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Fuzzy Analysis of A 365kva Caterpillar Generator

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ABSTRACT
To reduce equipment failures and downtime, we applied Fuzzy analysis that helped to skew the highly ranked critical failures subsystems to the following: Engine Cooling System(Eng59), Crankcase system subsystem (Crk29), lubricating system subsystem (lub32), flywheel subsystem (fly38), and the Governor control subsystem(Gov73) that need to be given the highest priorities in terms of preventive maintenance, spare parts replacement, components upgrading. Moreso those identified parts that have exhausted their useful life should be replaced with brand new spare parts and in addition to training and retraining equipment operators, maintenance engineers, technicians, and craftsmen to mention a few should be given the highest priorities. The other subsystems with lower ranks should be given attention to all the identified likely symptoms that deterred optimal performance of 365KVA Caterpillar generator

I. INTRODUCTION

Kumru andKumru,(2013)observed that fuzzy FMEA played significant role in improving the supplies of medical accessories to public health facility.To control the uncertainty that resulted from the fuzzy set, fuzzy logic is applied(Zadeh,1965). Singh and. Markeset, (2009) involved planning technique employing a fuzzy logic framework to efficiently monitor the amount of risk and maintenance strategy for oil and gas pipes.The application of risk management extends beyond the traditional scope, which often focuses on the construction phase, as it is a crucial component of project management (Emad and Fatemeh, 2015). To deal with ambiguity and uncertainty in decision making, fuzzy logic has proven to be advantageous, which have led to more intelligent systems that are human-like. Fuzzy logic has been applied to address uncertainty in a variety offields of human endeavors. Fuzzification, rule assessment, and defuzzification are the first three fundamental processes of a fuzzy logic system.

Defuzzification techniques was used to provide best option from among all the alternatives,(Sadia, et al. 2017). The usage of linguistic terminology enables the experts to communicate their opinions more realistically, boosting the FMEA's applicability in offshore wind farms;(Dinmohammadi, and Shafiee, 2013).Fuzzy logic is a technique for turning human perception and feeling into a mathematical formula. Additionally, it offers measurement for ambiguous and uncertain terms given in natural language. FMEA literature uses fuzzy linguistic terms for describing the three risk factors S, O, and D. Readers can refer to Yang, Bonsall, and Wang (2008); Keskin and Özkan (2009); Gargama and Chaturvedi (2011) as good sources of fuzzy-FMEA approach. Singh et al.(2013) observed that fuzzy logic is a tool used in decision-making when there is a high level of uncertainty concerning the best option tofollow.

II. METHODOLOGY

Figure 2.1: Procedure for conventional FMEA and Fuzzy FMEA Models(Pinnarat, Santirat, & Adisak, 2019)

