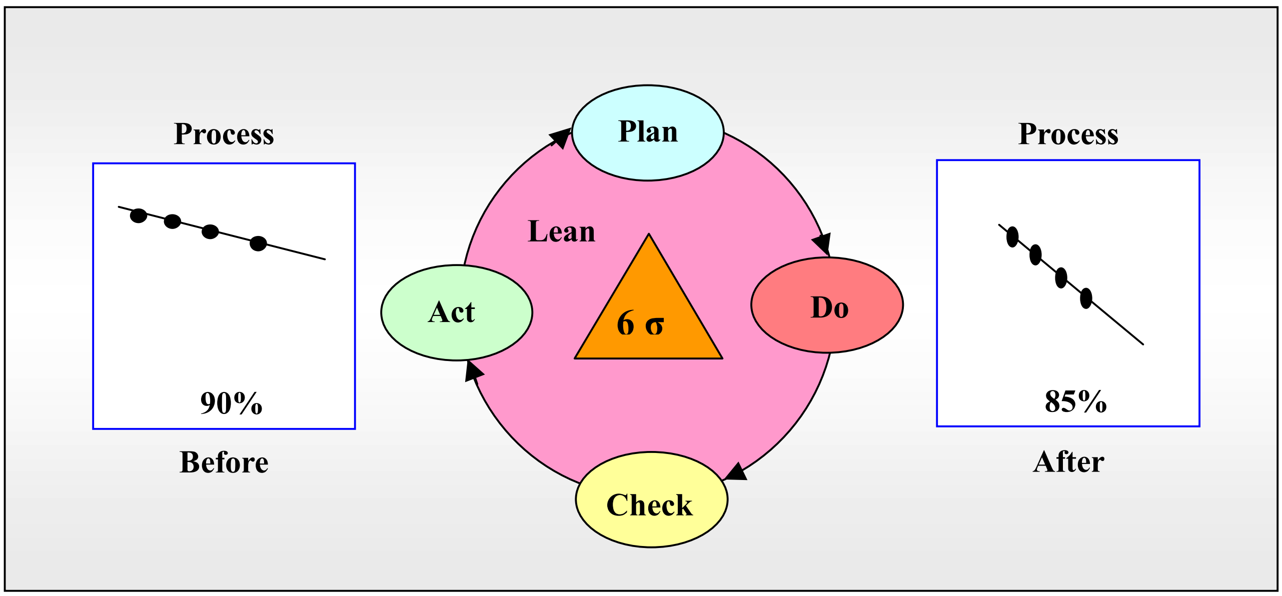
A Nifty Way to Assess Progress and Set Goals for Continuous Improvement

by

Tim Archer



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A Nifty Way to Assess Progress and Set Goals for Continuous Improvement

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This paper discusses the application of Learning Curve Theory to Continuous Improvement activities. This powerful but simple and inexpensive tool can help teams stay focused and on track by providing a means to assess improvements and set goals. Learning Curve Theory has been used extensively in areas like aircraft manufacturing, but can be applied to any activity for which Continuous Improvement is feasible. Learning Curves can also save time and money! Find out the beauty of the Learning Curve and a simple 5-step methodology to assess your project and set goals. Read on.

1. "Is setting goals and assessing progress a time-consuming, expensive, and dreaded activity in your team?"

When your team attacks a lean project and after you've selected an area for attention, do you spend a lot of time on these types of issues?

- "How much improvement is feasible for this area?"
- "How long is the analysis phase going to take? How much will it cost?
- "What's the performance history of this area?
- "We slashed 10% off the cycle time. Is that good? How good is it?"
- "We only cut these costs by .4%. Is that a failure?"
- "We only have x dollars to spend. Is that enough to collect all the data we need?"

Sometimes its even harder to set goals after a process has been scrubbed for Lean. Wouldn't it be nice to have a benchmark that's easy to calculate and only needs a few pieces of data? Take a look at Learning Curve Theory. See if it can apply to your project. You will find it is:

- Easy to understand
- Applies to almost any activity that can be continuously improved
- Has minimal data requirements, and
- Is surprisingly accurate

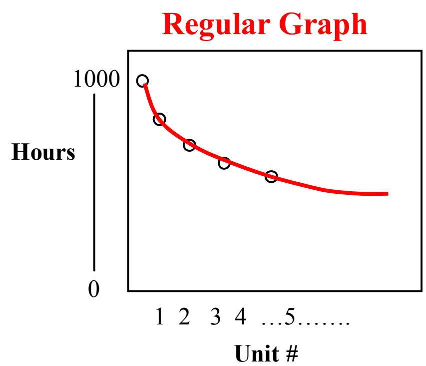
The following will discuss the technical aspects of Learning Curves and provide a methodology for incorporating Learning Curve Theory into your Lean and/or Six Sigma projects to assess progress and set goals.

