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Performance Indicators for Sustainable Cement Production in Nigeria

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Abstract: The cement industry is an intensive energy consuming process with attendant economic benefits and environmental caution. Cement processing comes with economic advantages and environmental implications, like dust and pollutants. Host communities and staff of cement factories are bound to experience and endure this barrage of emissions, which leads to serious health and environmental challenges. Using the Analytic Hierarchy Process (AHP), three cement manufacturing companies in Ogun State, South-West, Nigeria were investigated to determine how best they conform to industry best practices. Fifteen criteria were identified and used for this analysis. Results show that COMPANY B is operating at acceptable standards while COMPANY A should consider improving on safety, spares, emission levels and staff welfare.

Keywords: Sustainable, Cement, AHP, Best Practices, Pollution

I. Introduction

Cement manufacturing is an intensive energy consuming process considered to be one of the world's most highly energy intensive economic sectors. Cement manufacturing comes with economic advantages and environmental implications, which poses grave serious health and environmental implications on people and the environment. These include emissions of airborne pollution in the form of dust, gases, noise and vibration when operating machinery and during blasting in quarries, and damage as a result of quarrying operation. The typical gaseous emissions to air from cement manufacturing plants include Nitrogen Oxide (NOx), Sulphur dioxide (SO2), Carbon monoxides (CO), Carbon dioxides (CO2) and dust. Added to this, the industry has also been regarded as an intensive consumer of natural raw materials, fossil fuels, energy, labour [1-4]. According to the Cement Sustainability Initiative [5], fatalities are the most serious tragedy that can happen in the Cement Industry. It is of essence to derive the best possible fatality prevention strategy. Analysis by region indicated much higher risk in developing regions such as Asia, Africa and South America.

The study aims to carry out performance evaluation for selected cement plants in Ogun state Nigeria, to investigate how they keep to the industry's best practices and compare results to one another. The analysis of this study will be done using the Analytic Hierarchy Process AHP). One of the most useful methods for selecting, ranking and investigation that is becoming more and more important is the Analytic Hierarchy Process (AHP). This method was developed by Saaty as a tool to help with solving technical and managerial problems. The Analytic Hierarchy Process (AHP) can also be defined a multi-criteria decision making method that helps the decision-maker facing a complex problem with multiple and subjective criteria in making decisions. The main objective of the AHP is to identify the preferred alternative and also determine a ranking of the alternatives when all the decision criteria are considered at the same time [6-8].

Fifteen criteria were identified for a proper performance evaluation of the selected cement plants - production capacity, safety, ease of production setup, topography, availability, spares, down times, capital cost, energy cost, maintenance cost, staff welfare, emission levels, noise level, cost of raw materials and dust level. This study is limited to Ogun State in South-West, Nigeria and can be expanded in the near future. The three cement plants investigated are COMPANY A, COMPANY B and COMPANY C and are located in Ogun State, South-West Nigeria. These cement plants are also referred to as alternatives in this paper.

II. Materials and Methods

Identifying relevant criteria

The study adopted the identification of relevant criteria that will bridge the gaps between product quality, quantity, sustainable manufacturing, energy consumption, pollutant emissions and safety in the cement industry. Upon review of literatures and assessing performance indicators, fifteen relevant criteria were chosen.

Conducting Industry Survey

Data was sourced using questionnaire method. The questionnaires were completed by engineers who are staff of the case study companies. They work in the production, logistics, safety and quality control departments. Twenty properly completed questionnaires were selected for each company and used for this study. In order to define a unique value for the judgments of these engineers based on our questionnaire, the arithmetic mean of each question scale was calculated.

