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# Predictive Model for Project Construction Labour Productivity versus Flow of Project Materials and Components

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**Abstract**

*Researching labor productivity has significant impact on welfare and economic prosperity. In building projects, resource management can result in significant time and cost savings. This study concentrates on construction project labor productivity because the sector is labor-intensive. Contemporary problems to this topic are considered in this study. It includes definitions, characteristics, measurements, factors influencing labor productivity in building projects, various methods for assessing it, and modeling prediction methodologies. Through project materials and components flow, this study offers a roadmap for the actions that must be taken in order to increase construction labor productivity and project performance. Data from 129 housing projects in Nairobi, Kenya were gathered using a questionnaire survey administered to the projects. The survey included two (2) variables of construction project materials and components flow and three (3) measures of project level construction labor productivity (CLP) that the literature research had determined. Eleven (11) items concerning construction project materials and components flow were rated on a six (6) point scale and from these the level of flow of materials and components for the project were determined. The level of project construction labour productivity was equally measured. A model for predicting the level of project construction labour productivity using the flow of materials and components into the projects was developed for practical use in managing labour productivity in projects. The results indicated that materials and components explain 87.0% of the variability in construction project labour productivity and that a unit increase in Project Materials and Components Flow (PMCF) resulted in 26.7% increase in construction project labour productivity. The study thus recommended project materials and components to be supplied and managed in an effective and efficient manner within projects for improvement of construction project labour productivity.*

**Keywords:** Labour productivity, flow, project success, man-days, output, input

## INTRODUCTION

The issue of productivity and more so, labour productivity, is of global importance. The welfare of national economies and individual enterprises is dependent on the productivity of its people (Alwey et al., 2019). Moreover, increasing productivity per worker is the primary factor that determines a nation's capacity to boost living standards over time (OECD, 2001). Labour productivity is therefore one of the most important factors affecting the overall performance of any organization, whether large or small and the pertinent factor is the performance of labour. (Thiyagu & Dhenadhalayan, 2015).

Hence to improve the overall productivity of a nation, sector, industry or organisation labour productivity needs to be improved. The National Productivity Council (NPC) was established by the Kenyan government through Sessional Paper No. 3 of 2013 on National Productivity Policy. Its purpose is to guide efforts by the public and private sectors to improve the implementation of productivity improvement programs and provide policy advice to the government (Lukalo & Kiminyei, 2018; Government of Kenya, 2013). The nation is trapped in a low productivity trap despite these efforts, as evidenced by low buying power, low capacity utilization, restricted capital formation, rising unit costs and domestic prices, and spiral agitation for wage increases (Lukalo & Kiminyei, 2018, Rao et al., 2015).

The construction industry is labour intensive in both the developed world and in the developing countries (Alinaitwe, 2006; Chan & Kaka,

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2004). Reducing the cost of labour and therefore construction costs is best carried out by labour productivity improvement (Alinaitwe, 2006). Labour productivity is further, closely related to quality, schedule efficiency and economy of budget (Gwaya et al., 2014; Thiyagu & Dhenadhalayan, 2015). Therefore, raising labor productivity in the construction industry is critical to the sector's overall performance. Loss of labour productivity through on-site delays and disruptions is a significant problem in the construction industry (Magil et al., 2020). Furthermore, managing material supplies and components is an essential instrument for managing project performance (Mossman, 2015).

## THEORY

There is no universal agreement on factors influencing labour productivity in construction. The complexity of the construction business is the primary cause of this. Many studies have researched into the factors affecting Labour Productivity (Muqeem et al., 2011; Naoum et al., 2009). Most studies delve into the factors that are pertinent to their particular situation, construction product, environment, site conditions, geographical location, management features, resources, level of evaluation which may be at national level industrial level, company/organisation level, project level or site level, choice evaluation method as well as uniqueness of each individual construction worker (Kisi, 2015). Labour productivity studies will therefore seek to improve the most pertinent factor under the prevailing circumstances it in order to realise greater productivity.

Generally, Labour Productivity in construction gets the most attention as it is intuitively linked to pay levels and in turn to living standards. It appears additionally that there are no large differences between labor and total productivity trends in construction because those industries that do well in labor productivity also have the best development rate in total productivity (Pekuri et al, 2011). It has been observed that labor might account for up to 65% of a building project's overall cost, further justifying its use as a measure for construction productivity (Rao et al., 2015). Thus improving labour productivity is analogous to improving total productivity in construction.

