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Evaluating the effectiveness of maintenance practices: Case study of a university power generating plant

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Abstract

The study was conducted in one of the Federal universities in Nigeria. The aim was to evaluate the effectiveness of the maintenance practices in a power generating plant using an availability ratio method. The plant was placed under study for a period of six months. The operation records were obtained from which the availability ratio was obtained. Questionnaires were also distributed to the 21 staff members in the unit and oral interviews were conducted to ascertain the maintenance strategy practiced by the unit. The study revealed that the unit has an availability of 61%, which is low compared to the standard availability ratio of power generating plants (99.9%). The maintenance practices of the unit were determined ineffective. This ineffectiveness was attributed to poor documentation, low-skilled manpower, lack of a spare parts stock, and deficient operating maintenance strategy, as well as poor maintenance funding and management policy. The study recommended autonomy of the maintenance unit, a better inventory system for work materials and spare parts, practice of a predictive or condition monitoring maintenance strategy, training and retraining of the workforce and acquisition of relevant equipment, such as vehicles and computers, as measures that will, in part, improve the effectiveness of maintenance of the plant. The recommendations of this study can be applied to the power sector in Nigeria, which is considered by many to be grossly ineffective.

Keywords: Maintenance, Key performance indicators (KPI), Availability, Maintainability engineering, Maintenance effectiveness

1. Introduction

The world in recent times has experienced economic growth with advances in technology and globalization. However, most industries still practice passive maintenance or failure maintenance in which equipment are run to failure before maintenance is done [1]. One of the major problems facing Nigeria and other developing countries is sustainability of public utilities. Most government expenditures and investments are centred on providing infrastructural development, which includes roads, power, water and housing. These developments cannot be sustained due to a poor maintenance culture [2].

Maintenance is a collaboration of all technical and administrative actions intended to retain an item or restore it to a state of optimum performance [3]. Maintenance is also defined as any work undertaken to keep or restore a facility to any acceptable standard [4]. A good maintenance culture comprises accurate diagnosis of defects, appropriate remedial measures, in-depth technical knowledge of material usage, and management of resources as well as formulation and implementation of integrated strategy and policies to sustain utility [5]. In production and manufacturing environments, good maintenance engineering is necessary for smooth and safe daily plant operations. This must be done while optimizing operating procedures and budgets to attain and sustain the highest level of efficiency, availability, reliability and profitability. Good maintenance engineering requires accurate and up to date information about assets. From this, predictions can be made and acted on [6-7]. The main goal of maintenance is to keep equipment running while at the same time ensuring its health. The more the equipment is kept running, the more money it makes for the organization. Additionally, over the design life of most equipment, periodic maintenance is required.

Anytime maintenance activities are not performed according to the equipment's designer, the operating life of the equipment is shortened. To this end, there are various approaches to doing maintenance to ensure equipment reaches or exceeds its design life [4, 8]. Some of these strategies include pre-emptive detection and elimination that tends to remove the causes of maintenance faults, quality control and assurance carried out at the design stage, preventive maintenance that serves as a proactive measure to avoid equipment breakdown and its consequences, shutdown overhaul maintenance, predictive maintenance, intentional

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over design, improved technologies, root cause elimination, proactive education and training [2, 4, 8-11].

The cost of not carrying out proper maintenance is enormous as it leads to downtime. Downtime is the time production stops because machinery is not working and it includes the time spent to inspect machinery for the causes of failure, time to order the necessary parts to effect repairs and the time actually spent to carry out the repairs. The cost of downtime includes the cost of machine unavailability, production losses, loss of raw materials, customer's dissatisfaction and labour relations. All of these can be minimized through an appropriate maintenance strategy.

