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Evaluation of Equipment Maintenance Effectiveness in Selected Typical Granite Quarries in South-West Nigeria

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ABSTRACT: Equipment maintenance performance indices allow quarries to understand the value created by maintenance, in a bid to re- evaluate and revise their maintenance policies and techniques, to justify investment in new trends and techniques for maintenance management. This research has attempted to evaluate and compare three maintenance performance indices I_1, I_2 and I_3 (maintenance index; downtime index; and production index respectively) for the studied quarries computed from their records of operational output and maintenance costs for the period reviewed. The index I_1 was determined to be between 10 and 20% as against the global standard of less than 6%; index I_2 ranged between 19 and 25% as against the industry norm of less than 1% and index I_3 averaged 28.5%, while global standard is between 12 and 14%. These indices are not in conformity with the global best standard, this performance is worrisome and has a negative impact on the viability of the quarry business. It becomes imperative therefore that their maintenance policies be revised and their maintenance strategies overhauled to enhance higher performance that can impact positively on the overall corporate goal of the quarries.

Keywords: Quarry equipment, maintenance, evaluation and performance indices.

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INTRODUCTION

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. Investigations have shown that mining equipment maintenance costs range from 20% to over 35% of total mine operating costs and are increasing steadily (Unger and Conway, 1994), most importantly nowadays, that the competitive global economy is forcing mining companies around the world to modernize its operations through increased mechanization and automation making the equipment become more complex and sophisticated. Equipment cost is also increasing at alarming rate which in turn makes it ineffective to have back up 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. Past experience have shown that most quarries

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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. Poor performances of most of the quarries have also been pinned to poor maintenance management system resulting in elongated payback period and sometimes premature closure of the quarries. Recent surveys of maintenance management effectiveness indicate that one-third of all maintenance costs is wasted as the result of unnecessary or improperly carried out maintenance (Mobley, 2002). 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 intends to evaluate maintenance performance indices for the selected quarries and analyze the maintenance management system of the equipment in the selected quarries.

MAINTENANCE PERFORMANCE MEASUREMENT

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. The result is that 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*, 2001). 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.Successful maintenance organizations regularly measure their performance through various means. Performance analyses contribute to maintenance department efûciency and are essential to revealing the downtime of equipment, peculiarities in operational behaviour of the concerned organization, developing plans for future maintenance, and so on. Management employs various approaches to measure effectiveness of the maintenance function. Often it uses indices to manage and control maintenance. These indices show trends by using past data as a reference point. Usually, a maintenance organization employs various indices to measure maintenance effectiveness, as there is no single index that will accurately reûect the overall performance of the maintenance activity (Dhillon, 2002).

The main objective of these indices is to encourage maintenance management to improve on past performance. The broad indices indicate the overall performance of the organization with respect to maintenance and the speciûc indices indicate the performance in particular areas of the maintenance function. The values of all these indices are plotted periodically to show trends.

(a) Broad Indicators

This class comprises of three such indicators which evaluate performance of the organization as a whole with respect to maintenance (Dhillon, 2008):

Index I: This is deûned by

$$I_1 = \frac{TMC}{TS} \qquad (1)$$

Where, I_1 is index parameter, TMC is total maintenance cost, and TS is total sales.

Past experience indicates that average expenditure for maintenance for all industry was around 5% of sales (Dhillon, 2008). However, there was a wide variation among industries. For example, the average values of I_1 for steel and chemical industries were 12.8 and 6.8%, respectively (Dhillon, 2008).

Index II: This is expressed by

$$I_2 = \frac{TMC}{TO} \qquad (2)$$

Where, I_2 is index parameter and TO is total output expressed in gallons, tons, megawatts, etc. This index relates the total maintenance cost to the total output by the organization.

Index III: This is deûned as follows:

$$I_3 = \frac{TMC}{TIPE} \qquad (3)$$

Where, I_3 is index parameter and TIPE is total investment in plant and equipment.

This index relates the total maintenance cost to the total investment in plant and equipment. The approximate average ûgures for I_3 in the steel and chemical industries are 8.6 and 3.8%, respectively (Dhillon, 2008).

(b) Specific Indicators

This class of indicators consists of twelve such indices that evaluate the performance in particular areas of maintenance functions (Dhillon, 2008):

Index IV

This is a useful index to control preventive maintenance activity within a maintenance organization and is deûned by Dhillon (2008):

$$I_4 = \frac{TTPM}{TTEM} \qquad (4)$$

Where, I_4 is index parameter, TTPM is total time spent in performing preventive maintenance, and TTEP is total time spent for the entire maintenance function.

