REDUCING VARIABILITY IN CONCRETE ACTIVITY LABOUR PRODUCTIVITY TO IMPROVE LABOUR PERFORMANCE

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The management of daily labour productivity variability on site is an important aspect of construction management thinking. The lean technique suggests that reducing variability gives better labour performance. Therefore this paper examines the analysis of labour productivity data of concrete activity from sixty one construction sites of single storey buildings in Abuja metropolis. The objective was to determine the relationship between labour productivity variability and labour performance in concrete activity. The data used were collected from sixty one live projects within the study area. The daily method of data collection was adopted in this research. A total of 778 data points were observed for all concrete activities from these sites. The analysis of the performance index that is Project Waste index (PWI) revealed that some the projects studied were poorly managed because the projects had low productivity rating. While some other projects performed well. The PWI values computed for the project studied ranged from 0.12 to 0.67. It was observed that low outputs were accomplished with high labour inputs. The values for coefficient of variation in labour productivity range from 0.09 to 0.48. These values and the performance indexes calculated for all projects were tested for correlation analysis. The coefficient of correlation for the two variables was found to be 0.601**, which is significant at 0.01 confidence level. The result showed that the variability in daily labour productivity is more highly correlated to project performance than workflow output variability which means that reducing variability in labour productivity appears to have a significant effect on performance. Also the performance gap value for concrete work was found to be 3.62 man hrs/m^3. It was recommended that the site managers should determine to get more output with a reduction in input.

Key Words; variability, labour, management, performance, productivity, input, output.

INTRODUCTION:

Labour productivity has been identified as an index for measuring efficiency because labour is acknowledged as the most important factor of production since it is one of the major factors that creates value and sets the general level of productivity (Ameh and Odusami, 2002). Enshassi, Mohammed, Mustafa and Mayer (2007) identified labour productivity as the key factor contributing to the inability of many indigenous construction contractors to achieve their project goals which include most importantly, the profit margin amongst others. They suggested the need to investigate and

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understand the key variables of labour productivity and to keep accurate records of productivity levels across projects.

Andersen and Petterson (1995) suggested the application of benchmarking technique to accelerate change in attitude and behaviour in an organisation. In view of the fact that it is a mechanism for "improvement and change", it will further help an organisation to search for industry best practices that will bring about superior performance by examining the performance and practices of other firms. Therefore to complement government efforts to promote and develop building industry (Olugboyega, 1995 and Olugboyega, 1998) there is the need to investigate variability in terms of output and input resources for indigenous building firms in Nigeria with a view to increasing performance. In literature the application of modern production concept like reducing variability to increase labour performance in the local industry in Nigeria is very sparse. In this research work, with the application the lean technique concept, labour productivity data was obtained from concrete activity on a number of projects sites to test relationships between output variability and performance.

Therefore this paper covers review of related works, method of data collection, determination of research variables, analysis of data and discussion, research findings and conclusion.

Review of Literature

A survey of the literature revealed several primary contributions to the theory and practice of lean production principles. Some of the research works provided support for this study. In construction the application of lean production model stems from the discussion of koskela's research work (1992), which emphasized the importance of the production processes flow, as well as aspects related to converting inputs into finished products as an important element to the creation of value over the life of the project. Many other researchers (Ballard and Howell, 1998; Alarcon and Calderon 2003; Bertelsen 2004; Salem *et al.*, 2005) have expanded this concept and provided evidence of it applicability in the construction industry. The pioneering work of koskela opened up streams of researches into lean construction principles. The core lean concepts were identified and translated from the manufacturing production management into construction language (Shingo 1984; Koskela 1992, 1993; Ballard and Howell 1994a). To operate these core concepts in the construction industry a new set of management techniques were developed (Paez *el al.*, 2005). The last planner system of production control was introduced in 1992 but developed by Ballard, and Howell (Ballard and 1994b). In the application of these tools, previous researches revealed substantial improvement in productivity for those who improved plan reliability to the 70% level, Howell and Ballard (1994) in their study on the last planner technique showed that the use of formal and flexible production planning procedures is the first step to keep the production environment stable. The technique emphasizes the use of daily production plans, constrains analyses, Lock ahead and percentage of planned and completed items. Thomas *et al.* (2002) asserted that, with the last planning technique, the percentage of planned tasks (PPC) is measured to show changes in planning reliability. However, they argued the extent to which a larger PPC improves project performance. According to them, there is limited evidence showing that productivity performance for crews with a PPC above 50% is 35% better than that of crews with a PPC below 50%. This remains unclear. Also while these techniques have proven useful, El Mashaleh *et al.*, 2001 believed that their application has no methodology that could relate the activity and project level accomplishment to firm's accomplishment.

Abdel – Razek *et al.* (2007) suggested that better labour and cost performance can be achieved by reducing variability and measuring benchmarking. However, all the previous studies on benchmarking were done on non homogenous projects (Thomas and Zavrski 1999; Abdel – Razek *et al.*, 2007; Enshassi *et al.*, 2007). Thomas and Zavrski (1999a),1999b) developed the framework for international labour productivity benchmarks of selected construction activities.

