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Productivity of Concrete Placement by Dumpers in Nigeria

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Abstract:- The impressive economic growth rate of Nigeria is weakened by towering poverty statistics attributable to low productivity on construction sites. While in-situ concreting operations are important to the construction industry, labour productivity is often crudely estimated or lumped together irrespective of placement method. This research aims at investigating the effects of site productivity factors in the most prevalent mechanized concrete placement method in Nigeria with a view to optimizing its usage. To achieve this objective, data involving 26 concrete pours extracted from a total observation of 167 concrete pours on Lagos building construction sites were analyzed using the multiple regression method. The results which were subjected to optimization analysis using the Microsoft Excel spreadsheet package indicated that major productivity increases could be achieved with efficient scheduling of dumper concreting operations. Further research into the effects of other productivity factors using simulation modeling is recommended to establish optimal situations for a wide range of operating conditions that can be used to provide estimating and planning information for planning engineers on construction sites.

Keywords:- Optimization, labour productivity,dumper,regression analysis , simulation.

I. INTRODUCTION

Construction is a key sector of national economies around the world.According to Ameh and Odusami (2002), the output of the construction industry is about 3-8% of the Gross Domestic Product (GDP) in most countries. Construction traditionally contributes to a country's total employment figures and the nation's revenue as a whole [7]. In the US, construction accounts for 14% of the gross national product (GNP) and about 8% of total employment [41]. The construction industry is reported to be the largest Nigerian industry, employing a good proportion of the work force and controlling over 50% of GNP ([16], [32]).

Productivity is a vital consideration in the construction industry because improvement in productivity has a direct impact on all other industries and on the national economy ([10], [14]). Productivity is also a central determinant of man's standard of living and plays a crucial role in the national economy of countries because for the economy to improve, the productivity of the various sectors in the economy has to increase. Onitiri (1983) submits that the major reason for the Japanese dominance of the international world market today is their exemplary high level of productivity, arguing that other developing countries like Hong Kong, Singapore, the Philippines, India, Mexico and Brazil have similarly made inroads into the industrial market because of their consciousness and commitment to a high level of productivity borne out of a disciplined application of technical knowledge.In the same vein, Tran and Tookey (2011) admit that productivity growth is strongly correlated to economic growth and increase in welfare. Nigeria, Africa's most populous country, ranked as the 14th largest country in Africa and the 40th in the world, has a GDP annual growth rate of 7.1% more than the annual population growth rate of 3.2% (Vision 20: 2020). According to Pison and Co (2013), this impressive economic growth rate has however been weakened by the high figure of poverty of 54.4% which is only second to Columbia's worst figure of 64%. Hence,several empirical studies have revealed that output in Nigerian construction is rather low when compared with many developed countries, and workers' productivity on sites is poor [15].

Labour productivity is particularly important in developing countries like Nigeria because labour-intensive production is still widely employed in most places and much of the building work is carried out manually [1, 24]). Hanna, et. al (1999) posit that labour represents the most significant risk to contractors while Tah and Carr (2001) submit that labour productivity is one of the most important risks in construction projects. According to Jang, et. al, (2011), the construction industry is labour-intensive and relies heavily on the skills of its workforce which is the industry's most valuable asset, accounting for over a quarter of the total project cost. Moreover, workforce can significantly influence cost, schedule, and quality of a construction project, owing to its volatile nature [19]. Labour is also regarded as an important resource because it links all the other resources, namely, materials, plant/equipment, and finance, in order to produce various construction products [16]. Furthermore, all the advantages supplied to productivity growth by equipment and material control can only be obtained with the effective and optimum use of human resources, making labour a most important factor in production [24].

Various authors (Yates, 1993; Assaf, et. al, 1995; Kaming, et. al, 1997; Chan and Kumaraswamy, 2002 and Odeh and Battaineh, 2002) have shown that construction industries in many developed and developing countries suffer from delays and cost overruns due to poor labour productivity. Alinaitwe (2006) confirms that poor productivity of craftsmen is a prime cause of cost and time overruns on building projects. Construction labour productivity is one of the most frequently researched topics because in most countries, labour cost comprises 30 to 50% of the overall project's cost and thus regarded as a true reflection of the economic success of the operation [36]. Since labour cost represents a considerable proportion of the final cost of the building, labour is confirmed as the most important factor of production [1]. Moreover, because it creates value and sets the general level of productivity, labour productivity is usually adopted as an index for measuring overall productivity while concrete work is an important and fundamental part of modern construction practice common to international construction and can provide a meaningful indication of the comparative performance of contractors since it is essentially a cyclical task similar on all construction sites, regardless of international location[49].

II. CONCRETING AND CONCRETE PLACEMENT METHODS

In most parts of the developed world,there are six concrete placement methods/equipment such as backhoe, direct tip, hoist and barrow, pump, crane and 1-skip and crane and 2-skip (Lu, *et. al,* (2003) and Lu and Anson, (2004). Olaoluwa (2008), however reports that in Nigeria, the most prevalent concrete placement methods and/or equipment employed by contractors in Lagos State, Nigeria, in order of usage were:

- Head pan – used in about 71% of the building sites
- Wheelbarrow – used in about 57% of the building sites.
- Dumper – used in about 48% of the building sites and
- Crane and Skip – used in 44% of the building sites.

