No scheduled maintenance: as the name implies, this default entails making no effort to anticipate or prevent failure modes to which it is applied, and so those failures are simply allowed to occur and then repaired.

The proposed methodology combines FMEA fuzzy logic and RCM, as shown in Figure 8.

RCM PROCESS

The process begins with identification system and related components. Critical Analysis is performed after identification has finished. Critical Analysis has used the application of fuzzy logic in order to prevent similarity of RPN value despite their differences implication risk input. The result of Critical Analysis would be the list of critical component and non-critical component based on their RPN value description. If the RPN value is low or below low, then the component would be registered as non-critical component and if the RPN value is moderate to very high then the component would be registered as critical equipment. After that maintenance tasks and intervals can be performed based on their characteristic. Those characteristics are achieved from the P-F interval (Potential to Failure Interval),showed in Figure 7.For non-critical equipment simple decision making is performed by experts, in order to get whether a simple task procedure or run to failure procedure. After that, all of the components will be reviewed by a team, in order to get an appropriate maintenance task. RCM would be developed and circulated, that we can conclude RCM is a living program.

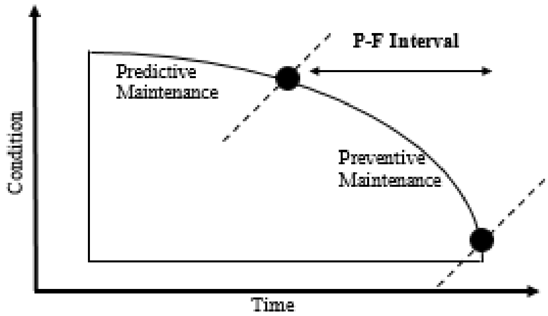

Figure 7 : P-F Interval

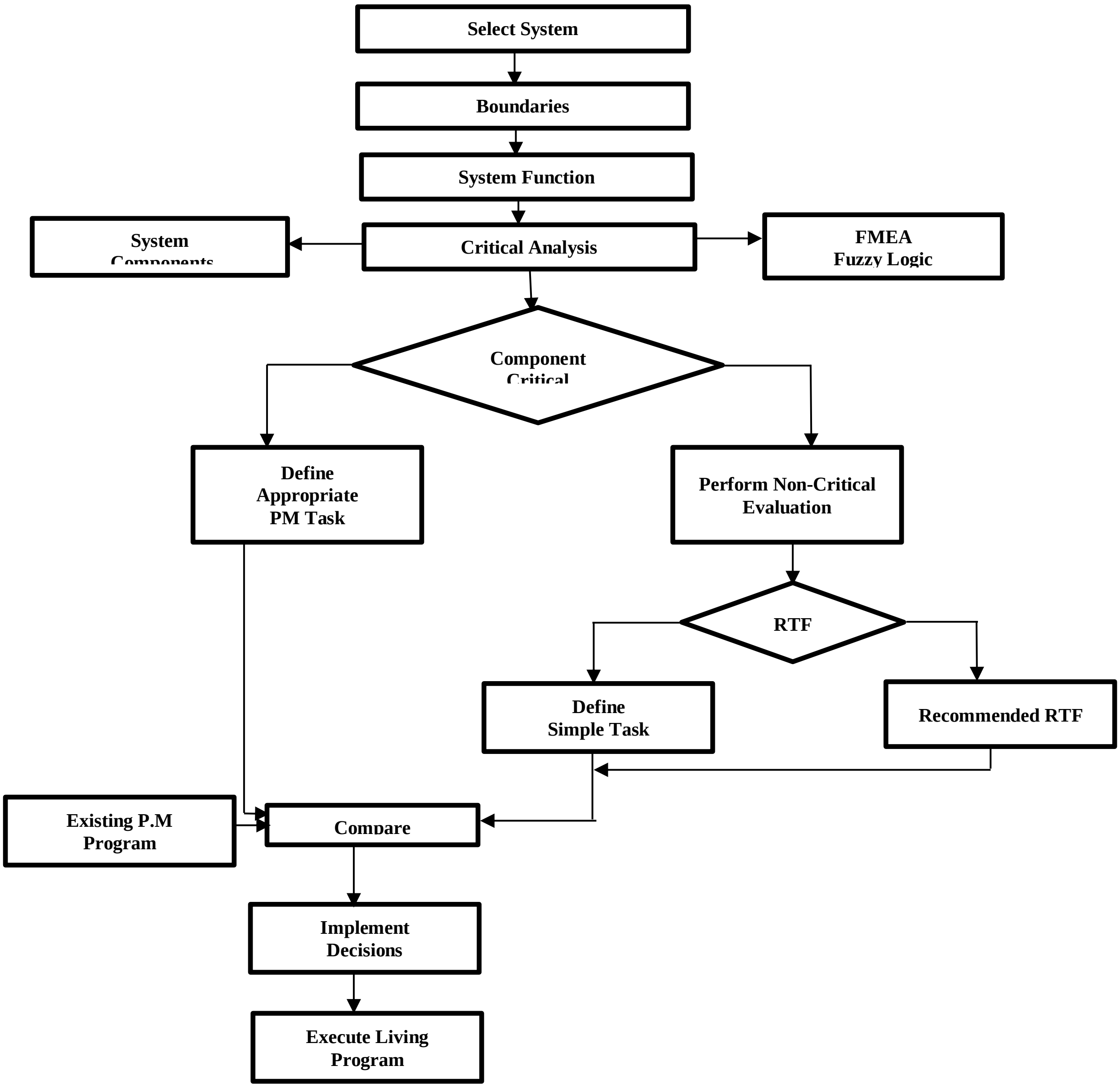

Figure 8 : RCM process diagram with fuzzy logic approach.

RCM IMPLEMENTATION USING FUZZY LOGIC

The proposed method is applied to geothermal steam turbine system. Geothermal steam turbine is an equipment to convert steam mechanical energy into power electricity. Geothermal steam turbine system composes of much complex equipment, therefore in this paper the boundary of discussion just talked about steam turbine and auxiliaries system, governing steam valve and lubrication oil system. After identifying each equipment root causes, FMEA fuzzy logic is applied due to determining equipment criticality as shown in Table 6.

