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Increasing Reliability and Availability in CBM System

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Abstract

This paper studies reliability, availability, maintainability (RAM) and risk factors for critical machines in an inspection condition based maintenance (CBM) system in other to evaluate them and establish its usefulness. Risk and RAM models were used and input data obtained from an oil flow station in the Niger delta of Nigeria. The availability of the machines were 0.99973, 0.99972, 0.999318; with maintainability values of 0.93950, 0.99752 and 0.65571 respectively. Results obtained from the study justify the use of CBM by the company. The cost of exposure for one month, two months and three month inspection interval were determined. This methodology presented is quite useful for assessing and evaluation of risk parameters in a system.

Keywords: *RAM, risk analysis, Inspection, CM, CBM*

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I. Introduction

Equipment or asset failures are often caused by inadequate maintenance and inability to predict problems that may occur later during equipment usage. Paying due attention to the maintenance needs of the system, during maintenance planning considerable savings can be made in the operation processes. But with wise consideration of RAM and risk analysis in maintenance decision making, the frequency of failures and the consequence can be reduced considerably. RAM and risk analysis should lead to the balancing of needs and functional requirements against various constraints resulting from material, technological, economic, physical, operational, environmental and legal factors [1]. [1] Benchmark characteristics of world's best power stations.

The maintenance needs for a system is determined by its design and manufacturing procedure. RAM and risk analysis for various types of products under varying condition, there exist a large volume of literature: [2], [3] and [4]. But on RAM and risk analysis there is scarcity of literature.

More emphasis is now placed on identifying the cause of failure rather than the traditional approach of breakdown and repair [5]. [5] Identified key aspects of the initial findings to include: system focus technique, recognizing complexity as important attribute in modern equipment classification by modes, assessment of failure effects on systems and numerical and statistical data evaluation of equipment populations. This new approach to maintenance was able to assess what maintenance can and cannot do - the completeness of maintenance plans, and options for equipment assessment. With the advent of reliability centered maintenance, a standard common methodology for assessing, ranking and evaluating any maintenance environment was provided.

RCM provides the structure for binding operation, maintenance and engineering. The key points in RCM include strategic mission oriented thinking, systems equipment approach, functional failure focus, risk management, cost benefit consideration, and continual improvements. The overall objective of RCM is to meet mission goals which usually are costs, safety, risks, reliability, availability and, maintainability

Reliability is the probability that equipment or process will function without failure when operated correctly for a given interval of time under stated conditions [6]. Failure of an asset terminates reliability-leading to the cost of unreliability. High cost motivates engineering solutions to reliability problems for controlling and reducing costs. Enhancing reliability satisfies customers for on time deliveries through equipment increased availability and reducing costs and problems from products that fail easily [6]. Measuring the reliability of plants by quantifying the cost of unreliability puts reliability into a business perspective. Higher plant reliability reduces equipment failure costs. Failure is a loss of function when the function is needed. Failure demonstrates evidence of unreliability. Organization seeking reliability improvements require a clear definition of failure [6]. Higher plant reliability reduces failure cost.

Availability deals with the duration of up time for operation and is a measure of how often the system is alive and well when needed. It is often expressed as (up time/ (up time + downtime) with many different variants. Uptime refers to a capability to perform the task and downtime refers to not being able to perform the task [6].

Maintainability deals with the duration of maintenance outages or how long it takes to achieve the maintenance actions compared to a datum. It is a function of design and installation. The datum includes maintenance actions necessary for retaining as equipment in, or restoring the equipment to a specified good condition by personnel having specified skill levels, using prescribed procedure at such prescribed level of maintenance [6]. Maintainability characteristics are usually determined by equipment design which set maintenance procedures and determine the length of repair times. The key figure of merit for maintainability for a reparable system is often the mean time to repair (MTTR) and limit for the maximum repair time. It refers to the ease with which hardware or software is restored to a functioning state. It is described in terms of probabilities and is measured based on the total downtime for maintenance actions The set objective of maintainability is to achieve short repair times for keeping availability high so that downtime of productive equipment is minimized when availability is critical. To meet a specified maintainability target requires control of three main items of downtime: active time (a function of design, training and skill of maintenance personnel), logistics time (time lost for supplying the replacement part), and time administrative time (a function of the operational structure of the organization).

Risk analysis is defined as the combination of the frequency or probability and consequences of a specified hardware event [7]. In discussing prioritization of maintenance action, [8] maintains that in order to identify risks analysis in terms of their seriousness and where they are located in the system, risk analysis should provide detailed guidance as to what specifically maintenance actions should be directed. Risk analysis is used to estimate the consequences of a failure and help in prioritizing maintenance actions. There many opinions regarding what risk analysis implies and how it should be used. Risk analysis can form the basis for maintenance decisions.