The application of these benchmarks can lead to evaluating the labour productivity and identifying the best and worst performing projects. Therefore, from these series of inferences it could be said that the exploration of improving construction labour performance in Nigeria by applying some lean construction principles, namely benchmarking and reducing variability is a possibility.

RESEARCH METHODS

Collection of Data

The data collection for on-site productivity study was conducted on concrete building activity. The research procedures involved the engagement of ten research assistants, who were trained on how to observe the workmen and record observations in terms of input and output. Data collection covers concreting work in 61 live projects from building contractors within the study area (Abuja). Daily visit method of observation of labour productivity was adopted. This involved personal observation of labour activities on the selected work on live projects. The strategy here was to visit the site daily and interact with the foreman and workers in order to record the dates, number of workers, starting time, closing time and measurement of length/breadth of work done (quantities) of each worker. Entries were made on research instrument collection sheet designed for this purpose. The figures collected were analysed using lean benchmarking approach of calculating performance using Thomas *et al* (1990) mathematical model.

Determination of Research Variables

Thomas and Zavrski (1999a), 1999b) expressed the projects attributes in the following forms.

$$\textit{Total work hours} = \sum \textit{Daily work hours} \qquad (1.1)$$

$$\textit{Total quantities} = \sum \textit{Daily quantities} \qquad (1.2)$$

$$\textit{Cumulative Productivity} = \frac{\textit{Total work done (wh)}}{\textit{Total quantity } (m^2)} \qquad (1.3)$$

Baseline Productivity: This is defined as the paramount performance a contractor can get from a particular model or design. To compute the baseline productivity values certain laid down steps were applied to the daily productivity figures for each project (Abel Hamid *et al.*, 2004 and Enshassi *et al.*, 2007).

Establish the figures for workdays that consist 10% of the workdays studied.

The number established in one above should be rounded off to the next highest odd number which should not be less than (5) five. This number, n, explains the size of the baseline division.

The contents of the baseline division are the n workdays that have the highest daily production or output.

The next step is to compute the summation of the work hours and quantities for these n workdays

The baseline productivity can now be expressed as the ratio of work hours and the quantities contained in the baseline division.

Project Management index (PMI) or Project Waste Index (PWI) According to Abdel-Hamid

et al. (2004); Thomas and Zavrski, (1999a), 1999b) it is expressed as follows:

$$\textit{Project Waste Index (PWI)} = \frac{\textit{Cumulative Productivity} - \textit{Baseline Productivity}}{\textit{Expected Baseline Productivity}} \quad (1.4)$$

Project Waste Index (PWI) has been identified in previous studies as a useful tool to measure performance (Thomas and Zavrski 1998, 1999).

$$\textit{Coefficient of productivity variation } (CPV)_j = \frac{PV_j \times 100}{(\textit{Baseline Productivity}_j)} \quad (1.5)$$

Where CPV_j = coefficient of productivity variation for $project_j$. Alternatively it can be computed as a ratio of the standard deviation to the mean.

Population of the Study and Sampling Technique

The population of the study was drawn from contractors handling building projects in the study area. The builders were involved in different types of construction activities such as mass housing projects of bungalow category, storey building housing projects and infrastructures. In order to meet the objectives of the study, the research samples were drawn from contractors constructing single storey buildings for the purpose of homogeneity. The research team was able to collect data from sixty one (61) construction sites, randomly drawn from the available list of builders. A total of 778 data points were obtained for all concrete activities from these sites. At the time of data gathering, it was observed that most of the firms were executing projects at various levels of completion.

Data Analysis and Evaluation was conducted using the following statistical tools;

1. Descriptive Statistics
2. Inferential Statistics

Box and Whisker analysis

Regression analysis

Mathematical Model by Thomas *et al* (1990; 1991)

Conversion Factor for Concrete Elements

There are certain factors that affect concrete work on site in terms of transporting, placing and compacting. This means that productivity rates for each concrete element will differ from one another depending on where the concrete element is located in the structure. Also methods employed in the construction process, such as method of placing, transporting and compacting concrete will affect the labour output. Therefore, the assumption here is that the methods are same for all studied projects. The pre-determined standard unit is established using statistical median. Based on this assumption the labour outputs for transporting, placing and compacting concrete for all concrete elements per one labourer expressed in man hours over output were obtained as follows for foundations, concrete beds, suspended slabs, columns, beams, walls and staircases as 3.50, 4.00, 7.50, 13.50, 13.50, 13.50 and 15.5man-hrs/m^3 respectively. The corresponding conversion factors are 0.259, 0.296, 0.556, 1.00, 1.00, 1.00 and 1.148 for foundations, concrete beds, suspended slabs, columns, beams, walls and staircases respectively (Ross *et al.*, 2007).

