Study on influence of floor number on block masonry work labour productivity in high rise buildings

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Abstract - *Labour productivity is one of the most important factor affecting the overall performance of the construction industry. There are many factors that positively and negatively affects the labour productivity. Construction activities are repetitive from floor to floor in multi-storey building construction. The learning curve theory has found application in the construction industry. Productivity for performing repetitive type of construction work will improve due to additional experience and practice. This research explores the relationship between floor number and labour productivity of the multi-storey work, focusing on block masonry work. The findings of the study shows that the cubic power learning curve is applicable for the study of labour productivity in high rise buildings having identical floors. A cubic power learning curve model, which predict the progress of block masonry work in high rise buildings with identical floors has been developed.*

***Key Words*: Labour Productivity, Block Masonry Work, Cubic Power Learning Curve, Learning Rate, Repeated Floors**

1. INTRODUCTION

Construction is the world's largest and most challenging industry. Human resource today has a strategic role for productivity increase of any organization, and this makes it superior in the industrial competition. Productivity is the one of the most important factor that affects overall performance of any small or medium or large construction industry. There are number of factors that directly affect the productivity of labour, thus it is important for any organization to study and identify those factors and take an appropriate action for improving the labour productivity. At the micro level, if we improved productivity, ultimately it reduces or decreases the unit cost of project and gives overall best performance of project. There are number of activities involved in the construction industry. Thus the effective use and proper management regarding labour is very important in construction operations without which those activities may not be possible.

1.1. Labour productivity

In general, productivity signifies the measurement of how well an individual entity uses its resources to produce outputs from inputs. Productivity can be defined in many ways. In construction, productivity is usually taken to mean labour productivity, that is, units of work placed or produced per man-hour. The inverse of labour productivity, man-hours per unit (unit rate), is also commonly used. Productivity is the ratio of output to all or some of the resources used to produce that output. Output can be homogenous or heterogeneous. Resources comprise: labour, capital, energy, raw materials, etc.

Productivity = output /input

Labour Productivity = Output /Work hour

1.2. Learning curve theory

A learning curve is a graphical representation of the relationship between unit production time and the number of units produced. The concept of the learning curve theory was first introduced to the aircraft industry by T. P. Wright. Despite the existence of different terminologies for the learning curve, at the most basic level, they all describe one phenomenon: as the number of produced units increases, the resources required per unit of production, i.e., man-hours, cost, or time, decrease. The learning curve theory is based on a basic principle of human nature; the ability to learn from past experience. The learning process stems from individuals or crews repeating the same task and gaining skill or efficiency from their own experience or practice.

The learning curve theory states that whenever the production quantity of a product doubles, the unit or cumulative average cost required for production, i.e., man-hours, cost, or time, declines by a certain percentage of the previous unit or cumulative average rate. This percentage is referred to as the “learning rate,” which identifies the learning achieved in the process. Moreover, it establishes the slope of the learning curve. The lower the learning rate, the greater the learning achieved. A learning rate of 100% indicates that no learning takes place.

1.3. Applicability of learning curve theory to the construction industry

The application of the learning curve theory in the construction industry, however, is accompanied by some concerns. On the one hand, construction activities usually take place under different and unique site conditions, and on the other, construction tasks are typically varied and non-repetitive; thus operatives may not have the opportunity to perform the same task repeatedly. Consequently, it may be argued that this is one of the critical reasons why the construction industry shows rather low productivity comparison with other manufacturing industries such as aircraft and automotive assembly. Despite the negative response of the construction industry to the application of the learning curve theory, several previous investigations proved the importance of its concept to construction productivity.

Abdulaziz investigated the applicability of learning curve theory to rebar fixing labour productivity (1). The objective of the research was to explore the influence of recurring building floor configurations on rebar fixing labor productivity. According to the learning curve theory, labor inputs are expected to decrease by a certain percentage as the cycle number increases. Contrary to the basic principle underlying the theory, the majority of buildings observed exhibited either an increase or a negligible reduction in labor inputs as the cycle number of recurring floors increased.

Long and Hung examined the relationship between floor number and labor productivity of the multistory structural work, focusing on formwork installation and rebar fabrication/installation (2). They found that productivity improvement of the formwork activity stopped more quickly than that of the rebar activity. They explained that it is because the formwork activity was more modular than the rebar activity. The rebar activity in his case study, including reinforcement fabrication and installation, was more labor extensive and less modular. Its productivity levelled off more slowly. This implies that when considering learning effects in construction scheduling and estimating, practitioners should examine the nature of each activity to apply an appropriate learning rate and the number of cycles which learning may take place.

