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Risks Associated with Maintenance Decisions Concerning the Afam Electricity-Generation Station

Tobinson. A. Briggs (corresponding author)
Mechanical Engineering Department,
Faculty of Engineering,University of Port Harcourt,East-West Road, Choba,Port Harcourt, Nigeria
E-mail: briggstee@gmail.com
M.C. Eti
Mechanical Engineering Department, Rivers State University of Science and Technology,
Nkpolu, Port Harcourt, Nigeria.

Abstract

For the nationally-deregulated Nigerian electric-power industry, an increasingly competitive environment has resulted to an important question being asked, the costs of maintenance in the plants. To survive the competition, the power stations have to reduce maintenance costs, i.e. handle maintenance effectively. Risk analysis is one tool decision makers in the power stations can use to help them prioritize as their plan maintenance actions. The results of such analysis will form a reliable basis for decision making, it is important to consider whether the quality of the results will vary significantly with the risk analysis approach chosen. This paper presents a factual dataset, with few risk of failures used to illustrate how Weibull analysis can forecast the risk of failures based on a small dataset. Using Gas Turbine number 17 of the Afam thermal power station, two perspectives are described: the statistics and engineering views. The study establishes the importance of the need to analyze and interpret risk analysis results, before making maintenance decisions

Keywords: risk analysis, statistical/engineering methods, and optimization. Afam thermal power station

1. Introduction

The prioritization of maintenance measures in electricity generating stations has become increasingly important because of privatization and competition of the power industry. An effective use of resources can be achieved by using wise risk-based maintenance decisions to guide it, where and when to undertake maintenance. Risk analysis has had a major impact on the identification of the magnitude and location of faults. In order to sustain adequate profit margins, the management of Afam power station has to control costs. In doing so, they have to minimize risks to individuals, the environment and assets. In order to identify risks, in terms of where faults are likely to be located and how serious they are, risk analysis is used. This provides guidance as to where and when maintenance effort should be directed. Moubray [20] and Nowplan and Heap [21] point out that maintenance method, such as reliability-centered maintenance (RCM) which uses function analysis in combination with risk analysis in prioritizing maintenance actions, are very helpful. There are many different opinions regarding (i) what risk analysis implies, (ii) how it should be performed and (iii) what terminology should be adopted [34, 11]. Plant/equipment failure and risk analysis for power plants are often based on very few actual failure data. The risk procedure is to forecast likely future failures. Corrective action can then be taken to mitigate these forecasted Failures. Barringer and Weber [7] maintain that operating from a fact-based system requires making failure forecasts even with small number of actual data set. Each dataset usually includes information in the form of censored data. Good use of engineering judgment and data are used with a Weibayes estimate (i.e. Weibull analysis using an estimate of the failure mode characterized by a Weibull slope (β) to produce a Weibull distribution relating the age to probability of failure). This should be made to make the datasets understandable and practical. For some datasets, confidence intervals can be established. Three perspectives exist for evaluating the problem, namely the statistical view; the engineering view; and the management view [6]. Most businesses must take risks in order to survive. This requires quantification of risks and the financial exposures incurred. The chance of failure concept is based on using the current data in the form of mean time between failure (MTBF) and its inverse which gives a failure rate.

Resources can be used more effectively by using risk-analysis based maintenance decisions to guide as to where and when to perform maintenance functions. Risk analysis requires a careful identification, systematic approach with clear aims and goals, to overcome them. It requires having a sufficiently competent analyst to evaluate and understand the approach and result from the risk analysis performed. If the risk analysis can be well performed and executed for the Afam power station, it will help to control, interpret and evaluate risks and thereby obtain reliability results so that maintenance efforts are expended according to priority. Making maintenance decisions based on risk analysis and evaluation is an effective way of improving preventive maintenance. The integration of risk analysis strategy into the Nigerian electric power-stations maintenance protocols will enhance reliability productions of plant/systems for proactive maintenance and reliable power supply.