Analytic Hierarchy Process

An AHP-based evaluation model can be developed for investigating the degree of adherence of cement plants to best practices to ensure proper safety, health and energy standards by following the steps below [9]:

- Step 1: Define the evaluative criteria for investigating the degree of adherence of cement factories to best practices to ensure proper safety, health and energy standards.
- Step 2: Establish a hierarchical structure. Acquire important indicators into a hierarchy of interrelated decision elements, including goal, criteria and sub-criteria where necessary. The established hierarchy tree is shown in Figure 1

Figure 1: Problem hierarchy tree

- Step 3: Establish the pair-wise comparison matrix. Each decision maker makes a pair-wise comparison of the alternatives with respect to a criterion and assigns them relative scores.

For this analysis,

- Let n be the size of the square matrix, i represents a row index of an element of A and j represents a column index of an element of A, then:
- Let the pairwise comparison matrix be A, then the elements of A can be identified by indices, i and j. Therefore: A=Aij. The numeric values assigned to each element is based on Saaty's Rating Scale as shown in Table 1.

Table 1: Saaty's Rating Scale

Value	Description of comparison
1	Two elements contribute equally to the objective
3	Experience and judgment slightly favour one element over another
5	Experience and judgment strongly favour one element over another
7	An element is favoured very strongly over another; its dominance demonstrated in practice
9	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values

- Step 4: Determine the eigenvalue and eigenvector of each pair-wise comparison matrix. Given that AHP analysis is defined by the expression:

 $A \times \omega = \lambda_{max} \cdot \omega$

 Where **ω** is an eigenvector and $\boldsymbol{\lambda_{max}}$ is the mean eigenvalue.

$$N_j = \sqrt[n]{\prod_{j=1}^{j=n} A_{ij}}$$

$$N = \sum_{j=1}^{n} N_j$$

$$\omega_j = {N_j}/{N} \qquad \{j=1, 2, 3 \ldots n-1, n\}$$

ω_j is an element of **ω** which is a column vector and:

$$\sum_{j=1}^{n} \omega_j = 1$$

- Step 5: Test the consistency of each comparison matrix, using the following expression:

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)}$$

- Step 6: Select the appropriate Random Index. The Random index (RI) is useful in order to determine how good[10] the Consistency Index (CI) is. AHP compares CI to RI and this comparison result in what is termed as Consistency Ratio. Random Index is the Consistency Index of a randomly generated reciprocal matrix from the scale 1 to 9 [11]. A sample of RI values for matrix of the order 1 to 15 can be found in the Appendix section.
- Step 7: Calculate the consistency ratio. Consistency ratio can simply be defined using the expression below:

CR = $\frac{CI}{RI}$

For a set of judgment, the consistency index estimated is divided by the random index corresponding to the order of the matrix. The resulting value is termed as the consistency ratio. The value determined is very useful in indicating consistency of judgments made during pairwise comparison. The difference, if any, between λ_{max} and **n** is an indication of the inconsistency of the judgments. If λ_{max} = **n** then the judgments have turned out to be perfectly consistent. Perfect consistency rarely occurs in practice. In the AHP the pairwise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding consistency ratio (CR) is less than 10% [12].

- Step 8: Steps 3 to 7 are repeated for all criteria. The column vector **ω** is derived for each criteria considered. The derived column vectors are assembled into an 'eigenvector matrix'.
- Step 9: Pairwise comparison is also done for all criteria by comparing them with each other. Steps 3-7 are also repeated to determine consistency. The elements of derived eigenvector in this step are the 'criteria weights'. Criteria weight show priorities or importance of the criteria considered by experts or decision makers.

  The criteria weights arrived at in this paper were based on the judgment of experts and are presented in the appendix section.
- Step 10: Calculate the overall composite weight to rank the alternatives. The alternatives are ranked from the most suitable to the least based on the magnitude of their corresponding overall composite weight.

Eigenvector matrix **x** Criteria weights = Overall Composite Weight [13]

III. Results

The criteria weights of all the criteria are presented graphically in Figure 2. It can be deduced that safety and the cost of raw materials are of the highest priority while topography is of the least priority.

