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Equipment Maintenance Management Audit of Some Granite Aggregate Quarries in Part of South - West Nigeria.

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A B S T R A C T

This paper analyses an existing maintenance management system in some selected typical granite aggregate quarries (represented as K1, K2 and K3) in part of South- west Nigeria using modified questionnaire and interview. The quarries' current maintenance management effectiveness was evaluated with respect to five basic elements of maintenance management. The quarries were rated in accordance with global best practices with credits / points ranging from 1 to 3. Investigation shows that K1 and K2 had average overall ratings of 1.45 and 1.39 respectively. These scores fell below average performance, which informed their inability to operate at profit and call for urgent improvement decisions in all elements of maintenance management benchmarked. K3 scored 2.48, which indicates that the quarry adopts an effective maintenance management system, but will also need to improve on its preventive maintenance and maintenance scheduling. This paper is therefore an assessment initiative for maintenance and productivity continuous improvement and can be integrated as a part of a decision support system for maintenance management in the quarry industry.

1. Introduction

Maintenance was considered as a grey and neglected area in mine management during recent past when a very small part of total production cost went into maintenance due to low level of mechanization. Often maintenance is a secondary process in commercial quarries that have production as their core business. As such, maintenance does not receive enough management attention. Another reason for the lack of management attention is the belief that maintenance costs are not controllable. Management often looks at maintenance as a "necessary evil", not as a means to reduce cost (Samanta et al, 2001a). Rapid advances in mining equipment manufacturing technology have led to more opportunity for mining industry to procure and to use sophisticated, automated, higher capacity, precise design, complex and capital intensive equipment in production system for meeting energy demand, productivity, profitability and competitive threat. Due to the resultant automation and mechanization, production processes of commercial quarries move from labour oriented to machine oriented, but inefficient operation and deficient maintenance often prevent utilization of its full capacity. The developments in mechanization, automation and even of integration, and the resulting complexity in design of the equipment involved, have made the reliability of the machines even more important (Samanta and Sarkar, 2003). This is especially true in the mining industry, characterized by expensive specialized equipment and unstructured, stringent and somewhat hostile environment where the position of the work piece or equipment is somewhat uncertain. This implies that as technical complexity increases, the required level of maintenance expertise and quality of maintenance task done increases, and the demand for maintenance, including preventive maintenance, increases. As a result, in most mining operations today, maintenance-related costs for a typical surface mining operation accounts for about 40-50% of operating cost (Dhillon, 2002). For low level of maintenance, more numbers of machines are required to meet the production target. More standby equipment increases the capital cost and overall cost of production. Again, downtime cost or loss of production of such expensive specialized equipment due to unnecessary machine downtime from poor machine design/ reliability/operation/maintenance plays an important role for profitability of the mine. Poor availability of the machine is no longer affordable to mine management in the competitive and dynamic business environment. Nowadays, profit

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margins are getting eroded. As mine management demands better and greater performance of their machines, the machines also demand more of them (Samanta et al, 2001a).

The true cost-effectiveness of a quarry project is its performance and cost through its life cycle, maintenance costs are a major part of the total operating costs of quarries. Equipment cost is also increasing at alarming rate which in turn makes it ineffective to have backup or unreliable units. To control these costs, mining companies have centred their efforts on areas such as optimizing scheduled maintenance operations, deferring non-essential maintenance, reducing maintenance manpower, controlling inventories of spare parts more effectively and using contract maintenance support (Unger and Conway, 1994).

Over the years, South-West Nigeria has witnessed the greatest number of quarry development in the country. Although these quarries create thousands of jobs resulting in significant decrease in unemployment in the minerals industry, as well as projected increase in the wealth and growth of the region's economy, they bear a high risk in achieving their forecast profitability through maintaining budgeted costs. Most of the problems encountered in the quarries stem from lack of proper evaluation of the quarry design integrity (Abdulraman, 2016). Past experience have shown that most quarries have either exceeded their budgeted establishment costs or have experienced operational costs far in excess of what was originally estimated in their feasibility study reports.

