CRUSHING PLANT PERFORMANCE EVALUATION USING OEE

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ABSTRACT

Over the years, economy of scale has been adopted as a panacea to the poor return on investment (ROI) in aggregate quarry establishments. This has forced quarries to increase their capital expenditure (CAPEX) due to acquisition of large capacity equipment that are often very costly. Low commodity (chippings) prices and high energy costs have further compelled quarry operators to adopt cost effective operating strategy. The true cost effectiveness of aggregate quarries lies in their performances and life cycle costs, of which their performances depend on their equipment availability; utilization and efficiency. Quarry equipment availability, utilization and efficiency are therefore very important performance indices that a quarry operator needs to constantly evaluate to work within the threshold, if the quarry business must deliver high ROI or quick payback which ultimately is the prime objective of any business. Overall Equipment Effectiveness (OEE) is a well-known performance metric which combines availability, utilization and efficiency for the evaluation of crushing plant effectiveness in an aggregate quarry. The performance metrics of F and P quarry, Abuja, Nigeria have been determined, and the plant availability (A); utilization (U); efficiency (E); and OEE evaluated to be 77.55%, 65.08%, 33.15%, and 16.62% respectively. The OEE value is far below the global best standard of 85% for manufacturing system, and reflects the influence of plant availability, utilization and efficiency on OEE value. However, there is no literature on the use of OEE for granite crushing plant, though; attempts have been made to use the metric on drilling machines, loading and haulage facilities. This paper presents a procedure for estimating OEE of a crushing plant; explains the cause for poor OEE in Nigerian plants during rainy season; and reason why Nigerian crushing plants should run with generators of adequate power outputs; and not on external power source.

Key words: OEE, Quarry, ROI, Availability, Utilization, Efficiency

1.0 INTRODUCTION

All industries as well as quarry establishment are dependent on their assets. Advancement in equipment manufacturing technology and automation has provided quarry operators with opportunities of employing large capacity equipment.

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The competitive global economy is equally forcing mining companies around the world to modernize their operations through increased mechanization and automation making the equipment become more complex and sophisticated. Equipment cost is also increasing at an alarming rate which in turn makes it ineffective to have back up or unreliable units. This unfriendly business climate is causing quarry managers to consider the use of appropriate metric to determine the effectiveness of their equipment so that they can take necessary steps to increase the effectiveness of their equipment and minimize production cost.

Granite aggregate quarries in Nigeria 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 experiences have also shown that most quarries never exceed three (3) years before realizing they are operating at loss. Usually, the low sales with consequent huge stockpiles in the quarry never avert them the opportunity of realizing operational losses early enough to seek optimization. Investigation into the poor performances of the quarries revealed problems with regard to achieving design throughput. This is due to low crushing plant utilization because of poor process flow and equipment reliability; short operating periods as a result of frequent stoppages (shutdown and breakdowns) among others. Investigations have also revealed that most management team of Nigerian quarries (i.e. operation, maintenance and administration) lack adequate skill to run the quarry business. Often, maintenance decisions are made intuitively without employing appropriate engineering analysis. 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, 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. Mining being a very capital-intensive industry; ineffective mine management therefore, can significantly affect productivity and consequent profitability which have had a dramatic impact on some Nigerian quarries' ability to run successfully. This often results in elongated payback period and premature closure of the quarries. It is equally true that equipment utilization and accurate evaluation of this metric are germane, since quarry managers want to utilize their equipment as effectively as possible to quarry at profit. Many studies have been carried out on mining equipment selection, but little has been done on the measurement of effectiveness of these equipment. Only maintenance policies and models have been studied widely to improve availability of these equipment. Therefore, the aim of this study is to extend the application of a metric, which is widely accepted in manufacturing industries, used in measuring overall effectiveness of equipment known as OEE to crushing plant in aggregate quarries. Operation metrics of data collected through crushing plant report system (CPRS) of F and P quarry, Abuja, Nigeria, have been adopted for the OEE calculation of the crushing plant. with the numerical working of the metrics, this paper explains the step by step method for the evaluation of the metrics. It is expected that this study should arose significant interest within the quarry investors and managers.

During 1980's Total productive maintenance (TPM) has become known in manufacturing industries and OEE was proposed by Nakajima (Jeong and Phillips, 2001) to evaluate the progress of TPM. It is interpreted as the multiplication of availability, performance and quality. Since that time, many studies have been done in this area such as Jonsson and Lesshammar (1999), Dal *et al* (2000). Elevli and Elevli (2010) in their paper "performance measurement of mining equipment by using OEE" emphasizes the need to accurately estimate equipment effectiveness as a way to improve productivity of equipment, the paper identifies causes of time losses for shovel and truck operations and introduces procedure to record time losses. Samanta and Banerjee (2005) in their paper: “Improving Productivity of Mining Machinery through Total Productive Maintenance (TPM)” postulates that TPM has a positive influence on operating cost, output per man shift and safety.