As per the past experience, the value of I_4 should be kept within 20 and 40% limits (Dhillon, 2008).

Index V

This index can be used to measure the accuracy of the maintenance budget plan and is expressed by Dhillon (2008):

$$I_5 = \frac{TAMC}{TBMC} \qquad (5)$$

Where, I_5 is index parameter, TAMC is total actual maintenance cost, and TBMC is total budgeted maintenance cost.

In this case, large variances indicate the need for immediate attention.

Index VI

This is a useful index for maintenance overhead control and is expressed by Dhillon (2008):

$$I_6 = \frac{TMAC}{TMC} \qquad (6)$$

Where, I_6 is index parameter, TMAC is total maintenance administration cost, and TMC is total management cost.

Index VII

This index is useful in scheduling work and is expressed as follows (Dhillon, 2008):

$$I_7 = \frac{PJCED}{TPJ} \qquad (7)$$

Where, I_7 is index parameter, PJCED is total number of planned jobs completed by established due dates, and TPJ is total number of planned jobs.

The value of I_7 should be high to keep backlogs down (Dhillon, 2008).

Index VIII

This index is useful in material control area and is deûned by (Dhillon, 2008):

$$I_8 = \frac{TPJAM}{TPJ} \qquad (8)$$

Where, I_8 is index parameter, and TPJAM is total number of planned jobs awaiting material.

Index IX

This index can be used to measure maintenance effectiveness and is deûned by Dhillon (2008):

$$I_9 = \frac{MHEUJ}{TMMH} \quad (9)$$

Where, I_9 is index parameter, MHEUJ is man-hours of emergency and unscheduled jobs, and TMMH is total maintenance man-hours worked.

Index X

This index can also be used to measure maintenance effectiveness and is expressed by Dhillon (2008):

$$I_{10} = \frac{DTCB}{TDT} \quad (10)$$

Where, I_{10} is index parameter, DTCB is downtime caused by breakdowns and TDT is total downtime.

Index XI

This is an important index used to measure inspection effectiveness and is deûned by Dhillon (2008):

$$I_{11} = \frac{NJI}{TIC} \quad (11)$$

Where, I_{11} is index parameter, NJI is number of jobs resulting from inspections, and TIC is total number of inspections completed.

Index XII

This index relates material and labor costs and is expressed by (Dhillon, 2008):

$$I_{12} = \frac{TMLC}{TMMC} \quad (12)$$

Where, I_{12} is index parameter, TMLC is total maintenance labour cost, and TMMC is total maintenance materials cost.

Index XIII

This index relates maintenance cost to manufacturing cost and is deûned by Dhillon (2008):

$$I_{13} = \frac{TMC}{TMFC} \quad (13)$$

Where, I_{13} is index parameter,and TMFC is total manufacturing cost.

Index XIV

This index relates maintenance cost to man-hours worked and is expressed by Dhillon (2008):

$$I_{14} = \frac{TMC}{TNMW} \quad (14)$$

Where, I_{14} is index parameter, and TNMW is total number of man-hours worked.

Index XV

This is a useful index to monitor progress in cost reduction efforts and is deûned by Dhillon (2008):

$$I_{15} = \frac{PMMSJ}{MCPP} \quad (15)$$

Where, I_{15} is index parameter, PMMSJ is percentage of maintenance man-hours spent on scheduled jobs, and MCPP is maintenance cost per unit of production.

MATERIALS AND METHODS

2.0 Locations of the Study Areas

The selected quarries are three in number, designated as Granite Quarries A, B and C located in Ogun and Oyo States, Nigeria. Table 1 shows the coordinates of the study locations. The quarries are all accessible by good network of roads. Figure 1 depicts the geological map of Nigeria showing the source rock terrains and the study locations. The equipment studied in the selected quarries are drill rig, hydraulic excavator, dump truck and crushing plant.