In risk analysis, the total asset is scrutinized by identifying the more likely risk sources in each sub-process. The percentage of each risk source that contributes to the risk of each subsystem is computed. For example, the percentage of total estimated asset risk in a subsystem, such as a gas scrubbers, turbine, compressor or filter, can be analyzed. In order to make proper risk-based maintenance decision, Buckland and Hannu [12] present a comparative study based on three independent risk analyses performed on a specific hydro-power plant. The study establishes the importance of a well-planned specification and the need to analyze and integrate risk analysis results before making maintenance decisions. Buckland and Hannu [12] presented a report on the analysis and evaluation of risk situation.

Mathew and Kennedy [18] presented a model based on failure due to random loads, and then followed it up with a strategy for preventing or minimizing such failures at minimum cost. Random shocks are a leading cause of equipment failure. The shocks arise because of large variations in the value of parameters like operating loads, voltages, pressures, thermal loads, contamination, tolerances on clearances and alignments. However, few maintenance strategies consider random shocks and their contribution to failure due to the cumulative effect of random shocks has also been referred to as a non-self announcing failure. Wortinan et al, [25] have developed a model for passive elements like alarms and protection systems which suffer deterioration each time they are triggered off. Aven and Gaarder [4] develop an optimal replacement procedure under shock load condition. Chelbi et al [13] presented an inspection strategy for random failures to guarantee robust schedules. An important influence on product reliability is temperature: electronic control devices are highly susceptible to increased failure rates at elevated temperatures. Barringer [9] concludes that there are four environmental-stress factors, which substantially influence the occurrence of degradation of faults, incurably thermal cycling, vibration, corrosion and frequency of mechanical stress cycles. He further notes that these stresses are accompanied by interaction and influences of lesser stress

The transformation of maintenance strategies brought about a new pace to already fast growing for strategies. There is a great need, which can combine RCM and total productive maintenance (TPM) in order to improve a systems reliability and availability. Hazard identification can be performed by means of a checklist, mode effect and analysis (FMEA), failure-mode effect mode effect and criticality analysis (FMECA) and also fault-tree analysis (FTA). It is useful to identify individual and asset risk when the most serious risk sources are being considered. Total individual or total asset risk is of interest when comparing risk costs between different plants or subsystems [12]. Al–Najjair [2] maintain that in order to identify the maintenance significant items (MSIs) of a system, a comprehensive survey of all components of the system is carried out, e.g. by a FMECA. For example, one-way of selecting a significant item is dependent on the value of its risk priority number component.

$$RPN = FI \times PC \times FDF \qquad (1)$$

Where FL, is the failure intensity, FC, is failure criticality and FDF is the probability that a failure is not detected. If the RPN of an item exceeds a predetermined value, then such an item is considered to be significant with respect to maintenance. The most appropriate maintenance strategy is a failure-based process. Operating from a fact-based system often requires making a failure forecast based on a small set of actual data Barringer [8]. The data set usually includes information in the form of carefully examined data. Good use of engineering judgment is needed and the data used via Weibayes estimates. (Weibayes is a Weibull analysis using an estimate of the failure mode characterized by a slope (β) to produce a Weibull distribution (relating to age and probability of failure) in order to make the data sets capable of being used more clearly. For some data sets, confidence intervals can he established. Failures can occur by normal ageing or in specific events (i.e. necessarily not time related/age alone). Equipment failure can also occur by combination of events, such as inferior workmanship, ageing, and accumulation of dirt or foreign elements in the compressor [8, 20].

2. Theoretical analysis

The pertinent theories include all the equations and formulae that are used to quantify all measurable parameters in solving risk related problems of this study. Risk is defined as a combination of the frequency or probability of occurrence and the consequence of a specified hazardous event [10].

The amount of risk is defined as the probability of failure $F_{(t)}$ times the consequence of failure [17], i.e.

$$\text{Reliability} = F_f\, C_f \qquad (2)$$

$$\$E = F_f\, \$C_f \qquad (3)$$

Where: $\$E$ = cost of risk exposure in dollars
F_f = probability of failure
$\$C_f$ = cost of the consequence of the failure occurring in dollars

2.1. Mean time between failures (MTBF)

Mean time between failure MTBF which is a yardstick for both reliability and statistical problems, measures the time between any two consecutive failures.

