ASSESSING THE IMPACT OF DELAYS ON THE PRODUCTIVITY OF CONCRETE PLACEMENT BY CRANES IN NIGERIA

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Abstract
Infrastructural construction investment in Nigeria is currently estimated at US$5bn annually and of the key trades in the industry, concreting makes up about 15% of the total frequency of operations. One of the most dominant concrete-placement methods in Nigeria is by crane and skip and it has been established that fractional delay (delay time expressed as a fraction of pour duration) is the most significant factor affecting its productivity. This study therefore focused on evaluating the extent of delays on craned concrete placement in Nigeria and determining their effects on concreting productivity. The study involved a close observation of 35 daily concrete pours placed by crane and skip on 25 project sites selected through stratified random sampling procedure in Lagos. Productivity data obtained were analysed by multiple regression to obtain a model relating productivity to fractional delay. The results showed an average delay of above 23% of the pour time while the productivity is reduced by more than 2.5 m³/h for every 10% increase in delay. The latter is over 5 times the productivity reduction obtained in Hong Kong study for the same percentage increase in delay and confirms that delay has a far greater impact on the productivity of concrete placement by cranes in Nigeria than in other countries. It was recommended that serious, and concerted, managerial actions be directed at proper planning and scheduling of material deliveries as well as labour and equipment inputs by adopting the developed model to monitor and eliminate most delays and sustain productivity.

Keywords: concrete placement, crane, delays, impact, Nigeria, productivity

INTRODUCTION
Concreting is one of the most common operations in today’s construction industry and concrete operations including batching, transporting and placing are familiar on many construction sites throughout the world.
Concrete work is also an important and fundamental part of modern construction practice common to international construction which can provide a meaningful indication of the comparative performance of contractors since it is essentially a cyclical task which is similar on all construction sites, regardless of international location (Proverbs, Holt and Olomolaiye, 1999). Furthermore, as submitted respectively by Chan and Kumaraswamy (1995), Wang, Ofori and Teo (2001) and Dunlop and Smith (2003), the operational productivity of equipment and labour in concrete placement is an essential, intrinsic parameter influencing the construction industry.

Productivity, however, combines effectiveness with efficiency because while effectiveness relates to performance, efficiency is related to resource utilisation (Mali, 1978). Such productivity rates rank amongst the most essential data needed in the study of construction productivity for the reason that planning engineers require them to estimate and schedule concrete pours and resource levels as well as for accounting control. Dunlop and Smith (2003) submit that planning engineers often maintain a large databank of basic productivity rates which they adjust for individual projects taking into account specific site factors and conditions which may influence such rates.

According to Graham, Smith and Tommelein (2005), the problem of inefficiency and high cost of manufacture, transportation and placing of concrete has been continuing for decades. Unfortunately in Nigeria, where the infrastructural construction investment in 2007 was about NGN 350bn (approximately US$2.8bn dollars) and is expected to grow annually by about 11% up till 2013, there is a shortage of data and information on the overall demand and production of concrete as well as concreting productivity benchmarks (Nigerian Infrastructure Report Q2, 2009). Meanwhile, it has been estimated that of all the key trades in the Nigerian building industry, concreting represents 15% of the total frequency, after carpentry which represents 19.5% of the overall frequency (Olomolaiye, 1984).

Furthermore, Olaoluwa, Adeyemi and Lawal (2010), in a recent study of the concreting process and the factors influencing the productivity of concrete placement by cranes in Nigeria, submitted that productivity in the Nigerian construction industry has been branded as extremely low by a number of industry researchers and recommended that the three variables of type of pour, pour size and
fractional delay be noted by planning engineers in the future planning of concrete placement by crane. It is against this background that the present study purposes to evaluate the delays associated with craned concreting and assess the extent of their impact on concreting productivity.

CONCRETING PRODUCTIVITY RATES

Productivity can be defined in different ways depending on the purpose of measurement. In construction, trade productivity is usually 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. Wang (1999) and Abd, Abd, Hj, Zain and Ismail (2008), however, submitted 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 (Ok and Sinha, 2006).

Different yardsticks are usually employed for measuring the productivity of concrete placement by giving the placement labour or equipment productivity as the ratio between the quantity of concrete placed to the man-hours (mh) or equipment hours (eh) committed by the placing gang or equipment respectively, the mixer productivity as the ratio between the quantity of concrete placed to the mixer-hours spent on site (Wang, 1995, Anson, Wang and Wang, 1996). Concreting productivity consequently entails relating a single input (worker-hour (wh) or equipment-hour (eh)) to a single output (concrete volume in m3) and the simple productivity ratio of this input and output is calculated by assuming a closed system with all other factors held constant except for the desired input and output (Wang, 1999). Such productivity measures relating output separately to each major class of input proportions reflect changes in these input proportions as well as changes in productive
efficiency and allow organisations to analyse the changing costs of the inputs when combined or when separated in terms of both their prices and quantities (Kendrick, 1977; Mali, 1978).