Table 1: Coordinates of Study Locations

S/N	Name of Quarry	Nominal Production Capacity	Location	GPS Coordinate
1	GQA	250T/H	Ajebo, Ogun State, Nigeria	N07º 07′ 25″ E003º 37′ 46″
2	GQB	250T/H	Ibadan, Oyo State, Nigeria	N07º 18′ 21″ E003º 50′ 14″
3	GQC	250T/H	Ibadan, Oyo State, Nigeria	N07º 19′ 27″ E003º 47′ 50″

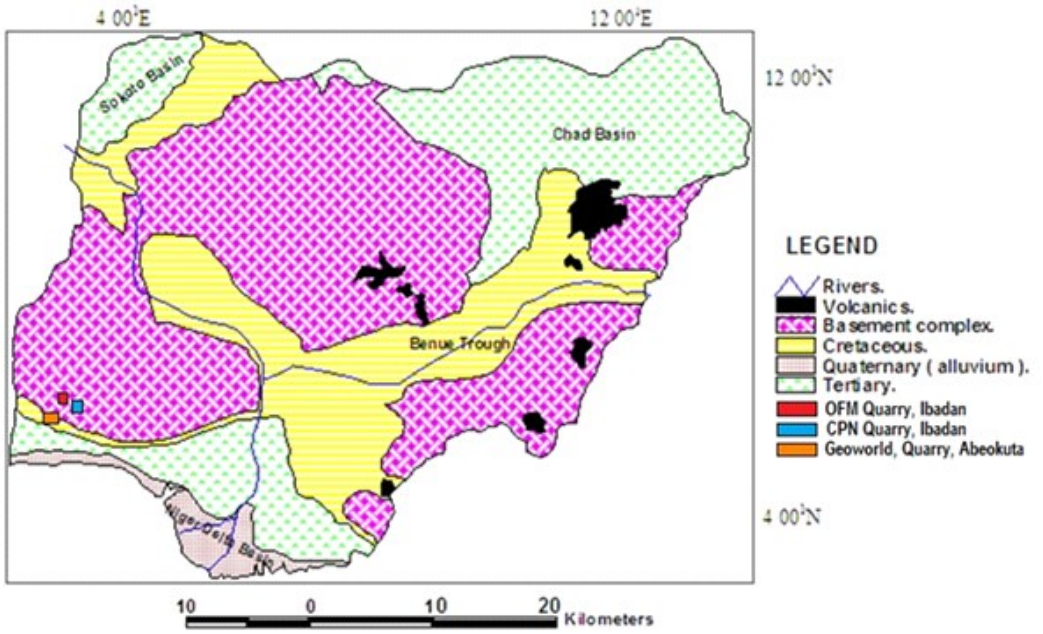


Figure 1: Geological map of Nigeria Showing the Source Rock Terrains and the Study Locations. (Adapted from Anikoh and Olaleye, 2013)

Determination of Maintenance Management Effectiveness

Maintenance management audit of studied quarries was carried out. The maintenance cost and production data for a period of one year were collected and correlated to evaluate maintenance performance indices and plotted to show trends in the studied granite quarries. The following indices were evaluated:

Maintenance Index (I_1)

This is expressed as:

$$I_1 = \frac{TMC}{TO} \qquad \text{(i)}$$

Where, TMC is total maintenance cost, and TO is total output expressed in, tons.

This index relates the total maintenance cost to the total output by the quarry.

Downtime Index (I_2)

This index can be used to measure maintenance effectiveness and is expressed as:

$$I_2 = \frac{DTCB}{TDT} \qquad \text{(ii)}$$

Where, I_2 is index parameter, DTCB is downtime caused by breakdowns, and TDT is total downtime.

Production Index (I_3)

This index relates maintenance cost to production cost and is deûned as:

$$I_3 = \frac{TMC}{TPC} \qquad \text{(iii)}$$

Where, I_3 is index parameter, and TPC is total production cost.

RESULTS AND DISCUSSION

The performance of maintenance in the studied quarries have been rated under three performance indices I_1, I_2 and I_3 and their values tabulated (Tables 2 – 7) and plotted to show the trends in the studied quarries. The trends are correlated as depicted by the graphs shown in Figures 2 – 4.