However, OEE applications in mining industry differ from manufacturing industry. Therefore, it is necessary to develop equipment’s own classification framework for the losses, which should be associated with the components of availability, performance and quality (Bamber *et al*, 2003). The necessary data classification to be collected will vary from equipment to equipment. In addition to that, it is more difficult to gather data for quarrying equipment due to the following reasons:

a) Aggregate quarrying is a serial operation of drilling- blasting, loading, conveying and processing. Therefore, the utilization of each equipment employed in the various sections of the operation affects the others;
b) The impact of utilization on total production of aggregate quarry is enormous considering the huge capacities of equipment employed in the operation;
c) Quarrying environment is less than ideal compared with other production plants; and the dynamics of quarry operation are with many unknowns that are capable of influencing the utilization of the equipment.

2.0 METHODOLOGY

2.1 OEE Calculation for Crushing Plant

Crushing plants are used in granite aggregate quarries for processing and classifying crushed granite materials. Abuja market for aggregates consists of varying sizes of crushed and screened products 0 - 9.5mm; 10 - 12.5mm; 12.5 - 18.5mm; 19 - 25mm and hard core 150 - 250mm for special engineering applications. A typical crushing plant is an assemblage of different machines (crushers, classifiers, conveyors and feeders); all arranged in series. Their performances and productions determine the total output of the quarry. As such, production loss in a crushing plant of a commercial quarry has direct impact on the production cost of the quarry and consequently affects the quarry’s return on investment (ROI). The general trend therefore, is for the quarry management to ensure that the plant runs with minimal or no equipment downtime (i.e. high plant availability and utilization) as well as efficiently. It becomes imperative that an appropriate crushing plant report system (CPRS) be established and adopted to capture all downtime losses of the crushing plant to enable for prompt evaluation of operation and required optimization. Generally, during a typical crushing plant operation, the following factors can lead to downtime losses:

i. Pre- start checks and plant upkeep: This is a daily routine check for loose fittings, bolts and nuts; necessary lubrication and clearing of spillages constitute the preventive maintenance period and estimated in hours “M_p”
ii. Raw feed delay: A circumstance where, there is a delay in the supply of raw feed from the downstream section of the quarry usually caused by inappropriate evaluation of the design integrity; equipment failures and poor work ethics. The time loss consequent upon these events in hours is classified as the plant’s standby time “S_h”

iii. Feeding error (human factor): This usually leads to either hopper blockage or primary crusher opening blockage or crusher jam and can be classified as Plant's breakdown time "*b*"

iv. Plant components breakdown: This constitutes the total time spent attending to a faulty component of the plant and is referred to as corrective maintenance time "M_c"

v. Weather delay (weather not suitable for operation): This happens only during rainy season where a heavy downpour could hinder smooth plant operation. This is a natural occurrence beyond the quarry management's control and should be classified as standby time "S_h"

vi. Changeover (either power source and work shift): Where more than one power source is employed for operation or the plant runs more than one shift daily, then there is likelihood of delays in changeovers "S_h"

vii. Logistic delay: delays in spare part for maintenance or idle time without operator "S_p".

2.2 Procedures for Calculating OEE of a Crushing Plant

The procedures include keeping records of planned hours, working hours, failure times and maintenance periods. All events leading to downtime losses in a typical crushing plant would be classified into five (5) periods namely, standby hour S_h; preventive maintenance hour M_p; corrective maintenance hour M_c; breakdown hour ***b;*** and time loss waiting for spares or staff S_p.

From these records (CPRS), Plant availability; utilization; efficiency; and overall equipment effectiveness (Hibbard, 2011) would be determined. Availability deals with duration of operation of equipment. Calculation of planned hours (P_h), which is the total number of available hours for work, is expressed as follows (Momoh and Salihi, 2010):

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

Where,

w is working hour;

S_h is Standby hour;

b is breakdown hour;

m_c is corrective maintenance hour;

m_p is preventive maintenance hour; and

s_p is waiting for spare parts or staff (hour).

Equation (1) can also be expressed as

$$P_h = w + s_h + dt \qquad (2)$$

Where dt is downtime hour due breakdown or maintenance

$$dt = b + m_c + m_p + s_p \qquad (3)$$

The plant availability is the actual level of availability realized in day to day operation of the crushing plant. Plant 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):

$$A = \frac{w + s_h}{w + s_h + b + m_c + m_p + s_p} \times 100\% \qquad (4)$$

Equation (4) can also be expressed as

$$A = \frac{w + s_h}{P_h} \times 100\% \qquad (5)$$

Utilization is the ratio of working hours to summation of working and standby hours expressed as percentage:

$$U_e = \frac{w}{w + s_h} \times 100\% \qquad (6)$$

$$Efficiency\ (E) = \frac{Average\ Actual\ production\ capacity\ \left(\frac{T}{H}\right)}{Nominal\ Proction\ capacity\ \left(\frac{T}{H}\right)} \times 100\% \quad (7)$$

$$Overall\ Equipment\ Effectiveness\ (OEE) = A \times U_e \times E \quad (8)$$

Where,

A is Plant Availability;

U_e is Plant Utilization; and

E is Plant Efficiency.