Bogyeong et al. suggested three influence factors of the learning curve effect and the traditional learning curve was modified for high-rise buildings construction(4). The influence factors of task change, adaptation, and vertical transportation time were examined and it was found that these factors can directly or indirectly affect learning development and the manifestation of learning. Additionally, a case study in their work confirmed that the modified learning curve with these three factors is more reliable than the traditional learning curve for high-rise building construction. The applicability and accuracy of the learning curve for the construction industry is expected to be improved on their estimation of labor productivity through their work.

Levente and Attila made an exploratory study to evaluate the predictive capabilities of various learning curve models and data presentation methods for labor-intensive construction operations(5). The study evaluated mathematical models for different learning curves for construction work. Several mathematical models, Wright model, De Jong model and Stanford B model and data presentation method, unit, cumulative average, moving average and exponential average were identified, and each was used for prediction. They concluded that Stanford B model and cumulative average and exponential average give the best future prediction.

Randolph et al. identified five mathematical models and each of these are used to model unit rates for 65 sets of data(6). The correlation between predicted and actual unit rates is determined, and on this basis, it is concluded that the best predictor is a cubic model. According to them, the often cited straight-line model is only marginally adequate. The validity of the straight-line model is further undermined by showing that the learning rate is not a constant value.

2. RESEARCH METHOD AND ANALYSIS

For analyzing the labour productivity while doing repeated tasks, data regarding the number of repetitions, time and no of workers required for each cycle and amount of work done was collected by using a suitable data collection sheet. Ten buildings having more than eight numbers of identical floors are selected. The data is analyzed using the cubic power learning curve modeled in MATLAB. The learning rate was found out for each of the ten buildings. For the activities under study, a new model was developed that can predict the work hour and the progress of the work. Also, the new model was validated. Table 1 shows the characteristics of the projects observed.

A learning curve when plotted on ordinary graph becomes hyperbolic in shape since the amount of cost reduction is not constant. Instead, the amount of decline continually diminishes as quantities double. When the data are plotted on logarithmic coordinates however, the hyperbolic shape transforms into a straight . Such a transformation is useful in correlating with past performances and projecting future costs.

The equation for the cubic learning curve model is:

$$\log Y = \log A - n1 \log X + C(\log X)^2 + D(\log X)^3 \quad \text{----------------(1)}$$

where Y = unit cost or cumulative average cost or man-hours;

A = cost of the first unit, a known value;

n1 = initial logarithmic slope at the first unit, a known value; X = unit number;

C = quadratic factor; and D = cubic factor.

Notice that the factors C and D are unknown. However, their values can be determined as follows. A second data point through which Eqn (1) passes must be known. This point is defined as the standard quantity, Xsp .The logarithmic slope, nsp, at this point must also be known. Eqn (1) can then be expressed in terms of the standard quantity as:

$$\log Ysp = \log A - n_1 (\log Xsp) + C (\log Xsp)^2 + D (\log Xsp)^3 \quad \text{--------------(2)}$$

where Xsp = standard quantity, a standard number of units produced, e.g., 100 or 1,000;
Ysp = unit cost or average cost per unit at the standard quantity, Xsp, a known value;
and nsp = logarithmic slope at the standard quantity, a known value.
The logarithmic slope, nsp, can also be expressed as the derivative of Eqn (2). The form is:

$$dy/dx = nsp = n1 + 2C(\log Xsp) + 3D(\log Xsp) \quad \text{----------------(3)}$$

The values of C and D can be calculated by the simultaneous solution of Eqns (1) and (2). Also the values of n_1, C, D and learning rate can be calculated using suitable coding in MATLAB software.

Table -1: Characteristics of projects observed

Project no	Project type	No of identical floors	Quantity of block masonry work (m^3)
1	Residential	8	83.7
2	Residential	19	89.7
3	Residential	10	150
4	Residential	12	98
5	Residential	8	187
6	Residential	20	170
7	Residential	14	150
8	Residential	18	135
9	Residential	26	80.8
10	Residential	11	150

Table -2: Sample data collected for the study of block masonry work labour productivity.

Floor no	No of workers (per day)	Quantity of work per floor (m^3)	Duration per floor (days)	Work hours (per day)
1	3	83.7	30	8
2	3	83.7	30	8
3	3	83.7	30	8
4	3	83.7	30	8
5	3	83.7	30	8
6	3	83.7	29	8
7	3	83.7	29	8
8	3	83.7	29	8

Table 2 represents the sample data used for modeling the cubic power learning curve model for one of the multistorey building selected for the study. Corresponding parameters of the cubic power learning curve model obtained from MATLAB is tabulated below.