The overall productivity for an entire concreting operation, which is the placement rate, is thus appropriately measured as the ratio of the quantity of concrete placed to the total time of the operation in m$^3$/h. However, 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 been adopted, since it has been found more appropriate for planning purposes (Proverbs et al., 1999; Dunlop and Smith, 2003).

**Earlier work**

Previous findings have indicated the effects of delay in concrete supply service on concrete placement productivity in the countries of Europe, Hong Kong and Singapore. For example, Anson and Wang (1998) measured the mean interruptions (delays) in concrete supply as percentages of pour duration for pumped, craned and barrowed pours in Hong Kong buildings and plotted the placement speed (productivity) achieved against delay in the supply of concrete. The regression lines computed for each of the three types of placement method in their study showed how productivity dropped with a delay in supply. Similarly, Wang et al. (2001) measured delays caused by the RMC supplier for crane and skipped, tremied and pumped pours in Singapore and compared the average delay due to concrete supply as a percentage of pour duration for crane and skipped pours with those for the United Kingdom, West Germany and Hong Kong.

**Concreting in the Nigerian construction industry**

In the early construction industry in Nigeria, head pans served as the standard concrete handling/placement unit with women using them to haul hand- and site-mixed concrete on building sites. Although the construction industry has come a long way with cranes now in use, many buildings are still constructed using the head pans for in situ concrete placement. The results of a pilot survey conducted by Olaoluwa (2008) on construction sites in Lagos, Nigeria, showed that the most prevalent concrete-placement methods and/or equipment in use are head pans (used in about 71% of the building sites), wheelbarrows (used in about 57% of the building sites), dumpers (used in
about 48% of the building sites) and cranes and skips (used in 44% of the building sites). Concrete placement by crane and skip in Nigeria is the least labour intensive of the placement methods and is the most efficient and effective way, being about twice as fast as when using a wheelbarrow and nearly four times faster than when using a head pan (Olaoluwa and Adeyemi, 2009). Apart from these methods, the two methods of placing concrete that are most applicable to multi-storey frame construction are by pumping and by crane and skip where a site crane hoists a skip from ground level to the required location in the frame.

Most empirical studies have, however, revealed that the output of the construction industry in Nigeria is quite low when compared with that of many developed countries and workers’ productivity on construction sites has been shown to be very poor (Fagbenle, Adeyemi and Adesanya, 2004). Concreting and the selection of the concrete-placement method on construction sites is still largely governed by cost and availability of resources without much regard for the economy of location and size of the pour, the rate of progress required, and the productivity levels of the method of concrete placement (Olaoluwa, 2008). Many buildings in Nigeria are also still constructed using the traditional method of in situ concrete placement in which concrete is mostly site-batched and mixed. The use of ready-mixed concrete in concrete truck pumps, truck mixers and conveyor belts is almost non-existent.

This study of the influence of delay on the productivity of in situ concrete placing will therefore provide insight into one major area of the construction industry where productivity can be improved and provide benchmark results for control and monitoring of the productivity of Nigerian contractors. The study will build and expand on previous works in other countries by identifying the effect of delay on concreting productivity by crane, which currently is the fastest of the four prevalent concrete-placement methods in Nigeria.

**RESEARCH METHODOLOGY**

The 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 delay in concrete supply service on the concreting productivity rates of cranes.
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. This was decided on because only such contractors are formally adjudged as being capable of concreting to acceptable standards. Lagos was selected for the study because it is a typical mega-city with the largest concentration of construction sites and workers in Nigeria.

**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:

\[
 n = \frac{\sum_{i=1}^{L} N_i p_i q_i}{N_0 D + \sum_{i=1}^{L} N_i p_i}
\]

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

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

\( N \) = 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 =

\[
 w_1 = \frac{8}{64} = 0.125, \quad w_2 = \frac{34}{64} = 0.531, \quad w_3 = \frac{22}{64} = 0.344
\]
$D = B^2/4 = (0.1)^2/4 = 0.0025$

in which $B$ is the error bound on the estimate ($= 0.1$), and $1 - B$ is the confidence level.