After computing the OEE through the equations (1) – (8), the value is then compared with industry norms. Accepted benchmark value for manufacturing industries is about 85%. If the estimated OEE is less than 85%, then the plant should be evaluated for improvement. It is also pertinent that, for the OEE value to be truly meaningful, the data collection and computation must not lack in integrity.

From F and P quarry's crushing plant operation report for the month of September, 2018, the computed (Table 1) average working hours (*w*) is 5.2 hrs; downtime (d_t) is 2.38 hrs; standby time (s_h) is 2.79 hrs; planned hour (P_h) is 10.37 hrs and the average actual production capacity is 66.30 tons/ hr.

Substituting the values in equations (5) – (8):

$$Availabilty\ of\ the\ plant\ (A) = \frac{(5.2 + 2.79)}{10.37} \times 100\%$$

$$= \frac{7.99}{10.37} \times 100$$

$$\approx 77.05\%$$

$$Plant\ Utilization\ (U) = \frac{5.2}{(5.2 + 2.79)} \times 100\%$$

$$= \frac{5.2}{7.99} \times 100\%$$

$$\approx 65.08\%$$

$$Plant\ Efficiency\ (E) = \frac{66.30}{200} \times 100\%$$

where the plant nominal capacity as given by the plant manufacturer is 200 tons/hr.

Plant efficiency (E) = **33.15%**

$$The\ Overall\ Equipment\ Effectiveness\ (OEE) = 77.05\% \times 65.08\% \times 33.15\%$$

$$\approx 16.62\%$$

3.0 RESULTS AND DISCUSSION

Table 1: F and P quarry's crushing plant report (CPRS) for September, 2018

Date	*w*	d_t	s_h	p_h	Production (tons/day)	Average production (tons/hr)
1/Sept/18	4.75	3.08	3.17	11.00	950	86.36
2/Sept/18	7.42	1.58	2.00	11.00	1025	93.18
3/Sept/18	0.00	0.00	11.00	11.00	0	0.00
4/Sept/18	5.33	4.33	1.33	11.00	650	59.09
5/Sept/18	2.42	1.58	4.00	8.00	250	31.25
7/Sept/18	7.08	2.58	1.33	11.00	950	86.36
8/Sept/18	6.92	2.50	1.58	11.00	675	61.36

9/Sept/18	6.67	2.58	1.75	11.00	800	72.73
10/Sept/18	5.08	3.58	2.33	11.00	450	40.91
11/Sept/18	6.17	2.83	2.00	11.00	725	65.91
12/Sept/18	3.75	1.42	2.83	8.00	475	59.38
14/Sept/18	6.08	2.92	2.00	11.00	800	72.73
15/Sept/18	5.50	3.58	1.92	11.00	750	68.18
16/Sept/18	6.50	2.50	2.00	11.00	1075	97.73
17/Sept/18	6.50	2.33	2.17	11.00	900	81.82
18/Sept/18	5.75	3.08	2.17	11.00	975	88.64
19/Sept/18	2.25	1.08	4.67	8.00	275	34.38
21/Sept/18	5.00	3.58	2.42	11.00	725	65.91
22/Sept/18	5.62	0.13	2.25	8.00	750	93.75
Total	**98.78**	**45.3**	**52.92**	**197.00**	**13,200**	**1259.66**
Average	**5.20**	**2.38**	**2.79**	**10.37**	**694.74**	**66.30**

The table above shows the actual operating hours of F and P quarry's crushing plant in the month of September, 2018 with the average values as estimated. The performance metrics for the plant have been determined using the equations.

The availability, utilization, efficiency and OEE of the plant for period studied are 77.55%; 65.08%; 33.15% and 16.62% respectively. To attain the threshold of global best practice of 85% OEE, each of the component metrics (availability, utilization and efficiency) must be at least 95%. It is obvious from the plant's metrics that; the plant is not running optimally. The management of the quarry would have to make frantic effort to put the quarry on the path of progress through holistic re-engineering of the entire quarry process in addition to appropriate improvement of their work ethics.

4.0 CONCLUSION AND RECOMMENDATIONS

This study provides the crushing plant performance using overall equipment effectiveness. The following conclusions were drawn:

i. Downtime and standby periods in any production system are KILLERS of the system and all efforts must be adopted to avoid or minimize them;
ii. with the consequential standby time in the rainy season, it is obvious that 85% OEE would not be attainable during rainy season in Abuja;
iii. electricity supply in Nigeria is epileptic and its resultant effect on continuous running of crushing plant with high standby time due to change over of power supply cannot guarantee high OEE; as such, crushing plant should run with generator of adequate power output; and not on external power source; and
iv. right numbers of plant labour should be engaged to adequately clean the plant immediately after plant shutdown and predictive maintenance methods should be developed to shorten the downtime due to preventive and corrective maintenance.

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