RELATIONSHIP BETWEEN LABOUR PRODUCTIVITY AND CURVED WALL CONSTRUCTION IN HIGH-RISE BUILDING PROJECTS

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Construction labour productivity has been declining. This paper examines the learning effect of labour productivity in a curved wall operation using the application of the Learning Curve Theory (LCT). The research adopted a quantitative approach, utilising a standard observation sheet to record labour productive time on a live project. The study investigated a 15-storey office building project in Nigeria. Data were analysed using regression analysis and straight-line learning model. The result of the effect of learning on curved wall operations shows a significant influence on improvement in labour productivity. The labour productivity observed reveals average learning rate of 93.76%, resulting in an improvement rate of 6.24% in labour productivity. This impact can decrease the duration of the project at a rate of 1% - 6%. A learning rate of less than 100% indicates that learning has occurred and is verified by the LCT. The research contributes to development of a model for investigating labour productivity curved wall operations with the application of LCT. The model developed in this research can help the construction industry, project managers and planners to view the rate of labour productivity in a learning curve diagram. This study was limited to a single site multi-storey building due to the deductive method of the research. The implication is that the study result may lack generalisability. It is suggested that this investigation is replicated with other models, i.e. piecewise unit model, exponential model and cubic unit model of learning.

Keywords: curved-walls, learning-curve-model, operations, measurement

INTRODUCTION

For decades, the construction industry has been afflicted by productivity growth. One explanation is nature of construction operation vis-a-vis workforce influences on global average value-added per hour. Productivity issues are particularly dismal in rich countries. For example, France, Italy, German and Japan has seen productivity growth fallen by about a sixth (Office National Statistics (2019). Arguably, construction productivity growth is worst in developing countries such as Nigerian, India and Brazil. Indeed, construction of curved walls has a remarkable influence on labour productivity and is often most noticeable characteristic in buildings (Granadeiro *et al.,* 2012). Curved wall construction is a component of modern forms of architecture that significantly influences construction labour productivity (Mashina

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and Gadi, 2010). Ourghi *et al.,* (2007) developed a tool to predict the influence of curved walls productivity on limited shapes and found that curved wall influences construction labour productivity significantly. However, there is rare study about learning effect of labour productivity in a curved wall operation using Learning Curve Theory (LCT).

The significance of labour in construction productivity cannot be overemphasized; particularly as it relates to project completion within cost and time targeted. The construction industry, particularly contractors usually consider productivity of labour rates as a fundamental factor of project success (Missbauer and Hauber, 2006). Construction labour productivity has witnessed a downward turn in the last two decades (Durdyev and Mbachu, 2018, Naoum, 2016). Perhaps, this is exacerbated by deteriorating relationship between different labour unions and other associations within construction supply chain. Moreover, labour productivity is regularly considered as slow to responding to clients' evolving requests. Various studies opine that contractual worker's practices need to change from engendering obsolete techniques to quick information assimilation from both external and internal environments for progressive, gainful and productive techniques (Rao *et al.,* 2015, Kululanga *et al.,* 2002). The merits of incorporating the Learning Curve Theory (LCT) as a feature of everyday contractual workers' schedule was recently addressed in some investigations (Thomas *et al.,* 1986, Couto and Teixeira, 2005, Jarkas, 2010, Ugulu and Allen, 2018).

LCT supposition is that labour productivity can be enhanced by performing a task repetitively (Thomas *et al.,* 1986). LCT states that whenever production quantity of an item doubles, the cumulative average cost or labour hours decreases by a level of percentage of total average rate or first unit rate. This percentage is depicted as the learning rate (Couto and Teixeira, 2005). However, other researchers advocated positive learning effect of labour productivity (Jarkas, 2010, Couto and Teixeira, 2005). Thomas (2009) stated that a talented labourer can profit on the lessons gained from experience. Everett and Farghal (1997) expanded the work of Thomas *et al.,* (1986) and found that labour productivity could be improved if workers can gain from previous experience. A phenomenon regularly portrayed as an effect of learning. Franco *et al.,* (2004) uncovered that improved performance in construction projects is synonymous with labour learning from performance feedback perspective. Wong *et al.,* (2012) assert that impact of labour performance is dependent on construction organizations' training and commitment to learning.

