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Prioritisation of Maintenance Policies for Upstream Equipment in A Typical Quarry Using Decision Maintenance Grid (DMG)

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Abstract: This paper provides a frame work for equipment maintenance management with options that allow decision makers to select the most successful ways to manage maintenance. Keeping diverse range of equipment working efficiently, managing downtime and achieving output targets in quarries can be something of a juggling act for quarry operators/ managers. The paper also provides an overview of maintenance strategies suitable for upstream equipment in Construction Products Nigeria(CPN) quarry. It considered their respective applications based on operation and failure data of equipment evaluated from the quarry report system (QRS). A decision maintenance grid (DMG) was employed to decide the most appropriate maintenance strategy for the equipment based on their availability values and failure frequencies.It was found out that forward planning is critical to prevent unscheduled downtime and setting up an effective preventive maintenance schedule should be an essential part of the quarry upstream equipment management process.
Keywords: Upstream, quarry equipment, maintenance policy, Decision Grid.

I. INTRODUCTION

Adopting an appropriate maintenancemanagement system for quarry equipment is very essential in the current world of high degree of business competitions, high technology advancements and strict environmental laws and policy.According to EN 13 306 (2001) standards, maintenance practices approaches can be grouped into two major groups, namely Preventive Maintenance (PM) and Corrective Maintenance (CM). Preventive approach can further be subdivided into condition based maintenance and predetermined maintenance; this implies that PM can be time based or condition based. Corrective maintenance has been subdivided into two subgroups which are deferred and immediate; CM is an approach which is reactive in nature as compared to PM which is a proactive form of maintenance. Timing plays a major role in all these approaches (Smith, 2002).

Investigations have shown that the key problems of maintenance functions identified in quarries are economic issues (inefficient use of financial resources) and production issues (increased equipment downtime). The underlying reasons for these problems were equally identified as organizational factor (inefficient business processes) and methodological factor (absence of a differentiated maintenance approach for each category of equipment).

II. EQUIPMENT MAINTENANCE OVERVIEW

Dealing with maintenance practices especially in a commercial quarry, needs careful means for data recording and management. This can be done efficiently through the use of statistical approaches. Rashid (2011) emphasized the application of statistics in analysing maintenance data in the mining industry as it normally leads to opportunities for cost reduction. It is clear that replacing a component before it fails (preventively) may, under certain circumstances, make better economic sense than replacing the component when it fails correctively (Samanta and Sarkar, 2003). It can be seen that the corrective replacement costs increase as the operating time interval increases (Figure 1). In other words, the less often you perform a PM action, the higher your corrective costs will be.

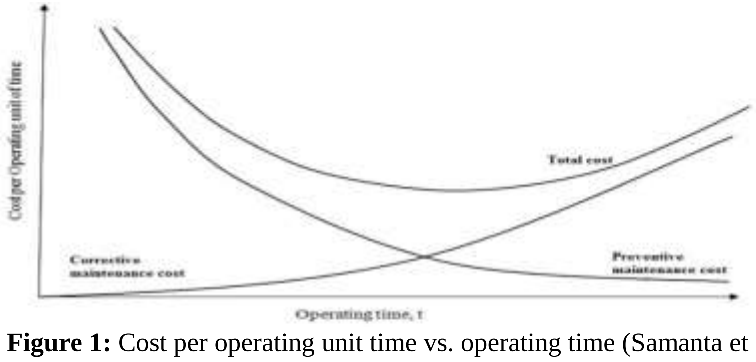

Figure 1: Cost per operating unit time vs. operating time (Samanta et al, 2002).

The Decision Maintenance Grid (DMG) is a model that helps to choose different models in maintenance. The model identified 5 levels of maintenance strategies that have impact on performance and productivity which include Design Out Maintenance (DOM); Condition Based Maintenance (CBM); Skill Level Upgrade (SLU); Fixed Time Maintenance (FTM) and Operate to Failure (OTF) as shown in Figure 2. A maintenance decision grid adapted from Labib (2004) is shown in Figure 3.