MTBF= $\dfrac{(\text{Total operating time})}{(\text{Number of failure during that period})}$ (4)

The failure rate (λ) is the reciprocal of MTBF

$$i.e. \lambda = \frac{1}{MTBF} \quad (5)$$

2.2. Expected life of equipment

This is the working-time period the item is required to function (Baring all unforeseen circumstances) to deliver its designed function effectively. Statistically, equipment life is most widely evaluated at 90% Poisson confidence level. Citing Barringer [5] showed Poisson confidence levels for on failure exponential, at 95% and 5% confidence levels. At 95% confidence level, expected number of failures $Ef_{(95)}$= 4.7439. Barringer [5]

Hence Expected Life at 95%:

$E1_{(95\%)}$ = MTBF/4.7439 i.e. $El_{(95\%)}$ = MTBF/$Ef_{(95\%)}$ (6)

At 5% confidence level, expected number of failures $Ef_{(95\%)}$ = 0.3554 Hence expected life at 5% confidence level:

El $_{(95\%)}$ = MTBF/$Ef_{(95\%)}$ (7)

So, at 90% confidence interval that is (95% - 5%), the expected life at 90% confidence level: El $_{(90\%)}$ lies between El $_{(95\%)}$ and El $_{(5\%)}$. A Poisson failure is one that occurs outside (i.e. premature) the established/forecasted interval of time; Hence the probability of Poisson failure

$F_{(t)p}$ = 1 – ($e^{-\lambda t}$) (8)

Where, $F_{(t)p}$ = probability of Poisson failure
λ = the failure rate of the system
T = time before the failure

2.3. Characteristic life (η)

The characteristic life of equipment is the range of interval of time during which the equipment is expected to operate with minimal or no problems (barring unforeseen circumstances). It is after this problematic (i.e. less profitable to operate). In Weibull probability characteristic life η is deduced at 36.8% reliability or 63.2% cumulative distribution function (unreliability).

2.4. Cumulative failure

If Weibull slope β <1, failure are in infant mortality failure mode and β =1 is for chance failure mode and β >1 is for wear out failure mode. Cumulative failure (N_t) is the total time between failures for the dataset of the considered system, and can be defined by:

$N_{(t)}$ = $\lambda * t^{A} \beta$ (9)

Where: λ = intercept of the y-axis at the time = 1
β = Weibull slope (shape factor) beta
t = cumulative time of failure

The reliability can be defined by

$$R_{(t)} = \exp\,(-t/MTBF) = \exp\,(-\lambda t) \quad (10)$$

It can also be expressed in Weibull terms as = $R_{(t)}$ = $\exp(-t/eta)^{beta}$. Where λ = constant failure rate and MTBF = mean time between failures. MTBF is easier to understand than a risk model to predict the number of failures expected to occur during a period (probability number) [1]. For exponentially distributed failure modes, MTBF is a basic figure-of-merit for reliability. The failures of most equipment must be analyzed from small samples this can be accomplished using the very practical reliability Weibull analysis [20] for each failure mode.

The mathematical probability of failure (i.e. unreliability) F_t:

F_t = 1- [(N –n) + 1]/ (N + 1) (11)

Where, F_t = probability of failure
N = cumulative failures
η = failure numbers

The availability

A = (uptime)/ (uptime + downtime) (12)

The maintainability

$$M(t) = 1 \exp\,(t/MTTR) = 1 - \exp(-\mu t) \quad (13)$$

Where μ = frequency at which maintenance is undertaken

The risk priority number
RPN=(S) (O) (D) (14)
where: Severity (S): a rating of the seriousness of each potential effect;
Occurrence (O): a rating of the likelihood of occurrence for each potential failure; and
Detection (D): a rating of the likelihood of detecting the cause of a failure.
Critically = (Q) (FMFR) (P_1) (15)

Where; the unreliability (Q) is the probability of failure. The failure-mode ratio unreliability (FMRU) is the ratio of the system's unreliability that can be attributed to the particular failure mode. For example, if an item has four failure modes, then one mode may account for 40% of the failures, a second may account for 30% and the two remaining modes may accounts for 15% each. The probability of loss (P_L) is the probability that the failure mode will cause a system failure (or will cause a significant loss of performance). This is an indication of the severity of the failure.