Most models evaluating the construction system use laminar flow to depict it (Kisi, 2015; Muqeem et al., 2011; Naoum et al., 2009). This is where the project system works akin to laminar flow in bringing inputs to the site and in the process delivering transformation and adding value to the said inputs as outputs are flowing out as products of the process (Mossman, 2013; Koskela, 2000). Mossman (2015) evaluated the Transformation-Flow-Value theory and proposed that to enhance flow of critical components into the project would enhance project performance and thus labour productivity. Prior research has examined various forms of flow variation and their impact on the performance of construction projects. In general, the findings indicate that increased predictability of work flow leads to increased productivity (Mossman, 2015; Kisi, 2015; Muqeem et al., 2011; Naoum et al., 2009).

According to The Association for Advancement of Cost Engineering (AACE) International (AACE, 2004), Labor Productivity is the rate of output per unit of time or effort, typically expressed in labor-hours. Examples of labor productivity include measurement per crew hour of such items as concrete works in cubic meters, installed length of conduits or placed pipework. As per these definitions, labour productivity may therefore be expressed mathematically according to equation 1 hereafter.

$$Labour\ Productivity\ (LP) = \frac{Output}{Labour\ Cost}\ or\ \frac{Output}{Work\ Hour} \ldots\ldots\ldots (1)$$

Where:

- Output is the delivered construction product measure either in monetary terms if several components form the overall output or units of the product if a single output like m3 of concrete or m2 of floor area.
- Labour cost is the cost of delivering the output measured in monetary terms, man-days or man-hours.
- Work hour is the labour utilized in one hour by one person working on the output.

To realise increased productivity, the output must remain constant or continue increasing while the labour must continue reducing. To improve labour productivity, the flows that realise the output must be enhanced. However, in construction there is more than one flow involved in the delivery of the output. Understanding and managing the flows is an important issue (Bertelsen et al., 2007). The study proceeds to explain how the transformation-flow-value model may be beneficial to improved construction project performance.

TFV seeks to explain the nature of the flows and their interactions in the construction process in a bid to improve performance of the construction process (Bertelsen et al, 2006). The flows work jointly in the construction process to generate value for the client (Mossman, 2015; Mossman, 2013; Bertelsen et al., 2007). Heinrich et al. (2008) identify the seven critical flows shown in **Figure 1** which must be managed effectively for performance improvement: (i) Construction design; (ii) Components and materials; (iii) Workers; (iv) Equipment; (v) Space; (vi) Connecting Works; and (vii) External Conditions.

Mossman (2013) simplifies the seven critical flows as information, materials, people, equipment, safe space, prior work safe external conditions. The study adds that if any of the seven flows is interrupted or is out of sequence then value cannot be created. Bertelsen et al. (2007) posit that only one of the flows is the critical one that determines the pace of the construction process at any particular time. How to identify this critical flow, the study adds, is the crucial part. This study evaluated materials and components as one of the critical flows that deliver output in construction projects. This was evaluated against project construction labour productivity, one of the KPIs of project performance.

## RESEARCH METHODS

This research employed a cross-sectional survey research design whose objective was to create a model for forecasting the Project Construction Labor Productivity (PCLP) for housing projects in Nairobi, Kenya. The sampling frame was housing projects having a financial scope of less than Kenya Shillings Three Hundred Million (< Kshs. 300m) (USD 1.0 = Kshs. 145.00) approved for construction by The Nairobi City County Government and National Construction Authority (NCA) within the 2020/2021 and 2021/2022 financial years. Nairobi had 1,501 approved housing projects of which 225 (15%) were commercial residential possessing the required traits for the study (KNBS, 2023; Wanzala, 2023). The project sample was 180 projects obtained through simple random sampling from the sampling frame with the unit of analysis being the project construction site. Sample size was calculated using the Yamane formula (Kothari, 2004). The data collection used a questionnaire administered to the project manager, construction manager or project contractor. One hundred twenty nine (129) were deemed responsive and from these, data was analyzed.