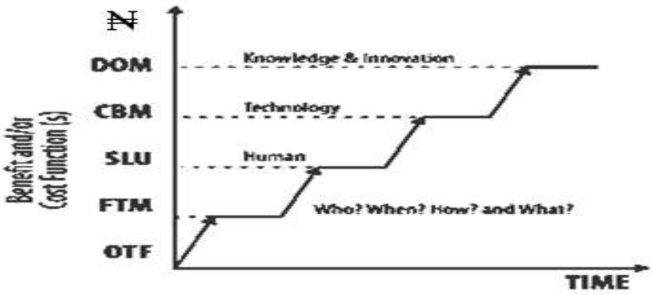

Figure 2: Evaluation and Ranking of Maintenance Policies (Labib, 2004)

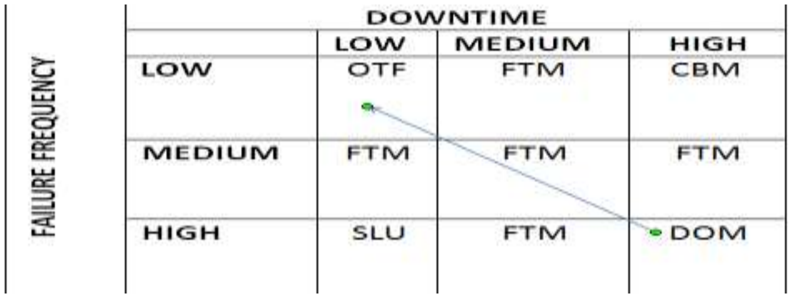

Figure 3: Design Maintenance Grid (DMG)(Adapted from Labib, 2004)

III. MATERIALS AND METHODS

3.1 Materials

Construction Products Nigeria (CPN) Ltd Quarry, Ibadan, Nigeria was studied. The quarry performs its operation with the idea of continuous improvement on equipment maintenance. The plan is to frequently improve its maintenance management system to ensure better equipment reliability, availability and productivity.

The basic equipment employed at the upstream section of the quarry (Table 1) and their data as they relates to their operation, failure and maintenance management have been studied. Equipment user and maintenance manual (Caterpillar and Atlas Copco maintenance and repair guides) were also consulted.

Table 1: Equipment studied in CPN Quarry

EQUIPMENT TYPE	MODEL
Drill Rig	Atlas copcoPowerroc T25
Hydraulic Excavator	CAT 336 D
Dump Truck	MAN DIESEL (25T)

3.2 Methods

Quantitative and qualitative data were collected and analysed. Specifically, operation and failure data of the equipment (Equipment Availability and Failure Frequencies) were evaluated from the Quarry Report System (QRS) for a period of one year. Any obstruction to equipment's operation that results in downtime greater than thirty minutes (0.5 hour) is categorized as a failure. The data collected were presented using MS Excel software and Pareto analysis was used to compare the failure frequencies of the equipment. The procedures employed to determine the operational availability of the studied equipment are keeping records of planned hours, working hours, failure times and maintenance periods. From these records (QRS), operational availability values of the equipment were determined using equation 2. Availability deals with duration of operation of equipment.

Calculation of planned hours (ph), which is the total number of available hours for work, is expressed as follows (Momoh and Salihi, 2010):

$$P_h = w + s_h + b + m_c + m_p + s_p \quad (1)$$

Where w is working hours;
S_h is a Standby hours;
b is breakdown hours;
m_c is corrective maintenance hours;
m_p is preventive maintenance hours; and
s_p is waiting for spare parts or staff

The operational availability is the actual level of availability realized in day to day operation of equipment. Operational availability is related to preventive maintenance and logistics, delay to obtain spare parts or lack of maintenance staff expressed as follows (Momoh and Salihi, 2010):

$$A = \frac{w + s_h}{w + s_h + b + m_c + m_p + s_p} \times 100\% \quad (2)$$

The DMG acted as a map where the performances of the worst equipmentwere placed based on multiple criteria. Itwas employed to implement appropriate design actions that led to the movement of machines towards an improved state with respect to multiple criteria. The stepsused to develop the model are:

a) Classification of design related policies,
b) Prioritization of the proposed actions.

When prioritizingthe maintenance strategies, the followings were carried out:

1. identified available policies,
2. performed a trade-off analysis to choose most appropriate policy that satisfies the business objectives at a specific instant of time and, at minimum cost.