Substituting values into the above equation

$$n = \frac{\sum_{i=1}^{3} \frac{N_i^2 p_i q_i}{w_i}}{N^2 D + \sum_{i=1}^{3} N_i p_i q_i}$$

$$\sum_{i=1}^{3} N_i^2 p_i q_i = \frac{8^2 (0.5)^3}{0.125} + \frac{34^2 (0.5)^2}{0.531} + \frac{22^2 (0.5)^2}{0.344}$$

$$= 128 + 544 + 352 = 1024$$

$$\sum_{i=1}^{3} N_i p_i q_i = 8^2 (0.5)^2 + 34^2 (0.5)^2 + 22^2 (0.5)^2$$

$$= 2 + 8.5 + 5.5 = 16$$

$$N^2 D = (64)^2 \times 0.0025 = 10.24$$

$$n = \frac{1024}{10.24 + 16} = \frac{1024}{26.24} = 39$$

Therefore, $n_i$, the number of samples or observations allocated to the $i^{th}$ stratum shall be obtained from:

$$n_i = n w_i, \ i = 1, 2, 3$$

where:

$$n_1 = 0.125 \times 39 = 4.88 \approx 5 \text{ sites manned by large-sized construction firms}$$

$$n_2 = 0.531 \times 39 = 20.701 \approx 21 \text{ sites manned by medium-sized construction firms}$$

$$n_3 = 0.344 \times 39 = 13.416 \approx 14 \text{ sites manned by small-sized construction firms}$$

From the pilot survey, it was observed that while all the sites manned by large-sized construction companies were supervised and managed by qualified professionals, only 10 of each of the sites manned by medium- and small-sized construction firms were supervised by qualified professionals. Based on the stratified random sampling formula adopted, the outcome of the pilot survey conducted, and the need to achieve a common quality evaluation system for the construction projects selected for the productivity studies, only 25 projects were selected for a 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

To select sites in the first stratum on a simple random basis, the balloting system was adopted whereby the sites in this stratum are numbered from 1 to 8. Each number was squeezed into a ball-like shape and gathered in a container, which was properly shaken to mix the ‘paper balls’ well. Five of the balls are drawn one after the other from the container and the sites corresponding to each of the drawn numbers were included in the sample.

On these 25 project sites, a total of 167 separate concrete-placement 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.

**Methods of data collection and field work**

The method of data collection in this study 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 concrete-placement operatives in order to eliminate the problem of no response. The structured survey sheet was developed to gather primary data on the concreting operations and to 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, i.e., 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.

Table 1 summarises the data and productivity characteristics that were observed and calculated for the 35-crane concreting operations. The observed data included 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, including inadequate planning or scheduling and poor management which adversely affected the timely supply of concrete to and from the placing equipment. The calculated quantities are the fractional delay (delay time expressed as a decimal fraction of the pour duration) as well as the productivity (overall and labour) values indicated in the table.

Table 1: Summary of data and calculated productivity characteristics for each type of pour

<table>
<thead>
<tr>
<th>Type of pour</th>
<th>Pour size (m$^3$)</th>
<th>Delay (min)</th>
<th>Total duration (h)</th>
<th>Fractional delay</th>
<th>No of operatives</th>
<th>Distance to pour location (m)</th>
<th>Overall productivity (m$^3$/h)</th>
<th>Worker-hour per m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam &amp; slab</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>1319.2</td>
<td>1222.88</td>
<td>92.72</td>
<td>4.31</td>
<td>443</td>
<td>278.00</td>
<td>333.24</td>
<td>55.21</td>
</tr>
<tr>
<td>Mean</td>
<td>59.96</td>
<td>55.58</td>
<td>4.21</td>
<td>.19</td>
<td>20.14</td>
<td>12.63</td>
<td>15.14</td>
<td>2.51</td>
</tr>
<tr>
<td>N</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td><strong>Column &amp; wall</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>10.50</td>
<td>40.2531</td>
<td>2.62</td>
<td>.18</td>
<td>12.92</td>
<td>.77</td>
<td>4.63</td>
<td>6.77</td>
</tr>
<tr>
<td>N</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Sum</td>
<td>1455.65</td>
<td>1746.17</td>
<td>126.80</td>
<td>6.65</td>
<td>611</td>
<td>288.00</td>
<td>393.43</td>
<td>143.23</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>41.59</td>
<td>49.89</td>
<td>3.63</td>
<td>.19</td>
<td>17.46</td>
<td>8.23</td>
<td>11.24</td>
<td>4.09</td>
</tr>
<tr>
<td>N</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

The definitions of all the variables used in Table 1 and in the analysis which follow 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 (m3/h)
ix. Labour productivity or how many operatives are required to pour 1 m3 of concrete in wh/m3

DATA ANALYSIS AND DISCUSSION OF RESULTS

The mean pour size for all the 35 pours in the sample was 41.59 m3. The bigger mean pour size was about 60 m3 for beam and slab pours while about 10.5 m3 was the mean pour size for column and wall pours. This shows that the size of column and wall pours is generally less than 20% (actually 17.5%) of beam and slab pours. This is to be expected because column and wall volumes are usually much less than beams and slabs.