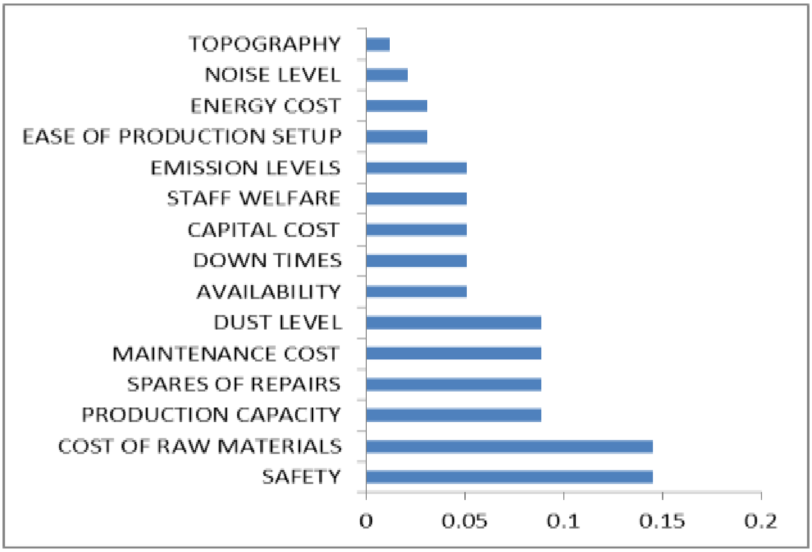

Figure 2: Graphical presentation of criteria weights

Using Ease of Production Setup Criteria for Comparison

Based on the criterion, Figure 3 depicts that COMPANY B cement plant has the highest value while COMPANY A has the least.

Using Production Capacity Criteria for Comparison

By relative weights, COMPANY B cement plant has the highest relative weight and COMPANY A has the smallest, as shown in Figure 4.

Using Safety Criteria for Comparison

Figure 5 illustrates that COMPANY C cement plant has the highest relative weight and COMPANY A has the smallest.

Using Topography Criteria for Comparison

Figure 6 graphically presents COMPANY B cement plant having the highest relative weight, while COMPANY A has the smallest.

Using Availability Criteria for Comparison

COMPANY B cement plant has the highest relative weight and COMPANY A has the smallest. This is presented in Figure 7.

Using Spares Criteria for Comparison

Figure 8 illustrates that COMPANY B cement plant has the highest relative weight and COMPANY A has the smallest.