There are several methods of evaluating the effectiveness of maintenance. They include analysis of availability, key performance indicators (KPI), overall equipment effectiveness (OEE), total effective equipment performance and maintenance effectiveness analysis simulations. Key performance indicators combine key metrics and indicators to measure performance. Some of the indicators include availability and reliability of equipment, the number of outstanding backlog repairs, the number of equipment failures, amount of maintenance rework, component and system availability, the availability of spare parts, mean time between failure (MTBF), ratio of planned to unplanned maintenance actions, and cost of repairs, as well as equipment and material inventory, among others [10, 12-13]. The overall equipment effectiveness (OEE) is a function of three indicators (availability, performance and quality). It is calculated using Equation 1 [10]:

$$OEE = Availability \times Performance \times Quality \quad (1)$$

where availability and quality are calculated using Equations 2 and 3, respectively:

$$Availability = \frac{Operating\ time}{Planned\ production\ time} \quad (2)$$

$$Quality = \frac{Good\ units}{Parts\ produced} \quad (3)$$

Data obtained from several studies in Nigeria over the past decades indicated that most private and government utilities do not expend the necessary resources to maintain equipment in proper working order [11, 14-15]. Rather, studies have shown that they wait for failure to occur and then take whatever actions are necessary to repair or replace the equipment. A critical example is in the electricity industry, which has faced strong criticism from scholars. The maintenance culture in the electricity industry has been described as appalling. Most power plants generate at 60-80% of their installed capacity. A colossal amount of money has been spent over the years in replacing power equipment left without maintenance. The implication of this is that power generation has become unattractive to investors despite government efforts to privatize the sector [11, 14-15]. Therefore, this study attempts to investigate and mathematically evaluate the effectiveness of maintenance practices in a typical Nigerian enterprise using key performance indicators. This is done to ascertain gaps to effective operations and make adequate recommendations. The study focuses on the power sector using the central generating plant of a Federal University as a case study.

2. Methodology

The following key performance indicators were adopted for this study, based on the available records, to evaluate the effectiveness of maintenance of a power generating plant at a Federal University in Nigeria. They are:

i. Availability of the equipment or plant
ii. Operating maintenance strategy
iii. Organizational structure
iv. Skills and training of maintenance personnel
v. Job planning
vi. Equipment and material inventory
vii. Source of financing

Three different approaches were adopted for the evaluation of the effectiveness of maintenance in this generating plant:

i. Collection of operations records for six (6) months from four generators (G1, G2, G3 and G4)
ii. Distribution of a well-structured questionnaire to the workers in the electrical plant
iii. An oral interview with the head personnel of the mechanical section

2.1 Data collection approach

Operation records were collected from the generating plant unit spanning the period from April to September, 2017. The adopted methodology is similar to that of Kolawole et al. [16]. Other records such as maintenance schedules, equipment breakdown records, and job planning records were not available. The data collected only gave an account of when the generators were expected to run and when they actually operated. The data could not account for the downtime (total time taken for repairs to be carried out when a machine was out of service) and the maintenance schedule of the unit. Hence, the study used the method of an availability ratio to ascertain the effectiveness of maintenance. The availability ratio is defined mathematically by Equations 4 and 5.

$$\text{Availability ratio (A.R)} = \frac{\text{Hours run (U)}}{\text{total hours expected to run(T)}} = \frac{U}{T} \quad (4)$$

$$\text{Average Availability Ratio } (A.R_{av}) = \frac{A.R_1 + A.R_2 + A.R_3 + A.R_4}{4} = \frac{\sum A.R_i}{4} \quad (5)$$

For a well-run power plant, this ratio is about 0.995 which implies that it is on-line 99.5% of the time [17]. This availability ratio method was used to evaluate maintenance effectiveness by Salonen and Bengtsson [18]. It is a tactical approach to evaluating maintenance effectiveness.