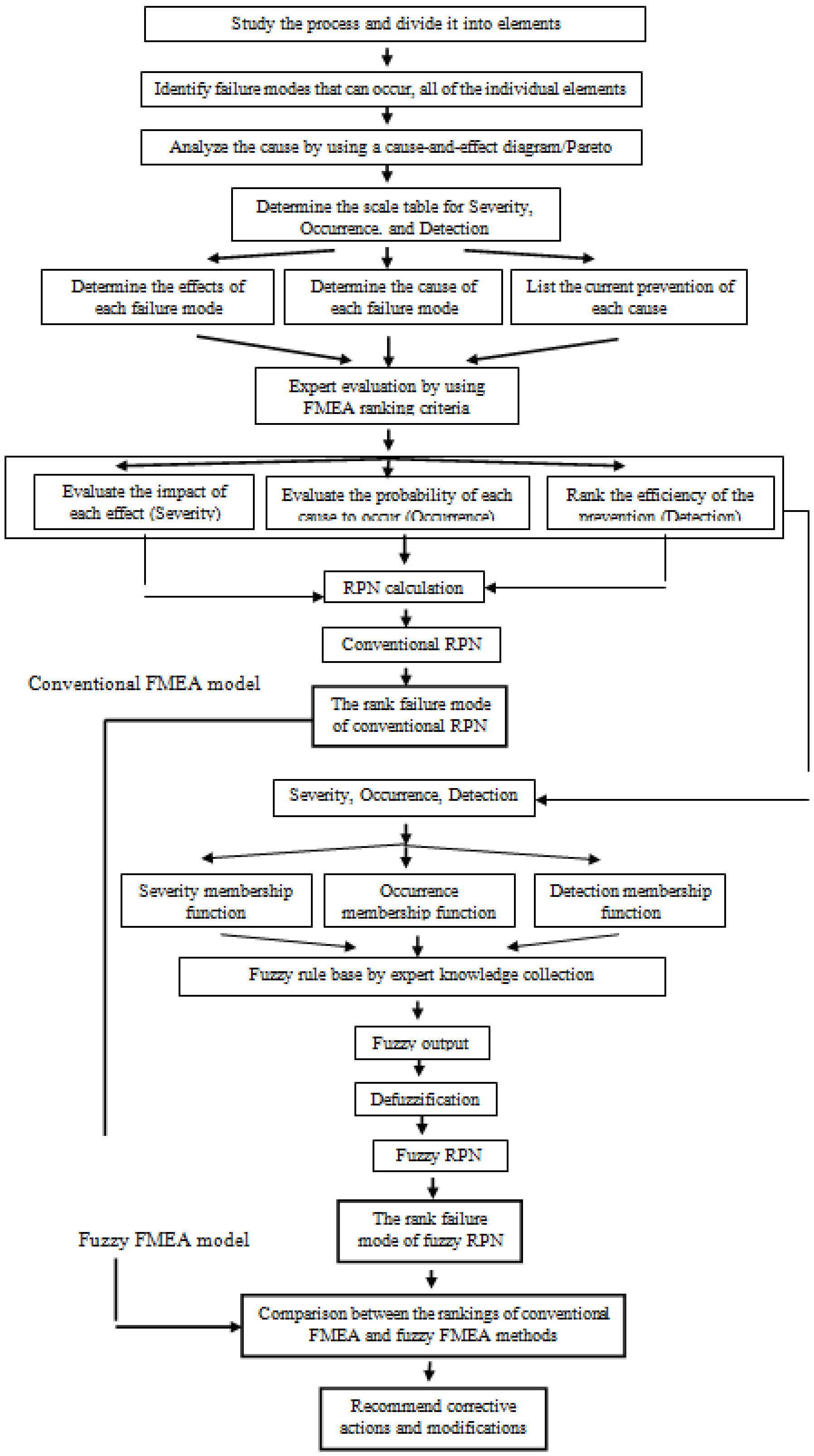
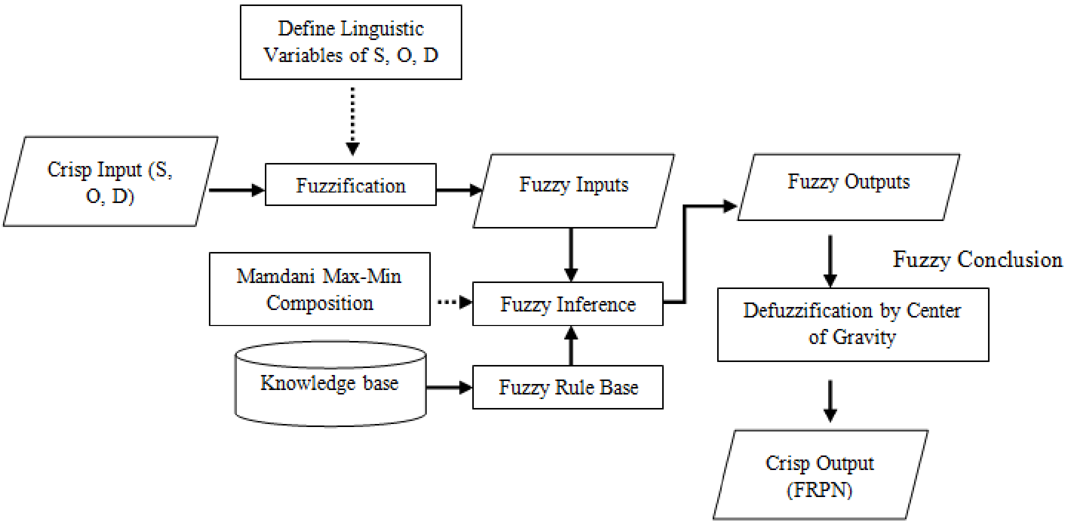


Figure 2: Process of Fuzzy systems (Pinnarat, Santirat, & Adisak, 2019)