The mean duration of all pours was found to be approximately 3.6 h, the longer mean duration of about 4.2 h being for the 22 beam and slab pours while the mean duration for the 13 column and wall pours was about 2.6 h or about 60% of the mean duration for beams and slabs. This is also reasonable because concreting of columns and walls is much slower than concreting of beams and slabs and shows that while 60 m3 of beam and slab concrete took 4.2 h to pour, 10.5 m3 of column and wall concrete took 2.6 h to pour, i.e. about 3½ times slower.

The mean number of concrete-placement operatives for all the 35 concrete operations was about 17, i.e., approximately 20 for the 22 beam and slab pours and about 13 for the 13 column and wall pours. Considering that the average concrete volume of beam and slab pours is 60 m3 while that of column and wall pours is 10.5 m3, the number of operatives employed per m3 for the column and wall pours is about 4½ times higher than for beam and slab pours. On the other hand, since the concreting of beams and slabs is only 3½ times faster than the concreting of columns and walls, the number of operatives employed for the column and wall pours is comparatively on the high side. This confirms earlier observations made by Olaoluwa and Adeyemi (2009) that there is no proper, adequate planning or work scheduling effort to ensure optimal utilisation of labour by streamlining the number
of concrete-placement operatives engaged with the type and method of pour.

It has been stated that the delays recorded include idle times encountered during the concreting operations, due jointly or severally to poor weather, poor site conditions, plant breakdowns, fuel or material shortages and problems relating to difficulties in mixing and placing the concrete, including inadequate planning or poor management which adversely affect the timely supply of concrete to and from the placing equipment. These were within the range of 56 min to 40 min for all the craned pours or an average of 50 min out of a mean duration of 3.6 h, implying that the average delay is above 23% of the pour time. This is excessively high when compared with the figure of 8.1% obtained by Wang et al. (2001) for other delays encountered on craned concrete-placement sites in Singapore (i.e. outside those caused by truck mixers being idle and waiting times for truck mixer).

For all pours, the mean distance between the mixing/batching point and the pour location was about 12.6 m for beam and slab pours but less than 1 m (0.77m) for column and wall pours. Although the latter is on a practically very low side, it is not unreasonable because most column and wall concrete have to be poured in a controlled manner (Dunlop and Smith, 2003) while cranes are used mainly for their advantage in slewing over vertical distances and not usually for horizontal distances.

**Actual productivities achieved**

The overall productivities were monitored and calculated in m3/h for each type of pour and for all the pours as shown in Table 1. The productivity achieved overall is the ratio of pour size to the total duration including all delays. For labour productivity, it is the ratio between the times committed by the concrete-placement operatives to the pour size.

From Table 1, it can be observed that the mean productivity of craned pours is 11.24 m3/h for the 35 pours of 41.6m3 mean pour size. The mean productivity of beam and slab pours (15.15 m3/h) is, however, more than 3 times the mean productivity of column and wall pours (4.63 m3/h), as previously indicated. The mean productivity of 11.24 m3/h for craned pours observed in this study compares very well with those of 12.2 m3/h for 43 craned pours obtained in Hong Kong with a mean pour size of 89 m3 (Anson and Wang, 1998) and 11.3 m3/h for 10 craned pours obtained in Hong
Kong with a mean pour size of 49 m³ (Chan and Kumaraswamy, 1995).

The mean labour productivity was 4.09 wh/m³ for all pours, 2.51 wh/m³ for beam and slab pours and 6.77 wh/m³ for column and wall pours. The labour productivity of 4.09 wh/m³ for crane and skip observed in this study is, however, nearly 5 times lower than that of 0.81 wh/m³ obtained in Anson and Wang’s (1998) study of craned pours in Hong Kong buildings corroborating earlier submissions by Ameh and Odusami (2003) and Fagbenle et al. (2004) that workers’ productivity on Nigerian construction sites is very poor and much lower than that achieved in the developed world. It also confirms the observation made by Olaoluwa and Adeyemi (2009) that there is poor site management, including the improper planning and scheduling of site labour, in the concreting operations carried out in Nigeria.