2.2 Questionnaire approach

Well-structured questionnaires were developed to ascertain the perception of maintenance practice in the power generating plant. The questionnaires examined key performance indicators such as availability of maintenance budget, contents of toolboxes, materials and spare parts inventory, personal protective equipment and maintenance applications, among others. SPSS 20.0 was used to analyze the questionnaire via descriptive analysis. From the analysis,

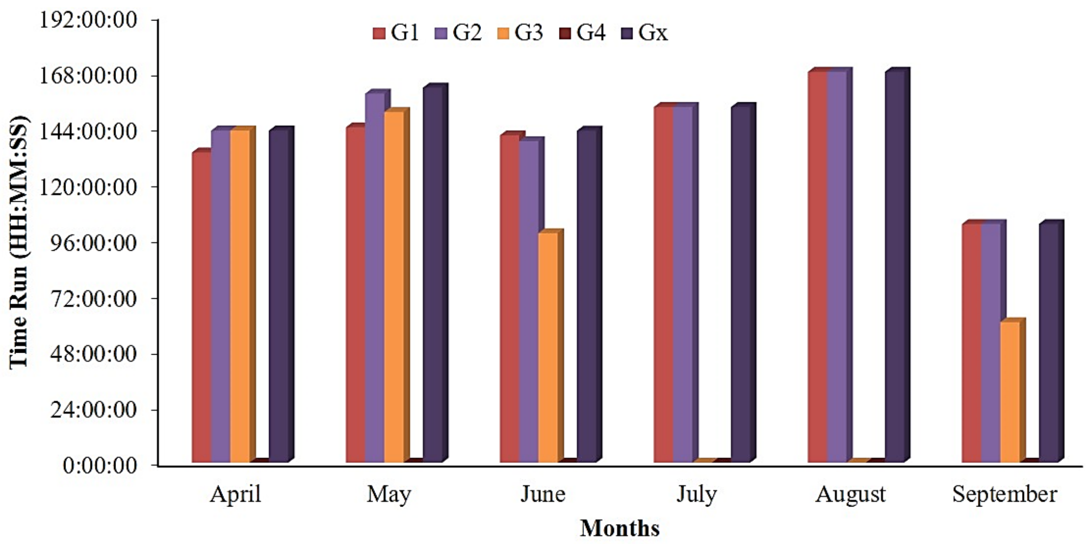

Figure 1 Runtime for generators G1-G4, and Gx is the total time expected to run

the maintenance strategy and other relevant information about the maintenance practices were established.

2.3 Oral interview approach

An interview was conducted with the head of the mechanical department of the maintenance unit. From the interview, the normal operation schedule per day for the unit was obtained and is shown in Table 1. The operational capacity of each generator is 1000 KVA and they were expected to run simultaneously when required, as depicted in Figure 1.

Table 1 Operation schedule per day

	Time run	Hours run
Morning	05:00 AM – 07:30 AM	2 .0
During the day	10:00 AM – 04:30 PM	6.5
Night	07:00 PM – 02:00 AM	7.0
Total per day		15.5

Table 2 Availability Ratio

Generator	Availability Ratio
G1	0.9667
G2	0.9983
G3	0.4740
G4	0.0000
Average	0.6098

3. Results and discussion

3.1 Availability ratio

Table 2 shows the availability ratio for the various generators. The availability ratios for G1 and G2 were 0.9667 and 0.9983, but for G3 and G4 they were 0.474 and 0. This is because G4 was completely shutdown throughout the period of the research due to a major breakdown, while G3 experienced frequent breakdowns. The average availability for the plant was 0.60975. This implies an efficiency of 61% which when compared with standard value for a power plant unit of 99.9% indicates ineffectiveness [18].

3.2 Interview response

Table 3 shows the responses of the Head of the Maintenance unit during the interview. He explained the reasons for the low availability ratio obtained for the plant. Although the department operates preventive maintenance, it was observed that preventive maintenance was only done once during the six-month period of the study. Most times maintenance was done in the event of a major fault. Uma *et al*. [19] indicated that the poor organization and implementation of maintenance strategy in Nigeria has led to substandard results from the country's engineering assets. The absence of proper record keeping also contributed to the ineffectiveness of the maintenance philosophy of the plant. The trend of maintenance work carried out in the past cannot be followed. Trouble shooting was done every time a major breakdown occurred. There was also no maintenance schedule which indicates that preventive maintenance was not carried out. There is also lack of training programmes for maintenance personnel, which according to Ikuobase *et al*. [20] impedes power generation effectiveness. New ideas on how equipment should be maintained are vital to improve maintenance of equipment.