The survey sought to measure the flow of material s and components into the project as the predictor variable and PCLP as the criterion variable. PCLP was measured through three factors Project Labour Speed (PLS), Project Labour Efficiency (PLE) and Project Labour Cost Competitiveness (PLCC). Project Materials and Components Flow (PMCF)

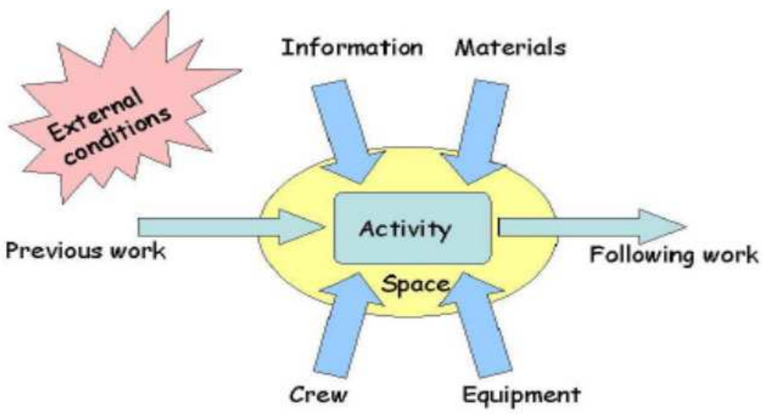


**FIGURE 1**
The Seven Flows of TFV
**Source:** Heinrich et al., (2008)

on the other hand was measured through two (2) factors – Material Related Factors (MFactors) and Supplier Related Factors (SFactors) - with a sum total of eleven (11) measures accordingly. These measures were rated on a six (6) point Likert scale and through a summated total score, PMCF for the project was determined.

In order to establish a predictive model that would ascertain the impact of PMCF on PCLPI of the sampled construction sites, the obtained data were analyzed using mean scores, standard deviation, Relative Importance Index (RII), coefficient of variation and simple regression analysis. PLS was calculated from the data obtained using Equation 2. The Monthly value of work undertaken measured in Kenya Shillings was obtained by quantifying the construction output of the month either from the monthly payment certificate calculations or through direct calculations of work undertaken from the project Bills of Quantities (BQ). The monthly labour in man-days was obtained from the project labour records.

$$PLS = \frac{Monthly\ value\ of\ work\ undertaken\ (Kshs.)}{Monthly\ Labour\ (Man-days)} \ldots.. (2)$$

PLE was a measure of the percentage of project construction plinth area constructed during that month. PLE was calculated from the data obtained using Equation 3. Both the monthly value of work undertaken in Kshs. and Total Monthly Labour in Man-days were obtained as earlier described under PLS. The Total project plinth area was measured in square meters (m2) from the project drawings and the Total Contract Sum (Total Project Cost) in Kshs. was obtained from the project BQ.

$$PLE = \left(\frac{Monthly\ value\ of\ work\ undertaken\ (Kshs.)}{Total\ contract\ sum\ (Kshs.)}\ X\ \frac{Total\ Project\ Plinth\ Area\ (SQM)}{Monthly\ labour\ (Man-days)}\right) \ldots\ldots (3)$$

PLCC was a monthly evaluation ratio of the construction output against the Monthly labour with both measured in Kshs. PLCC was calculated from the data obtained using Equation 4. The Monthly value of work undertaken was obtained as defined earlier and the Monthly labour cost was acquired from Project Labour payment records.

$$PLCC = \frac{Monthly\ value\ of\ work\ undertaken\ (Kshs.)}{Monthly\ Labour\ Cost\ (Kshs.)} \ldots. (4)$$

The three Productivity measures were summated into one criterion variable called the Project Construction Labour Productivity Index (PCLPI) through Equation 5.

$$PCLPI_i = \frac{1}{3}\left[\frac{PLS_i}{PLS_{mdn}} + \frac{PLE_i}{PLE_{mdn}} + \frac{PLCC_i}{PLCC_{mdn}}\right] \ldots. (5)$$

Where:

PCLPIi = Project Construction Labour Productivity Index for the $i^{th}$ observation

$PLS_i$=Project Labour Speed for the $i^{th}$ observation

$PLE_i$=Project Labour Efficiency for the $i^{th}$ observation

$PLCC_i$=Project Labour Cost Competitiveness for the $i^{th}$ observation

$PLS_{mdn}$ = The median Project Labour Speed for the number of observations

$PLE_{mdn}$ = The median Project Labour Efficiency for the number of observations

$PLCC_{mdn}$=The median Project Labour Cost Competitiveness from the observations

**Flow of Project Materials and Components**
The six-point scale measuring the rate of flow ranging from 1 (never) to 6 (always) was transformed to relative importance index (RII) for each factor as follows:

$$RII\ (\%) = \frac{6n6 + 5n5 + 4n4 + 3n3 + 2n2 + 1n1}{6(n6 + n5 + n4 + n3 + n2 + n1)} * 100 \ldots\ldots\ldots (6)$$

The mean scores, standard deviation, Relative Importance Index (RII), coefficient of variation and simple regression analysis for the data is discussed hereafter.