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

- Type of pour, – coded ‘1’ for slab and beam and ‘2’ for column and walls
- Pour size, (m³)
- Total duration (h)
- Delay (min)
- Number of operatives
- Fractional delay
- Distance to pour location (m)
- Weather, – coded ‘1’ for fine weather, ‘2’ for cloudy weather, ‘3’ for sunny and ‘4’ for rainy weather

For the regression analysis, the in-built functions of SPSS 16.0 for windows was used because it allows one to store the data, perform transformations and analyse and produce charts and graphs of results. In this instance, a stepwise regression of productivity was run on the 8 identified variables and the regression results were examined in turn so as to determine the functional relationship among
the variables and obtain a model that will predict productivity rates for the craned concreting operations.

The regression analysis used is multiple linear regression which begins with all the explanatory variables (type of pour, pour size, fractional delay, weather and distance to pour location) in the model, and eliminates the ‘non-significant’ variables for the craned method of concrete placement (Dunlop and Smith, 2003; Tabatchnick and Fidell, 1996). The output of the regression analysis, according to Oluwadiya (2004) includes the following:

- ANOVA table which signifies the acceptability or otherwise of the regression results.
- Model summary table, which indicates the strength of the relationship between the model and the variations in the dependent variable.
- ‘Coefficients’ table which displays the values for predicting the dependent variable given the scores of the independent variables and using the ‘Unstandardised Coefficients’ as the values for the constant and the coefficients of the variables.
- Table of correlation coefficients between all pairs of the explanatory variables, including productivity, which indicates the relationships between the variables and confirms the appropriateness or otherwise of the regression coefficients above.

A set of the regression analysis and correlation coefficients matrix was computed for the set of multiple regression analysis performed to explain the effectiveness of the eight responsive parameters on productivity. The regression is of the form:

\[ \text{Productivity, } P = y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8 \]

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.
For concrete placement with cranes, the ANOVA results are shown in Table 2 where the last column of the table titled ‘Sig’ shows that the ‘Goodness of Fit’ is less than 0.05, implying that the model fits the data and the variations explained by the model are not due to chance. The summary of the ANOVA table indicates that the model is significant at the 0.000 level. This is less than the chosen confidence level of 0.05 and is therefore acceptable.

Table 3 is the coefficients table of the first run regression on actual productivity for the craned pours and displays the statistics of each explanatory variable and the significance of the ‘t’ statistics. From Table 3, all the variables, type of pour 2 (column and wall), pour size, delay, total duration, fractional delay and number of operatives were significant because their ‘Sig’ values were less than 0.05 or 5% error of estimation.
Table 2: ANOVA statistics for regression on actual productivity for craned pours – first run

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>2409.37</td>
<td>5</td>
<td>481.87</td>
<td>6.541</td>
<td>.000</td>
</tr>
<tr>
<td>Residual</td>
<td>2136.27</td>
<td>29</td>
<td>73.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4545.63</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Coefficients of regression on actual productivity for craned pours – first run

<table>
<thead>
<tr>
<th></th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>25.505</td>
<td>3.417</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typour2</td>
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<td>2.875</td>
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<tr>
<td>Pour Size (m³)</td>
<td>.166</td>
<td>.037</td>
<td>1.001</td>
<td>4.473</td>
</tr>
<tr>
<td>Delay (min)</td>
<td>.138</td>
<td>.057</td>
<td>.812</td>
<td>2.401</td>
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<tr>
<td>Total duration (h)</td>
<td>-3.524</td>
<td>.940</td>
<td>-.1109</td>
<td>-3.750</td>
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<tr>
<td>Fract delay</td>
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<td>-3.823</td>
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<tr>
<td>Number of operatives</td>
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<td>.121</td>
<td>-.419</td>
<td>-2.171</td>
</tr>
<tr>
<td>Distance of pour location (m)</td>
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<td>.068</td>
<td>-.025</td>
<td>-.209</td>
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<tr>
<td>Weather</td>
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<td>5.556</td>
<td>.045</td>
<td>.394</td>
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</table>
### Table 4: Correlation coefficients between all pairs of variables for craned pours – first run