A significant number of investigations carried out utilised the use of surveys and practitioners perceptive based on literature reviews. Generically, there seems to be a general understanding among researchers that change in performance of labour is not incidental (Jarkas, 2015, Mohamed *et al.,* 2019). To a certain extent, it can be as a result of a subtle learning process, though little consideration has been paid to addressing what exactly workers learn (Jarkas, 2010, Ugulu and Allen, 2018). Nevertheless, such a recommendation has yet been supported by enough scientific evidence (Jarkas and Horner, 2011). Besides, it is justifiable that there are a variety of ways by which productivity improvement can be accomplished (Greve and Audia, 2006). For instance, the performance of labour might be improved by the learning experience gained during construction, the capability of management of the project manager, as well as the capacity to control project monitoring outcomes (Everett and Farghal, 1997, Love and Josephson, 2004).

The aim of this paper is to examine how learning affects labour productivity during curved wall operations in high-rise construction. Study of curved wall operations and the learning effects with the application of the LCT on repetitive operations would be of great benefit to construction managers and the construction industry.

LITERATURE REVIEW

Labour Productivity in Construction

Productivity is the relationship between work hours used to produce output and production. It is also the relationship between the output and input factors used to produce the output by a system. This description is derived from earlier definitions on productivity (Ugulu and Allen, 2018, Thomas and Zavrski, 1999, Tran and Tookey, 2011). Productivity rates are an essential aspect to be considered in the construction industry because they are output efficiency indicators of the sector (Mohamed *et al.,* 2019). According to Mohamed *et al.,* (2019) the ‘project type' is the most important factor that influences productivity of labour in rebar construction.

Durdyev and Mbachu (2018) investigated factors influencing the productivity of construction labour in residential projects. These factors were grouped into four main groups: workforce, resource, management and external. The study found that the main factors affecting labour productivity are leadership, change order management, defective work and flow of cash. In South Africa, studies found that "late drawing, issue of specifications, delay, illegal strike action and lack of motivation as major factors that influences productivity" (Bierman *et al.,* 2016, Ugulu and Allen, 2017).

Ugulu and Allen (2018) investigated the influence of craft gangs onsite learning productivity using observation method and found a significant impact of learning on craft gangs' productivity. Learning curve theory relies on a crucial human nature, and capability to gain from past understanding, the strategy begins from individuals or groups repeating a comparative task and gaining experience from their association or practice. Long *et al.,* (2013) "examine the relationship between building floor and labour productivity of the structural work including formwork installation and rebar fabrication/installation," utilising the LCT. The study found 86.9% significant improvement. In a similar study, Jarkas (2010) investigated the "effects and relative influence of grid patterns; variability of foundation sizes; total surface area; and average surface area, on formwork labour productivity of isolated foundations". The study found strong correlation and high determination coefficients between labour productivity and the factors investigated i.e. 90.40 and 92,90 per cent. The rule of the LCT, which has been used reasonably in manufacturing, can moreover be used in building and construction industry (Thomas *et al.,* 1986).

Apparently, different learning curve models are used for improving labour productivity with repetitive activities in the construction industry exist, but learning curve mathematical models commonly used are: straight line unit model, Stanford unit ‘8' model, cubic unit power model, piecewise unit model and exponential unit model (Thomas *et al.,* 1986). The investigation carried out by Thomas *et al.,* (1986) utilised the output and construction production data gathered from 65 construction labour activities to examine the best evaluating model between the cubic and exponential and straight-line models. The straight-line model has the advantage of straightforwardness. However, it may not be reliable since the learning rate is expected to be consistent. The cubic unit model of learning always brought about a higher coefficient of determination and was the reasonable model for displaying the impact of earlier learning developed (Thomas *et al.,* 1986).