Table 6 : FMEA fuzzy logic on geothermal steam turbine

No	Part	Failure Mode	S	O	D	RPN fuzzy	Indication
1	Moving blade	Blade erosion	6	4	6	391.4697	High (H)
2	Turning Gear	Gear can't latch with rotor	6	4	6	391.4697	High (H)
3	Rupture Disc	Relief diaphragm broken	6	4	6	391.4697	High (H)
4	Inner ring rotor	Material damage	6	4	5	389.3556	High (H)
5	Main Control Valve	Distortion	8	3	3	315.4406	Moderate (M)
6	Main Stop Valve	Distortion	8	2	3	307.1271	Moderate (M)
7	Turbine rotor	Mechanical damage to journal bearing and rotor	6	4	3	307.1271	Moderate (M)
8	Stationary Blade Ring	Crack on stationary blade ring	7	1	7	302.0877	Moderate (M)
9	Hold Stationary Blade	Crack at groove	7	1	7	302.0877	Moderate (M)
10	Coupling rotor	Misalignment	7	1	6	295.4384	Moderate (M)
11	Journal Bearing	Internal misalignment	5	3	6	295.4384	Moderate (M)
12	Thrust Bearing	Worn out	5	3	6	295.4384	Moderate (M)
13	Gland Steam	Control valve malfunction	5	3	4	220.4232	Low (L)
14	Pump (Main Oil Pump)	Leakage inside Main Oil Tank	5	3	4	220.4232	Low (L)
15	Gland Packing	Gland packing scratch	3	4	4	216.4706	Low (L)
16	Control Valve Gland Steam	Control valve malfunction	4	3	4	206.4572	Low (L)
17	Motor (Main Oil Pump)	Shaft misalignment	4	3	4	206.4572	Low (L)
18	Lube Oil Filter	Lube Oil Filter blocked	4	3	3	206.4532	Low (L)
19	Pump (Jacking Oil Pump)	Axial piston broken	4	3	3	206.4532	Low (L)
20	Lube Oil Cooler	Cooler tube leakage	4	3	3	206.4532	Low (L)
21	Steam Strainer	Strainer blocked by foreign object damage	4	3	3	206.4532	Low (L)
22	Pump (Auxiliary Oil Pump)	Shaft misalignment	4	2	4	206.4532	Low (L)
23	Casing	Seal package leakage	2	4	3	206.2122	Low (L)
24	Motor (Auxiliary Oil Pump)	Motor failure due to connection trouble	4	2	3	203.3434	Low (L)
25	Motor Jacking Oil Pump	Motor Malfunction	3	3	4	143.9447	Very Low (VL)
26	Pump on Emergency Oil Pump	Coupling misalignment	3	2	4	138.3511	Very Low (VL)
27	Motor Emergency Oil Pump	Bearing failure	2	3	4	133.7383	Very Low (VL)

