International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 04, April-2018

Study of the Applicability of Learning Curve Theory to Recurring Activities of Formwork, Reinforcing Steel Fixing and Concreting

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Abstract— **Construction productivity is one of the most frequently researched topics due to its importance to the viability of the industry. It is regarded as a true reflection of the efficiency and economic success of the operations. the evolution of repetitive scheduling methods led to the introduction of the learning concept in construction planning. It is common knowledge that performing the same activity repeatedly, and in the same conditions, takes less and less time as the activity is repeated. This phenomenon is clear in many construction activities and is known as learning experience or learning effect. The increase in productivity is mainly due to the increasing knowledge acquired by work repetition.In this paper we can determine the learning effect of different construction activities.**

Keywords—Spss, Regression Analysis, Learning Curve

I. INTRODUCTION

Construction is the world's largest and most challenging industry. On average, it contributes one-half of the gross capital and 3% to 8% of the Gross Domestic Product (GOP) in most countries. Productivity, in its most general term, is an economic measure defined as a ratio of output to input. Depending upon the objectives of measurement, numerous definitions and mathematical expressions are encountered. Since productivity is defined as a ratio of output to input, construction productivity can be regarded as a measure of outputs which are obtained by a combination of inputs. One of the most important available construction materials is reinforced concrete. It is used as the structural component for almost all types, sizes and heights of structures. Low and high-rise buildings, bridges, dams, towers, pavements, tunnels, water and wastewater treatment plants are prime examples. Due to the importance of this material to the construction industry, this research focuses on the effects of partial factor buildability, on the labour productivity of major elements and building frames of in situ reinforced concrete construction.

II. OBJECTIVES

1. To identify the major buildability factors influencing labour productivity of the main trades involved in in-situ reinforced concrete buildings, namely, formwork, reinforcing steel fixing and concreting

2. To investigate the applicability of learning curve theory to recurring activities of formwork, reinforcing steel fixing and concreting.

III. METHODLOGY

The datas were collected from five different industries which include the datas for formwork, reinforced steel and reinforced cement concrete. There are some buildability factors which affect productivity, those datas are also collected. Data analysis is the next step, for which the productivity and average labour hours for each floor calculated. After calculating the productivity regression analysis is done by using SPSS software. From this the learning rate is calculated.

IV. LITERATURE REVIEW

J. P. Couto and J. C. Teixeira (2005) explained in their journal named as “Using linear model for learning curve effect on high-rise floor construction”, the evolution of repetitive scheduling methods led to the introduction of the learning concept in construction planning. It is common knowledge that performing the same activity repeatedly, and in the same conditions, takes less and less time as the activity is repeated (Gates and Scarpa, 1972). This phenomenon is clear in many construction activities and is known as learning experience or learning effect. The increase in productivity is mainly due to the increasing knowledge acquired by work repetition. Graphic representation is through a learning curve that admits duration decreases as the activity is repeated, according to a predictable and constant learning rate.

Everett J. G and Farghal S (1994) explained in their journal named “Learning curve predictors for construction field operations”, many repetitive construction field operations exhibit a learning curve, over which the time or cost per cycle decreases as the cycle number increases. This paper evaluates several mathematical models to determine which best describes the relationship between the activity time or cost and the cycle number.

V. CATEGORICAL-VARIABLE REGRESSION

Although linear regression method assumes that the independent variables included in the model are continuous, i.e. quantitative in nature, it is not uncommon to use categorical or qualitative independent variables. Some variables such as, column or slab geometry, layer location of reinforcement or the category of concrete workability, defy explicit quantifications and could be expressed only in a qualitative manner.

International Journal of Engineering Research & Technology (IJERT)
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A multiple regression model may include continuous variables, dummy variables or a combination of both. A typical multiple regression model involves both types of variables is shown below:

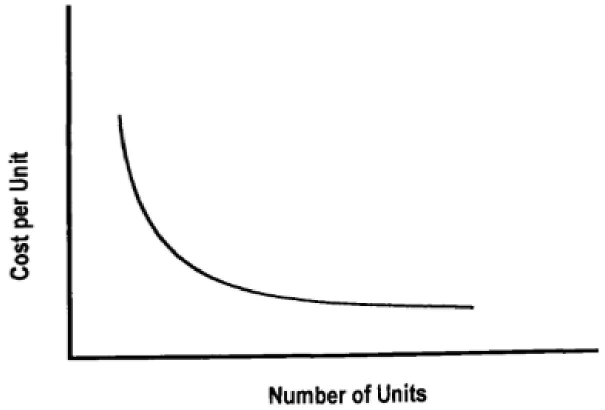
$$Y = b0 + b1X1 + b2D2 \ldots\ldots\ldots\ldots \text{ Equation 1}$$

Where X1 = continuous variable; and D2 = dummy variable. The coefficient of the dummy variable b2 is interpreted as the average difference in the dependent variable Y, between the category coded 1 and the category coded 0 of the dummy variable D2, holding the continuous variable constant.