The piecewise unit model involves three different stages, each of the stages with a learning percentage, the exponential model was founded on the hypothesis that portion of cycle per time is permanent and subject to improvement through repetition of the same task (Norwegian Building Research Institute, 1960). Previous investigation revealed that the cubic and piecewise learning curve model has a better coefficient of determination compared to the straight-line learning model (Duff *et al.,* 1987). However, these researchers observed that either the piecewise or the cubic model of learning curve provides a reasonable benefit regarding phenomenon of learning for the generalization of labour productivity in the construction project.

Straight-line learning model techniques was introduced to overcome such drawbacks and has comparative advantages compared to others because it helps project managers and planners to view rate of labour productivity learning in a LCT diagram (Thomas *et al.,* 1986). The LCT diagram enables the user to easily get all the needed information. It identifies relationship easily between activities, represent the different production rates between productivity rates of activities, and are regarded as an easier way for determining progress rates and estimating the present crew's construction performance. It is evident from the study literature that construction activities have been applying learning curve theory to their activities due to repetitive features and labour intensive. The study examined curved wall operation in a high-rise building project and used straight-line learning curve model to understand its effect on labour productivity

METHODOLOGY

This research adopted a quantitative approach. According to Leedy and Ormrod (2013) quantitative research includes the utilization of logical inquiry that embraces a speculative deductive method that deals with testing theories. This method considers huge indicators of credibility, for example, reliability, validity, generalizability, and reproducibility. Quantitative research is typically considered as an objective positivist endeavour with little depth (O'leary, 2010).

This research utilised a standard observation sheet as the research instrument to record the labour productivity input and output as supported by earlier researchers (Jarkas, 2010, Couto and Teixeira, 2005). The design of the observation sheet includes the following important features: observed time, weather condition, wall thickness, crew composition, wall type, height worked and method of work. The description of the observed project was a 15-storey office building in Abuja, Nigeria. The project office complex has a gross area of about 81,000 sqm comprising 445 car parking spaces. The focus on the project was on curved walls which have common features as stated in the design of the observation sheet.

The observed information was gathered on daily basis to decide the variation in output for the curved wall labour productivity on selected project sites. The observer would arrive on the site ahead of schedule as 7:00 am, note the progress of the work under observation, and record time of the work and delays experienced during the day and output from 7:00 am to 6:00 pm every day. The observed productivity data was collected over a total period of 12 weeks. The data collected were then used to calculate impact of learning on curved walls labour productivity. The investigation is a field study of actual data rather than data collection from recycled literature.

Data Analysis on Curved Walls Productivity

The least squares model which is similarly referred to as the linear regression model was adopted in the introductory statistical analysis of the study. The regression predictive model in this study was developed using the workers observed time to represent the dependent variable and the cycle numbers as the independent variables. The regression analysis was calculated using PHStat software that is normally used for Microsoft Excel. The relationship amid the curved wall inputs and cycle numbers was derived by substituting the observed recorded time into the straight-line linear regression model in equation 1: $Y = \alpha + \beta X$ …. 1.

From equation 1, α, and β demonstrates the intercept and the slant of the model. The intercept and the slant are predictable as thus:

$\beta = (n\sum xy-\sum x\sum y)/ (n\sum x2-(\sum x) 2)$ …. 2.

$\alpha = \bar{Y}-\beta\dot{X}$ …. 3.

In equation 3, Y, stand for the man-hours while X, signify the cycle numbers. The above equation α and β were utilised to appraise the regression model for the labour productivity of the curved wall.

The intercept and the slope were determined from the regression model in this manner:

$\beta = (n\sum xy-\sum x\sum y)/ (n\sum x2-(\sum x) 2)$, and $\alpha = \bar{Y}-\beta\dot{X}$. …. 4.

In equation 4, Y signifies the worker hours and X stand for the cycle numbers.