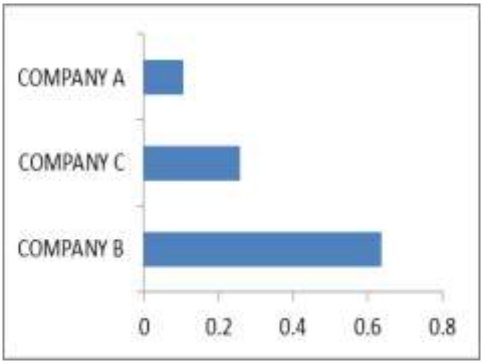

Figure 2: Relative weights for Ease of production setup

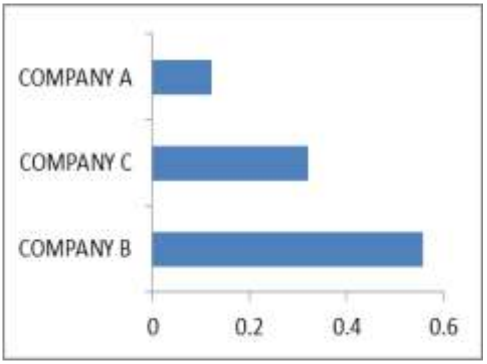

Figure 3: Relative weights for production capacity

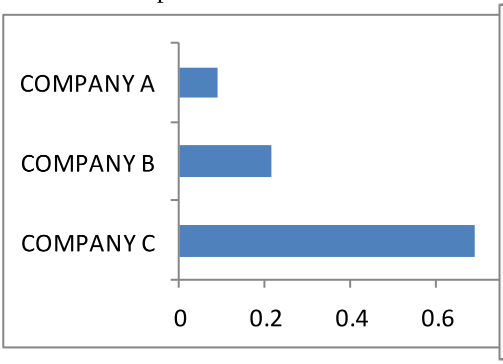

Figure 4: Relative weights for safety

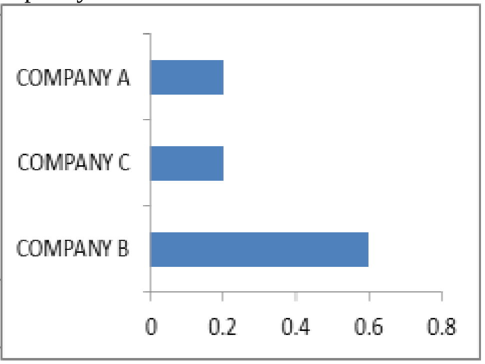

Figure 5: Relative weights for topography

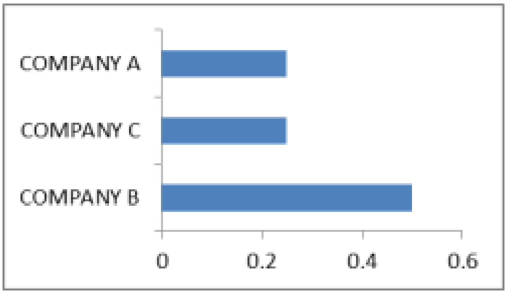

Figure 6: Relative weights for availability

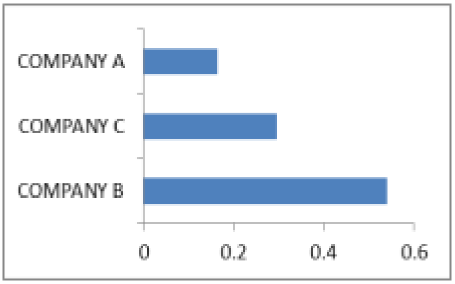

Figure 7: Relative weights for spares

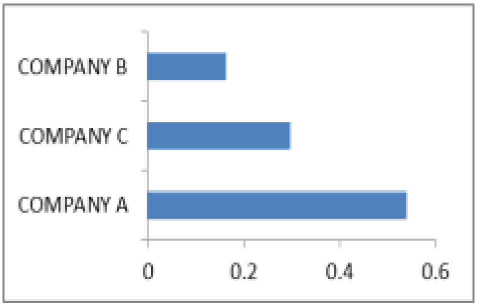

Figure 8: Relative weights for down times

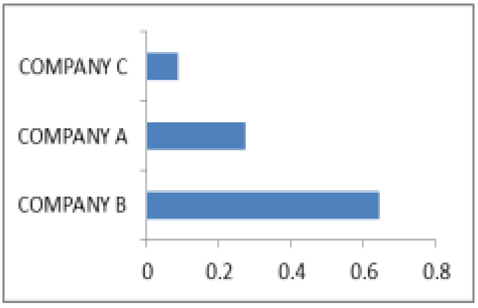

Figure 9: Relative weights for capital cost

Using Down Times Criteria for Comparison

Using down times criterion, COMPANY A cement plant has the highest relative weight and COMPANY B has the smallest. Figure 9 shows the graphical illustration of the result.

Using Capital Cost Criteria for Comparison

Based on the capital cost criterion, COMPANY B cement plant has the highest relative weight and COMPANY C has the smallest. This result is presented graphically in Figure 10.