III. RESULTS AND DISCUSSION

Table1: ASSESSED INFORMATION ON FAILURE MODES GIVEN BY FMEA TEAM NUMBER

Occurrence

S/N	1	2	3	4	5	6	7	8	9	10
Ign1	0	0	1	4	0	4	1	0	4	0
Blk9	0	0	0	0	0	2	1	7	1	3
Hed15	0	3	2	1	0	2	5	1	0	0
Pis21	0	0	0	0	4	4	2	4	0	0
Crk29	0	0	0	0	4	2	2	6	0	0
LJb32	0	0	0	0	2	0	6	3	3	0
Fly38	0	0	0	0	0	2	9	1	0	2
FJ141	0	1	0	0	4	1	7	1	0	0
Alt49	0	0	0	0	3	2	1	3	1	4
Exh53	0	0	0	4	4	1	3	1	0	0
Eng59	0	0	0	1	6	2	3	2	0	0
Gov74	0	0	0	0	1	0	6	7	0	0
Gov73	0	0	1	0	0	1	8	2	1	1
MAX	0	3	2	4	6	4	9	7	4	4
SUM	0	4	4	10	28	23	54	38	5	10
λ	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
w	VL	VL	VL	VL	VH	M	L	M	M	H

Table 2: ASSESSED INFORMATION ON FAILURE MODES GIVEN BY FMEA TEAM NUMBER

SEVERITY

S/N	1	2	3	4	5	6	7	8	9	10
Ign1	0	0	1	1	9	2	1	0	0	0
Blk9	1	0	0	0	1	3	4	1	1	3
Hed15	0	3	1	0	0	4	5	1	0	0
Pis21	0	0	0	2	1	5	2	4	0	0
Crk29	0	0	0	0	0	0	9	6	0	1
LJb32	0	0	0	0	0	1	2	8	2	1
Fly38	0	0	0	0	0	1	10	1	0	2
FJl41	0	0	0	1	0	4	7	2	0	0
Alt49	0	0	0	0	0	2	6	1	2	3
Exh53	0	0	0	2	2	4	5	1	0	0
Eng59	0	0	0	0	2	5	7	0	0	0
Gov74	0	0	0	0	0	2	2	10	0	0
Gov73	0	0	0	0	0	3	7	3	0	1
MAX	1	3	1	2	9	5	10	10	4	3
SUM	1	3	2	6	15	36	67	38	5	11
λ	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
w	VL	VL	H	VH	H	L	L	M	M	H

Table 3: ASSESSED INFORMATION ON FAILURE MODES GIVEN BY FMEA TEAM NUMBER

DETECTION

S/N	1	2	3	4	5	6	7	8	9	10
Ign1	0	0	2	1	5	5	2	0	0	0
Blk9	0	0	0	0	1	0	10	0	0	0
Hed15	0	0	0	0	3	4	7	0	0	0
Pis21	0	0	0	1	0	7	6	0	0	0
Crk29	0	0	0	0	7	3	1	3	0	0
LJb32	0	0	0	0	0	3	10	1	0	0
Fly38	0	0	0	0	1	0	10	2	0	1
FJl41	0	0	0	0	0	5	9	0	0	0
Alt49	0	0	0	0	2	2	4	1	4	1
Exh53	0	0	0	1	4	4	1	4	0	0
Eng59	0	0	0	1	8	4	1	0	0	0
Gov74	0	0	0	0	0	4	5	5	0	0
Gov73	0	0	0	0	0	0	11	3	0	0
MAX	0	0	2	1	8	7	11	5	4	1
SUM	0	0	2	4	31	41	77	19	4	2
λ	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
w	VL	VL	H	VH	M	L	L	H	M	H

Table 4: LINGUISTIC VARIABLES

Occurrence				
EH	9	10	10	VH
VH	8	9	10	
RF	7	8	9	H
H	6	7	8	MH
MDH	5	6	7	
MD	4	5	6	M
RL	3	4	5	ML
L	2	3	4	
R	1	2	3	L
N	1	1	2	VL

Severity				
EH	9	10	10	VH
VH	8	9	10	
RF	7	8	9	H
H	6	7	8	MH
MDH	5	6	7	
MD	4	5	6	M
RL	3	4	5	ML
L	2	3	4	
R	1	2	3	L
N	1	1	2	VL

Detection				
EH	9	10	10	VH
VH	8	9	10	
RF	7	8	9	H
H	6	7	8	MH
MDH	5	6	7	
MD	4	5	6	M
RL	3	4	5	ML
L	2	3	4	
R	1	2	3	L
N	1	1	2	VL

Table 4: Weighting Factor

				λ
VL	0	0.1	0.2	0.1
L	0.1	0.2	0.3	0.2
ML	0.2	0.35	0.5	0.35
M	0.4	0.5	0.6	0.5
MH	0.5	0.765	0.8	0.65
H	0.7	0.8	0.9	0.8
VH	0.8	0.9	1	0.9

