INTRODUCTION

The concept of the learning curve was introduced to the aircraft industry in 1936 when T. P. Wright published an article in the February 1936 *Journal of the Aeronautical Science*. Wright described a basic theory for obtaining cost estimates based on repetitive production of airplane assemblies. Since then, learning curves (also known as progress functions) have been applied to all types of work from simple tasks to complex jobs like manufacturing a Space Shuttle. Wright theorized that this phenomenon occurred primarily because the time required to perform a repetitive task will decrease each time the task is repeated. Wright’s “Learning Curve” theory has become widely used because it is simple and applicable to a broad range of industries and situations. Subsequent research in the late 1940’s by James R. Crawford confirmed Wright’s observations and led to the unit theory of the learning curve, which will be discussed in this note.

The theory of learning is simple. It is recognized that repetition of the same operation results in less time or effort expended on that operation. For the Wright learning curve, the underlying hypothesis is that the direct labor man-hours necessary to complete a unit of production will decrease by a constant percentage each time the production quantity is doubled. If the rate of improvement is 20% between doubled quantities, then the learning percent would be 80% (100-20=80). While the learning curve emphasizes time, it can be easily extended to cost as well.

LEARNING CURVE THEORY

The unit theory of the learning curve states that as the quantity of a product produced doubles, the recurring cost per unit decreases at a fixed rate or constant percentage. The best way to understand this theory is to look at the following example.

The XYZ Widget Co. has gathered the following data on production costs of its new Super-Widget:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Recurring Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1000</td>
</tr>
<tr>
<td>2</td>
<td>$ 800</td>
</tr>
<tr>
<td>3</td>
<td>$ 702</td>
</tr>
<tr>
<td>4</td>
<td>$ 640</td>
</tr>
<tr>
<td>5</td>
<td>$ 596</td>
</tr>
<tr>
<td>6</td>
<td>$ 562</td>
</tr>
<tr>
<td>7</td>
<td>$ 535</td>
</tr>
</tbody>
</table>

Learning Curve Theory
From this data, we can see that as the production quantity doubled from Unit 1 to Unit 2, the recurring unit cost decreased by $200, or 20% of the Unit 1 cost of $1,000. Note also that as the production quantity doubled from Unit 2 to Unit 4, the recurring unit cost decreased by $160, which is also a 20% decrease from the previous recurring unit cost of $800 for Unit 2. Based on this data and the learning curve theory, XYZ predicts that the recurring unit cost for Unit 8 will be 20% less than that of Unit 4, or $512.

Plotted on an arithmetic graph (Figure 1), this data takes on a curved shape, hence the term “learning curve”.

![Figure 1](image)

The learning curve described in this example is called an “80% learning curve”, since the cost of a particular unit of production is 80% of the cost of the unit exactly half-way back in the production sequence. For example, just as Unit 4’s cost ($640) is 80% of Unit 2’s cost ($800), so Unit 8’s cost should be 80% of Unit 4’s cost, or $512.

The mathematical equation that describes the unit learning curve theory described above is:

\[ Y_X = AX^B \]

where \( Y_X \) = Cost of Unit X

\( A \) = Cost of Unit 1

\( B \) = \( \frac{\log \text{(learning curve slope)}}{\log(2)} \)
The most straightforward application of the Learning Curve Theory can be done where the following conditions exist:

1. Uninterrupted serial production (i.e., no production breaks),
2. Consistent product design, and
3. Management emphasis on productivity improvement.

These conditions promote the behaviors underlying the decline of unit cost with increased production quantities:

1. Worker familiarization with the required tasks (learning), and
2. Process improvements resulting from experience with the tasks (e.g., more efficient layout of assembly line; simplification of methods sheets; reduction of rework, repair, and scrap; improved parts bin accessibility; and new or improved tooling).

APPLYING LEARNING CURVE THEORY TO SYSTEM ACQUISITION

Learning curve theory should be applied to the touch labor portion of the production portion of a system’s cost estimate but learning curves can also be applied to costs if the costs have been normalized to the same economic (or base) year. This type of learning curve is sometimes referred to as a “cost improvement curve”. The challenge is in determining the appropriate learning curve to use for a particular system. Ultimately, the only way to know the “true” learning curve for a particular system is to observe it after the fact. However, this is not useful when cost estimates and resource plans must be submitted years in advance of production. Therefore, most estimators will use historical data from other similar type systems to estimate the learning curve of the new system.

Caution should be applied to simple straightforward use of historical learning curve data, however. The primary concern should be how well the historical data reflects the expected production conditions for the new system. To the extent that such production conditions differ from the past, the analyst should attempt to quantify the effects of those differences on the historical learning curve.

Some examples of production conditions that can affect a system’s learning curve:

1. **Manufacturing methods and processes.** The less “touch” labor involved in a production process (i.e., more automation), normally the **flatter** will be the learning curve (i.e., the value of the learning curve will tend to be higher). Thus, if the historical learning curve is 85% and the manufacturer intends to automate the production more than in the past, we would expect the learning curve for the new process to be something greater than 85% (e.g., 90%).

2. **Item complexity.** The more complex an item, normally the **steeper** the learning curve. This is because there are more opportunities to improve the production process and more for workers to learn. Thus, if a historical item experienced a 93% learning curve, a new and more complex item of the same type would be expected to have a learning curve of less than 93% (e.g., 88%).
3. **Workforce stability.** The higher the turnover rate of the workforce, normally the flatter will be the learning curve; this occurs because productivity increases achieved by the average worker is inhibited by turnover in the workforce.

4. **Production breaks.** Interrupting production can lead to changes in the historical learning curve. For example, after a break in production there will usually be new workers assigned to the job or there may be a lack of experienced veterans to train new workers on the job; both conditions result in a flatter learning curve, at least initially, compared to the historical learning curve. In addition, even if a production break does not actually change the learning curve itself, the break will likely change where you are on the learning curve, as the workers tend to have lost some of their skills. Thus, if the production process had a 90% learning curve and 799 units were produced prior to the production break, the first unit after the production break (Unit 800) is unlikely to cost 90% of the cost of Unit 400, as would have been expected without the break. Instead, Unit 800 may cost the same as some prior unit (e.g., Unit 700). In this case, we have effectively *lost* 100 units for the purposes of gaining the benefits of the learning curve, which then restarts with Unit 700.

It should also be noted that a system may not experience the same learning curve during its entire production run, depending on changes in conditions during the production run.

**SUMMARY**

Learning curve theory states that as the quantity of a product produced doubles, the recurring cost per unit decreases at a fixed rate or constant percentage. A learning curve should be applied to the production portion of a system’s cost estimate. This learning curve may be derived from actual observation of the production line or by analogy to similar systems that have previously been produced.

For further information on learning curves, see the NASA cost estimating online handbook:

http://cost.jsc.nasa.gov/learn.html