3.3 Analysis of the research questionnaire

Table 4 shows the educational qualifications of the respondents interviewed in this study. The results showed that 24% of the respondents are Bachelor's degree holders while 14% hold a Higher National Diploma. This suggests that there is need to organize more training programmes for the maintenance personnel through short and long courses to better their skills [21].

Table 5 represents the responses of the respondents to the questions posed to them in the research questionnaire. The results showed that 90% of the respondents agreed that the department had a maintenance budget, whereas 60% opined that the department has all the relevant equipment needed for work. Also 60% of the respondents stated that the department did not have maintenance log book and 70% are of the opinion that response to damaged tools and equipment is slow. In the same light, majority of the respondents

Table 3 Result of the interview with the head of the maintenance unit

S/N	Variable Posed	Response given
1	Operating maintenance strategy	Preventive and breakdown
2	Availability of documentation	Only equipment operation logbook is available. Other documentations such as operations manual, list of equipment, work in progress, failure history and backlog are unavailable.
3	Work materials and spare parts	Availability of store room and toolboxes although not properly equipped. Materials and spare parts are purchased when needed
4	Training	Not regularly done
5	Application	The unit lacks basic applications such as computers, vehicles for easy movement of materials and well-organized offices for staff
6	Source of financing	The unit is financed by the management of the school. It does not have its own financing. In the event of major breakdown internal memoranda are sent to school management which may take months to be addressed.

Table 4 Respondents' qualification

Respondent's qualification	Frequency (%)
Trade test	19
OND Ordinary National Diploma	24
HND Higher National Diploma	14
BEng	24
None	19
Total	100

Table 5 Response from Questionnaire

S/N	Maintenance Checklist	Yes (%)	No (%)
1	Do you have maintenance budget	90	10
2	Does your department have all the necessary equipment needed to work	60	40
3	Does your department have some equipment that are never used	29	71
4	Do you have an equipment maintenance logbook	40	60
5	Response to damaged tools and equipment is quick	30	70
6	Response to replacement of work materials is quick	24	76
7	Do you have routine maintenance program for your program	57	43
8	Do you sometimes lack materials for work?	81	19
9	Do you have toolbox?	76	24
10	If yes, is your toolbox well equipped?	67	33
11	Do you hold a toolbox meeting before commencing a job?	71	29
12	Availability of PPE	86	14
13	Can you operate a computer?	43	57
14	Availability of computer and other maintenance applications	14	86
15	Do you have a planned maintenance programme?	86	14
16	Do you have equipment breakdown records?	67	33
		Often (%)	**Rarely (%)**
17	How often does equipment breakdown?	10	90
		1-2 weeks (%)	**2-3 weeks (%)**
18	How long does it take to effect repairs?	86	5

(76%) affirmed that there is slow response to replacement of work materials. Another notable index from Table 5 is that only 14% of the respondents agreed that there are computers and other maintenance applications that have made maintenance work easier and faster. Most of the indices shown in Table 5 account for the low availability ratio of the unit.

4. Conclusions

The study was designed to ascertain the maintenance practices of a power plant in a case study of a university's central power generating unit. After monitoring the unit for a period of six months and obtaining operation records for the said period, a plant efficiency of 61% was recorded using the availability ratio method. This indicates ineffectiveness when compared to the acceptable efficiency of a standard power plant, 99%. This ineffectiveness was attributed to management decisions, lack of adequate spare parts/materials stock, lack of relevant applications, a poor operating maintenance strategy and lack of training for staff. It is therefore recommended that a maintenance unit should be autonomous by allotting it budgetary needs which are controlled by the unit. There should also be an inventory of the store room to assure adequate tools and spare parts. Other ways through which maintenance can be made effective include a good inventory system for work materials and spare parts, improving the educational qualifications of the workforce, regular training of the workforce, acquisition of relevant applications such as vehicles and computers, improved office conditions, proper documentation, periodic evaluation of maintenance performance, development of computerized models and practice of predictive maintenance based on a strategy rather than engaging in breakdown maintenance.

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