	Occurrence	Severity	Detection
	4.48	6.93	5.00
	5.48	3.52	7.00
	3.83	4.62	6.29
	4.71	4.52	7.10
	5.29	9.31	4.67
	5.14	6.19	7.86
	6.93	7.52	7.52
	5.71	5.95	8.36
	4.62	4.81	3.90
	3.90	4.52	4.48
	4.81	6.57	6.76
	7.10	7.76	5.71
	5.95	5.81	8.45
Weight	**0.08**	**0.13**	**0.12**
MIN	**3.83**	**3.52**	**3.90**
MAX	**7.10**	**9.31**	**8.45**
Weight	**0.08**	**0.13**	**0.12**

Table 6: AGGREGATED FUZZY NUMBER DECISION MATRIX

Occurrence			
Ign1	3.57	4.43	5.43
Blk9	4.57	5.43	6.43
Hed15	2.93	3.79	4.79
Pis21	3.71	4.71	5.71
Crk29	4.29	5.29	6.29
LJb32	4.14	5.14	6.14
Fly38	6.29	7.07	7.43
FJl41	4.86	5.64	6.64
Alt49	3.71	4.57	5.57
Exh53	3.07	3.86	4.79
Eng59	3.86	4.79	5.79
Gov74	6.14	7.07	8.07
Gov73	5.14	5.86	6.86
Max	6.29	7.07	8.07
Min	2.93	3.79	4.79
Average	4.33	5.20	6.15
Std Dev	1.05	1.04	0.96
Weight	0.0841	0.0829	0.0768

Severity			
Ign1	6.29	7.07	7.43
Blk9	2.71	3.43	4.43
Hed15	3.71	4.57	5.57
Pis21	3.57	4.50	5.50
Crk29	8.43	9.50	10.00
LJb32	5.29	6.14	7.14
Fly38	6.86	7.71	8.00
FJl41	5.00	5.93	6.93
Alt49	3.86	4.79	5.79
Exh53	3.57	4.50	5.50
Eng59	5.57	6.57	7.57
Gov74	7.00	8.00	8.29
Gov73	4.86	5.79	6.79
Max	8.43	9.50	10.00
Min	2.71	3.43	4.43
Average	5.13	6.04	6.84
Std Dev	1.67	1.72	1.49
Weight	0.13329	0.13727	0.1189357

Detection			
Ign1	4.07	4.93	6.00
Blk9	6.50	7.21	7.29
Hed15	5.29	6.29	7.29
Pis21	6.14	7.07	8.07
Crk29	3.86	4.57	5.57
LJb32	7.14	8.07	8.36
Fly38	6.86	7.71	8.00
FJl41	7.57	8.57	8.93
Alt49	3.00	3.86	4.86
Exh53	3.57	4.43	5.43
Eng59	5.86	6.71	7.71
Gov74	4.71	5.71	6.71
Gov73	7.71	8.71	8.93
max	7.71	8.71	8.93
min	3.00	3.86	4.86
Average	5.56	6.45	7.16
Std Dev	1.60	1.64	1.35
Weight	0.1277	0.1309	0.1081

Table 7: Fuzzy ranking

VIKOR					*S*	*R*	*Q*
Ign1	0.02	0.08	0.03		0.121859	0.076404	0.43
Blk9	0.04	0.00	0.08		0.124126	0.0832	0.47
Hed15	0.00	0.02	0.06		0.088577	0.064	0.3
Pis21	0.02	0.02	0.09		0.130146	0.08576	0.5
Crk29	0.04	0.13	0.02		0.186495	0.129833	0.83
LJb32	0.03	0.06	0.11		0.198703	0.10624	0.74
Fly38	0.08	0.09	0.10		0.264149	0.09728	0.85
FJl41	0.05	0.05	0.12		0.221036	0.11968	0.86
Alt49	0.02	0.03	0.00		0.048426	0.028852	0.05
Exh53	0.00	0.02	0.02		0.03958	0.02244	0
Eng59	0.02	0.07	0.08		0.169508	0.0768	0.54
Gov74	0.08	0.10	0.05		0.225004	0.095104	0.75
Gov73	0.05	0.05	0.12		0.226321	0.12224	0.88
				MIN	0.040	0.022	
				MAX	0.264	0.130	

RANKING			
	S	*R*	*Q*
Ign1	4	4	4
Blk9	5	6	5
Hed15	3	3	3
Pis21	6	7	6
Crk29	8	13	10
LJb32	9	10	8
Fly38	13	9	11
FJl41	10	11	12
Alt49	2	2	2
Exh53	1	1	1
Eng59	7	5	7
Gov74	11	8	9
Gov73	12	12	13

FUZZY RANKING INTERPRETATIONS

In considering the Ignition system subsystem with the acronym (Ign1) of the generator, it was observed that proper analysis should be carried out on AGO (Automotive Gas Oil) with a low octane rating that will not burn in the combustion chamber.