Thus, four major concrete placement methods – head pan, wheelbarrow, dumper, and crane and 1 bucket/skip – are used.

Of the placement methods employed in Nigeria, the most unproductive rates are related to the traditional head pan and wheelbarrow solutions (Olaoluwa,2008). Concrete placement by crane and skip is the least labour intensive and yields the most efficient productivity rate while concrete placement using dumper is the next most labour productive placement method, and although restricted to column/wall foundations and ground floor beams and slabs, is the most popular of the mechanized methods, being used in about 50% of the building sites.

Dumpers are used for massive concrete foundation slabs and walkways including lawn verges in public space landscaping, running through and connecting different playfields within large sports complexes and stadia.They can travel across almost any terrain where soft, sandy composition of the ground prevents the use of conventional trucks and enable concrete to be placed efficiently over large areas while monitoring quality control. Dumpers also have the advantage of travelling at speeds up to 30 km/hr with high manoeurability where access may be limited;working with either forward tipping or effective placement on either side, which is very useful for foundation trench filling and concreting storm water drains.In Nigeria, dumpers have become a favourite for Contractors who have found it to be the ideal solution for job-site construction and in-situ concrete laying on small and medium concreting projects because they cannot afford pumps and cranes.

This study examines labour productivity in concrete placement by dumpers to provide additional knowledge and insights into concrete production and placement in Nigeria and enhance the use of dumpers for concrete placement and in the construction industry generally. The factors with an impact on concreting productivity are first identified by a review of relevant literature before determining the scope and method for measuring concreting labour productivity using dumpers.

III. CONCRETING PRODUCTIVITY RATES

Just as flow processes are easily thought of in terms of time, construction operations are easily thought of in terms of productivity rates [13]. Productivity is however usually defined in different ways depending on the purpose of measurement. In construction, trade productivity is ordinarily defined for conceptual and analytical simplification as the ratio of the output in a particular trade related to the tradesman's inputs and can be expressed in quantitative terms as physical productivity. According to Park H-S (2008), two forms of productivity are used in the construction industry:

a) productivity = output/input and
b) productivity = input/output.

The first form is widely used in construction and existing literature while the second is often employed for estimating. Wang (1999) and Abd, Abd, Hj, Zain and Ismail (2008), however submit that it is important to specify the input and output to be measured when calculating productivity because there are many inputs to the construction system, such as labour, materials, equipment, tools, capital and design.Also, the conversion process from inputs to outputs associated with construction operations is complex, being influenced by the technology used and by many externalities such as government regulations, weather, unions, economic conditions and management and by various environmental components. Even for an operation like concreting, with well-known equipment and work methods, construction productivity estimation can be challenging owing to the unique work requirements and changeable environment of each construction project as well as the complexity of the influences of job and management factors on operational productivity [33].

According to Proverbs et. al, (1999) and Forbes, et. al, (2004), an accurate estimate of the productivity for in-situ concreting operations is desirable for planning purposes because planning engineers require productivity rates to estimate and schedule pours, resource levels, and accounting control. Dunlop and Smith (2003) further submit that planners maintain a large databank of basic productivity rates adjustable for individual projects considering specific site factors and conditions that influence the productivity of construction operations so that they could modify the productivity rates for specific estimates to reflect anticipated delay times.

Different yardsticks are usually employed for measuring the concreting productivity by giving the placement labour or equipment productivity as the ratio between the quantity of concrete poured to the man-hours (mh) or equipment hours (eh) committed by the concreting gang or equipment respectively, the mixer productivity as the ratio between the quantity of concrete poured to the mixer-hours spent on site ([6], [45]). Concreting productivity consequently entails relating a single input (worker-hour or equipment-hour) to a single output (concrete volume in m^3) and the simple productivity ratio of this input and output is calculated assuming a closed system with all other factors held constant except for the desired input and output (Wang, 1999.The overall productivity for an entire concreting operation, which is the placing rate,is thus appropriately measured as the ratio of the quantity of concrete placed to the total time of the operation in m^3 /hr (Wang, 2001, [28], [29]). In this study, the convention of measuring labour productivity as input divided by output or operative hours per unit of work, (wh/m^3 of concrete) has however been adopted, since it has been found more appropriate for planning purposes ([12, [38, [42]).

IV. FACTORS AFFECTING CONCRETING PRODUCTIVITY

Construction productivity is difficult to study because the factors that affect it are never constant, varying from job to job (Logche, 1978; Olomolaiye, 1984; Motwani *et al*, 1995).

Concreting and concrete placement, being an integral and major operation in the construction industry is subject to these same factors, because one of the many areas of the construction industry that rely heavily upon cyclical processes is the process involved in the concreting operation (Dunlop and Smith,2000). Concrete operations are littered with variables and uncertainties and unless these are considered at the early planning stages, many can result in wasteful activities which are difficult to manage once construction has started (Dunlop and Smith, 2004). In the majority of concrete pours, it is possible to determine a number of factors that are detrimental to the concreting process and Crumbine (1999), set about defining these factors by spliting them into two groups – technical and managerial factors. By considering these factors in the context of the main parts of the concreting process and the general concrete placement cycle, one may begin to understand how the variability can be reduced (Dunlop and Smith, 2000).