The maintenance approach best suited to an item can be determined using the reliability centered maintenance (RCM) methodology. It provides a structure for determining the maintenance requirement of any physical asset in its operating contest, with the primary objective of preserving system function cost effectively [9]. Identification of system functions and functional failures, as well as failure mode and effects analysis are important elements in RCM.

In risk analysis there is need to identify hazards. Hazard identification can be identified by means of checklist: Failure Mode Effect Analysis (FMEA), Failure Mode Effect and Criticality Analysis (FMECA) and also Fault Tree Analysis (FTA). It is useful to identify individual and asset risk and when the most serious risk sources are of interest. [10] Suggested that in order to identify the maintenance significant factor (MSIs) of a system, a comprehensive survey of all consisting items of the system should be carried out by FMECA. For example, one way of selecting a significant item is dependent on the value of the Risk Priority Number (RPN).

Condition based maintenance (CBM) is an equipment maintenance procedure based on detecting the condition of the equipment in order to evaluate whether it will fail during some future period and then acting appropriately to avoid the consequence of that failure [11]. It is maintenance action furthered on actual condition derived from tests. Maintenance is not carried out until there is an obvious need which will increase the availability of the equipment, as well as lower the maintenance cost.

[12] Presented and solved a CBM problem for a system subject to inspection.

The objective of this work is to present a methodology for RAM and risk analysis in condition based maintenance system and to verify this approach using a case study.

II. Methodology

Three machines in a flow station of a major oil company in Nigeria were used in the case study. The flow station has two operational pumps and a standby pump and a generator used for lighting and administrative purposes (with a standby generator). Operational data were obtained from this source. The machines were inspected periodically with condition monitoring instruments. The data were applied on the models presented to verify the results.

2.1 RAM AND RISK MODELS

For an exponential distribution mode of failure, the expression is given in equation 1

$$f_i(t) = \lambda_i e^{-\lambda_i i t} \qquad (1)$$

Where λ_i is the failure rate of machine i.

Where n_{fi} the actual is number of failure of machine i in a planning horizon.
T is the time unit (one year) . The failure rate is presented in equation 2

$$\lambda_i = \frac{1}{MTBF_{ni}} \qquad (2)$$

Where the mean time to failure is given in equation 3

$$MBTF_{ni} = \frac{U_T}{n_{fi}} \qquad (3)$$

U_T is the uptime of machine i
The cumulative distribution function (CDF) is given in equation 4

$$\bar{F}\left(t_{ij}\right) = 1 - \int f_i(t)dt = R(_{i.t}) \qquad (4)$$

The reliability is presented in equation 5

$$R(_{i,t}) = e^{-\lambda t} \qquad (5)$$

The unreliability is expressed in equation 6 (6)

$$U_R = 1 - e^{-\lambda t}$$

Availability (A) is expressed in equation 7

$$A = \frac{U_T - D_r}{U_T} \qquad (7)$$

Where U_T is the uptime and D_r is the downtime
For a system in which the repair times are distributed exponentially, its maintainability M (t) is given in equation 8

$$M(t) = 1 - e^{-\mu t} \qquad (8).$$

Where μ is the repair rate
For maintainability calculations a mission time of 8 hours is used as shown in equation 9

$$\frac{1}{\mu} = MTTR \qquad (9)$$

The exposure cost is given by equation 10

$$E = U_R C \qquad (10)$$

Where U_R is the average unreliability and C, the consequence of failure of the machine.

III. Results And Discussion

The system has three machines (M/C1, M/C2, (M/C3). The relevant system's characteristics are presented herein:

T = 1 year planning horizon
N = 3 (number of machines)

λ_1 = 0.00011/hr (1/yr.), λ_2 = 0.00023/hr (2/yr.), λ_3 = 0.00023/hr (2/y)

U_{T1} = 8736 hrs, U_{T2} = 8740 hrs, U_{T3} = 8700hrs

$Dr_1 = 24hrs \quad Dr_1 = 20hrs \quad Dr_1 = 60hrs$

n_{f1} = 1 , n_{f2} = 2, n_{f3} = 2

$MBTF_1$ = 8736 hrs , $MBTF_2$ = 4370hrs, $MBTF_3$ = 4350 hrs

$$MTTR = \frac{Dr_i}{8}$$

$$MTTR_1 = 3,\ MTTR_2 = 1.5, MTTR_3 = 7.5$$

$$\mu_1 = 0.3333, \mu_2 = 0.6667\ \mu_3 = 0.1333$$

$0.1584m^3$ of crude oil @ $67.21 - ₦24,181.2 [13]

M/C 1 Pump flow rate $(15{,}000barrels - 2376m^3)/day - 71280m^3/month$

M/C 2 Pump flow rate; $(15{,}000barrels - 2376m^3)/day - 71280m^3/month$

M/C 3 Generator (450KVA)-(₦450,000.00)/day,-₦ 13,500,000/month (If rented)

The average reliability and unreliability of the machines in the system for one, two months and three months inspection interval are presented in Tables 1, 2 and 3 respectively.