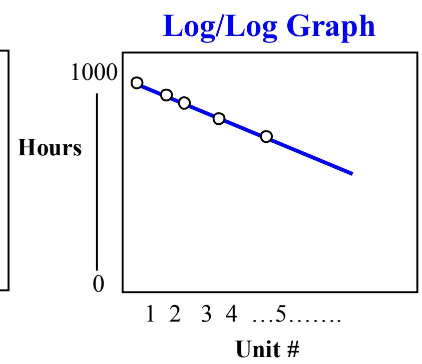
2. "What is Learning Curve Theory?"

Learning Curve Theory was developed primarily by observing real manufacturing processes and developing a mathematical model for the observed phenomena of Continuous Improvement. Early researchers (notably Wright and Crawford) noticed that improvements in labor hours occurred as the process matured and workers "learned" how to do the tasks more efficiently. These researchers noticed that when a plot is made of production unit numbers versus labor hours on log/log graph paper, a straight line could be drawn between the points (see below). This points to an exponential type of relationship between experience (learning) and improvement.

Data

Unit	Hours
1	1000
2	900
3	846
4	810
Etc,	……..





Other observations were that as production doubles, the labor resources are reduced by a fixed percentage. This percentage is the learning factor. So, say Unit 1 costs 1000 hours, Unit 2 is 900 Hours, Unit 4 is 810 Hours, Unit 8 is 729 hours, etc. The learning factor is 90%. This is a 90% Learning Curve. Based on these observations, an equation was formulated to express these relations mathematically. The Learning Curve Equation is:

$$\mathbf{Y_N = KN^{(\ln C/\ln 2)}}$$

Where:

- $\mathbf{Y_N}$ is the amount of resource* for the N^{th} unit produced,
- **K** is a constant representing the amount of resource assigned to the first unit produced,
- **N** is the sequential production number (also referred to as the cumulative number of units produced),
- **lnC** is the natural logarithm of the learning curve improvement percentage (**C** is the learning curve percentage expressed as a decimal and is < or = to 1), and
- **ln2** is the natural logarithm of 2.

Note: either the natural logarithm (ln) or the base 10 logarithm (log) can be used in the equation as long as it is done consistently.

* Resource can be any measurable characteristic that you want to improve: e.g. labor hours, number of defects, cycle times, costs, incidents, etc.

In our example of a 90% Learning Curve, the resource for unit 3 is calculated as:

$$
\begin{aligned}
Y_3 &= (1000)(3^{(\ln(.90)/\ln 2)}) \\
&= (1000)(3^{(-.1053/.6931)}) \\
&= (1000)(3^{-.1519}) \\
&= (1000)(.846) \\
&= \underline{846}
\end{aligned}
$$

This type of Learning Curve is based on a Unit Learning Curve Model. There is another type of model that is based on cumulative averages. The cumulative average model was once popular because an analyst could easily estimate cumulative costs over certain periods of time with only a few calculations (some may argue that it is also a better technical model). Both models use the same power equation with one exception. For the parameter $\mathbf{Y_N}$, the Unit Model uses per unit data, and the Cumulative Average Model uses cumulative averages of unit data. A comparison of these different data relationships is shown below.

Column A is used with both Models **A=N**

A	B	C	D
Production Unit	Unit Data	Cumulative Data (Running Total of B)	Cumulative Average Data (C/A)
1	1000	1000	1000
2	900	1900	950
3	846	2746	915.3
4	810	3556	889

Enter Columns A and B when using the Unit Model **$B=Y_N$**

Enter Columns A and D when using the Cumulative Average Model **$D=Y_N$**

Different LC Models Use Different Input Data

The Unit Model will be used throughout the following discussions as the calculations for Unit Targets are somewhat simplified. Either model will perform satisfactorily in most situations.

3. "Can you see the beauty of the Learning Curve?"