From the coefficient of correlation and regression model, α = 6.17, β= -0.09, y= -0.87. Where α stand for the intercept of the standard linear equation, β signify the slant of the linear curve, while y stand for the coefficient of correlation of the skill labour curved wall observed. The regression model for the curved wall labour observed was determined as Y = 6.17- 0.09X, where Y indicate workhours = 6.17 - 0.09 cycle numbers. From β, it shows that the relationship of the slop is negative, implying that there is a declining effect in working hours as the cycle numbers increases.

Influence of learning on curved wall productivity

The logarithmic straight-line expectation to learn and adapt is numerical express as:

Y = TI× (×) b …. 5.

Where, Y stand for the man-hours or cost or time required to do the repetitive unit, while T1 signifies the cost or man-hours or time required to carry out the first unit, X stands for the cycle number of the unit and b is the slant of the learning curve, determined as:

b=InS/ln2 …… 6.

In equation 6, S= rate of learning, which is depicted as the percentage of unit input decrease, i.e., man-hours, cost or time, because of replication of the quantity number of units finished.

Therefore, we can re-write equation 6 as: S= (2^b) *100 …. 7.

Figure 1.0 represents the learning rate of the labour productivity of the curved wall in the project site observed. The x-axis stands for the cycle numbers while the y-axis signifies the man-hours.

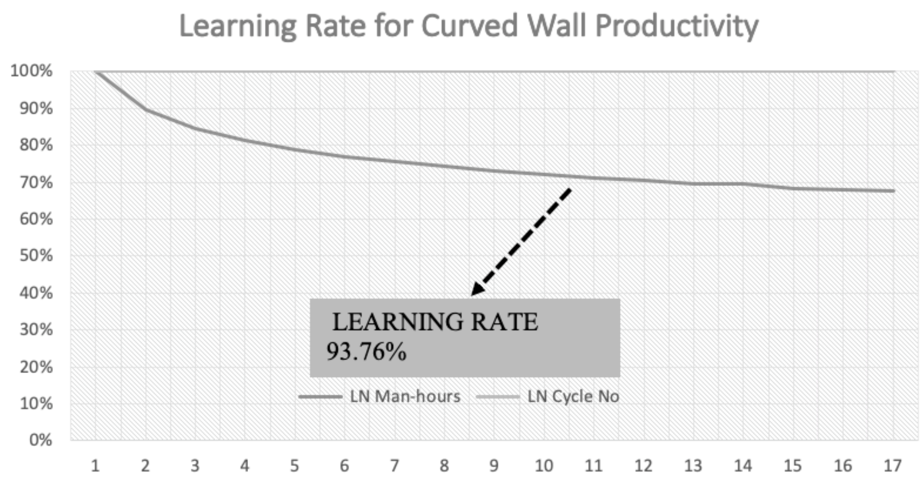

Figure 1. Relationship of Curved Wall operation and Cycle Numbers

The learning rate (S), communicated as a percentage, is measured by substituting the slant (b) appeared in equation 7, that is -0.09, into the learning rate equation as:

S = (2-0.09) x 100 = 93.76% as showed in figure 1.0. Table 1.0 illustrate learning rate table which was utilised in plotting the graph of the learning curve for the curved wall labour productivity observed. The LCT states that whenever the quantity of production of product doubles, the cumulative average cost or unit required for production, i.e., workers hours, cost, or time, decreases by a specific level of the past unit or total average rate. This rate is alluded to as the "learning rate" which recognise the learning accomplished. Also, it sets up the slant of the learning curve. The lower the learning rate, the more noteworthy learning is accomplished. A learning rate of 100% shows that no learning happens (Thomas *et al.,* 1986, Couto and Teixeira, 2005).

The learning rate reveals 93.76% which is significant for improving labour productivity in the construction industry. The study utilised 0.05% significance level as satisfactory degree of the inferences. A learning rate under 100% demonstrates that learning has happened and the justification of the LCT. The learning rate observed from this examination agrees with previous studies carried out in Vietnam, Asia (Long *et al.,* 2013). Jarkas (2010) found 96.40 and 92.90 per cent strong correlation and high coefficients of determination between labour productivity and the investigated factors. This finding is related with the findings of Jarkas (2010).