ANALYSIS AND DISCUSSION OF RESULTS

Concreting: The concrete work labour productivity data was tested for normality and was found to be slightly normally distributed for concrete. The normal probability plot for the labour productivity data for concrete activity is shown in figure 1, with slight deviation from the straight line of fit. A sample size of 353 was computed to be adequate but a data set of 778 was used for the study. The purpose for large data set gathering was for improvement of results. The mean of the sample was found to be 13.326 whr /m^3 and the median was determined to be 13.807 whr /m^3. It was observed that the mean of the estimate was less than the median. This

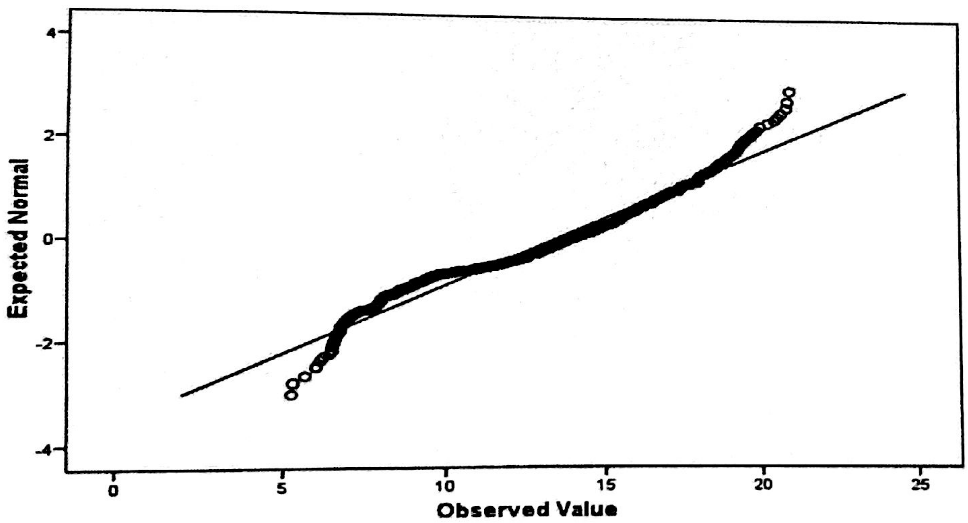

Fig 1. Line of Fit Probability Plot of Labour Productivity Data for Concrete Activity

indicates that the frequency distribution is not symmetrical. Also observation of the line of fit graph for concrete work in figure 1 does not show any clear fit to the normal distribution. It is a skewed distribution as shown in figure 2. Also the distribution is negatively skewed having a skewness value of - 0.247 and standard deviation of 3.776.

The distribution of the sample variable was assumed to be slightly normally distributed. The measure of variability was determined from the normal probability statistics computed. The range was found to be 15.71 which is the difference between the highest and the lowest scores in the distribution. The average coefficient of variation for all the projects which is a function of the standard deviation and the mean was calculated as 28.26%.

The labour productivity values calculated or synthesized from the raw data were used to compute the cumulative productivity. Which is the overall attempt required to accomplish a concrete task. This is a key element in assessing crew performance from project management index perspective. Statistical analysis of data showed that the mean and standard deviation of cumulative productivity were found to be 13.326 whr / m^3 and of 3.776 respectively.

Figure 2. Normal Distribution Curve of Labour Productivity Data for Concreting Trade

Box and Whisker's Test

The productivity data were tested for any extreme outliers. The box and whiskers technique was adopted to examine the level of possible extreme outliers present in the data. Extreme outliers were found and dealt with which made the data for the concrete site activities to be free from extreme outliers. Figure 3 shows the box and whisker's plot for concrete work. A graphical observation of the plot for concrete activity points out that the line of symmetry in the box was tilted towards the upper arm. This reveals that the data were not symmetrical hence the skewness. The plot shows that the concrete work data set was negatively skewed to the left. The large range value would have been responsible for the negative skewness.

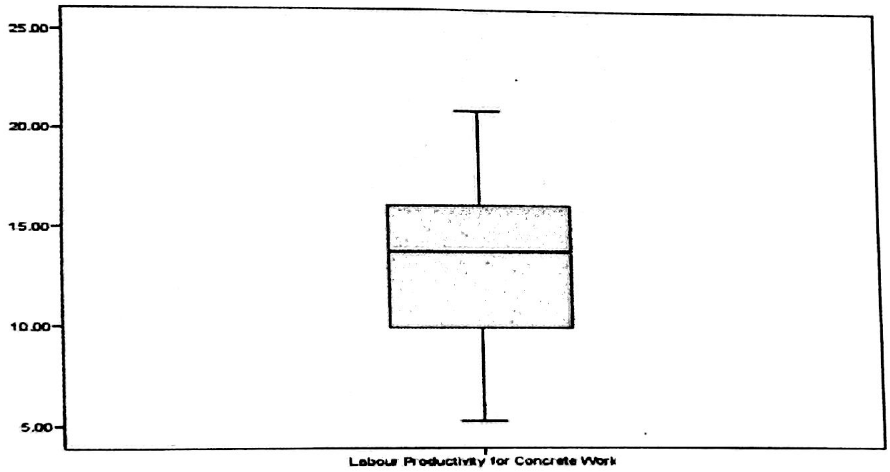

Fig 3. Box and Whisker's Test for Concrete Activity Labour Productivity Data.