The methodology involved three steps:Criteria Analysis; Decision Mapping and Decision Support.

Step 1: Criteria Analysis

Pareto analysis of two important criteria were established; Availability of equipment (the main concern of production) which depends on downtime; and Frequency of failures; (the main concern of asset management). This was to assess how bad the worst performing equipment are for a certain period of time. The worst performers in both criteria were sorted and grouped into High, Medium, and Low sub-groups. These ranges were selected so that machines are distributed evenly among every criterion.

Step 2: Decision Mapping

The aim of this step is twofold; it scales High, Medium, and Low groups and hence genuine worstmachines in both criteria can be monitored on this grid. It also monitors the performance of different machines and suggests appropriate actions. The next step is to place the machines in the "Decision Making Grid" shown in Figure 4, and accordingly, to recommend asset management decisions to management. This grid acts as a map where the performances of the worst machines are placed based on multiple criteria. The objective is to implement appropriate actions that will lead to the movement of machines towards the north - west section of highavailability, and low failure frequency.

IV. RESULTS AND DISCUSSION

4.1 Results

The performance evaluation and failure analysis resultsof the equipment (drilling machine, excavator and dump truck)are presentedfor the studied quarry,from which appropriate maintenance strategy for the different machines determined using Decision Maintenance Grid (DMG).Table 2 presents the availability values of the equipment studied in the quarry.

Table 2: Availability Values for the studied equipment in CPN Quarry

Month	DR	EXC	TR
Jan, 2014	90.39	90.77	95.54
Feb, 2014	95.05	91.21	92.19
Mar, 2014	93.07	96.25	96.96
Apr, 2014	93.08	96.43	96.43
May, 2014	94.21	95.11	96.36
Jun, 2014	95.19	95.36	95.36
Jul, 2014	93.58	97.01	97.01
Aug. 2014	92.52	95.29	97.07

Sep, 2014	93.33	95.98	95.98
Oct, 2014	93.84	97.95	97.95
Nov, 2014	93.94	97.71	99.14
Dec, 2014	93.26	98.21	100.0
Average	**93.45**	**95.61**	**96.67**

DR = Drill; EXC= Excavator; TR = Truck

The failure analysis of the equipment in thequarryis presented in Tables 3 and Figures 4.

Table 3: Failure Frequency of studied equipment at the upstream section of CPN Quarry

Equipment	**Frequency**
Dump Truck	24
Wagon Drill	8
Excavator	4

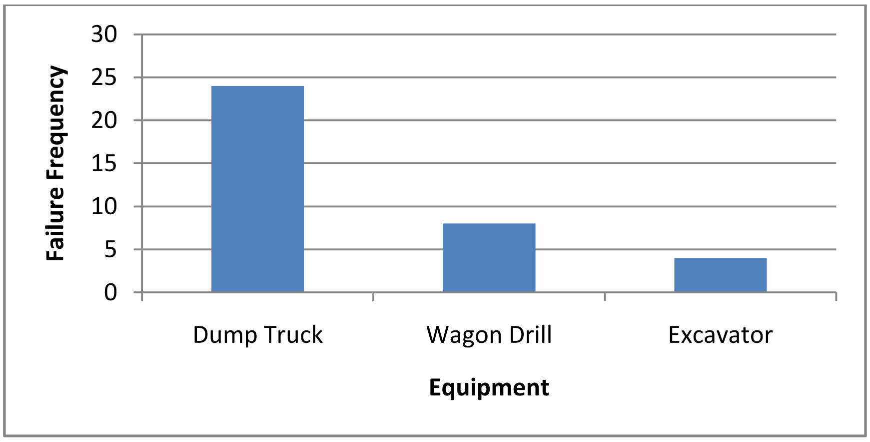

Figure 4: Pareto Analysis of failure data of studied equipment at the upstream section of CPN Quarry

4.1.1 Appropriate Maintenance Strategies For Upstream Equipment

The Decision Maintenance Grid (DMG) acted as a map where the performances of the worst equipment were placed based on availability and failure frequency criteria analysis. It was employed to decide appropriatemaintenance actions that led to the movement of machines towards an improved state.