Secondly, the cylinder block assembly sub-system (Blk9) of the generator should be examined knowing fully well that the following itemized factors should be the highest priority:

(i) Poorly processed engine oil without supplier product data and safety data sheet can cause engine overheating.

(ii) The highly dusty environment contributes to oil contamination which causes a restriction on the oiler, thereby causing overheating.

In conclusion, these two factors if not properly controlled can intensify the overheating of the engine thereby leading to the total breakdown of the generator.

Thirdly, cylinder head assembly with analysis code of (Hed15) was observed that the effect of high ambient temperature could lead to a decrease in engine performance.

In conclusion, the designed ambient temperature of the generator is 25^0C but the ambient temperature of Lokoja is 37^0C and above in the peak of the dry season.
Fourthly, the piston and connecting rod were examined to show that improper fixing of the piston rings does cause rubbing on the cylinder liner thereby having a reduction in engine performance.
In conclusion, the use of competent engineers and technicians that have shown proven skills in handling similar jobs should be hired to handle such complex installations.
Fifthly, the Crankcase system sub-system with the code (Crk29) showed that the following underlisted factors affect its overall performance:

(i) High engine operating temperatures do affect the performance of the output of a generator.
(ii) A highly dusty environment contributes to oil contamination which causes a restriction on the oiler thereby affecting the generator's performance
(iii) Untrained operator mal-operation in terms of improper gauging of engine oil can affect the output performance of the generator.

In conclusion, we should pay priority to the above-listed factor, so we can improve the full performance of the generator.
Sixthly, the lubricating system sub-system (lub32)

(i) Oil sump, a crack on the casing is caused by continuous vibration exerted on it,
(ii) Oil sump, a leak of oil caused by the failed seal,
(iii) The oil pump observed unusual noise caused by oil starvation

In conclusion, the above factors have a serious effect on the diesel generator lubricating system. There should be proper cleaning and inspection to notice any abnormality and call maintenance intervention.
Sevenly, the flywheel subsystem (fly38) was observed to play the following performance:

(i) The uncontrolled release of energy is caused by the broken shaft,
(ii) A seizure of rotation is caused by an unbalanced flywheel

In conclusion, if there are imbalance in the loading of the generator, the above identified performance will order of the day.
Eighthly, the alternator sub-system(Alt49) was observed as the cause of the armature coil's frequent failures as a result of insulation breakdown caused by short-circuiting.
In conclusion, the aspect of continued varnishing of the coils should be taken proper care and other preventive measures that will reduce the failure rate should be encouraged such activities as cleaning the dust in the coils using a vacuum cleaner, proper inspection, carrying out integrity test
ninthly Exhaust system sub-system (Exh53) it was observed that the exhaust silencer, continued rattling was caused by continuous observed rusting, commenting on its occurrence to the overall generator performance
Tenthly, Engine Cooling System(Eng59)

(i) From the research findings, it was observed that the heat exchanger tube collapse was the root cause of the oil/water mixture (emulsion), so there need for frequent clean-up of the generator and every 4 years the heat exchanger should be isolated, inspected, and pressure test to ensure availability of the heat exchanger.
(ii) It was observed that the crack on the crankcase has affected the water jack and can result in coolant leakages in the engine, so proper preventive maintenance.
(iii) The use of water hydrant coolant should be avoided, because of effects of ferric red oxide which intensify corrosion effects in the engine

Finally, Worktable for Governor System Sub-System
It was observed that the weak tension spring tends to cause pulsative fuel supply to the generator engine, there is a need for periodic inspection of the governor assembly to ascertain that there is no dust encroachment.

IV. Conclusion

This researched have really stressed the fact that each components in the generator required proper care in terms of sticking to routine maintenance schedules and making use of useful life data sheet, in order to take decision when a component required total and complete replacement in order to improve the generator performance. Furthermore the use of trained operators, utilization of trained and well known contractors in handling critical equipment repairs like overhauling and rewinding should be taken seriously because fake spare parts are used, it will definitely increase the generator failure rate.

Finally the use of fuzzy analysis has helped to skew the components critical level to above ranked from the least to highly critical components that should be given serious attention Ignition system subsystem, cylinder block assembly sub-system, cylinder head assembly

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