<table>
<thead>
<tr>
<th></th>
<th>Productivity (m³/h)</th>
<th>Pour type 1</th>
<th>Pour type 2</th>
<th>Pour size (m³)</th>
<th>Delay (min)</th>
<th>Total duration (h)</th>
<th>Fract. delay</th>
<th>No. of operatives</th>
<th>Dist. to pour location (m)</th>
<th>Weather 1</th>
<th>Weather 2</th>
<th>Weather 3</th>
<th>Weather 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity (m³/h)</td>
<td>1.000</td>
<td>.446</td>
<td>-.446</td>
<td>.433</td>
<td>-.109</td>
<td>.021</td>
<td>-.452</td>
<td>.190</td>
<td>.081</td>
<td>-.238</td>
<td></td>
<td></td>
<td>.238</td>
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<tr>
<td>Pour type 1</td>
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<td>-1.000</td>
<td>.348</td>
<td>.110</td>
<td>.215</td>
<td>.038</td>
<td>.192</td>
<td>.286</td>
<td>-.189</td>
<td></td>
<td></td>
<td>.189</td>
</tr>
<tr>
<td>Pour type 2</td>
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<td>-.110</td>
<td>-.215</td>
<td>-.038</td>
<td>-.192</td>
<td>-.286</td>
<td>.189</td>
<td></td>
<td></td>
<td>-.189</td>
</tr>
<tr>
<td>Pour size (m³)</td>
<td>.433</td>
<td>.348</td>
<td>-.348</td>
<td>1.000</td>
<td>.625</td>
<td>.790</td>
<td>.004</td>
<td>.764</td>
<td>.058</td>
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<td></td>
<td>.039</td>
</tr>
<tr>
<td>Delay (min)</td>
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<td>.110</td>
<td>-.110</td>
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<td>1.000</td>
<td>.847</td>
<td>.547</td>
<td>.635</td>
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<td>.183</td>
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<td></td>
<td>-.183</td>
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<tr>
<td>Total duration (h)</td>
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<td>-.215</td>
<td>.790</td>
<td>.847</td>
<td>1.000</td>
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<td>.667</td>
<td>.086</td>
<td>.066</td>
<td></td>
<td></td>
<td>-.066</td>
</tr>
<tr>
<td>Fract. delay</td>
<td>-.452</td>
<td>.038</td>
<td>-.038</td>
<td>.004</td>
<td>.547</td>
<td>.205</td>
<td>1.000</td>
<td>-.004</td>
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<td>.241</td>
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<td>-.241</td>
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<tr>
<td>No. of operatives</td>
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<td>.192</td>
<td>-.192</td>
<td>.764</td>
<td>.635</td>
<td>.667</td>
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<td>.013</td>
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<td>-.013</td>
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<tr>
<td>Distance to pour location (m)</td>
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<td>.286</td>
<td>-.286</td>
<td>.058</td>
<td>-.069</td>
<td>.086</td>
<td>-.199</td>
<td>.117</td>
<td>1.000</td>
<td>-.280</td>
<td>.280</td>
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<td>weath1</td>
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<td>.189</td>
<td>-.039</td>
<td>.183</td>
<td>.066</td>
<td>.241</td>
<td>.013</td>
<td>-.280</td>
<td>1.000</td>
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<td></td>
<td>-.1000</td>
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<td>weath2</td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>weath3</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
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<tr>
<td>weath4</td>
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<td>-.189</td>
<td>.039</td>
<td>-.183</td>
<td>-.066</td>
<td>-.241</td>
<td>-.013</td>
<td>.280</td>
<td>-1.000</td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
</tbody>
</table>
Table 4 displays the correlation coefficients between the pairs of variables for the first-run stepwise regression on productivity for craned pours and shows how their separate effects on the response variable can be determined. Since the objective is to determine the factors influencing productivity significantly, emphasis was placed on identifying the variables that are highly correlated with productivity. A glance at Table 4 shows that only the correlation coefficients (positive or negative) of each of type of pour (1 and 2), pour size, and fractional delay were high enough (i.e. above 0.250) to be considered to have significant relationships with productivity. It was therefore necessary to carry out further runs of regression, while eliminating the insignificant variables, i.e. delay, total duration, number of operatives, weather and distance to pour location in a stepwise analysis until a final run in which all the variables that were left have ‘Sig’ values less than 0.05 and were thus significantly correlated with productivity. The resulting ANOVA statistics, coefficients of regression and correlation tables are shown, respectively, in Tables 5, 6 and 7.

The F-ratio for the final-run regression on productivity for craned pours shown in Table 5 is 10.516, which is higher than the critical F-ratio of 2.92 at a significance level of 0.5%, F (0.05, 3, 31).

Table 6 shows the coefficients and t-statistics for the final run and indicates that the final run regression equation model is:

\[
\text{Productivity} = 17.43 - 8.39(\text{pour type 2}) + 0.05(\text{pour size}) - 27.41(\text{fractional delay}) \text{ ----Equation (1)}
\]

This equation shows the key determinants of productivity, \(y\), for craned pours as type of pour 2 (column and wall) at the 0.013 level of significance, pour size at the 0.028 level of significance, and fractional delay at 0.001 level of significance, indicating that the fractional delay at the 0.001 level of significance is the most significant of these factors.