Investigation into the poor performances of quarries revealed problems with regard to achieving design throughput. This is due to low crushing plant utilization because of poor process flow and equipment/process reliability and short operating periods as a result of frequent stoppages (shutdowns and breakdowns), interrupted feed, production loss and wastages. It is evident from the findings that most quarry operation and equipment problems are as a result of inappropriate evaluation of their design integrity and poor maintenance management system resulting in elongated payback period and sometimes premature closure of the quarries (Abdulraman, 2016). Therefore, the need for adequate or appropriate maintenance strategy becomes obvious to reduce the business risk. Ineffective maintenance management significantly affects productivity and consequent profitability which have had a dramatic impact on some Nigerian quarries' ability to run successfully.

This paper is aimed at benchmarking the studied quarries' maintenance management system, to determine where they need to leverage improvement and identify areas of opportunities to correct, in accordance with global best practice. By establishing a picture of the quarries' current maintenance management status, there will be clue to the way forward for efficient and effective maintenance management system.

2.0 Maintenance Management

Maintenance Management is an orderly and systematic approach to planning, organizing, monitoring and evaluating maintenance activities and their costs. A good maintenance management system coupled with knowledgeable and capable maintenance staff can yield longer assets life with fewer breakdowns; and result in lower operating costs (Samanta et al, 2001b). Generally, as the size of the maintenance activity and group increases, the need for better management and control become essential.

In the past, the typical size of maintenance staff in quarry industry varied from 5 to 10% of the work force (Niebel, 1994). Today, the proportional size of the maintenance effort compared to the operating group has increased significantly, and this increase is expected to continue due to the tendency in the industry to increase mechanization and automation of the production processes. Consequently, this means lesser need for operators but greater requirement for maintenance personnel. A complete maintenance/asset management strategy will increase profits in two main ways: decreasing expenses and increasing capacity (Wireman, 2005).

Research has shown that one- third of all maintenance expenditures are wasted because of inefficient and ineffective utilization of maintenance resources (Wireman, 2005). Khan and Darrab (2010) reported that the purpose of maintenance is not only to upkeep the plant machinery and equipment preventing them from failures and breakdowns, increasing reliability, maintainability, and availability of the operating system for maximizing production, but also to improve quality and boost higher productivity through improving capacity, faster and more dependable throughput, reducing inventory, and lowering operating cost. A research in maintenance in Nigerian industries (Eti et al, 2004) shows that maintenance is not given a high priority, hence plants are often underutilized and run at high costs. And the inherent problems associated with maintenance in Nigerian industries have also been enumerated to include, inadequate management skill among maintenance supervisors; high skill gap among maintenance personnel; no maintenance education course in Nigerian universities; inadequate maintenance budgets; and poor perception of maintenance as a cost centre activity rather than business centre. Alsyouf (2006) showed in a case study that at least 14% of potential improvement in return on investment are directed to contribution of maintenance functions to lost profit, which is due to unplanned stoppages and bad quality caused by maintenance related problems. Blanchard (2004) demonstrated that a large percentage (e.g. 70% for some systems) of total life cycle cost for a given

2.1 *Elements of Effective Maintenance Management*

There are many elements of effective maintenance management whose effectiveness is the key to the overall success of the maintenance activity. Many of these elements are described below (Dhillon, 1987):

2.1.1 *Maintenance Policy*

A maintenance policy is a clear understanding of the maintenance management program, regardless of the size of a maintenance organization. Maintenance policies can be broadly categorized into the technology or systems oriented (systems, or engineering), management of human factors oriented and monitoring and inspection oriented. Below are some maintenance policies:

2.1.1.1 *Reliability Centered Maintenance (RCM)*

Reliability Centered Maintenance (RCM) is a technological based concept where reliability of machines is emphasised. RCM is a structured methodology for determining the maintenance requirements of any physical asset in its operation context. The RCM process consists of looking at the way equipment fails, assessing the consequences of each failure (for production, safety, etc), and choosing the correct maintenance action to ensure that the desired overall level of plant performance (i.e. availability, reliability) is met. Techniques allied to RCM are Fault Tree Analysis, and Reliability Block Diagrams.