The maintenance strategy is implemented after critical analysis is known. Task list of every equipment is based on the fuzzy RPN risk value indicator. If the RPN value is low or below low, then the component would be registered as non-critical component and if the RPN value is moderate to very high then the component would be registered as critical equipment. P-F interval is used to determine the exact time to do the preventive maintenance before failure occurring, known as Predictive Maintenance. Mean Time to Failure (MTTF) would be get by using predictive maintenance, otherwise they're using time based maintenance or preventive maintenance. For non-critical equipment simple decision making is performed by experts, in order to get whether a simple task procedure or run to failure procedure. The maintenance strategy is shown in Table 7.

Table 7 : Maintenance strategy on geothermal steam turbine system based on FMEA fuzzy logic.

Rank	Part	Failure Mode	Indication	Maintenance Strategy	Task List	MTTF	Interval Task List (times/once)
1	Moving blade	Blade erosion	High (H)	Predictive Maintenance	Vibration trending	4 years	1 days
					Vibration monitoring		3 months
					Vibration Analysis		3 months
					Major Overhaul		4 years
					Precision Inspection		12 years
2	Turning Gear	Gear can't latch with rotor	High (H)	Preventive Maintenance	Inspection *turning gear*	-	2 years
					Function test turning gear		4 years
					Precision Inspection		12 years
3	Rupture Disc	Relief diaphragm broken	High (H)	Preventive Maintenance	Minor Overhaul and Replacement	4 years	4 years
					Major Overhaul		12 years
4	Inner ring rotor	Material damage	High (H)	Preventive Maintenance	Visual inspection for damage, deformation, looseness ,burrs	-	4 years
					Cleaning inner wall		4 years
5	Main Control Valve	Distortion	Moderate (M)	Preventive Maintenance	Visual Inspection	-	1 days
					Movement check stroke test		2 years
					Inspection and cleaning		1 weeks
6	Main Stop Valve	Distortion	Moderate (M)	Preventive Maintenance	Visual Inspection	-	1 days
					Movement check stroke test		2 years
					Inspection and cleaning		1 weeks

Rank	Part	Failure Mode	Indication	Maintenance Strategy	Task List	MTTF	Interval Task List (times/once)
7	Turbine rotor	Mechanical damage to journal bearing and rotor	Moderate (M)	Predictive Maintenance	Vibration trending	4 years	1 days
					Vibration Analysis		1 months
					Vibration Monitoring		1 weeks
					Lubrication Analysis		1 weeks
					Major overhaul, bearing inspection ,check bearing vibration, oil lubricating		4 years
					Inspection and cleaning		1 weeks
8	Stationery Blade Ring	Crack on stationery blade ring	Moderate (M)	Preventive Maintenance	Inspection and cleaning	-	1 weeks
9	Hold Stationary Blade	Crack at groove	Moderate (M)	Preventive Maintenance	NDT Test (Dye Penetrant) on the groove at stationary blade holder	-	4 years
					Visual Inspection		1 weeks
10	Coupling rotor	Misalignment	Moderate (M)	Preventive Maintenance	Check *alignment*	-	4 years
					Visual Inspection		1 weeks
11	Journal Bearing	Internal misalignment	Moderate (M)	Predictive Maintenance	Precision Inspection	4 years	12 years
					Oil Analysis		3 weeks
					Vibration trending		1 weeks
					Vibration Monitoring		3 months
					Vibration Analysis		3 months
12	Thrust Bearing	Worn out	Moderate (M)	Predictive Maintenance	Precision Inspection	4 years	12 years
					Oil Analysis		3 months
					Monitoring temperature thrust bearing and recorded data		1 weeks