## RESULTS AND DISCUSSION

**Material Factors (MFactors) Measure**
The results of the degree of the presented six (6) factors on materials in the construction project based on a scale of 1 – 6 from 'never' to 'always' have been presented on **Table 1**.

**TABLE 1**
Material related factors

| MFactors | N | Mean | Std. Dev. | RII | Rank |
|---|---|---|---|---|---|
| Availability of the correct sequence/harmony of material on site | 129 | 3.52 | 1.38 | 65.37% | 1 |
| Availability of correct type of materials on site | 129 | 3.91 | 1.41 | 64.60% | 2 |
| Availability of easy access of materials at the work area on site | 129 | 3.57 | 1.52 | 63.44% | 3 |
| Availability of the correct standard/quality of materials on site | 129 | 3.94 | 1.35 | 63.31% | 4 |
| Availability of the correct quantities of material on site | 129 | 3.58 | 1.52 | 61.89% | 5 |
| Availability of the correct organization of materials on site | 129 | 3.42 | 1.53 | 59.17% | 6 |
| Overall | 129 | 3.66 | 1.45 | | |

**Source:** Author (2024)

The two best performing material related factors (MFacts) were found to be 'availability of correct standard/quality of materials on site' and 'availability of the correct type of materials on site' with means of 3.94 and 3.91 respectively. The two least performing material factors were found to be 'availability of the correct organization of material on site' and 'availability of the correct sequence/ harmony of materials on site' with means of 3.42 and 3.52 respectively. An overall mean of 3.66 indicates that performance on the material factors was above the acceptable level or slightly above average without being exceptional. On RII 'Availability of the correct sequence/harmony of material on site' was the highest at 65.37% and the lowest was 'Availability of correct organization of materials on site' at 59.17%.

**Supplier-related Factors (SFactors) Measure**
The results of the assessed five (5) project supplier-related factors are presented on **Table 2.**

The two best performing supplier-related factors were found to be 'suppliers provide materials on time as expected' and 'the same regular suppliers are used' with means of 3.67 and 3.43 respectively. The two least performing supplier-related factors were found to be 'suppliers are chosen based on best prices of quotation' and 'suppliers are paid on time as expected' with means of 3.16 and 3.23 respectively. The performance of the factors ranged from 'average' to 'above average'. An overall mean of 3.37 for "supplier-related factors" can be described as satisfactory. This means that suppliers, whether working with the contractor, subcontractors, or the client, are handled fairly in the sampled construction projects. Based on RII, 'Suppliers are chosen based on best prices of quotation' was the highest at 67.57% while 'Suppliers provide materials on time as expected' was the lowest at 56.98%.

**TABLE 2**
Supplier-related factors (SFact)

| SFact | N | Mean | Std. Dev. | RII | Rank |
|---|---|---|---|---|---|
| Suppliers are chosen based on best prices of quotation. | 129 | 3.16 | 1.29 | 67.57% | 1 |
| The same regular suppliers are used. | 129 | 3.43 | 1.49 | 65.63% | 2 |
| Suppliers are paid on time as expected. | 129 | 3.23 | 1.55 | 61.50% | 3 |
| Suppliers are changed based on need. | 129 | 3.37 | 1.46 | 61.11% | 4 |
| Suppliers provide the materials on time as expected. | 129 | 3.67 | 1.54 | 56.98% | 5 |
| Overall | 129 | 3.37 | 1.47 | | |

**Source:** Author (2024)

**Project Construction Labour Productivity (PCLP)**

**Project Labour Speed (PLS)**

The results for the Project Labour Speed have been presented on **Table 3**. The values ranged from Kshs. 765/man-day to Kshs. 9,091/man-day with a mean of Kshs. 4,978/man-day and a standard deviation of Kshs. 1,970/man-day.