3. Data Collection

This was achieved mainly by monitoring and observing (i) the operation and maintenance of gas turbine (GT17) and (ii) failed units in Afam thermal power station see the Appendix. For more than seven weeks experiment, information was collected and life data collected from manufacturer's operation/maintenance manuals, maintenance and operation department's failure documentations as well as articulate discussion/interviews with maintenance and operation staff. Useful information was also gained concerning similar plants using wise engineering judgments [14, 19, and 20]. This study is for gas turbine GT17 which is one of the twenty-two such turbine at the Afam thermal power station. The data was collected over the period from January 2004 to June 2011 for some major components, namely the air filter, air compressor, gas scrubber, combustion chamber and turbine.

The performance data were taken from:

1. operation's daily equipment-downtime logbook;
2. maintenance of equipment daily repair logbook;
3. manufacturer's maintenance/operation manual
4. information from similar plants obtained via the internet; and
5. interviews with key personnel involved in the maintenance and operation of turbine GT17.

The collected data were used for calculating the unreliability (i.e. probability of failure), consequence of failure, cumulative number of failures, cumulative time before failure, and time before next failure, characteristic life and cost of exposure for the next risk. The data are shown in, Table 3, Table 4 and in Table 5. To analyze the data and undertake the necessary calculations, the following estimates and assumptions were made using personal judgment, as well as prevailing local and world-class practices. However, only engineering and statistical methods are considered in this study.

4. Engineering method

From an engineering viewpoint of a dataset for the turbine, failure forecasts can be made using good practices and the Crow/AMSAA plot as described in Abernethy [20]. When the distribution mode of failure is by chance events (in Weibull analysis, β = I), a second failure would he predicted to occur when N (t) = $\lambda_1 t^v \beta$ where N = cumulative failure, λ_1 = intercept on the Y-axis at time = I for cumulative failures, β = Weibull slope, and t = time. For the wear-out failure mode, indicative of increasing hazard rate (i.e. instantaneous failure rate), the Weibull line slope β would be > 1. The probability of failure is constructed with commercially available software, [2] which gives **Weibeyes** of estimated life. Probability of failure (i.e. unreliability), equation 11 and Table 4 were used in evaluating $F_{(t)}$ i.e. the probability of failure of the turbine. Figure 3 shows Crow/AMSA using β = 3

5. Discussion and result

From an engineering viewpoint, failure forecasts can be made using good practices of engineering and Crow/AMSAA plots as shown in figures 2 and 3. The condition for chance of failure is when β=1. Wear-out failures modes give an indication of increasing hazard rate, when the line's slope β >1. The engineering method gives the failure and the life of a plant or component based on the practical observations along with an estimate of financial exposure.

For the statistical method the first step is to find statistic computation to use as yardstick and the most often used value is mean time between failures. The other is the expected life of the item. Here the Poison confidence level for failure is used. The 90% confidence interval lies between 132 and 1736 days/failure. More accurate statistical method for reducing uncertainty is to get more failure data. Reliability often improves by reducing human errors or failures bring expectations for improving availability, decreasing downtime, improved secondary failures and risks.

6. Conclusion and Recommendations

Weibull analysis shows high level problems since from the graphs patterns it did not tell what is wrong or where the problem exists. As a result, the power-station's assets utilization reports must be used to identify specific problems for corrective actions. Risk problems should be identified with time and money so that every one can understand them, then fixes them on a priority basis so that power generation could be more efficient and cost effective (reducing cost of operation and maintenance).

Because decision making in practice is often characterized by the need to satisfy multiple goals, the formulation of multi-criteria decision making is a worthwhile topic for risk analysis research in Afam thermal-power station. Reliability engineering theory, RCM and total productive maintenance (TPM) policies will provide excellent guidance for the maintenance management in Afam thermal power station. The Afam electric-power station with frequent failures needs the implementation of failure prevention strategies. In a deregulated environment, with many new plant and equipment designs, emergency capital investments are put to greater and greater risks. This increases the need for reliability tools for the maintenance assessment for the Afam thermal power station and other similar stations. Recognizing futures risk analysis requires knowledge, experience, mental skills, tools, anti-failure standards assessment- perfect link with operators' plant monitoring assessments. With competitive electric-power generating in the deregulation, Afam thermal power station should have a strong maintenance engineering culture, should be able to establish operating and maintenance standards that would lead to improved reliability and cost-effective reducing undesirables, and unexpected events. Effective system engineers require people with multi-skills, operating experience, and general engineering competitiveness supported by cost-effectiveness awareness and computer information management skills. August [3] points out that flexible powered skilled system/plant reliability engineers favourably influence plant operations by reducing operating costs. In the Afam electric-power station, the lack of understanding of the problems, their causes, options, lack of value-added benefits, or cost-effectiveness, the combination of regulated environments and traditional maintenance aversion to cost awareness have combined to increase the need for risk analysis and evaluation. What can be learnt from this study is that careful preparation of risk analysis, ensuring a systematic approach with clear aims and goals is desirable whenever a risk analysis is being undertaken. The desired functions of a system are the main reason why the system exists at all. Therefore, the focus for risk analysis for the Afam thermal-power station should be based on actual data from the system and subsystems and maintenance policies based on the organizations missions' goal and objectives.