The ‘Beta’ column of Table 6 which contains the standardised coefficients confirms that fractional delay with a Beta value of -0.467 is the most powerful predictor of productivity, followed by column and wall type of pour with a score of -0.356 and lastly by pour size with a score of +0.311.
Table 5: ANOVA statistics for regression on actual productivity for craned pours - final run

<table>
<thead>
<tr>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>2292.72</td>
<td>3</td>
<td>764.241</td>
<td>10.516</td>
</tr>
<tr>
<td>Residual</td>
<td>2252.91</td>
<td>31</td>
<td>72.675</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4545.63</td>
<td>34</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Coefficients of regression on actual productivity for craned pours - final run

<table>
<thead>
<tr>
<th>Unstandardised coefficients</th>
<th>Standardised Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Std. error</td>
<td>Beta</td>
<td>-</td>
</tr>
<tr>
<td>(Constant)</td>
<td>17.425</td>
<td>2.694</td>
<td>6.468</td>
</tr>
<tr>
<td>Fract. Delay</td>
<td>-27.410</td>
<td>7.426</td>
<td>-.467</td>
</tr>
<tr>
<td>Pour type 2</td>
<td>-8.391</td>
<td>3.183</td>
<td>-.356</td>
</tr>
<tr>
<td>Pour size (m$^3$)</td>
<td>.052</td>
<td>.022</td>
<td>.311</td>
</tr>
</tbody>
</table>
Table 7: Correlation coefficients between all pairs of variables for craned pours - final run

<table>
<thead>
<tr>
<th>Overall productivity (m³/h)</th>
<th>Pour type 1</th>
<th>Pour type 2</th>
<th>Pour size (m³)</th>
<th>Fract. delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Productivity (m³/h)</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pour type 1</td>
<td>.446</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pour type 2</td>
<td>-.446</td>
<td>-1.000</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Pour size (m³)</td>
<td>.433</td>
<td>.348</td>
<td>-.348</td>
<td>1.000</td>
</tr>
<tr>
<td>Fract. delay</td>
<td>-.452</td>
<td>.038</td>
<td>-.038</td>
<td>.004</td>
</tr>
</tbody>
</table>

**Effect of delay on productivity of craned pours**

From the coefficients in Equation (1) and Tables 5, 6 and 7, it is thus obvious that although fractional delay is not the only independent variable that is statistically significant in predicting concreting productivity for craned pours, it is the most significant determinant. Consequently, the relationship between concreting productivity and fractional delay is examined for further regression analyses to generate a scatter diagram from which a model relating productivity to fractional delay can be developed assuming a closed system with pour size and type of pour held constant (Wang, 1999).

Figure 1 is a scatter plot of concrete-placement speed or concreting productivity achieved against delay in the concreting operations expressed as a decimal fraction of the concrete pour duration for the 35 pours placed by crane and skip. Although there is a lot of scatter, the regression line averaged a linear relationship as shown by the plots that are equally clustered close to either side of the straight line except for cases 24 and 25 that are clear outliers.
Fractional delay

Figure 1: Plot of productivity against delay as a fraction of poor duration for craned pours

Table 8 shows the Pearson correlation coefficient between fractional delay and productivity, to be – 0.452 as in Table 7 when all the pairs of significant variables were correlated together. The linear regression modelled by the line can also be viewed from the regression coefficients in Table 9 based on Figure 1 where the model becomes:

Productivity = 16.3 – 26.5 fractional delay  

Equation (2)
A look at Table 9 shows that although the constants differ, both the unstandardised and standardised coefficients as well as the ‘t’ and ‘Sig.’ values for fractional delay are practically the same confirming that the removal of the other variables type of pour and pour size from the regression analysis has not significantly affected the statistical relationship between fractional delay and productivity. The significance from Table 9 is also 0.006, proving again that the correlation is significant at the 0.01 level or 99% degree of confidence. This derived model represented by Equation (2) implies that the productivity drops significantly with a delay in the supply, delivery, and mixing of materials for in situ concrete placement by cranes. Specifically, for every 10% increase in fractional delay, the concreting productivity reduces by 2.65 m$^3$/h for craned concreting based on the results obtained from the 35 pours observed.