LEARNING CURVE CONCEPT

A learning curve is a graphical representation of the relationship between unit production time and the number of units produced. The learning curve concept is based upon the premise that individuals, gangs or organisations become more efficient at doing a task when they perform the same task repeatedly. The learning curve concept was first recognised in the aircraft industry when the direct-labour hours required for assembly work were considerably reduced as the task was repeated. In 1936, T.P. Wright disclosed the results of an empirical test showing that as the average number of units produced doubled, the time needed to produce the units decreased at a specific rate .

Many field operations of a repetitive nature may also exhibit the learning phenomenon, in which the time required to complete a cycle decreases as the number of cycles increases. Learning curve data can also be presented in units such as man-hours per cycle, Rupees per cycles and so on, depending upon how the output and input are associated with the observed operation. The learning curve is generated when the time or cost required to complete a cycle of an activity is plotted as a function of the cycle number. A typical learning curve is shown in figure below.



LEARNING CURVE THEORY

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 or cost, decrease. The learning curve theory is based upon a basic principle of human nature: the ability to learn from past experience. The learning process stems from individuals or gangs repeating the same task and gaining skill or efficiency from their own experience or practice. This acquired experience is attributable to: a) increased knowledge about the task being performed; b) greater familiarity with the task; c) improved work organisation; d) better coordination; and e) more effective use of tools and methods. On the other hand, organisational learning results from practice and changes in strategy, procedures and administration.

The learning curve theory states that whenever the production quantity of a product doubles, the unit or cumulative average cost, i.e. man-hours or cost, 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.

The expected range of learning rate for most construction activities falls between 70% and 90%. What this means in simple terms is that if a certain hypothetical activity follows the 70% learning curve, and if the cost to construct the first unit or cycle is 200 man-hours, then it would take 200 x 70% or 140 man-hours/unit on average to construct the next two units and would take 140 x 70% or 98 man-hours/unit on average to construct the next four units, etc. As the number of units or cycles increases, the production rate stabilizes as operatives become completely familiar with the produced task or activity. However, as we have previously indicated, the learning rate remains constant during the whole activity cycles.

VI. DATA ANALYSIS AND RESULTS

A sample of data used to plot the unit learning curve for high rise buildings observed

Table 1 formwork productivity details

F	QUANTITY			LABOUR HOURS			PRODUCTIVITY		
	S	C	B	S	C	B	S	C	B
1	1475	123.4	147	1980	198	440	0.74	0.62	0.33
2	1475	123.4	147	2662	231	440	0.55	0.53	0.33
3	1475	123.4	147	2376	264	396	0.62	0.47	0.37
4	1475	123.4	147	2475	198	330	0.6	0.62	0.45
5	1475	123.4	147	2200	231	440	0.67	0.53	0.33
6	1475	123.4	147	1980	154	352	0.74	0.8	0.42
7	1475	123.4	147	2112	132	264	0.7	0.93	0.56
8	1475	123.4	147	1760	198	440	0.84	0.62	0.33
9	1475	123.4	147	1760	132	352	0.84	0.93	0.42
10	1475	123.4	147	1540	154	352	0.96	0.8	0.42
11	1475	123.4	147	1650	132	264	0.89	0.93	0.56
12	1475	123.4	147	1386	198	385	1.06	0.62	0.38
13	1475	123.4	147	1254	132	308	1.18	0.93	0.48
14	1475	123.4	147	1617	154	308	0.91	0.8	0.48

International Journal of Engineering Research & Technology (IJERT)
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The above table shows the productivity details of slab, column and beam .which is collected from the reputed firm. The table consists quantity and man hour's details corresponding to each floor. Ground floor details are omitted because learning curve depends only on the repeated floors.