According to Jang *et. al,* (2011), some models have been developed using regression analysis to provide an evaluation of the impact of different factors on construction labour productivity. The Industrial Grant Review-GR/M50744/01 (2002) and Dunlop & Smith (2003) both report the use of multiple linear regression to determine the statistical relationship between actual productivity and the explanatory variables like number of truck mixers used, type of pour, average volume of concrete, etc for concreting via a pump. GR/M50744/01 (2002) implemented a stepwise procedure, which allows the regression model to be iteratively redefined until only the explanatory variables that are statistically significant remained in the model. The regression analysis methodology used by Dunlop and Smith (2003), on the other hand, was backward elimination, stepwise regression beginning with a full set of explanatory variables or factors that were identified to account for much of the variability in concreting operations such as:

1) Type of pour (wall, column, or base)
2) Total volume (m^3) of concrete poured
3) Number of trucks on the job
4) Average volume of load
5) Start time
6) Number of loads

7) Weather (overcast, sunny, rain, cold and clear or snow)
8) Average truck cycle (minutes)
9) Concrete mix

In both studies, the final model derived for actual productivity was given by the equation:

$$\mathbf{P_{actual} = 1.31T_p + 1.75V_a + 0.56T_n + 0.59W - 0.01C_t + 0.37L_a - 6.95}$$

where $\mathbf{T_p}$ = Type of pour
$\mathbf{V_a}$ = average volume of concrete
$\mathbf{T_n}$ = number of trucks on job
W = Weather (Overcast, Sunny, Rain, Cold & Clear or Snow)
$\mathbf{C_t}$ = average cycle time
$\mathbf{L_a}$ = number of loads,

Findings by Proverbs et. al, (1999) also indicate that certain construction methods/resource utilisation factors such as the concrete elements (column, beam and slab) and number of operatives impact labour productivity in principal high-rise concreting operations. Similarly, Anson and Wang (1998) found linear relationships existing between overall concreting productivity and size of pour on one hand as well as productivity and delay in supply on the other with regression lines describing or modeling the relationships.

The above literature confirm that concreting productivity is influenced by the placement method, weather conditions, the shape, size and location of the concrete pour (in beam, floor slab or column), the skill (qualification, training and experience) and size of the concreting gang, mixer location and positioning as well as regular and adequate supply of materials into the mixer equipment for mixing ready for transportation and placement.

Since productivity rates are dependent on the type of placing equipment and it is acknowledged that there are four major methods of placement, this study shall only consider concrete placement by dumper and quantify the factors that influence labour productivity in this specific case.

V. RESEARCH METHODOLOGY

The research approach was to study several concreting operations on selected building construction sites in the Lagos metropolis to obtain concreting productivity data which could be analysed to predict the influence of different factors on the concreting labour productivity rates of dumpers.

The focus was on selecting construction projects which shared common features such as geographical locations, and to a large extent, construction methods, yet differed in types and magnitudes, so that the impacts of the explored productivity factors could be unravelled. Consequently, sites observed included residential, office, and commercial buildings, industrial facilities, and warehouses where the negative influence of interruptions and disruptions on labour productivity and major encountered delays during the concreting process, e.g., material shortage, unavailability of tools, accidents, and inclement weather, were recorded and discounted, to quantify the labour productivity indices.

For the purpose of this study, all the bungalow and single-storey building sites where considerable in-situ concreting was being carried out were visited to identify 64 building sites manned by contractors duly registered with the Nigerian Federal Ministry of Works.

A. Sampling Size

Based on the population of 64 construction sites manned by contractors registered with the Federal Ministry of Works where concreting was being undertaken in the Lagos Metropolis, the sample size was calculated from the stratified random sampling formula given by Mendenhall, Ott, and Scheaffer (1971) as:

$$n = \frac{\sum^{L} \frac{N_i^2 p_i q_i}{W_i}}{N^2 D + \sum_{i=1}^{L} N_i p_i q_i}$$

where n = sample size
L = number of strata = 3 (for sites manned by large, medium, and small sized firms registered in categories A, B & C, and D respectively with the Federal Ministry of Works, i.e. large-sized firms being those registered in

category A, medium-sized firms those registered in categories B & C while small-sized firms are those registered in category D)

N_i = size of the i^{th} stratum, with $i = 1, 2, 3$; and

(N_1 = 8 sites of large firms; N_2 = 34 sites of medium firms; and N_3 = 22 sites of small firms)

N = population size = 64 building sites

p_i = population proportion for the i^{th} stratum with required characteristic (assumed to be 0.5)

q_i = denotes the population proportion for the i^{th} stratum without the required characteristic ($q = 1 - p$)

w_i = fraction of observations allocated to the i^{th} stratum

$D = B^2/4 = (0.1)^2/4 = 0.0025$

in which B is the bound on the error of estimation (= 0.1), and 1 – B is the confidence level.

Substituting values into the above equation and considering the outcome of the pilot survey and the need to achieve a common quality evaluation system for the construction projects selected for the productivity studies, 25 projects were selected for detailed study as follows:

5 sites manned by large-sized construction firms
10 sites manned by medium-sized construction firms and
10 sites manned by small-sized construction firms

On these 25 project sites, a total of 167 separate concrete operations were observed comprising 35 pours placed by crane and skip, 26 pours placed by dumper, 58 pours placed by wheelbarrow, 37 pours placed by head pan and 11 pours placed jointly by pump, wheelbarrow and head pan.The relevant productivity data on the 26 pours placed by dumper in this study were thus part of the 167 concrete pours, making it possible to achieve valid, reliable and robust statistical results.