2.1.1.2 *Total Productive Maintenance (TPM)*

Total Productive Maintenance (TPM) is human based technique in which maintainability is emphasised. TPM gives operators the knowledge and confidence to manage their own machines. Instead of waiting for a breakdown, then calling the maintenance engineer, they deal directly with small problems, before they become big ones. Operators investigate and then eliminate the root causes of machine errors. Also, they work in small teams to achieve continuous improvements to the production lines. Techniques allied to TPM are Overall Equipment Effectiveness (Willmott and McCarthy, 2000).

2.1.1.3 *Condition Based Maintenance (CBM)*

Condition Based Maintenance (CBM) is a sensing technique, in which availability based on inspection and follow-up is emphasised. In the British Standards, CBM is defined as the preventive maintenance initiated as a result of knowledge of the condition of an item from routine or continuous monitoring (EN 13 306, 2001). It is the means whereby sensors, sampling of lubricant products and visual inspection are utilised to permit continued operation of critical machinery and avoid catastrophic damage to vital components. The integral components for the successful application of condition monitoring of machinery are reliable detection, correct diagnosis, and dependable decision-making. Techniques allied to CBM are Vibration Analysis, Infra-red Thermography.

2.1.2 *Material Control*

Past experience indicates that, on average, material costs account for approximately 30 to 40% of total direct maintenance costs (ERHQ-0004, 1976). Efficient utilization of personnel depends largely on effectiveness in material coordination. Material problems can lead to false starts, excess travel time, delays, unmet due dates, etc. Steps such as job planning, coordinating with purchasing, coordinating with stores, coordination of issuance of materials, and reviewing the completed job can help reduce material-related problems. Deciding whether to keep spares in storage is one of the most important problems of material control.
Developing the appropriate policy / strategy concerning the management of spare parts is crucial since lack of the right parts upon need either for scheduled or for emergency maintenance may have financially remarkable consequences. On the other hand stocking large numbers of expensive parts, the demand of which is sometimes extremely low and sporadic, can be very costly for the company. Thus, it becomes obvious that it is very important for the maintenance managers as well as for the company itself to select the appropriate spare parts operating policy for their needs.

2.1.3 *Work Order System*

A work order authorizes and directs an individual or a group to perform a given task. A well-defined work order system should cover all the maintenance jobs requested and accomplished, whether repetitive or one-time jobs. The work order system is useful for management in controlling costs and evaluating job performance.

2.1.4 *Equipment Records*

Equipment records play a critical role in effectiveness and efficiency of the maintenance organization. Usually, equipment records are grouped under four classifications: maintenance work performed, maintenance cost, inventory, and files. Equipment records are useful when procuring new items/equipment to determine operating performance trends, troubleshooting breakdowns, making replacement or modification decisions, investigating incidents, identifying areas of concern, performing reliability and maintainability studies, and conducting life cycle cost and design studies.

2.1.5 *Preventive and Corrective Maintenance*

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2.1.5 *Preventive and Corrective Maintenance*

The basic purpose of performing preventive maintenance (PM) is to keep facility/equipment in satisfactory condition through inspection and correction of early-stage deficiencies. Three principle factors shape the requirement and scope of the PM effort: process reliability, economics, and standards compliance. A major proportion of a maintenance organization's effort is spent on corrective maintenance (CM) (Wireman, 2005). Thus, CM is an important factor in the effectiveness of maintenance organization.

2.1.6 *Job Planning and Scheduling*

Job planning is an essential element of the effective maintenance management. A number of tasks may have to be performed prior to commencement of a maintenance job; for example, procurement of parts, tools, and materials, coordination and delivery of parts, tools, and materials, identification of methods and sequencing, coordination with other departments, and securing safety permits. Strictly speaking, formal planning should cover 100% of the maintenance workload but emergency jobs and small, straightforward work assignments are performed in a less formal environment (Wireman, 2005). Thus, in most maintenance organizations 80 to 85% planning coverage is attainable (Wireman, 2005).