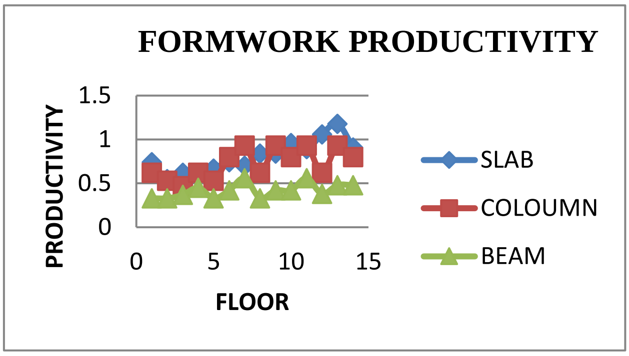

Figure 1 formwork productivity – graphical representation

Table 2 Equivalent work-hours for the use of the straight-line learning model

F	X	CUMULATIVE AVERAGE ELH (Y)			Ln (Y)			Ln(X)
		S	C	B	S	C	B	
floor 1	1	1980	198	440	7.59	5.29	6.09	0
floor 2	2	2321	215	440	7.75	5.37	6.09	0.69
floor 3	3	2339	231	425	7.76	5.44	6.05	1.1
floor 4	4	2373	223	402	7.77	5.41	6	1.39
floor 5	5	2339	224	409	7.76	5.41	6.01	1.61
floor 6	6	2279	213	400	7.73	5.36	5.99	1.79
floor 7	7	2255	201	380	7.72	5.3	5.94	1.95
floor 8	8	2193	201	388	7.69	5.3	5.96	2.08
floor 9	9	2145	193	384	7.67	5.26	5.95	2.2
floor 10	10	2085	189	381	7.64	5.24	5.94	2.3
floor 11	11	2045	184	370	7.62	5.21	5.91	2.4
floor 12	12	1619	163	359	7.39	5.09	5.88	2.48
floor 13	13	1933	181	366	7.57	5.2	5.9	2.56
floor 14	14	1489	154	323	7.31	5.04	5.78	2.64

The above table shows the Equivalent work-hours for the use of the straight-line learning model which is collected from the reputed firm. The table consists of natural log of cycle number and the corresponding cumulative average natural log man hours, and man hours details corresponding to each floor. Ground floor details are omitted because learning curve depends only on the repeated floors.

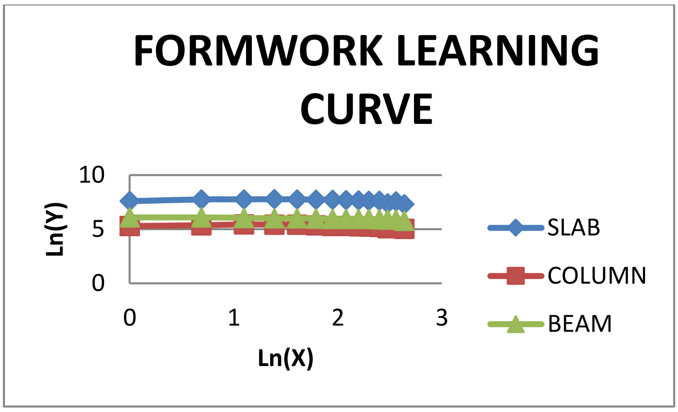

Figure 2 formwork learning curve

The unit straight-line learning curve shown in figure is fitted using simple linear regression. The overall regression model and coefficients statistics are tabulated and learning rate was calculated.

The straight-line unit model is expressed as a power function in the following form

$Y = T * X^b$

From the regression result

Constant = 7.632; b = -0.893

The learning rate (S), expressed as a percentage, is quantified by substituting the slope (b)

$S = (2^b) * 100$

$S = (2^{-0.893)}*100 = 53.84\%$

$Y = T * X^b$

$T = e^{7.632} = 2063$

Therefore, the standard power function format of the learning curve of this sample project is quantified as shown below:

Man – Hours= 2063* $CycleNo^{-0.893}$

In view of the results presented for this project, it can be seen that despite the repetition of the observed floors, the formwork activity did exhibit any significant productivity improvement as the cycle number of the monitored floors increased. According to the learning curve theory, the lower the learning rate, the higher the amount of productivity improvement. Consequently, the quantified learning rate of 78.94 % indicates that basically no productivity improvement has taken place in the process of forming identical recurring floors but 34.77% indicates that a significant productivity improvement taken place in the process of forming identical recurring floors. The quantified learning rate of productivities of slab, column and beam are tabulated below. All the values are greater than 30%. So a significant productivity improvement is taken place because of the identical plans in the floors.

Table 3 learning rate of productivity

Productivity	Learning Rate
Formwork Productivity Of Slab	53.84%
Formwork Productivity Of Column	61.77%
Formwork Productivity Of Beam	67.68 %
Steel Productivity Of Slab	42.95%
Steel Productivity Of Column	53.25%
Steel Productivity Of Beam	78.94%
Concrete Productivity	34.77%

VII. CONCLUSION

In today's economic conditions, there is widespread consensus that design is becoming increasingly important in determining competitiveness. The learning curve theory is based upon a basic principle of human nature: the ability to learn from past experience. Many field operations of a repetitive nature may also exhibit the learning phenomenon, in which the time required to complete a cycle decreases as the number of cycles increases. Learning curve data can also be presented in units such as man-hours per cycle, Rupees per cycles and so on, depending upon how the output and input are associated with the observed operation. The learning curve is generated when the time or cost required to complete a cycle of an activity is plotted as a function of the cycle number. From this research , we can concluded that ther is a productivity improvement has taken place on identical floors.

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