A mean Project Labour Speed (PLS) of Kshs. 4,978/man-day means that for every man-day, the value of work executed is KShs. 4,978 against a daily average man-day cost of Kshs. 1,266 obtained by calculating the average daily project man-day cost. This translates to an average project man-day conversation rate of 3.93 times the project man-day cost or a project man-day cost of 25.4% the converted project output value. The coefficient of variation is 39.6%.

**Project Labour Efficiency (PLE)**

The results for the Project Labour Efficiency have been presented on **Table 4**. The values ranged from 0.02m2/man-day to 0.29m2/man-day with a mean of 0.14m2/man-day and a standard deviation of 0.06 m2/man-day. The coefficient of variation is 42.86%.

**Project Labour Cost Competitiveness (PLCC)**

The results for PLCC have been presented on **Table 5**. With a mean of 5.34 and a standard deviation of 2.12, the values varied from 1.18 to 9.83. The huge disparity between the lowest value (1.18) and the highest (9.83) could be attributed to the same reasons as given earlier in the Project Labour Speed. The coefficient of variation was 39.70%.

The average PLCC of 5.34 means that an expenditure on labour realized 5.34 times the value in construction value. On the other hand, the reciprocal of PLCC indicates the fraction of the value of construction output that was spent on labour. The reciprocal of the obtained average PLCC of 5.34 is 0.187 indicating that the labour component was 18.7% of the value of the total construction output. The lowest PLCC value (1.08) yielded a reciprocal of 0.847 indicating that the labour cost was 84.7% of the monthly construction output value. The highest PLCC value (9.83) yielded a reciprocal of 0.102 indicating that the labour cost was 10.2% of the monthly construction output value.

**Predictive model for Project Materials and Components Flow on Project Construction Labour Productivity**

The goal of the study was to develop a model that will assess the influence of Flow of Project Materials and Components on PCLPI on Nairobi building projects. In order to accomplish the aforementioned goal, a statistical model was created utilizing Flow of Project Materials and Components as the predictor variable and PCLPI as the criterion variable with PCLPI being calculated as per Equation 5 described earlier. The total score for the eleven (11) Flow of Project Materials and Components Factors was computed for the projects sampled to give Total Flow of Materials and Components.

The statistical model is presented hereafter in the standard mathematical expression for a straight line.

$$Y = \alpha + \beta X + \varepsilon \ldots. \quad (7)$$

Where:-

Y = project construction labour productivity index
X = Project Materials and Components Flow.
α = intercept
β = labour productivity constant
ε = Error

**Regression analysis of PCLPI**

The results of the regression are depicted on **Tables 6, 7** and **8**.

The regression analysis's outcome, which is shown in **Table 6**, showed that the mathematical model represented by Equation 7 can accurately forecast the effects of Project Materials and Components Flow on Project Construction Labour Productivity Index (PCLPI). The estimated model is given as Equation 8.

$$PCLPI = 0.044 + 0.267PMCF \pm 0.138 \ldots\ldots (8)$$

PCLPI = Project Construction Labour Productivity Index (PCLPI)

PMCF = Project Materials and Components Flow (PMCF)

**TABLE 3**
Project Labour Speed (PLS)

| Factor | N | Min (Kshs/Man-day) | Max (Kshs/Man-day) | Mean (Kshs/Man-day) | Std. Dev. |
|---|---|---|---|---|---|
| Project Labour Speed (PLS) | 129 | 765 | 9,091 | 4,978 | 1,970 |

**Source:** Author (2024)

**TABLE 4**
Project Labour Efficiency (PLE)

| Factor | N | Min $m^2$/man-day | Max $m^2$/man-day | Mean $m^2$/man-day | Std. Dev. |
|---|---|---|---|---|---|
| Project Labour Efficiency(PLE) | 129 | .02 | .29 | .14 | .06 |

**Source:** Author (2024)

**TABLE 5**
Project Labour Cost Competitiveness (PLCC)

| Factor | N | Min | Max | Mean | Std. Dev. |
|---|---|---|---|---|---|
| PProject Labour Cost Competitiveness (PLCC) | 129 | 1.18 | 9.83 | 5.34 | 2.12 |

**Source:** Author (2024)

**TABLE 6**
Coefficients Results

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .044 | .034 | | 1.275 | .204 |
| | Materials and Components Flow | .267 | .009 | .933 | 29.151 | .000 |
| a Dependent Variable: Project Construction Labour Productivity Index | | | | | | |