B. Methods of Data Collection and Field Work

The method of data collection was through field survey where survey sheets were duly completed during personal site visits, backed up with face-to-face discussions with site personnel and operatives to reduce problem of no response.

A specifically designed data collection form was used in all sites monitored to systematically and consistently record the essential productivity parameters of the labour inputs, and to record the major delays encountered in the concreting operations.The structured survey sheet was developed to gather primary data on the concreting operations and ensure consistency of approach while making allowances for general discussions and peripheral comments which were noted and added to support contextual evidence. The data appropriate for the productivity study of the concreting operations (the activities of mixing, transporting and placing) were obtained through site survey and direct observation of the concrete pours on the 25 building construction sites. Direct measurements were made over the cycles of concreting operations to obtain operational data on each of the concrete pours.

The observation technique involved collecting labour inputs upon the completion of the activity which were cross-checked with superintendents and foremen for verification and accuracy.

VI. PRODUCTIVITY ANALYSIS OF THE CONCRETE OPERATIONS

A. Data and information collected

Table I summarizes the data and productivity characteristics that were observed and calculated for the 26 concrete pours. The observed data include the types of pour, the pour size or the quantity of concrete placed, the total duration of the pour or overall pour-time from the beginning of each operation to the end, and the total time of delay. The total time of delay comprised the idle times encountered during the concreting operation due to poor weather, plant breakdowns, fuel or material shortages and other problems relating to difficulties in mixing and placing the concrete. The calculated quantities are the fractional delay (delay time expressed as a decimal fraction of the pour duration) as well as the overall productivity (m^3/hr) and labour productivity values (workerhr/m^3) indicated in the table.

The mean pour size for all the 26 pours in the sample was 17.17m^3. The bigger mean pour size was about 17.9 m^3 for beam and slab pours while about 11.54m^3 was the mean pour size for column and wall pours. This reflects the amount of beam and slab pours observed (23 out of 26 or 88.5% of all pours) confirming that dumpers were mostly used for ground floor slab and pavement pours.

The mean duration of all pours was found to be approximately 3.65 hours (219 mins), with one-quarter of the pours being less than 1.5 hrs (90mins) and one-quarter greater than 6 hrs (360mins). The mean duration for the 3 column and wall pours was about 4.75 hours (285min) for a total mean volume of 11.54m^3 compared to

3.51 hours (about 210 mins) for a total mean volume of 17.9 m^3 for 23 beam and slab pours confirming that column and wall pours take a substantial amount of time,albeit they may not be large pours in terms of volume.
The mean number of operatives for all the 26 concrete operations and the 23 beam and slab pours was approximately 15 while it is about 16 for the 3 column and wall pours. The number of operatives employed for beam and slab pours appeared disproportionately high compared to column and wall pours which are more difficult to place. This confirms earlier observation made by Olaoluwa and Adeyemi (2009) that the numbers of operatives engaged in the concreting operations were not selected through proper planning or work scheduling effort.

Table I: Summary of Data and Calculated Productivity Characteristics for Each Type of Pour

Type Of Pour		Pour Size (m^3)	Delay (mins)	Total Duration (hr)	Fractional Delay	No Of Operatives	Distance to Pour Location (m)	Overall Productivity (m^3/hr)	Worker-hour per m^3
beam & slab	Sum	411.8000	1048.53	80.73	5.05	334	715.00	212.79	115.02
	Mean	17.904348	45.5883	3.5101	.2194	14.52	31.0870	9.2519	5.0010
	N	23	23	23	23	23	23	23	23
column & wall	Sum	34.6300	179.85	14.26	.58	47	45.00	9.07	18.33
	Mean	11.543333	59.9500	4.7525	.1937	15.67	15.0000	3.0220	6.1105
	N	3	3	3	3	3	3	3	3
Total	Sum	446.4300	1228.38	94.99	5.63	381	760.00	221.86	133.35
	Mean	17.170385	47.2454	3.6534	.2164	14.65	29.2308	8.5331	5.1290
	N	26	26	26	26	26	26	26	26

Footnote: The definitions of all the variables used in Table 2 above are:
i) Type of pour-either slab&beam or column and slab.
ii) Pour size-volume of concrete poured (in cubic metres)
iii) Delay or waiting time in minutes.
iv) Total duration in hours.
v) Fractional delay-ratio of delay to duration.
vi) Number of operatives-placing crew.
vii) Distance to pour location (dpl)-distance between concrete mixing point and placing location in metres.
viii) Overall productivity or output or quantity of concrete poured in unit time (cubic metres per hour).
ix) Labour productivity or how many operatives are required to pour 1 cubic metre of concrete in workerhour per cubic metre.

The total mean delays were within the range of 45 to 60 minutes for all the concrete pours or a total average of about 47 minutes out of the total mean duration of 3.65 hours. This implies that the average delay was about 21.5% of the pour time and is slightly lower than the 23% observed for craned pours by Olaoluwa, et al, (2011). The figure is however still excessively high when compared with the figure of 8.1% obtained by Wang, et al (2001) for delays encountered on craned concrete pours in Singapore.