Table 4: Matrix of Criteria Analysis for CPN Quarry

RITERIA	Availability	
	A (%)	Equipment
HIGH	91-99	Truck, Drill, Excavator
MEDIUM	86-90	
LOW	70-85	

Table 5: Decision Mapping for CPN Quarry

CRITERIA	Failure Frequency	
	Frequency	Equipment
HIGH	26-50	
MEDIUM	11-25	Truck
LOW	1-10	Drill, Excavator

		Availability		
		High	Medium	Low
Failure Frequency	Low	OTF	FTM (When?)	CBM
	Medium	FTM Truck, (Who?)	FTM	FTM (What?)
	High	SLU	FTM (How?)	DOM

Remarks:
Drill – OTF (Operate to failure)
Excavator – OTF (Operate to failure)
Truck – FTM (Fixed Time Maintenance)

4.2 Discussion Of Results

Going by the decision making grid (DMG) drawn from the criteria analysis of upstream equipment in CPN quarry, the drilling equipment and excavator fell in the top-left region, the action to implement, or the rule that applies, is OTF (operate to failure), which implies that the equipment can be ran to failure. When equipment fell in the bottom-left region, the rule that applieswill be SLU (skill level upgrade) because the data would have indicated equipment to have high failure frequency for limited periods(i.e high availability). This implies that the equipment maintenance management is a relatively easy task that can be passed to operators after upgrading their skill levels.

Equipmentthat enters the bottom-right region is considered to be a worst performing equipment based. Theequipmentcan be seen to have low availability due to high downtimes and high failure frequency. The appropriate maintenance strategy for such equipment is design out maintenance (DOM).

If one of the antecedents is a medium downtime or a medium failure frequency,then the rule to apply is to carry on with the preventive maintenance schedules. However, not all of the mediums are the same. There are some regions that are near to the top left corner where it is “easy” FTM (Fixed Time Maintenance) because it is near to the OTF region and it requires re-addressing issues regarding who will perform the instruction or when will the instruction be implemented (as in the case with the trucks). Also, an equipmentmight shift from the OTF region due to its relatively high downtime (medium availability and low failure frequency) and hence the timing of instructions needs to be addressed.Other preventive maintenance schedules need to be addressed in a different manner. The “difficult” FTM issues are the ones related to the contents of the instruction itself. It might be the case that the wrong problem is being solved or the right one is not being solved adequately. In this case, such equipment needs to be investigated in terms of the contents of their preventive instructions and an expert advice is needed.

Equipment that is located in the top-right region is problematic equipment, in maintenance words “a killer”. It does not breakdown frequently (low frequency), but when it stops it is usually a big problem that lasts for a long time (high downtime). In this case the appropriate action to take is to analyse the breakdown events and closely monitor its condition, i.e. condition base monitoring (CBM).

V. CONCLUSIONAND RECOMMENDATIONS

5.1 Conclusion

This paperhasadopted effective maintenance policies for upstream equipment in CPN quarry based on operational availability values and failure frequencies of the equipment. From the investigation carried out, it was realized that most preventive maintenance(time/ interval) of the equipment was based on the maintenance manual provided by equipment manufacturer other than the current states of the equipment. The actual operating states maybe quite different from the thought of the manufacturer; hence the outcome of the preventive maintenance will not optimally satisfy the needs of the equipment. Consequently, the benefits from the preventive maintenance (reducing costs, maximizing downtime etc.) cannot be maximized.Also, individual quarry equipment has different failure patterns and will require a differentiated maintenance management approach to enhance their productivity.

5.2 Recommendations

The following recommendations are made:

1. Adequate maintenance records should be kept for quarry equipment; these will aid excellent decisions for the choice of maintenance strategies;

2. Responsibility for ensuring equipment is in good condition should be transferred to foremen and not senior managers and there should be effective controls over maintenance expenditure; and

3. There should be an effective maintenance information management which will enhance availability and consequent productivity of upstream equipment in the quarry. The choice of equipment with telematics system (that relay real- time equipment data and machine condition information) will pay high return on investment when compared with production losses due to downtime events in the quarry.

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