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

Anjali Narayanan K M
Civil Engineering
Cochin College of Engineering and Technology
Valanchery, India

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 (GDP) 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. METHODOLOGY
The data was collected from five different industries which include the data for formwork, reinforced steel and reinforced cement concrete. There are some buildability factors which affect productivity, those data 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 “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.
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:

\[ Y = b_0 + b_1X_1 + b_2D_2 \]  

Equation 1

Where \( X_1 \) = continuous variable; and \( D_2 \) = dummy variable.

The coefficient of the dummy variable \( b_2 \) 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 \( D_2 \), 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 Graph](image)

**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 learning achieved.

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**

<table>
<thead>
<tr>
<th></th>
<th>QUANTITY</th>
<th>LABOUR HOURS</th>
<th>PRODUCTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>C</td>
<td>B</td>
<td>S</td>
</tr>
<tr>
<td>1</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>2</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>3</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>4</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>5</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>6</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>7</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>8</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>9</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>10</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>11</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>12</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>13</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
<tr>
<td>14</td>
<td>1475</td>
<td>123.4</td>
<td>147</td>
</tr>
</tbody>
</table>
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.

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

\[ Y = T \cdot X^b \]

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)

\[ S = (2^b) \cdot 100 \]

\[ S = (2^{-0.893}) \cdot 100 = 53.84\% \]

\[ Y = T \cdot X^b \]

\[ T = e^{7.632} = 2063 \]

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

\[ \text{Man – Hours} = 2063 \cdot \text{CycleNo}^{-0.893} \]

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 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.
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

<table>
<thead>
<tr>
<th>Productivity</th>
<th>Learning Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formwork Productivity Of Slab</td>
<td>53.84%</td>
</tr>
<tr>
<td>Formwork Productivity Of Column</td>
<td>61.77%</td>
</tr>
<tr>
<td>Formwork Productivity Of Beam</td>
<td>67.68%</td>
</tr>
<tr>
<td>Steel Productivity Of Slab</td>
<td>42.95%</td>
</tr>
<tr>
<td>Steel Productivity Of Column</td>
<td>53.25%</td>
</tr>
<tr>
<td>Steel Productivity Of Beam</td>
<td>78.94%</td>
</tr>
<tr>
<td>Concrete Productivity</td>
<td>34.77%</td>
</tr>
</tbody>
</table>

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 there is a productivity improvement has taken place on identical floors.

REFERENCES