Maintenance scheduling is as important as job planning. Schedule effectiveness is based on the reliability of the planning function. The aim of the work planning and scheduling is to make the applicable preparations to allow the right maintenance activities to be performed in the right manner and quality by using the right resources and at the right moments of time.

2.1.7 *Backlog Control and Priority System*

The amount of backlog within a maintenance organization is one of the determining factors of maintenance management effectiveness. Identification of backlogs is important to balance manpower and workload requirements. Furthermore, decisions concerning overtime, hiring, subcontracting, shop assignments, etc., are largely based on backlog information. Management makes use of various indices to make backlog related decisions.

2.1.8 *Performance Measurement*

Successful maintenance organizations regularly measure their performance through various means. They often use indices to manage and control maintenance. These indices show trends by using past data as a reference point. The main objective of these indices is to encourage maintenance management to improve on past performance.

3.0 Materials and Methods

This research is industry based and provides a view of the current status of equipment maintenance management system in the studied granite aggregate quarries in South – west Nigeria. The three quarries are named as Quarry K1 in Ogun State; Quarry K2 and Quarry K3, both in Oyo State. And their coordinates are shown in Table 1. The main equipment used in the quarries are listed in Table 2.

3.1 *Methodology*

This research involves three case studies from granite quarries in the south-western Nigeria, where equipment maintenance management audit was conducted through questionnaires and interviews. The copies of questionnaire were administered to quarry operators including project managers, operation and maintenance (O&M) managers, and maintenance technicians. This questionnaire addresses questions in five key maintenance areas; resource management, information management, preventive maintenance and equipment technology, planning and scheduling, and maintenance support. The questions were drafted so that the participants could rate their quarries' maintenance management status within three (3) classes: Below average, Average, and Above average; with credit ratings 1, 2 and 3 respectively.

Furthermore, the quarries' current maintenance practices were explored through interview and evaluated to identify the gap existing between the current maintenance management systems of the quarries and global best practices based on literature studies. To gain a general understanding of the current role of maintenance in the studied quarries, 18 interviews with stakeholders of the quarries were conducted; ranging from 2 to 5 hours in length. They were interviewed on the current maintenance management system being implemented within each quarry in relation to the five key maintenance areas considered. Their responses were rated subjectively as earlier (Below average, Average, and Above average) and credit points were awarded appropriately. The total scores for the different maintenance elements considered were computed, their average values were tabulated for each quarry and presented using Bell- Mason Spider diagram.

4.0 Results

The average credit points awarded to the studied quarries are shown in Tables 3 to 5 from which Bell-Mason type spider diagrams were constructed as shown in Figures 1 to 3.

Table 3: Maintenance Management Audit of Quarry K_1

Elements of Maintenance Management	Credit/ Point
Resource Management	1.27
Information Management	1.08
Preventive Maintenance and Equipment Technology	1.40
Planning and Scheduling	1.50
Maintenance Support	2.00
Average Overall Rating	**1.45**

Table 4: Maintenance Management Audit of Quarry K_2

Elements of Maintenance Management	Credit/ Point
Resource Management	1.50
Information Management	1.18
Preventive Maintenance and Equipment Technology	1.00
Planning and Scheduling	1.56
Maintenance Support	1.73
Average Overall Rating	**1.39**

Table 5: Maintenance Management Audit of Quarry K_3

Elements of Maintenance Management	Credit/ Point
Resource Management	2.73
Information Management	2.67
Preventive Maintenance and Equipment Technology	2.16
Planning and Scheduling	2.17
Maintenance Support	2.65
Average Overall Rating	**2.48**

Table 6: Range of scores for maintenance management effectiveness based on global best practice

Credit / Point	Remarks
3.00 – 2.66	World Class – best in practice
2.65 – 2.33	Very good, effective operations
2.32 – 2.00	Above average performance
1.99 – 1.66	Average performance
1.65 – 1.33	Below average performance – many opportunities for improvement

(Source: Marshall Institute Incorporation, 1999)