VARIABILITY IN DAILY LABOUR PRODUCTIVITY FOR THE SELECTED SITE CONCRETE ACTIVITY

Concreting activity: Figure 4 shows the variability in daily labour productivity of concrete task for project 28. The variability computation was done for each of the projects examined. It was determined from input and output relationship. The computed values of coefficient of variation for concreting activity range from 0.09 to 0.48. These values are the products of the standard deviation divided by the mean of the estimate.

The instrument used illustrates the days observed for concreting activity, the gang size, work hours, daily quantity, daily labour productivity, baseline days and abnormal days. The concreting task observed in the project was done for twenty days. The total team size employed to construct 203 metre cube of concrete work was 327 work men with a total work hours of 2818hrs. This indicates that the construction firm used one site worker to achieve approximately 0.621m^3 of concrete. The daily productivities ranged from 6.838 to 19.200whr/m^3. The concrete work has a cumulative productivity of 10.33whr/m^3.This indicates that labour input was fairly normal since this cumulative productivity is less than unity. The following days 7, 8, 10, 12, and 13 were identified as baseline days for concreting task. These are the highest productivity scores that were considered to define the baseline subset and the average of these five figures (6.897, 6.838, 7.742, 8.496 and 7.176whr/m^3) represents the baseline productivity or benchmark for the project which is calculated to be 7.430whr/m^3. The concrete task witnessed no abnormal days.

The project waste index which provides a measure of labour performance was found to be 0.666 which is the worst pwi of all projects investigated. This index facilitates the comparison of labour performance to a baseline criterion. The higher the pwi figure the poorer the labour performance. An examination of figure 4 showed some level of gap between daily labour productivities and the baseline productivity which was found to be 36.50% coefficient of variation. This level of variation shows some level of opportunity for improving labour performance. The wider the values of daily labour productivity are from the baseline productivity the poorer the labour performance. Project 60 in figure 5 for concreting activity shows a better performance with daily productivity closer to the baseline productivity value. The baseline productivity for the project was computed to be 13.113whr/m3. Also it was observed that the gap between the daily productivities and the baseline productivity provided a coefficient of variation of 9.2% which produced a better labour performance (pwi) index of 0.160 compared to 0.666 obtained for project 28. To achieve greater performance, the same output is maintained with fewer inputs to reduce output variability. This supports the theory that states reducing variability in labour productivity improves labour performance on site.

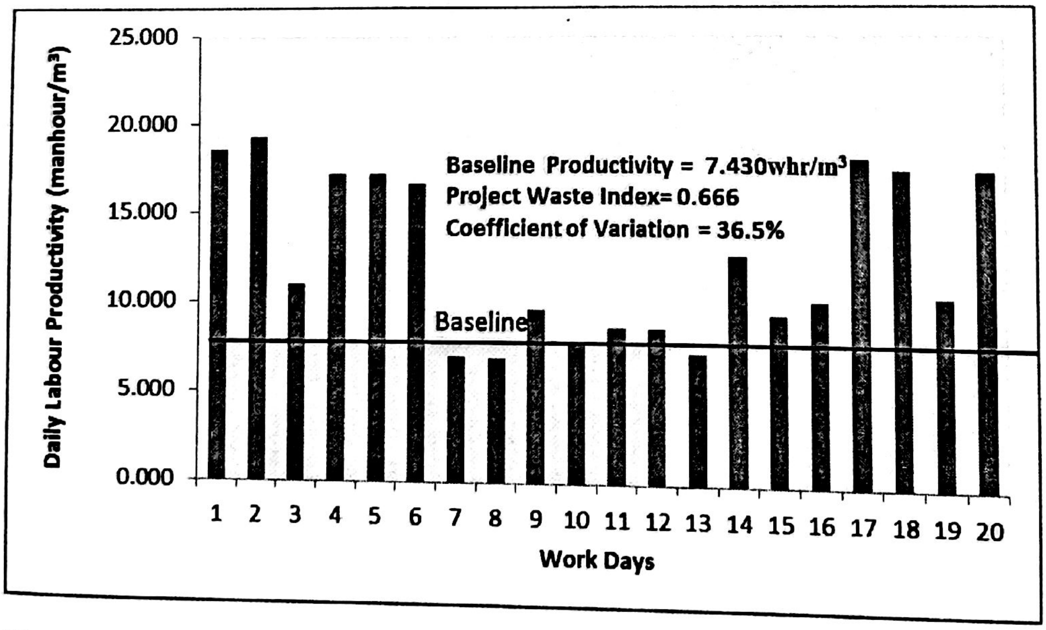

Figure 4. Variation in Daily Labour Productivity for Project 28 Concrete work with the Worst Project Waste Index Value