Table 2: Granite Quarry A's Performance Indices

Months	TMC (₦)	TO (t)	TPC (₦)	DTMC (Hr)	TDT (Hr)	$I_1 = \frac{TMC}{TO}$ (₦/t)	$I_2 = \frac{DTMC}{TDT}$	$I_3 = \frac{TMC}{TPC}$
Jan, 2014	7,233,891.14	7,499	16,329,325.38	16.00	76.50	964.6	0.209	0.443
Feb, 2014	3,719,892.50	9,201	14,761,478.16	37.00	120.00	404.3	0.308	0.252
Mar, 2014	1,516,513.64	9,665	13,540,300.35	32.60	144.62	156.9	0.225	0.112
Apr, 2014	3,120,127.55	10,537	18,572,187.77	1.80	80.30	296.1	0.022	0.168
May, 2014	3,019,098.81	10,646	16,497,807.71	4.25	80.45	283.6	0.053	0.183
Jun, 2014	1,347,981.29	8,086	2,482,470.15	29.80	70.80	166.7	0.421	0.543
Jul, 2014	3,045,912.23	7,643	10,431,206.28	22.73	64.63	398.5	0.352	0.292
Aug, 2014	2,739,375.22	9,343	19,291,374.81	17.62	75.32	293.2	0.234	0.142
Sept, 2014	3,077,424.68	8,623	14,795,310.95	11.74	53.49	356.9	0.219	0.208
Oct, 2014	6,753,398.65	9,730	23,863,599.48	12.72	52.42	694.1	0.243	0.283
Nov, 2014	5,686,438.96	10,081	21,218,055.82	20.79	75.09	564.1	0.277	0.268
Dec, 2014	2,105,138.75	6,440	10,907,454.65	23.01	64.71	326.9	0.356	0.193
					Average	408.8	0.243	0.257

Table 3: Granite Quarry B's Performance Indices

Months	TMC (₦)	TO (t)	TPC (₦)	DTMC (Hr)	TDT (Hr)	$I_1 = \frac{TMC}{TO}$ (₦/t)	$I_2 = \frac{DTMC}{TDT}$	$I_3 = \frac{TMC}{TPC}$
Jan, 2014	6,353,961	3,936	26,282,222	4.22	26.72	455.95	0.158	0.24
Feb, 2014	5,751,082	7,320	22,491,516	7.12	38.32	332.05	0.186	0.26
Mar, 2014	7,597,603	8,062	24,967,496	9.15	42.98	420.64	0.213	0.30
Apr, 2014	1,908,447	0,034	20,788,919	5.15	33.65	95.26	0.153	0.09
May, 2014	5,846,529	0,203	24,353,560	9.73	49.93	289.39	0.195	0.24
Jun, 2014	4,590,276	5,139	21,967,267	9.40	34.90	303.21	0.269	0.21
Jul, 2014	7,116,189	4,611	25,540,484	7.45	34.15	487.05	0.218	0.28
Aug, 2014	7,815,234	7,601	29,959,350	7.89	43.39	444.03	0.182	0.26
Sept, 2014	5,460,107	6,187	22,630,173	7.25	33.75	337.31	0.215	0.24
Oct, 2014	1,359,271	8,803	22,095,613	7.06	33.56	72.29	0.210	0.06
Nov, 2014	8,301,032	8,897	24,359,965	7.55	41.85	439.27	0.180	0.34
Dec, 2014	1,972,395	3,311	20,737,819	6.00	34.98	148.18	0.172	0.10
				Average		318.72	0.196	0.22

Table 4: Granite Quarry C's Performance Indices

Months	TMC (₦)	TO (t)	TPC (₦)	DTMC (Hr)	TDT (Hr)	$I_1 = \frac{TMC}{TO}$ (₦/t)	$I_2 = \frac{DTMC}{TDT}$	$I_3 = \frac{TMC}{TPC}$
Jan, 2014	2,612,133	31,397	31,602,247	8.00	30.50	83.2	0.262	0.08
Feb, 2014	2,326,596	30,523	35,744,207	12.70	40.70	76.22	0.312	0.07
Mar, 2014	3,944,914	47,610	37,261,147	2.50	35.50	82.86	0.070	0.11
Apr, 2014	9,640,147	31,943	42,413,757	1.00	39.00	301.8	0.026	0.23
May, 2014	2,047,326	29,823	33,211,809	8.50	38.70	68.65	0.220	0.06
Jun, 2014	9,048,222	7,271	33,146,685	7.40	30.40	1,244.44	0.243	0.7
Jul, 2014	3,486,192	26,496	29,058,397	3.00	26.70	131.58	0.112	0.12
Aug, 2014	712,222.94	5,397	18,604,207	9.70	38.20	131.96	0.254	0.04
Sept, 2014	906,371.06	10,121	22,061,147	7.00	29.00	89.55	0.241	0.04
Oct, 2014	804,914.43	25,210	22,413,006	4.20	24.60	31.93	0.171	0.04
Nov, 2014	1,100,132.94	28,190	23,203,809	6.00	31.40	39.03	0.191	0.05
Dec, 2014	1 ,026,596.06	27,123	29,116,685	4.00	24.00	37.85	0.167	0.04
					Average	193.26	0.189	0.094