This model is practically comparable to the model $R = 12.8 - 4.9T$ obtained by Anson and Wang (1998) for craned pours in Hong Kong buildings where $R = $ placing speed, (m$^3$/h) and $T =$ delay time spent waiting for truck mixer arrival, as percentage of pour time.

The reduction in the productivity of pours placed by cranes per 10% of increased delay observed in this study is, however, greater than 5 times the reduction obtained in the Hong Kong study, and shows that delay has a greater effect on the productivity of concrete placed by crane in Nigeria.

On the other hand, the models indicate that the productivity or placing speed when there are no delays is 16.3 m$^3$/h in Nigeria as compared to 12.8 m$^3$/h in Hong Kong implying that there is greater prospect for higher craned concreting productivity in Nigeria if delays can be eliminated.

Table 8: Correlation coefficients between productivity and fractional delay for craned pours

<table>
<thead>
<tr>
<th></th>
<th>Overall productivity</th>
<th>Fract. delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall productivity</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Fract. delay</td>
<td>-0.452</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Table 9: Regression coefficients of productivity on fractional delay for craned pours

<table>
<thead>
<tr>
<th>Unstandardised coefficients</th>
<th>Standardised coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Std. error</td>
</tr>
<tr>
<td>(Constant)</td>
<td>16.287</td>
</tr>
<tr>
<td>Fract. delay</td>
<td>-26.541</td>
</tr>
</tbody>
</table>

CONCLUSION

A key factor that was found to influence the concreting productivity of cranes significantly is the timely supply and delivery of concrete for placement (i.e. supply with little or no delay). The results of the multiple linear regression analysis undertaken to obtain a model for predicting productivity, \( P \), from values of fractional delay, \( FD \) (which is the delay time expressed as a fraction of the pour duration), shows statistically significant results for craned pours as represented by:

\[
P = 16.3 - 26.5FD
\]  

-Equation (3)

This model is comparable to the model \( R = 12.8 - 4.9T \) obtained by Anson and Wang (1998) for craned pours in Hong Kong buildings, where:

\[
R = \text{placement speed, (m}^3/\text{h)}
\]

\[
T = \text{delay time spent waiting for truck mixer arrival, as % of pour time, and}
\]

indicates, mathematically, how productivity falls with increased delay times.

From the model, the productivity for pours placed by cranes reduces by over 2.5 m\(^3\)/h for every 10% increase in time delay, which is over 5 times the reduction obtained in Anson and Wang’s (1998) study of Hong Kong buildings for the same percentage increase in delay. This shows that, although
the mean productivity of craned pours observed in this study compares very well with that obtained in the Hong Kong study, time delay has a far greater impact on the productivity of concrete placed by cranes in Nigeria than in Hong Kong.

From Table 1, an average delay of over 23% of the total pour duration was observed in all craned, *in situ*, site-mixed pours in this study as compared to 8.1% obtained by Wang et al. (2001) for site delays, i.e. for delays outside those caused by truck mixers being idle as well as delays encountered while waiting for the truck mixer to supply ready-mix concrete to craned concrete-placement sites in Singapore. A comparison of the two models above also indicates that the maximum productivity for craned concreting in Nigeria (when there are no delays) is 16 m³/h or almost 30% higher than the maximum productivity for craned concreting in Hong Kong (12.8 m³/h), confirming that there is an excellent prospect for high concreting productivity by cranes in Nigeria if delays can be mitigated.

The variance between the maximum and mean productivities in this study (5.06 m³/h) is, however, nearly 850% of that in the Hong Kong study (0.6 m³/h) indicating that there is a much higher, marked non-uniformity in the productivities observed on Nigerian sites due to excessive delays on these sites.

This study has demonstrated that delay is a most significant factor that needs to be greatly reduced before Nigeria can enjoy the benefits of high productivity attributable to concrete placement by cranes. The study has also shown that special, concerted efforts need to be made to forestall or reduce delay in craned concrete pours in Nigeria to sustain productivity. Particular strategies and appropriate measures which may be adopted to avoid or mitigate delays must be focused on the significant factors and contributors to delays such as poor site management, plant breakdowns and idleness of plant and labour.

**RECOMMENDATIONS**

Since most of the observed delays are materials, labour and equipment-related, as well as the interactions between these factors due to poor co-ordination, improper planning and lack of control of site activities, professionals in the Nigerian construction industry, especially contractors’
management staff members are advised to focus attention on these site-management conditions in their concreting operations. Furthermore, to make the research relevant to the construction practitioners and researchers, the model relating productivity to fractional delay may be standardised for use in improving productivity on Nigerian construction sites and for advice by professional bodies to site managers and practitioners.

REFERENCES