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APPENDIX: Observed and conclusions

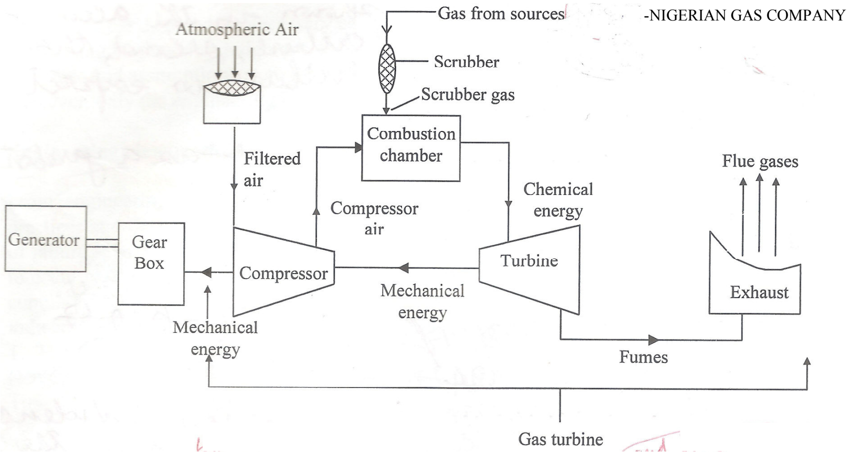


Fig. 1: Line diagram of the major components and processes of gas turbine (GT17)

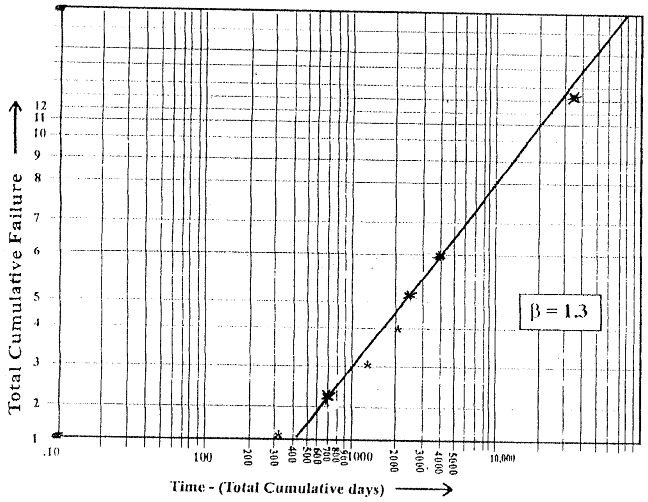
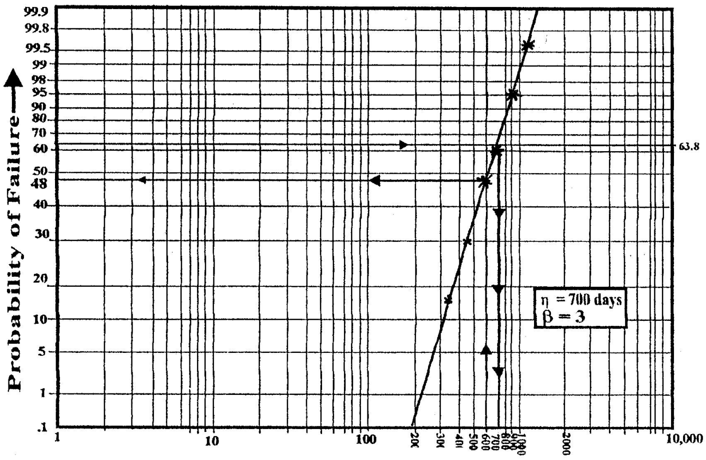