A learning rate under 100% demonstrates that learning has happened and the justification of the LCT. Figure 1.0 reveals a noteworthiness impact of learning on curved wall labour productivity, the productivity pattern created from figure 1.0, was observed to be concurrence with past examination on the impact of learning on labour productivity (Couto and Teixeira, 2005, Jarkas, 2010).

This investigation also compares with Thomas *et al.,* (1986) learning curve for construction operations. More precisely, it follows the 75 to 80 per cent trend of a learning curve, which applies to LCT of construction productivity. The learning influence observed in this study are consistently different from those of previous researchers (Jarkas, 2010, Ugulu and Allen, 2018, Thomas *et al.,* 1986, Couto and Teixeira, 2005). The significant productivity evaluation determinant observed in this study could be attributed to two prime factors: the impact of learning as work advances and the effect of cycle time which influence the technique of construction.

S/N	LN Man-hours	LN Cycle No	C	D	E	F	G	H	I	J	K	L	M
	Y	X	XY	X2	n∑XY	∑X∑Y	n∑X2	β=I/J	Ẏ	Ẋ	Bẋ	α=Ẏ-Bẋ	S=2b*100
1	6.2300	-	-	-				-0.0929					93.7642
2	6.0400	0.6931	4.1863	0.4804									
3	6.0400	1.1098	6.7032	1.2317									
4	6.0300	1.3862	8.3588	1.9216									
5	5.9900	1.6094	9.6403	2.5902									
6	6.0000	1.7917	10.7502	3.2102									
7	6.0100	1.9459	11.6949	3.7865									
8	6.0200	2.0794	12.5180	4.3239									
9	5.9600	2.1972	13.0953	4.8277									
10	5.9900	2.3025	13.7920	5.3015									
11	5.9500	2.3978	14.2669	5.7494									
12	5.9100	2.4849	14.6858	6.1747									
13	5.9000	2.5649	15.1329	6.5787									
14	5.9900	2.6390	15.8076	6.9643									
15	5.8700	2.7080	15.8960	7.3333									
16	5.8600	2.7725	16.2469	7.6868	3,394.2338	3,410.2021	1,295.1930		5.9853	1.9715	-0.1831	6.1684	
17	5.9600	2.8332	16.8859	8.0270									
∑	101.7500	33.5155	199.6608	76.1878									

Table 1. Learning rate for learning rate for curved wall productivity

CONCLUSIONS

The study observed curved wall construction operation in a building project and the learning curve technique was adopted for the examination of labour productivity with the use of straight-line model. The effect of the learning curve on duration of project is shown. the curved wall labour productivity observed signifies an average learning of 93.76%, resulting in an improvement rate of 6.24% in labour productivity. This impact can decrease the duration of the project at an approximate rate of 1%-6%.

The study is restricted to a single site storey building with various floors because of the deductive nature of the study. The implication is that this research result may lack generalisation. However, the researchers proposed repeated experiment or observations with significant number of cycles, for examples observation of other building sites curved walls. It is important to note that the model developed in this investigation does not directly account for management skills and strategies or specific project conditions. However, it mirrors the straight-line learning model and its impact on labour productivity in the observed site. There are similarities in the various learning curve models. Therefore, there is need to advance research on differences in learning rate of labour using other models, i.e. the piecewise unit model, the exponential model and the cubic unit model of learning.

It is pertinent to note that based on observed parameters, method of construction was discovered as the most important parameter with great influence on curved wall productivity followed closely by height of the wall and the crew composition.

This research contributes to the development of models that can be utilised to examine the impact of learning on labour productivity. This model will help project managers and planners to view rate of labour productivity on a project in a learning curve diagram. This diagram will also help to determine labour progress rates and estimate crew's construction performance. The findings presented in this paper requires mindful thoughts regarding effect of LCT on labour productivity in the construction industry.

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