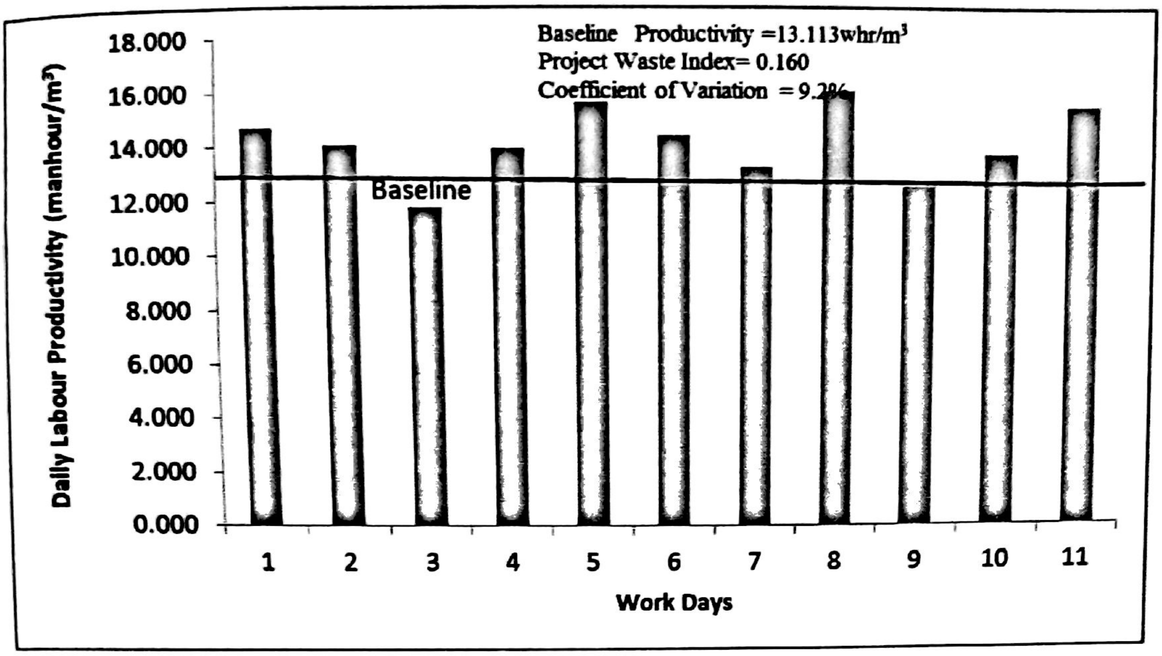

Figure 5. Variation in Daily Labour Productivity for Project 60 Concrete work with the Least Project Waste Index Value

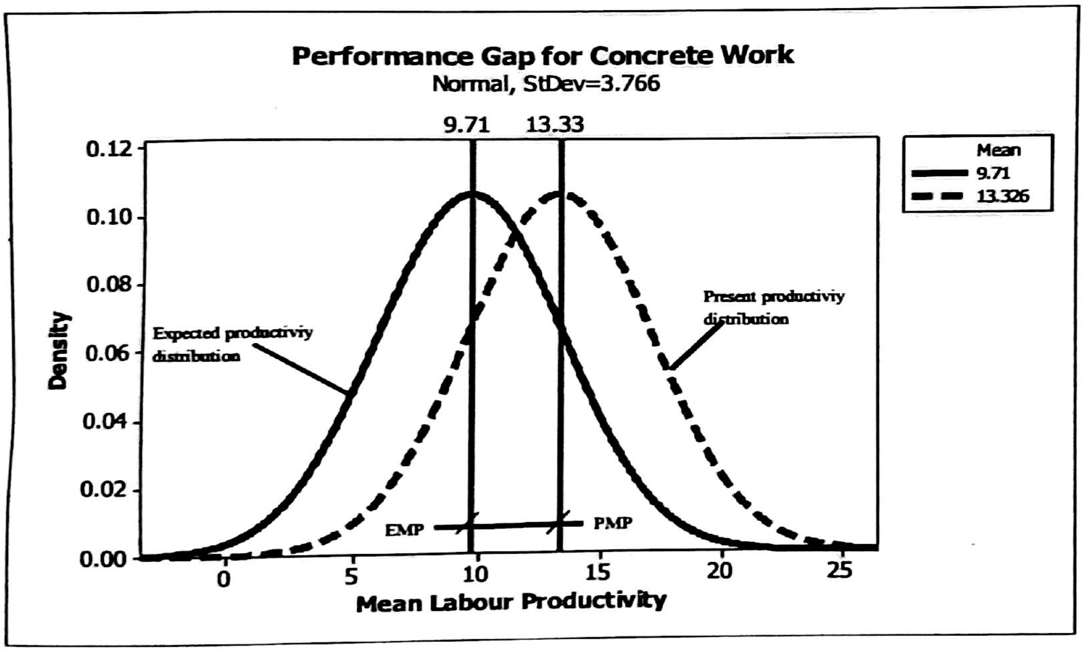

Fig 6. Performance Gap for Concrete Site Works.