Rank	**Part**	**Failure Mode**	**Indication**	**Maintenance Strategy**	**Task List**	**MTTF**	**Interval Task List (times/once)**
13	Gland Steam	Control valve malfunction	Low (L)	Simple Task	Check Vibration	-	1 weeks
					Visual Inspection		1 days
					Check shaft alignment		4 years
14	Pump Main Oil Pump	Leakage inside Main Oil Tank	Low (L)	Simple Task	Major Inspection	-	4 years
					Visual Inspection		1 weeks
15	Gland Packing	Gland packing scratch	Low (L)	Simple Task	Visual Inspection		1 days
					(major overhaul) Inspection gland & *labyrinth fin* packing	-	4 years
					Precision Inspection		12 years
16	Control Valve for Gland Steam	Control valve malfunction	Low (L)	Simple Task	Visual Inspection	-	1 days
					movement check stroke test		2 years
					Replace diaphragm		4 years
					Major Overhaul		4 years
17	Motor Main Oil Pump	Shaft misalignment	Low (L)	Simple Task	Replace bearing	-	4 years
					Check Vibration		1 months
18	Lube Oil Filter	Lube Oil Filter blocked	Low (L)	Simple Task	Visual Inspection	-	3 months
					Cleaning		4 years
					Major Overhaul		10 years
19	Pump Jacking Oil Pump	Axial piston broken	Low (L)	Simple Task	Monitoring discharge pressure	-	2 years
					Monitoring Oil Flow		2 years
					Inspection		4 years
					Precision Inspection		12 years
20	Lube Oil Cooler	Cooler tube leakage	Low (L)	Simple Task	Visual Inspection	-	1 weeks
					Cleaning		2 years
					Major Overhaul		4 years
21	Steam Strainer	Strainer blocked by foreign object damage	Low (L)	Simple Task	Visual inspection & Cleaning	-	1 weeks

Rank	Part	Failure Mode	Indication	Maintenance Strategy	Task List	MTTF	Interval Task List (times/once)
22	Pump Auxiliary Oil Pump	Shaft misalignment	Low (L)	Simple Task	Check Vibration	-	1 weeks
					Visual Inspection		1 days
					Check Shaft alignment		4 years
23	Casing	Seal package leakage	Low (L)	Simple Task	(Major Inspection) Inspection and cleaning casing split surface.	-	4 years
					Visual inspection		1 days
					Precision inspection		12 years
24	Motor Auxiliary Oil Pump	Motor failure due to connection trouble	Low (L)	Simple Task	Function test	-	3 months
					Inspection		2 years
25	Motor Jacking Oil Pump	Motor Malfunction	Very Low (VL)	Simple Task	Monitoring temperature winding	-	2 years
					Inspection		4 years
					Precision Inspection		10-12 years
26	Pump Emergency Oil Pump	Coupling misalignment	Very Low (VL)	Simple Task	Vibration analysis	-	3 months
					Visual Inspection		2 years
27	Motor Emergency Oil Pump	Bearing failure	Very Low (VL)	Simple Task	Function test		3 months
					Inspection		2 years

CONCLUSION

A fuzzy logic model has been applied to geothermal steam turbine system to determine the criticality of every component in steam turbine system. Based on the value RPN and RPN indication, it is easier to determine the appropriate task of the equipment. Furthermore, the application of fuzzy logic could be used to improve the quality of the results and be applied in the complex system, in order to reduce uncertainty.

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