For all pours, the mean distance between the mixing/batching point and the pour location was about 29 meters-about 31 meters for 23 beam and slab pours and 15 meters for 3 column and wall pours. This again confirms that the dumper is mostly used for ground floor slab and pavement pours due to their advantage to place concrete efficiently over large horizontally distant areas consequent upon their relatively higher travelling speed and manoeurability compared to the wheelbarrow and headpan.

B. Actual Productivities Achieved

The overall productivities calculated in m^3/hour for each type of pour and for all pours are shown in Table I. The productivity achieved overall is the ratio of pour size to the total duration including all delays while the labour productivity is the ratio between the times committed by the concreting operatives to the pour size.

From Table I, it can be observed that the mean overall productivity of all pours is 8.53m^3/hr for the 26 pours of 17.17m^3 mean pour size. The mean overall productivity of beam and slab pours (9.25 m^3 /hr) is however about 3 times the mean overall productivity of column and wall pours (3.02 m^3/hr) while the mean labour productivity for beam and slab pours (5.00 wh/m^3) is only about 1¼ times the mean labour productivity of column and wall pours (6.11wh/m^3).

The nature of beam and slab pours results in concrete being placed as fast as possible and therefore the overall and labour productivities indicate the upper limits of the capacity of the concreting dumper. This is in contrast to the column and wall pours which have to be placed in a controlled manner due to their shape so that no structural damage or weakness occurs (Dunlop and Smith, 2004).

Comparative figures for craned pours by Olaoluwa, et al, (2011) show that the mean overall productivity of craned pours is about 30% higher at $11.24m^3/hr$ while the mean labour productivity is 25% higher at $4.09wh/m^3$ for the 35 pours of $41.6m^3$ mean pour size.

C. Regression Analysis for predicting productivity

Regression analysis was carried out on the observed data to determine the statistical relationship between labour productivity and the significant explanatory variables and obtain probable models to estimate labour productivity rates for the concreting operations. In this regard, the explanatory variables originally identified for serious variability in concreting productivity were the following:

- Type of pour, – coded “1” for slab & beam and “2” for column & walls
- Pour size, (m^3)
- Total duration (hr)
- Delay (mins.)
- Number of operatives
- Fractional delay,
- Distance to pour location (m), and
- Weather, – coded “1” for Fine weather, “2” for Cloudy weather, “3” for Sunny and “4” for Rainy weather,

The regression is of the form

Labour Productivity, $P= y= a + b_1x_1 +b_2x_2+b_3x_3+b_4x_4+b_5x_5+b_6x_6 +b_7x_7+b_8x_8$ where $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8$ are the variables explained previously and a, b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8 are constants.

Statistical analyses were performed using the Stata statistical software package for Windows (version 12, 2011) to determine the impact of the identified resource utilization factors on labour productivity rates. The impact of the type of pour, i.e., beam/ slab vs. column/wall was quantified by introducing a binary “dummy” variable indicating the two types of pours observed.The value of “1” was assigned to beam/ slab, and “2” for column/wall. The coefficient of the dummy variable in the categorical regression model quantifies the average difference in labour productivity between the two types of pours investigated.Similarly, the impact of the type of weather, i.e., fine, cloudy, and rainy weather, was quantified by introducing “dummy” variables, “1”, “2” and “4” respectively for the three weather types observed.

Table II is the regression table which explains the proportion of variability in labour productivity rates due to all the variables taken as a set.The table shows the estimated partial regression coefficients and the corresponding *t*-statistics from the regression on labour productivity for each of the explanatory variables.The significant variables indicated with an asterisk are those for which the *p*-values of the *t*-statistic are less than 0.05 and are cloudy weather, size of pour and total duration.

Since a multiple regression model involves several independent variables having different units of measurement, a direct comparison of the size of the various coefficients to assess their relative influence on the dependent variable would not be authentic. The coefficients from linear regression are called B-weights and one cannot be sure which is the most important variable by looking at the B weights because the variables have different underlying dimensions. Hence, the regression coefficients must be standardized such that they are directly comparable to one another, with the largest coefficient in absolute value indicating the greatest influence on the dependent variable.Standardized regression coefficients are commonly referred to as “beta weights” and these, requested with the *beta option* of STATA, are shown in the last column of Table II. From the beta weights, it can be seen that total duration has over twice the contribution (.594 vs .265) that cloudy weather does in predicting or explaining labour productivity while cloudy weather has over 30% greater contribution (.265 vs .199) than pour size does in predicting labour productivity.

The goodness of fit of the regression model is assessed by the correlation and determination coefficients. The correlation coefficient (multiple R) measures the strength of the linear correlation between the dependent and independent variables in the regression model, whereas the coefficient of determination indicates the percent of variance in the dependent variable which can be explained by the independent variables of the model. The higher the coefficients of correlation and determination in the regression model, the better the goodness of fit. The algebraic sign of the regression coefficient on the other hand, denotes the direction of the corresponding factor’s effect on labour productivity, i.e., positive or negative.

The ANOVA statistics in Table III indicates the coefficient of determination, $R^2_{adj.,}$ =0.851, showing that over 85 per cent of the variation in the explanatory variables is explained by the regression model. It also indicates that Multiple R, the correlation coefficent between labour productivity and all the explanatory, predictor variables taken as a set is over 95%. Hence, there are strong correlation and high determination coefficients between the investigated factors and labour productivity. The *P*-value, which is the probability that the *F*-statistic is greater than the critical value, is less than 0.05 (=0.0000) and confirms that the coefficients of the regression model are jointly significant.