Table 5: Comparison of Maintenance Index, I_1 (₦/t) of the Quarries

Months	GQA	GQB	GQC
Jan, 2014	964.6	455.9	83.2
Feb, 2014	404.3	332.0	76.2
Mar, 2014	156.9	420.6	82.9
Apr, 2014	296.1	95.3	301.8
May, 2014	283.6	289.4	68.7
Jun, 2014	166.7	303.2	1244.4
Jul, 2014	398.5	487.1	131.6
Aug, 2014	293.2	444.0	132.0
Sept, 2014	356.9	337.3	89.6
Oct, 2014	694.1	72.3	31.9
Nov, 2014	564.1	439.3	39.0
Dec, 2014	326.9	148.2	37.9
Average	408.8	318.7	193.3

Table 6: Comparison of Downtime Index I_2 (%) of the Quarries

Months	GQA	GQB	GQC
Jan, 2014	20.9	15.8	26.2
Feb, 2014	30.8	18.6	31.2
Mar, 2014	22.5	21.3	7
Apr, 2014	2.2	15.3	2.6
May, 2014	5.3	19.5	22
Jun, 2014	42.1	26.9	24.3
Jul, 2014	35.2	21.8	11.2
Aug, 2014	23.4	18.2	25.4
Sept, 2014	21.9	21.5	24.1
Oct, 2014	24.3	21	17.1
Nov, 2014	27.7	18	19.1
Dec, 2014	35.6	17.2	16.7
Average	24.3	19.6	18.9

Performance indices highlight opportunities for maintenance improvement within the quarries. Various factors are required to be considered for maintenance performance measurement among which are: the value created by maintenance; alternative allocation of maintenance resources; and maintenance skill gap. Figures 2 – 4 depict the indices I_1, I_2 and I_3 for the studied quarries, where I_1 relates the quarry equipment maintenance cost per ton of product, I_2 evaluates the percentage of total downtime in the quarry that was caused by maintenance and I_3 compares the total maintenance cost with the total production cost. From Figure 2, GQC's maintenance cost is lower than GQA and GQB. This will certainly place GQC