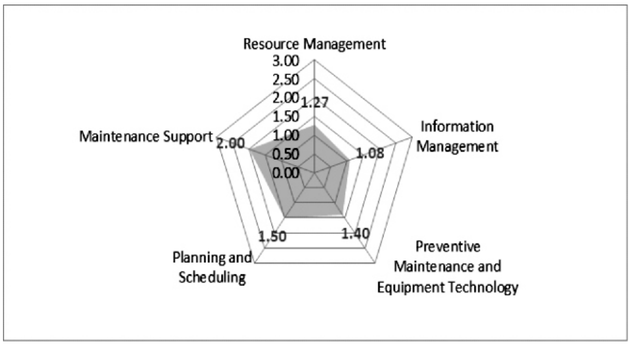

Figure 1: Bell-Mason Diagram for Maintenance Management Audit of Quarry K_1.

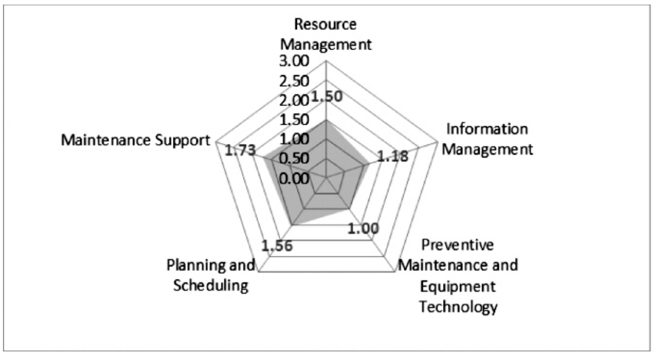

Figure 2: Bell-Mason Diagram for Maintenance Management Audit of Quarry K_2

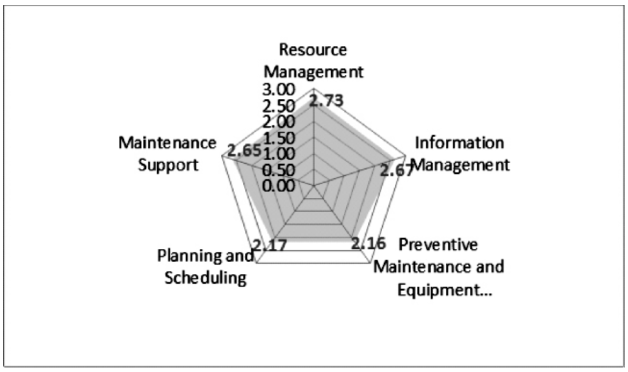

Figure 3: Bell-Mason Diagram for Maintenance Management Audit of Quarry K_3

4.1 Discussion of Results

The maintenance management audit revealed that quarries K1 and K2 scored 1.45 and 1.39 respectively as average overall points and K3 scored 2.48. According to the maintenance effectiveness ratings developed by Marshall Institute Incorporation (Table 6) based on global best practice, K1 and K2 performed below average which implies that there is need for improvement in all their maintenance management elements (Tables 3 and 4 and Figures 1 and 2). However, Quarry K3 is generally fair but also needs to improve on its preventive maintenance and maintenance scheduling (Table 5 and Figure 3). The information management of K1 and K2 is bad due to lack/inappropriate record keeping of maintenance activities.

5.0 Conclusion and Recommendations

It is obvious from the audit that the studied quarries have poor maintenance culture and their maintenance decisions are carried out intuitively culminating the usual poor performances of the quarries and resultant erosion of profitability that poses threat to their operations. Quarry, like any production system require high availability of the entire equipment complexes. Three critical factors affect equipment availability: equipment design, its usage and maintenance management system. Of these three, maintenance is the factor that offers the quarries the best opportunity to influence and control the performance and availability of their equipment for optimum productivity. The need for an excellent equipment maintenance management system coupled with good maintenance personnel cannot be over emphasized.

It is therefore imperative to source for competent maintenance managers who will urgently put in place appropriate maintenance management system with the full support of the quarries' owners through appropriate maintenance policies; adopting maintenance strategies in line with the needs of the equipment; skill upgrade for operators and maintenance personnel. Above all, establish performance indicators and strive to meet targets that have direct impact on the bottom line of the investment. This way only, the shareholders will give their total support for appropriate maintenance management system.

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