Fig. 2: Crow/AMSA plot for next failure



Age of Failure (days)

Fig. 3: Weibeyes estimate of expected life

Table I: Engineering methods results

	Filter	Compressor	Scrubber	Chamber	turbine
β (from Crow-AMSAA Plot)	1.4	2	1	I .3	1.3
Time before next failure (days)	587	354	743	864	585
Characteristic life η (days)	700	560	800	1150	700
β (from Weibeyes plot)	6	4	6	3.3	3
Cost of Exposure ($)	105,500	240,000	100,000	192,000	240,00c
Risk rate before η ($/day)	555	725	284	243.2	760
Risk rate beyond η ($/day)	670	1,207	536	363.43	840

Table 2: Statistical method results

S/N	TBF (Days)	Probability P(t)	F(t)x 100%
I	353	0,1428	14.28
2	454	0.2857	28.57
3	647	0.4285	42.85
4	685	0.571	57.10
5	788	0.714	71.40
6	817	0.857	85.70

Table 3: Failure data arranged in ascending order of magnitude

S/N	TBF (days)
1	353
2	454
3	647
4	685
5	788
6	817

Table 4: Statistical results

Parameter	Filter	Compressor	Scrubber	Chamber	Turbine
Time before failure (day)	618.2	469	743	908	624
MTBF (days failure)	618.2	469	743	908	624
Failure rate (failure/day)	0.00162	0.002132	0.001346	0.001101	0.001603
Expected life (days)	130 to 1739	99 to 1320	157 to 3091	191 to 2555	132 to 1756
Cost of exposure ($)	484.75	1216.5	336.32	550	934.13

Table 5: GT-17's shows major subsystems failure history from January 2004 to June 2011

a)	Air Filter			
S/N	**Date Failed**	**TBF (days)**	**Date Restored**	**Cause of Failure**
1	05/02/04	780	10/02/04	Filters clogged with contaminants
2	11/09/05	509	17/09/05	Silencers mounting corroded
3	10/01/07	756	07/01/07	Filters blocked with continuants
4	06/06/08	491	11/06/08	Filter blocked
5	23/01/10	555	03/02/10	Filter blocked
b)	**Air compressor**			
1	02/02/04	455	12/02/04	Rotor and Stator blades pitting (blades failure)
2	06/04/05	740	15/04/05	Rotor blades fouling (blades failure)
3	13/12/05	253	27/12/05	Warped rotor (rotor failure)
4	06/07/07	507	21/07/07	Blades failure due to fatigue (blades failure)
5	25/01/08	371	15/08/08	Journal bearing broken (bearing failure)
6	25/01/10	467	01/02/10	Stator blades crack (blade failure)
7	30/06/11	491	01/07/11	Rotor blades highly pitted (blade failure)
c)	**Scrubber**			
1	10/11/04	722	17/11/04	Condensate carry over to combustion chamber (NGC re-heater failure)
2	02/05/05	500	09/05/05	Insufficient gas supply to C.C. (Metering system corroded)
3	07/03/07	610	13/03/07	Wet gas supply to combustion chamber (NGC re-heater failure)
4	27/07/11	1139	03/08/11	Condensate introduction into combustion chamber (NGC re-heater failure)
d)	**Combustion Chamber**			
1	04/06/04	857	15/06/04	Chamber wall tiles cracked
2	03/03/06	920	19/03/06	Ignition failure
3	09/12/07	562	16/12/07	Wall tiles cracked
4	03/11/11	1294	13/11/11	Chamber over-heated
e)	**Turbine**			
1	04/08/04	454	16/08/04	Rotor blades fouling (blades failure)
2	19/07/05	647	17/07/05	Blade cracked (thermal shock) (blade failure)
3	19/10/07	788	27/10/07	Rotor and stator blade damage (thermal failure)
4	03/04/08	353	13/04 /08	Warped Turbine Shafts (shaft failure)
5	12/09/11	685	23/06/11	Rotor blades fouling (blades failure)

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