Performance Improvement Gap in Labour Productivity

The target performance improvement gap of the site activity under examination in this study is shown in figures 6 for block laying activity. The distributions define the productivity variability which provides opportunity for improvement.

The performance gap, which is as a result of variability is assessed or quantified by determining the different between expected mean productivity (EMP) (which is the mean baseline productivity) and present mean productivity (PMP). The wider the gap between PMP and EMP, the bigger the opportunity for labour performance improvement.

The performance improvement gap value for concrete work was found to be 3.62 man hrs/m^3. The process performance improvement can be achieved by adjusting the group of variables that mainly influence the performance indicator. Therefore reducing this performance gap value could mean a significant improvement in performance, profit and productivity for builders and contractors.

THE RELATIONSHIP BETWEEN COEFFICIENT OF VARIABILITY AND PERFORMANCE (PWI)

Construction Output

The values of coefficient of variation for construction output are shown in appendix 1. These values and that of performance (PWI) were tested for any significant relationship. The correlation between the two variables was computed as -0.229 which was not significant. The implication of this analysis with this coefficient of variation is that the variability in daily construction output has no correlation relationship with the project performance. Therefore the correlation coefficient obtained from this analysis confirms the earlier study that daily construction output and performance have minimal or no relationship. Furthermore, it appears from the test result that reducing variability in production output in order to improve performance has an insignificant or no effect on performance.

Labour Productivity

The figures calculated for coefficient of variation for labour productivity are shown in appendix 1. The values for coefficient of variation in labour productivity range from 0.09 to 0.48. These values and the performance indexes calculated for all projects were tested for correlation analysis. The coefficient of correlation for the two variables was found to be 0.601**, which is significant at 0.01 confidence level. The inference from this test result is that the variability in daily labour productivity is more highly correlated to project performance than

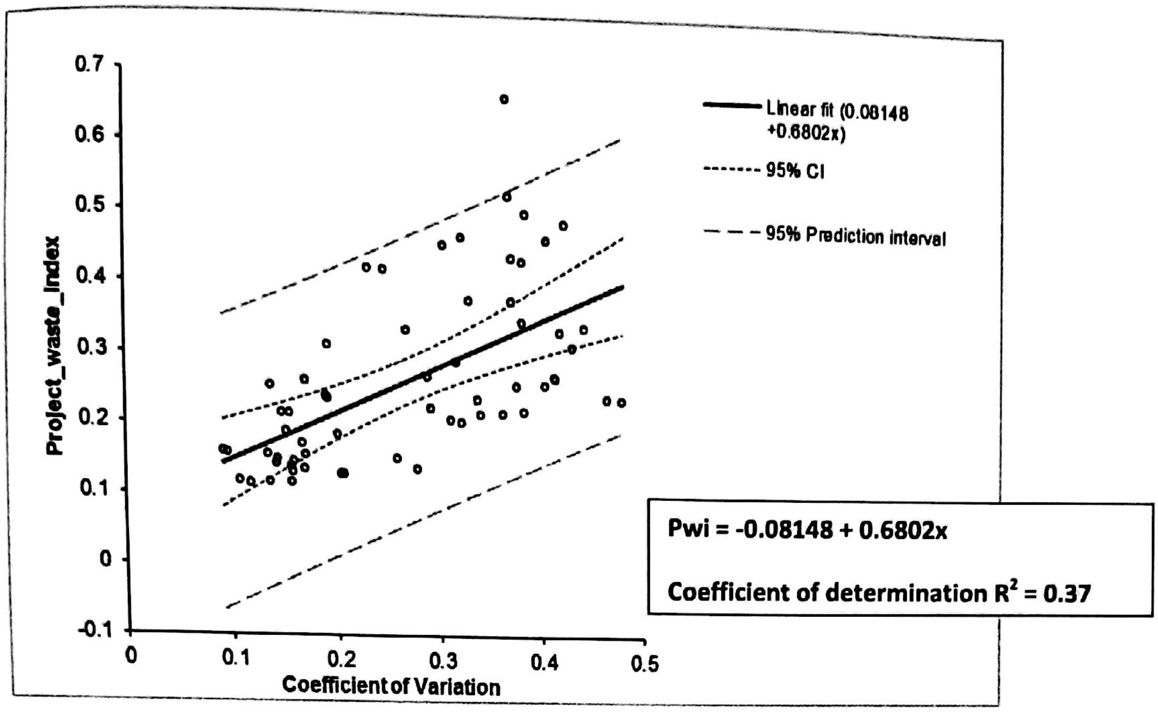

Figure 7. Linear Model for Concreting Activity Performance

construction output earlier determined. In addition, the result of the analysis shows that reducing variability in labour productivity appears to have a significant effect on performance. Linear regression analysis of the two variables showed a coefficient of determination for a linear relationship of about 0.37 which means that 37% variation in crew performance is accounted for by variability in labour productivity.