To show how the regression model fits the data, the actual labour productivity values are plotted against the values derived from the regression equation in Figure 1 to demonstrate a linear trend on 1: 1 slope with a close fit of most of the plots.This indicates that the values derived from the model are practically equal to the observed values of actual labour productivity.

A further check to verify the validity of the regression model is to carry out residual plots for different levels of the response or explanatory variables.Generally, for any regression model, if the constant variance assumption holds, the residuals will follow an $N(0, \sigma^2)$ distribution and a plot of the residuals for each *i* against the fitted values $\acute{y}_I$ .should follow a random pattern with 95% of the points lying within a 2σ horizontal band around zero.

Table II: Estimated Partial Regression Coefficents and the Corresponding t-Statistics from the Regression on Concreting Labour Productivity (wk-hr/m^3) for all Variables

Variable	Coefficients	t-statistic	P>|t|	Beta
Type of pour 2	.2711193	0.17	0.864	.0169983
Weather 2	5.067104	3.10	0.007*	.2649721
Weather 4	.2861036	0.24	0.810	.0236556
Size of pour	-.0533393	-2.14	0.048*	-.1987962
Waiting time	.0247836	0.89	0.389	.206065
Total duration	.9657382	2.91	0.010*	.5935416
Fractional delay	-.036645	-0.01	0.995	-.0013577
Number of operatives	-.0169974	-0.15	0.886	-.0208297
Distance to pour location	.0325044	1.07	0.301	.1592753
Intercept	.165451	0.06	0.955	

*significant at 95% level

Table III: ANOVA Statistics for Regression on Labour Productivity (wk-hr/m^3)

	Degrees of freedom	Sum of Squares	Mean Squares	P>F
Regression model	9	610.749691	67.8610768	0.0000
Residual	16	64.3801397	4.02375873	
Total	25	675.129831	27.0051932	
R^2_{adj}	0.8510			
Multiple R	0.9511			

Figure 2 is a plot of the residuals from the regression analysis against the fitted values of the regression equation. Since the mean square of the residual in the ANOVA is an estimator for σ^2, it can be determined from Table III that most of the residuals should fall between $\pm 2\sqrt{4.024}$ or ±4. Figure 2 shows that this is true for this study as no non-random pattern exists and only 2 points of the total observations lie outside this range (between the red horizontal lines) confirming that the constant variance assumption is satisfied.

The relationship between labour productivity (worker-hour/m^3) and the relevant factors identified when using dumper for concrete placement can therefore be quantified from Table II as

Labour Productivity, $P_L = 5.067W_2 - 0.053S_p + 0.966T_d + 0.165$

where W_2 = Weather 2 (cloudy weather)

S_p = Size of pour

T_d = Total duration

VII. DISCUSSION OF RESULTS

This study has determined the effects and relative influence of some on-site construction resource factors on labour productivity of concrete placement by dumpers.The regression model for actual productivity that has been undertaken provided an equation that describes over 85 per cent of the variance in the set of data obtained from real concrete operations.The productivity rates found from the regression model closely mirror the actual productivity recorded as expected since the regression model is based on these data. The regression analysis carried out showed the significant variables to be cloudy weather, size of pour and total duration of pour.

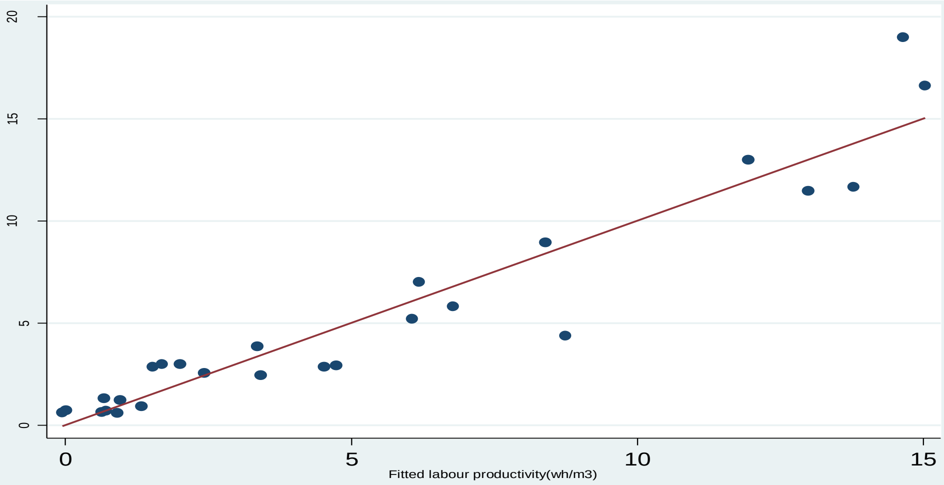

Figure 1:Actual labour productivity plotted against fitted labour productivity for linear regression model