Table -3: Model parameters obtained for each project

Project no	n_1	C	D	Learning rate (%)
1	0.0065	0.0066	0.0018	95.4
2	0.012	0.0078	0.0015	95
3	0.0048	0.0039	0.0008	97
4	0.011	0.002	0.0007	97.9
5	0.0008	0.0046	0.0021	95.2
6	0.014	0.0085	0.0015	94.7
7	0.013	0.005	0.0001	97.4
8	0.0109	0.0033	0.0003	97.7
9	0.037	0.0067	0.0008	95

Using the parameter values obtained for the observed buildings, a new cubic power learning curve model can be developed, which is able to predict the progress of block masonry work in high rise buildings with identical floors. The value of n1, C and D for block masonry work has been arrived from the data analysis of the block masonry work of the nine buildings. In the present study, the values of n1, C and D are obtained as:

n1 = 0.0122
C = 0.00537
D = 0.00106

Total work hour required for completing block masonry work in first floor, A can be found out by the formula

A = Q x K_1 x work hours per day

Where, Q = Quantity of work in m^3.

K_1 = Days of work per m^3.

After the data analysis of nine buildings, it has been observed that the value of K_1 has a range from 0.125 to 0.35. Considering the expert opinion of the top level employees, K_1 has been fixed as 0.175 days per m^3.

Considering 8 work hours per day, A = 150 x 0.175 x 8

= 216 hours.

Table -4: Actual and predicted duration required for block masonry work of project 10

Floor no	Work hour required for the completion of block masonry work		Error
	Predicted value	Actual value	(%)
1	216	216	0
2	214	216	1
3	214	216	1
4	213	216	1.4
5	213	208	2.4
6	213	208	2.4
7	213	208	2.4
8	213	208	2.4
9	213	208	2.4
10	213	208	2.4
11	213	208	2.4

Substituting the values of n1, C, D and A in the general equation, the cubic power learning curve for block masonry work is obtained as

$$\log Y = \log 216 - 0.0122 \log X + 0.00537 (\log X)^2 + 0.0016 (\log X)^3 \quad \text{------------ (4)}$$

Eqn (4) can be used to predict the progress of block masonry work in project 10. Table 4 shows the comparison of actual duration taken for the completion of work and the duration predicted using Eqn(4). It can be observed that the model is able to predict the progress of block masonry work with an error that varies from 0 to 2.4%.

3. Results and discussions

Table 5 summarizes the learning rate of the activity block masonry work in all the apartments considered. It can be observed that the learning rate ranges from 95% to 97%. Almost all the buildings have a significant productivity improvement in block masonry work due to the repeated activity.

Table -5: Learning rate of block masonry work

Project no	No of cycles	Learning rate (%)	Productivity Improvement (%)	Significance
1	8	95.4	4.6	Significant
2	19	95	5	Significant
3	10	97	3	Insignificant
4	12	95.6	4.4	Significant
5	8	95.2	4.8	Significant
6	20	94.7	5.3	Significant
7	14	97.3	2.7	Insignificant
8	18	97.7	2.3	Insignificant
9	26	95	5	Significant

The cubic power learning curve is used to study the relationship between floor number and improvement takes place. The learning curve theory states that the input required for making the same output should decline by a certain percentage. Block masonry work shows a learning rate of 95% to 97%, which means that there is improvement in productivity. i.e.; with the same input, the output is improved. So the findings of the study show the evidence of the applicability of cubic power learning curve in high rise building. Also, the results of validation of model have shown to have better match between the actual and predicted duration. So the model can also be used for predicting the duration in repeated activities and hence can be used for planning.

4. CONCLUSIONS

In construction industry, there are repetitive activities. Productivity for performing these types of construction activities will improve due to additional experience and practice in that type of work. Learning-curve theory has been applied to construction activities due to their labour-intensive and repetitive features. This research explores the relationship between floor number and labour productivity of block masonry work. Nine building having more than eight number of identical floor was selected for the study to find the influence of floor number on labour productivity. The learning rate obtained was 95 to 97% for block masonry work. Lower the learning rate, higher the learning takes place. A cubic power learning curve model was developed for the prediction of progress of work. The model was validated. The findings of the study show that the cubic power learning curve is applicable for the study of labour productivity in high rise buildings having identical floors.

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