**Source:** Author (2024)

**TABLE 7**
Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .933[a] | .870 | .869 | .138 |
| a Predictors: (Constant), Materials and Components Flow | | | | |

**Source:** Author (2024)

**TABLE 8**
Analysis of Variance

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 16.079 | 1 | 16.079 | 846.26 | .000[b] |
| | Residual | 2.403 | 127 | 0.019 | | |
| | Total | 18.482 | 128 | | | |
| a Dependent Variable: Project Construction Labour Productivity Index | | | | | | |
| b Predictors: (Constant), Materials and Components Flow | | | | | | |

**Source:** Author (2024)

The constant for Project Materials and Components Flow (PMCF) provides the amount of the change in PCLPI (0.267) that results from the change in PMCF. This indicates that there is a 26.7% increase in PCLPI for 100% increase in PMCF. The regression results are shown on **Tables 6, 7** and **8**. The R2 value is 0.870. It is the coefficient of determination and tells us the degree to which variability in PCLPI is explained by the Project Materials and Components Flow. In this case, 87.0% of the variability in the PCLPI is explained by PMCF, at a confidence level of 99.99%.

The *regression constant* (0.044) is not statistically significant as shown on **Table 6**, while the *Sum of Squares Regression* is statistically significant as shown on **Table 8**. These two results imply that the regression model is well specified. The regression equation above is therefore realistic and can be used to make credible recommendations on the way to improve PCLP.

The significance is measured using the F-test statistic, obtained by dividing the mean sum of squares from the regression by the mean sum of squares from the residual side as depicted in Equation 9.

$$\boldsymbol{F} = \frac{\mathbf{16.079}}{\mathbf{0.019}} = \mathbf{846.26} \ldots\ldots (9)$$

The F-statistic denominator denotes the within group variance. If the within group variance is very small then the variance that the model cannot explain, the random error, is very small. The numerator on the other hand represents the between groups variance.The Null Hypothesis is that the variances are equal ($H_0$: F = 1). The answer obtained provides an estimate of the variance explained by the model. For this model, the calculated F-statistic was 846.26. The between group variance is 846.26 times the within group variance. Since (F≠1) we reject the Null Hypothesis, H0 at a confidence level of 99.99% as indicated by the statistical signifiance on Table 8. Hair et.al (2010) affirm that if the resulting figure of the F-statistic is high, then the random error is tending towards zero and thus the similarity between the outcome of populating the model with any random members from the same population is 99.99%. The model is not only significant in predicting the criterion variable within the current sample but is equally significant in prediciting the criterion variable (PCLPI) in multiple samples across the same population. Thus the model is deemed sufficient for predicting PCLPI in projects within the study.

## CONCLUSION

This study has evaluated the effect of Flow of Project Materials and Components on Project Construction Labour Productivity Index (PCLPI). By describing the comprehension of the effect of PMCF on PCLPI, it allows the evaluation of how the construction management field may be affected theoretically through critical project Key Performance Indicators by Flow of Project Materials and Component. The study findings were that 87.0% of the variability in the PCLPI is explained by PMCF, at a confidence level of 99.99%.

The study's predictive model suggests a noteworthy correlation between Project Construction Labour Productivity (PCLP) and Project Materials and Components Flow (PMCF). Likewise, the nature of the link is directly proportionate, meaning that the project construction labor productivity increases with the project materials and components flow. More precisely there is a 26.7% increase in PCLPI for 100% increase in PMCF.

## RECOMMENDATIONS

The study's conclusions led to the formulation of the following recommendations for enhanced PCLP in construction projects:-

1. To benefit PCLP, project materials and components must be supplied and managed in an effective and efficient manner. Project owners need to invest towards ensuring project materials and components are of good quality, adequate, timely and orderly in delivery and site arrangement to ensure productivity of labour.
2. The study's managerial conclusions are related to ensuring comprehension among main project stakeholders of the importance of materials and components in the effectiveness of labour execution. It is key to foster their cooperation in giving the factor requisite attention.
3. The input of management resides in the recognition of managerial practices towards materials and components that will benefit

the work execution. A few immediate gains include adequacy of quantity and quality as well as ease of delivery to the work-face are starting points. The project manager or owner is responsible for making sure consistent use of regular suppliers in addition to timely remittance of payments to the said suppliers.

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