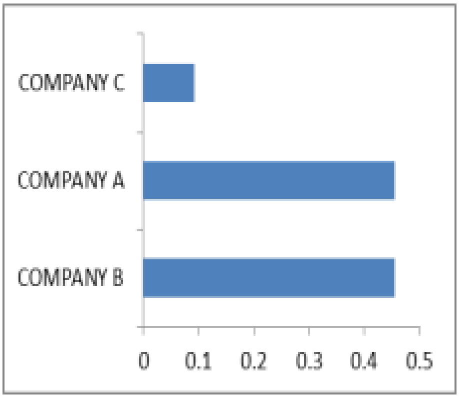

Figure 10: Relative weights for energy cost

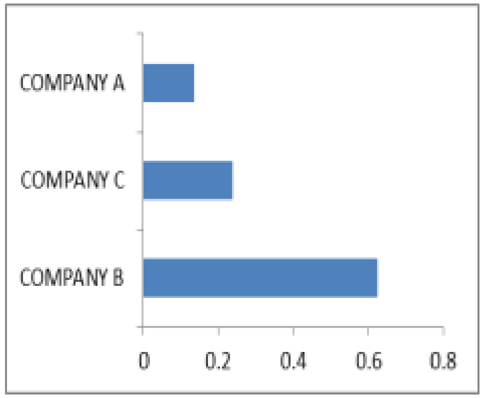

Figure 11: Relative weights for maintenance cost

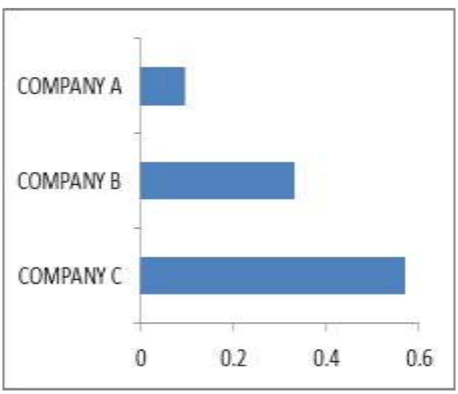

Figure 12: Relative weights for staff welfare

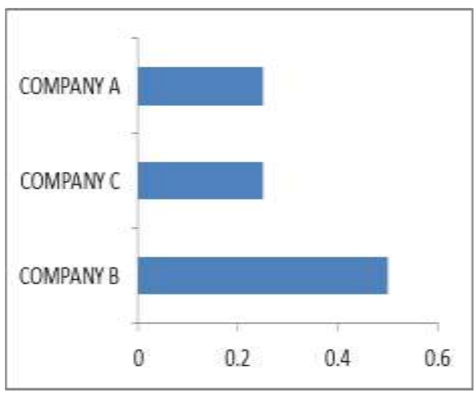

Figure 13: Relative weights for emission levels

Using Energy Cost Criteria for Comparison

Based on the energy cost criterion, COMPANY B cement plant has the highest relative weight and COMPANY C has the smallest. This illustrated graphically in Figure 11.

Using Maintenance Cost Criteria for Comparison

Based on the maintenance cost criterion, COMPANY B cement plant has the highest relative weight and COMPANY A has the smallest. This result is presented graphically in Figure 12.

Using Staff Welfare Criteria for Comparison

Based on the staff welfare criterion, COMPANY C cement plant has the highest relative weight and COMPANY A has the smallest. This is presented in Figure 13.

Using Emission Levels Criteria for Comparison

Figure 14 graphically illustrates that COMPANY B cement plant has the highest relative weight and COMPANY A has the least.

Using Noise Level Criteria for Comparison

Figure 15 presents COMPANY B cement plant has having the highest relative weight and COMPANY A has the smallest.

Using Raw Materials Criteria for Comparison

Figure 16 presents COMPANY C cement plant has having the highest relative weight and COMPANY A has the smallest.

Using Dust Levels Criteria for Comparison

Figure 17 presents COMPANY C cement plant has having the highest relative weight and COMPANY A has the smallest.

Using Overall Composite Weights Criteria for Comparison

For the overall composite weights, our analysis shows that COMPANY B cement plant is ranked top while COMPANY A is the one with the least weight. This is presented graphically in Figure 18.