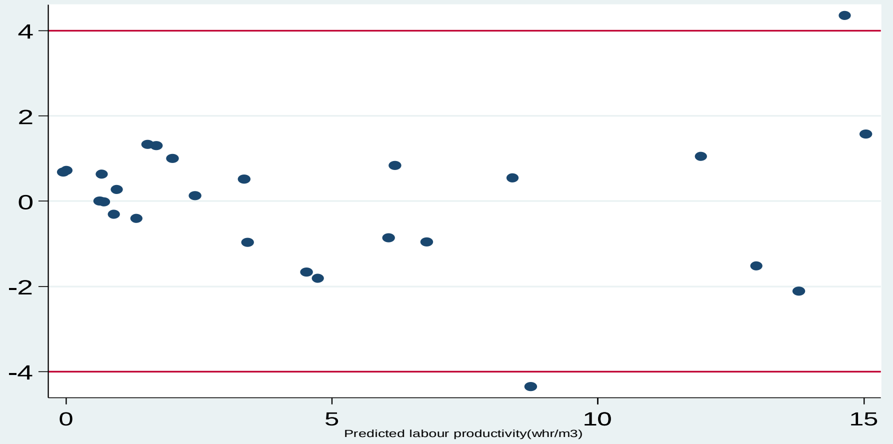

Figure 2:Residual plot for linear model on labour productivity

A. Relationship between pour size and productivity

The variable with the lowest t-ratio in Table II was found to be the size of pour in m^3. The result shows a significant negative relationship between the size of pour and worker-hour/m^3; as the size of pour increases by 1.00 m^3, holding all other factors constant, the worker-hour/m^3, on average, decreases by 0.053 worker-hour/m^3.This implies that actual labour productivity increases by approximately 0.05 worker-hour/m^3 for every 1.00 m^3 increase in pour size or 0.5 worker-hour/m^3 for every 10 m^3 increase in pour size since labour productivity in this research is expressed in terms of operative hours per unit of work instead of the usual method of defining labour productivity as output (in m^3 of concrete) divided by input (in operative hours). Thus the effect of pour size on labour productivity in this study is positive and correlates with the results obtained by Olaoluwa, et. al, (2012) and Anson and Wang (1998) in their respective investigations of concreting operations in Nigeria and Hong Kong where they found that overall concreting productivity increased by 1.1 m^3/hr for every extra 10m^3 of pour volume.

This positive influence of pour size on labour productivity may be ascribed to 'economy of scale' because

(i) an initial preparatory time is required by workers to set out the work details prior to commencing the concreting opearation such that for small concrete pours, a major part of the total input is directed towards the preparatory rather than the direct opearation;

(ii) closer attention to site preparation and work planning and control is observed for large pours than for small pours and

(iii) workers work harder and take less frequent breaks during large pours to ensure they are completed within a given day without 'carry-over' whereas small pours that require less than a day to execute are usually executed with less diligence, provided they can still be completed within the day.

B. Relationship between cloudy weather and productivity

Table II also indicates that cloudy weather (weather 2) positively and significantly impacts worker-hour/m^3 or has a significant negative relationship with actual labour productivity at 0.007 significance level and a coefficent of 5.067104.This regression coefficient of the categorical "dummy" variable weather group =2 (cloudy weather) measures the difference from the referrent weather group=1 (fine weather) and measures the decrease in labour productivity for cloudy weather as compared with fine weather, the difference being significant at the 5% level.

The results however surprisingly show that rainy weather (weather group=4) is not significantly different from fine weather (weather group=1) in terms of its effect on labour productivity. Considering that, in this study, the mean pour size of pours placed in cloudy weather is the smallest (between 40-60%) of the mean size of all pours including pours placed in rainy and fine weather, the labour productivity for pours placed in this study actually support the positive relationship between pour size and labour productivity as it decreased significantly for cloudy weather for the reason of the small pour sizes.

The small sizes of pours placed in cloudy weather may be due to effort by site management to minimize the negative influence of interruptions due to subsequent probable rainfall by deliberately reducing the volume of concrete mixed in cloudy weather.On the other hand, since the pours placed in rainy weather were the largest, workers will work harder to complete their placement as quickly as possible during the rain.This is apart from the closer attention to site preparation and work planning and control that is generally observed for large pours.

C. Relationship between pour duration and productivity

Table II and the regression equation show that the regression coefficient for total pour duration is 0.966, implying that actual labour productivity decreases generally by about 1 wh/m^3 for every additional hour of the concreting operation. Thus, while pour size has a positive influence on labour productivity, the effect of increased pour duration is, as expected, to reduce labour productivity.

D. Optimizing the productivity of concrete placement

From Table II and the discussions in VIIA-C above, the major statistically significant factors impacting labour productivity are pour size and pour duration since the effect of cloudy weather is really due to the small pour sizes placed in that weather. Delay or idle/waiting time was excluded because the relationship between it and labour productivity was found to be statistically insignificant in the regression analysis. From practical considerations, the delay or waiting time affects the pour duration and comprises three important areas of wastage within the concreting operation thus:

- firstly, the delay or idle time of the dumper during the delivery process leads to the concrete mixer or the placing crew being idle.
- secondly, the delay or idle time of the mixer when it is inactive or unable to discharge leads to dumper idleness and the placing crew being idle because of the consequent late dumper deliveries.
- finally, during the positioning and maneuvering times of dumper at the mixer and placing sites, a percentage of total mixer, dumper and placing crew times are wasted.

Hence the major factors/variables considered in the optimization analysis are pour size, pour duration, and delay or waiting time.