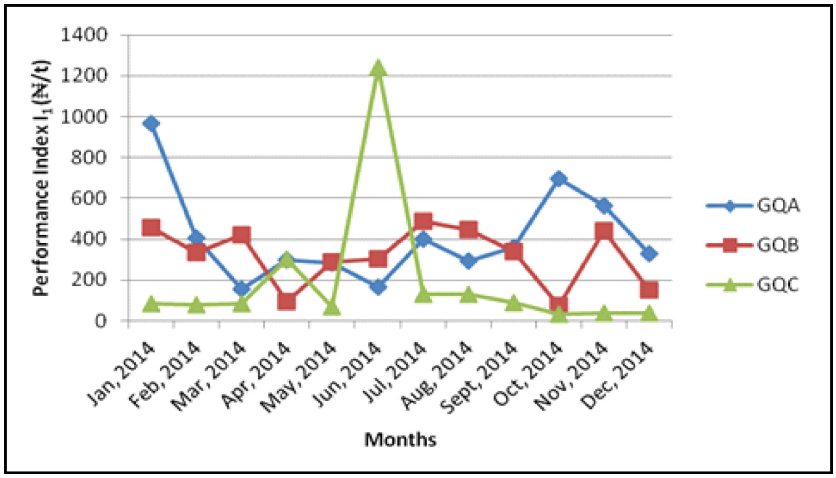


Figure 2: Comparison of Maintenance Index I_1

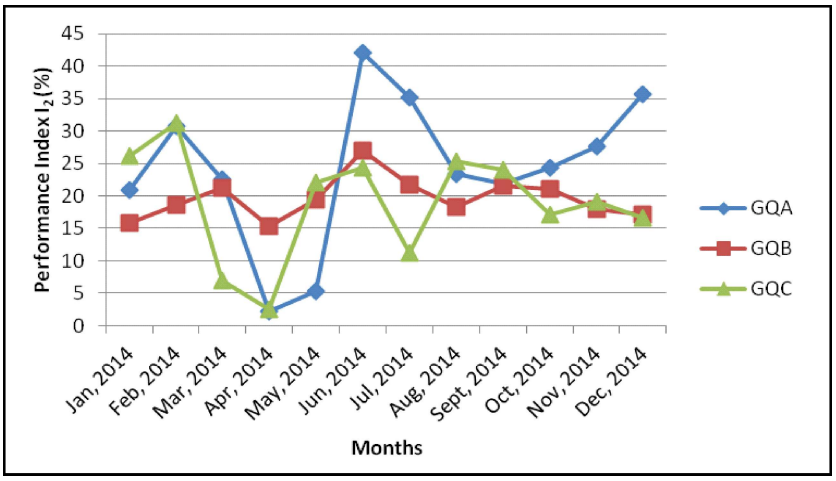


Figure 3: Comparison of Downtime Index I_2 of the Quarries

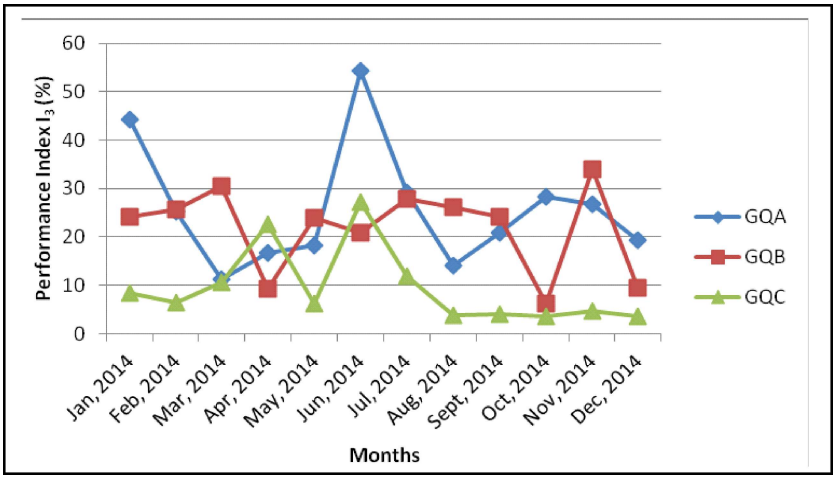


Figure 4: Comparison of Production Index I_3 of the Quarries

Table 7: Comparison of Production Index I_3 (%) of the Quarries

Months	GQA	GQB	GQC
Jan, 2014	44.3	24.2	8.3
Feb, 2014	25.2	25.6	6.5
Mar, 2014	11.2	30.4	10.6
Apr, 2014	16.8	9.2	22.7
May, 2014	18.3	24	6.2
Jun, 2014	54.3	20.9	27.3
Jul, 2014	29.2	27.9	12
Aug, 2014	14.2	26.1	3.8
Sept, 2014	20.8	24.1	4.1
Oct, 2014	28.3	6.2	3.6
Nov, 2014	26.8	34.1	4.7
Dec, 2014	19.3	9.5	3.5
Average	25.7	21.8	9.4

at a competitive advantage over them if they are to service the same market. A drop in price by GQC will force the remaining two quarries out of operation. Also, the quarries products are sold for averagely Two thousand naira per ton (₦2000 t), which implies that index I_1 ranged between 10% and 20% as against the global standard of less than 6%. Figure 3 depicts about 21% of total down time was as a result of maintenance in GQB. Comparatively, this forms a median trend within the studied quarries. Considering the impact of downtime on productivity, this implies that GQC's productivity is higher than GQB which in turn is higher than that of GQA. However, where there is a high demand for products, GQA and GQB may never meet up with product delivery to customers and will be branded as unreliable quarries.

Nevertheless, Figure 4 shows the impact of equipment maintenance on the production costs of the studied quarries. GQA and GQB show a higher trend which is likely to be caused by poor equipment selection and maintenance management system. This situation is likely to rob the quarries of the estimated profitability and adversely affect their payback period or repayment schedule. Generally, the index I_2 rose between 19 -25% as against the industry norm of less than 1% (Mobley, 2004) and I_3 averaged 28.5% while global standard ranges between 12% and 14% (Mobley, 2004).

CONCLUSION AND RECOMMENDATIONS

Maintenance performance indices allow the quarries to understand the value created by maintenance, re- evaluate and revise their maintenance policies and techniques, justify investment in new trends and techniques, revise resource allocations, and to understand the effects of maintenance on other functions and stakeholders. From this research, the performance indices (maintenance cost per ton of aggregate produced; percentage of maintenance to total production cost; and percentage of total downtime caused by maintenance) for the studied quarries are not in conformity with global best maintenance standard. This is worrisome and has a negative impact on the viability of the quarry business, as they affect the bottom line of the business.

In line with the poor performances recorded by the studied quarries, it is recommended that their maintenance policies be revised and their maintenance strategies overhauled to enhance higher performance that can impact positively on the overall corporate goal of the quarries.

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