IV. Conclusion

The economic weight of cement industry calls for constant monitoring and strict adherence to regulation. A performance evaluation was carried out in this study for three cement plants located in Ogun state Nigeria. The methodology used for this work is the Analytic Hierarchy Process (AHP) which is based on multi-criteria pairwise comparison. Data was collected using questionnaires that were structured for cement plants based on the Saaty's rating scale. The results the analysis show that COMPANY B cement plant is ranked top followed by COMPANY C and then COMPANY A cement plants is least in descending order of overall composite weights. We also inferred that the difference between the overall composite weights between COMPANY B cement plant and COMPANY C is small coming at 0.405 and 0.381 respectively. COMPANY A is a little below at 0.214 which signifies that more should be done to improve on some significant plant operation standards. From the relative weights areas such as noise level, emission levels, staff welfare, energy cost, safety, ease of

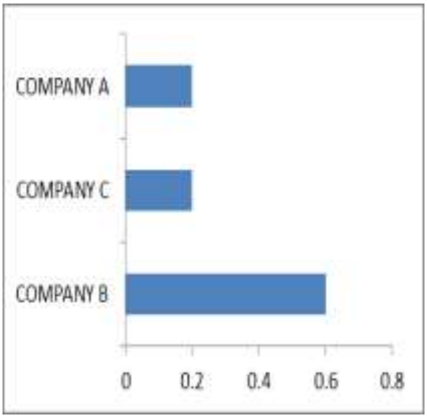

Figure 14: Relative weights for noise level

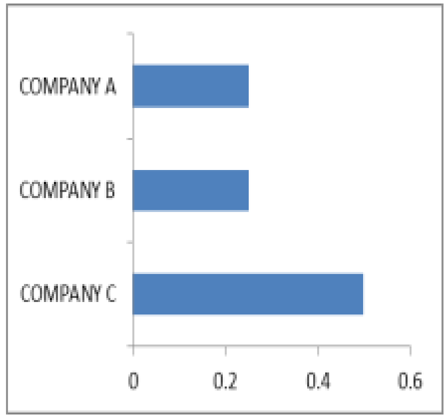

Figure 15: Relative weights for cost of raw materials

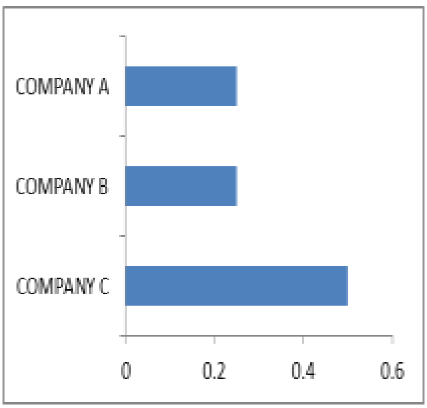

Figure 16: Relative weights for dust levels

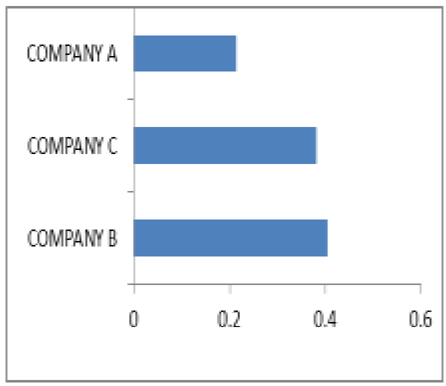

Figure 17: Illustration of overall composite weights

production setup and availability of spares parts should be improved. Production capacity should also be looked into and should be well scaled to accommodate all other production criteria and parameters. This study is however limited to Ogun State, Nigeria and can be extended to other regions in the country having cement industries. It should also be noted that most of the pairwise comparison done were based on expert judgment. Further studies will improve on this work and use actual values from plants. Our limitations were caused by difficulties in getting actual and accurate data from cement plant staff and related agencies. This can also be corrected if adequate time was given for proper sensitization of the cement plant management and agencies.

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