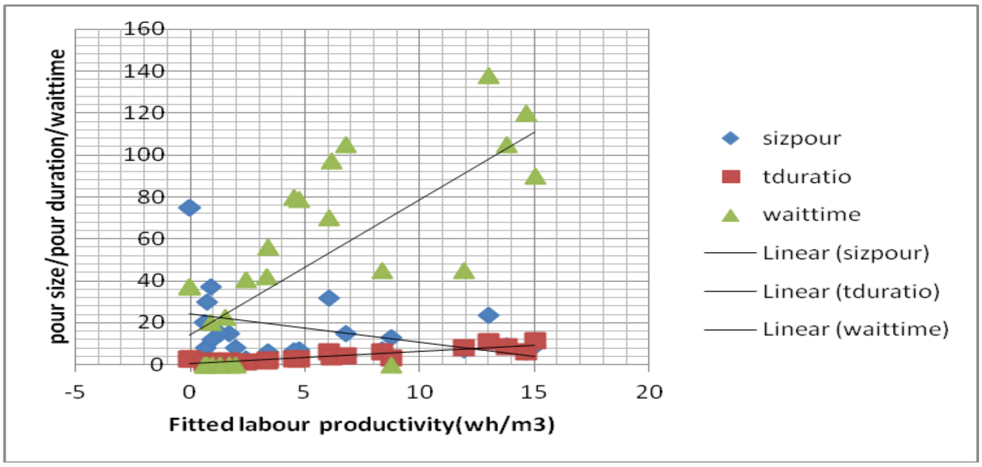

Figure 3 : Graph showing the combined effect of pour size, pour duration and waittime on fitted labour productivity in wh/m^3

The effects of these three factors-concrete pour size, pour duration and waiting time on fitted labour productivity (i.e. labour productivity values derived from the regression model)) in worker-hour/m^3, while all other factors are constant, is shown in Figure 3 which is a graph of the scatter plot of pour size/ pour duration /waittime/ labour productivity data on Microsoft Excel..The figure indicates that:

- as the pour size increases, labour productivity generally increases,
- as the pour duration increases, labour productivity decreases,
- when the waittime increases, the pour duration also increases as expected,
- both the plots of pour size and waittime as well as plots of pour size and pour duration cross.

Since the two indicators of what constitutes an efficient concreting operation are minimum pour duration and minimum waittime, the optimal concreting operation condition is achieved when the pour size and the waittime coincide. The alternative of minimum pour duration/minimum waittime is not practical while that of when the pour size and the pour duration coincide is neither ideal nor desirable. Thus, an optimal concreting operation can be achieved with a labour productivity of 1.2 wh/m^3 when the pour size is 22 m^3 and the total pour duration and waittime are about 2hrs and 22 mins. respectively.This labour productivity is over 4 times higher than the mean labour productivity observed in this study and over 3 times higher than the mean labour productivity observed for craned pours by Olaoluwa, *et al*, (2011). It is also fairly comparable to international standards, being only 1½ times lower than the mean labour productivity observed for craned pours in Anson and Wang's (1998) study of concreting in Hong Kong buildings.

VIII. CONCLUSION AND RECOMMENDATIONS FOR FURTHER RESEARCH

Due to the importance of in-situ concreting operations to the construction industry, this research focused on investigating the influence of the site productivity factors in one of the most prevalent concrete placement methods in Nigeria, namely the dumper.Despite the importance of concreting in Nigeria, the labour productivity of this trade is often either crudely estimated or lumped together irrespective of the placement method.This study has presented factual productivity rates for concrete placement by dumper within the Nigerian construction industry.

Data involving 26 concrete pours extracted from a total observation of 167 concrete pours on Lagos building construction sites were analyzed using regression analysis to quantify the impacts of major factors affecting labour productivity of concrete placement by dumpers so as to increase the efficiency of this activity and optimize the operation.The multiple linear regression analysis has shown that the explanatory variables or factors which can be identified and measured within the concreting operations to model the overall operation are cloudy weather, size of pour and total duration of pour. The regression model for actual productivity using these significant variables has provided an equation that describes over 80 per cent of the variance in the set of data obtained from the concreting operations.

From practical considerations, however, the two indicators of what actually constitutes an efficient concreting operation are minimum pour duration and minimum waittime and this leads to a certain set of operating conditions that provide an optimal situation. If this optimal situation is analysed using the Microsoft Excel spreadsheet package platform as presented in this paper, it is possible, with effective and efficient planning .and scheduling of the dumper concreting operations, to increase labour productivity from 5.1 wh/m^3 to 1.2 wh/m^3 and make it more comparable to international standards.

RECOMMENDATIONS

Notwithstanding the findings from this study, further research into the effects of other productivity factors such as the mixing, loading, delivery and placement times is recommended.In a real concreting system, these events (e.g. the interarrival times, placement and loading times) take place at irregular intervals, thus posing a serious problem to the determination of the time it would take to complete a typical concrete pour and achieve a satisfactory concrete placing circle. The analysis of such complexity and variability of interarrival, placement and loading times within the concreting site requires the use of a technique such as simulation to achieve improved estimates of the productivity and thus schedule deliveries better and determine the effect of unanticipated events such as excessive delivery or pour times.

With a simulation model, it is theoretically possible to carry out an infinite number of experiments to indicate the fundamental effects of changes to the input characteristics of the concrete model and establish results reflecting actual situations which are not easily or economically obtained using real operations.Thus an optimal situation can be established for a series of operating conditions and once established, the model can be adapted and used to provide estimating and planning information for a wide range of operating conditions.The planning engineer in a construction company could then ultimately improve operating performance on this basis.

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