Table 1: Average Reliability and Unreliability per year at one month inspection interval

	Reliability			Unreliability		
Month(s)	**Machine 1**	**Machine 2**	**Machine 3**	**Machine 1**	**Machine 2**	**Machine 3**
1	0.92284	0.84544	0.84544	0.0771	0.15456	0.15456
2	0.85163	0.71477	0.71477	0.14837	0.28523	0.28523
3	0,78592	0.60439	0.60439	0.21408	0.39571	0.39571
4	0.72528	0.51089	0.51089	0.27472	0.48911	0.48911
5	0,66932	0.42896	0.42896	0.33068	0.57193	0.57193
6	0,61767	0.36517	0.36517	0.38233	0.63483	0.63483
7	0.57081	0.30873	0.30873	0.42919	0.69127	0.69127
8	0,52603	0.26100	0.26100	0.47397	0.73900	0.73900
9	0.48544	0.22067	0.22067	0.51456	0.77933	0.77933
10	0.45293	0.19090	0.19090	0.54787	0.8091	0.8091
11	0.41342	0.15773	0.15773	0.58658	0.84227	0.84227
12	0.38152	0. 13335	0. 13335	0.61848	0.86665	0.86665
$\frac{\Sigma}{n}$	0.55141	0.37677	0.37666	0.38317	0.60485	0.60485

Table 2: Average Reliability and Unreliability per year at two months inspection interval

	Reliability			Unreliability		
Month(s)	**Machine 1**	**Machine 2**	**Machine 3**	**Machine 1**	**Machine 2**	**Machine 3**
2	0.85351	0.71806	0.71806	0.14649	0.28194	0.28194
4	0.72848	0.51561	0.51561	0.27152	0.48439	0.48439
6	0,62176	0.37024	0.37024	0.37834	0.62976	0.62976
8	0,53068	0.26586	0.26586	0.469322	0.73414	0.73414
10	0.45294	0.19090	0.19090	0.547062	0.80910	0.80910
12	0.38659	0. 13708	0. 13708	0.61341	0.86292	0.86292
$\frac{\Sigma}{n}$	0.59565	0.36791	0.36791	0.40436	0.63371	0.63371

Table 3: Average Reliability and Unreliability per year at three months inspection interval

	Reliability			Unreliability		
Month(s)	**Machine 1**	**Machine 2**	**Machine 3**	**Machine 1**	**Machine 2**	**Machine 3**
3	0.78852	0.60847	0.60847	0.21148	0.39153	0.39153
6	0,63179	0.37024	0.37024	0.368321	0.62976	0.62976
9	0.49021	0.22528	0.22528	0.50973	0.77472	0.77472
12	0.49021	0.13708	0. 13708	0.61341	0.86292	0.86292
$\frac{\Sigma}{n}$	0.47764	0.33527	0.33527	0.42574	0.66473	0.66473

The availability and maintainability of each machine is shown in Table 4.

Table 4: Availability and Maintainability per year

Machine	Availability	Maintainability
1	0.99973	0.93050
2	0.99772	0.99752
3	0.993318	0.65575

The cost of exposure of the machine are presented in Tables 5, 6 and 7. This was computed using equation 9

Table 5: Cost of exposure per year for one month inspection period

Machine	Unreliability	Consequences of failure (₦)	Cost of exposure(₦)
1	0.38317	$1.088154x^{10}$	$4.1694x^{9}$
2	0.60485	$1.088154x^{10}$	$6.5817x^{9}$
3	0.60485	13,500,000	8,165,475

Table 6: Cost of exposure per year for two months inspection period

Machine	Unreliability	Consequences of failure (₦)	Cost of exposure(₦)
1	0.40436	$1.088154x^{10}$	$4.40006x^{9}$
2	0.63371	$1.088154x^{10}$	$6.89557x^{9}$
3	0.63371	13,500,000	8,555085

Table 7: Cost of exposure per year for three months inspection period

Machine	Unreliability	Consequences of failure (₦)	Cost of exposure(₦)
1	0.42574	$1.088154x^{10}$	$4.63271x^{9}$
2	0.66473	$1.088154x^{10}$	$7.23329x^{9}$
3	0.66473	13,500,000	8,973,855

IV. Conclusion

Results from the study show that the average unreliability of machines one, two and three as 0.38317, 0.60485 and 0.60485 for a one month inspection interval, 0.40436, 0.63371 and 0.63371 for a two months inspection interval and 0.42574, 0.66473 and 0.66473 for a three months inspection interval. The availability of each machine was: 0.99973, 0.99772 and 0.993318 with maintainability values of 0.93050, 0.99752 and 0.65571 respectively. The cost of exposure of the machines is high in the system. The use of condition based maintenance in the system is duly justified as shown by these results. The methodology presented is very useful in CBM management and therefore recommended for application.

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