The linear equation is

Pwi = 0.08424 + 0.9732x (1.6)

The equation has a model probability value (P-value) = 0.02

From the linear model shown in figure 7 it has an intercept of 0.08148 and for every increase of one unit of variability in labour productivity there is an increase of about 0.6802 in performance.

Polynomial regression analysis was carried out to ascertain the best predictive curve fit for the model, it was found out that the second order polynomial gave an improved coefficient of determination R2 of 0.40 with an equation model

Pwi = -0.081 + 2.096x – 2.578x2 (1.7)

The equation has a model probability value (P-value) = 0.001

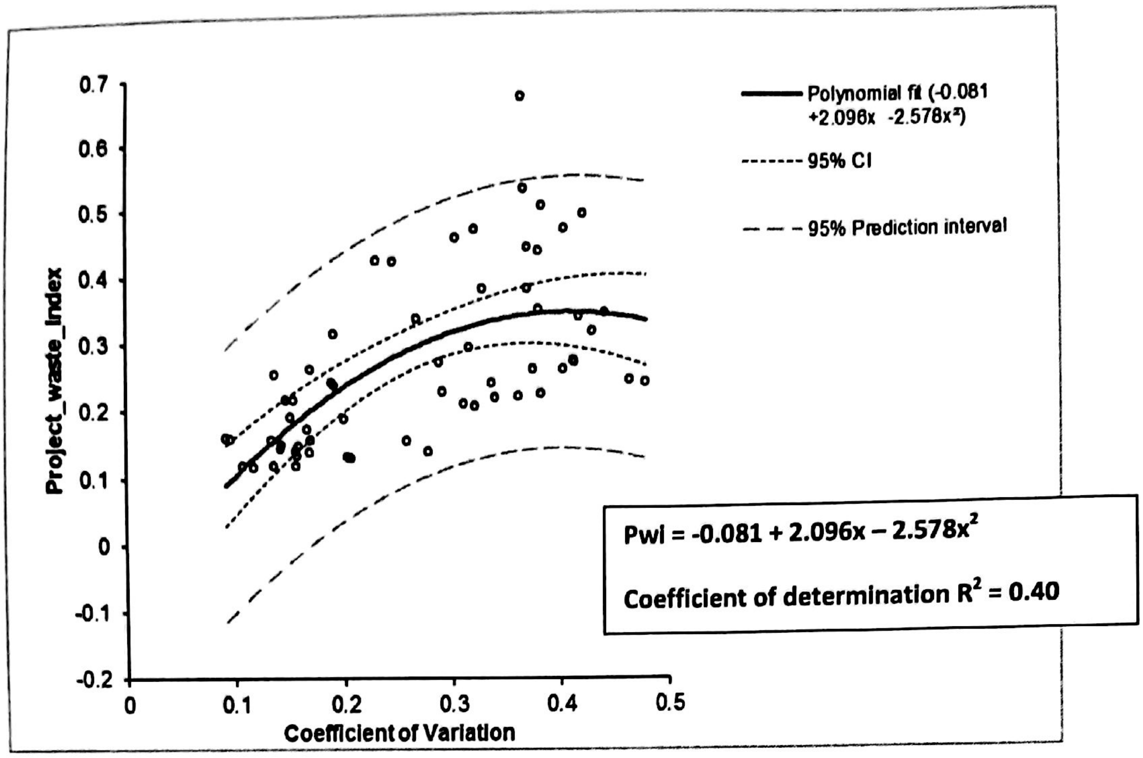

Figure 8. Best Curve Fit Polynomial Model for Concreting Activity Performance

From the equation model in figure 8, the intercept on Y axis is **-0.081** and for every increase of one unit of variability in labour productivity there is an increase of about **2.096** in Performance. But it was observed that for every unit increase in variability in labour productivity raised to the power of two, there is a decrease of about – **2.578** in Performance. The model revealed that most of the data points fell within the 95% prediction interval point.

FINDINGS

(1) Correlation between project waste index (performance) and coefficient of variability for construction output for concrete work = 0.229

(2) Correlation results show that there are strong associations between project waste index (performance) and coefficient of variability for labour productivity of concrete work = 0.601**

(3) It was found that 40% variation in crew performance in concrete activity is accounted for

by variability in labour productivity.

(4) The effect of labour productivity variability alone on performance was observed to be greater than the combined effects of construction outputs and labour productivity variability on performance for the activity under consideration.

(5) Labour productivity gap of 3.62 man hrs/m^3 was observed for concreting.

CONCLUSION

This research work investigated the effects of workflow variability and labour productivity variability on the job site performance. Using productivity data from concreting activities on multiple projects, various parameters of output variability were tested against construction performance. The labour workflow productivity data analyzed were found to be slightly skewed. Data from concrete work was skewed negatively perhaps due to large range of values encountered from the data. All values of skewness were greater than zero but less than one. This showed the level of reliability of data used in the analysis.

The correlation relationship between work flow variability and performance was found to be low for concrete activities. Similarly, the correlation between labour productivity and performance was discovered to be highly significant for the studied site activities therefore it is suggested that in measuring the impacts of variability on performance, emphasis should be placed on labour productivity variability instead of work flow or construction output variability. The values of variability in labour productivity were compared with the project performance (PWI) it was found out that the higher the values of labour productivity variability the poorer the performance. Also the baseline productivity computed for the studied activity was compared with the mean labour productivity.

It was discovered that a level of performance gap exist for the concrete site work. This is an indication of improvement opportunity for performance in labour utilization for the activity investigated. The present productivity distribution was higher than the expected productivity distribution, this represents a gap in performance.

The effect of variability on jobsite performance was determined using regression analysis. A level of effect was established for the concrete site activity which is 40%. This suggests that reducing variability will bring about improvement in labour performance.

RECOMMENDATIONS ON PERFORMANCE IMPROVEMENT STRATEGIES TO BE ADOPTED BY SITE MANAGERS AND OPERATIVES.

1 The correlation relationship between work flow variability and performance was found to be low for concrete activities therefore it is recommended that in measuring the impacts of variability on performance, emphasis should be placed on labour productivity variability instead of work flow or construction output variability.

2 The correlation between labour productivity and performance was discovered to be highly significant for all measured site activities therefore it is suggested that labour productivity variability be used to measure the impacts of variability on performance.

3 The variations in crew performance in the activity investigated was found to be as a result of variations in labour productivity therefore the following are suggested,

4 Multiple variables effect of work flow and labour productivity variability on labour performance was found to be lower than the single variable effect of labour productivity variability thus single variable effect is proposed for the assessment of variability effect on performance.

5 It is proposed that site managers should close up performance gaps in project execution by reducing the disparity in values between baseline productivity and the mean labour productivity for the project.

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Appendix 1 Computation of Research Variables

S/N	Project code number	Coefficient of Variation Qty	Coefficient of Variation LP	Total Work days	Average daily output m^3	Cumulative Productivity whr/m^3	Baseline Productivity	Project waste index
1	Project 1	0.64	0.43	10	155	9.77	6.70	0.32
2	Project 2	0.30	0.40	12	171	12.59	8.05	0.47
3	Project 3	0.38	0.42	19	214	11.57	6.81	0.49
4	Project 4	0.55	0.37	13	219	12.05	7.77	0.44
5	Project 5	0.37	0.19	19	237	15.18	12.14	0.31
6	Project 6	0.84	0.32	14	363	10.33	8.33	0.21
7	Project 7	1.08	0.41	10	231	10.08	7.43	0.27
8	Project 8	0.66	0.48	9	103	9.10	6.77	0.24
9	Project 9	0.57	0.17	10	69	13.10	11.76	0.14
10	Project 10	0.60	0.42	11	74	10.00	6.73	0.34
11	Project 11	0.83	0.44	11	84	9.84	6.50	0.34
12	Project 12	1.01	0.46	9	71	9.02	6.66	0.24
13	Project 13	0.98	0.41	11	79	10.12	7.50	0.27
14	Project 14	0.39	0.38	11	66	12.65	7.77	0.50
15	Project 15	0.57	0.37	11	70	11.88	8.20	0.38
16	Project 16	0.44	0.19	10	53	14.62	12.31	0.24
17	Project 17	0.57	0.38	10	65	11.39	8.00	0.35
18	Project 18	0.48	0.27	11	61	12.62	9.35	0.34
19	Project 19	0.88	0.32	10	200	11.55	8.72	0.29
20	Project 20	0.70	0.16	12	178	13.08	11.72	0.14
21	Project 21	0.47	0.29	13	219	9.27	7.07	0.23
22	Project 22	0.58	0.38	12	105	12.22	7.99	0.44
23	Project 23	0.53	0.37	14	179	12.55	7.43	0.53
24	Project 24	0.47	0.14	10	90	15.88	14.42	0.15
25	Project 25	0.78	0.26	9	133	11.28	9.79	0.15
26	Project 26	0.53	0.28	10	136	8.33	6.99	0.14
27	Project 27	0.81	0.38	10	77	11.32	8.81	0.26
28	Project 28	0.71	0.36	20	203	13.89	7.43	0.67
29	Project 29	1.03	0.31	13	113	10.79	8.76	0.21
30	Project 30	1.47	0.34	15	154	10.40	8.07	0.24
60	Project 60	0.68	0.09	11	92	14.67	13.11	11.47