The beauty of the learning curve is that it only has three variables: The Learning Rate, the Number 1 Unit's resource figure, and the Number of the Unit of interest. That's it! – just three variables! Here is how to determine what these variables are:

- Learning rate (**C**) – this can be chosen based on experience with other similar processes or determined empirically by fitting a curve to the data:

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  - Choose by similar process or guideline – Below is a guideline based on process type

Table 1. LC Guidelines

Process Type	LC Rate Factor
Labor Intensive	80%
Balanced (Labor and Automation)	85%
Highly Automated	90%

  - Fit a curve to your data. -This is the best approach if there is actual production unit data available. This is accomplished by using linear regression on the logarithmic version of the learning curve equation.

    (This is for do-it-yourselfers!)

    Taking the logarithm of both sides:

    (1) $\ln(Y_n) = \ln(K)+(\ln(C)/\ln(2))(\ln(N))$

    (2) Let: $y= \ln(Y_n)$; $b= \ln(K)$; $m= \ln(C)/\ln(2))$; and $x=(\ln(N))$

    Rearrange terms and substitute:

    (3) $y = mx + b$; the equation for a straight line.

    Since the equation is now in the form of a straight line, linear regression can be used to find estimates of **b** and **m** by plugging in the known **y**'s and **x**'s (Logarithms of Y_n and **N**). With estimates for **m** and **b**, **C** and **K** can be solved for from the equations in line (2) above. It is fairly easy to set this up on a spreadsheet or scientific calculator. Log/log paper and a special learning curve protractor to estimate the slope can also be used. (This is how I did it at Learjet many moons ago.)

    (This is the fast and easy way)

    Or even easier, just use a learning curve calculator like the Free ***Learning Curve Fitting Tool*** from Archer Tools. Simply input data pairs and press a button. This tool is used in the following examples. [http://www.theindustrialanalyst.com/analysis_software/learning_curve_software.htm]

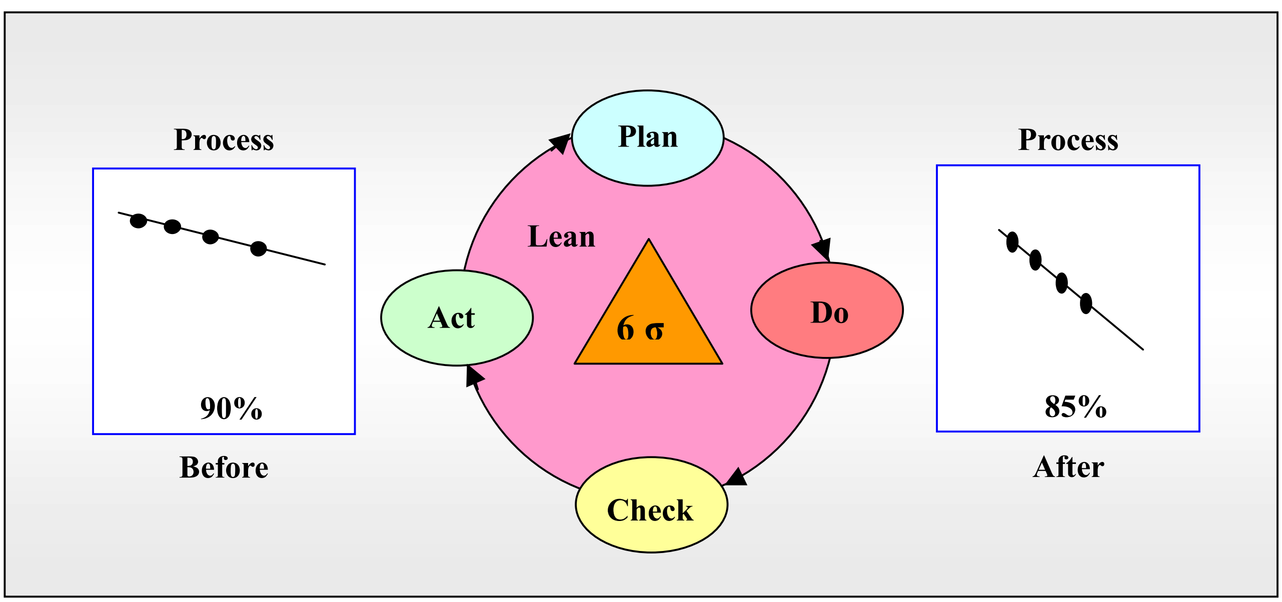
- Number 1 Unit's Resource – This can come from actual data or from data from a similar process, or if there is data on the nth unit and a Learning Rate has been selected, it can be calculated from the Learning Curve Equation. The parameter (**K**) is also estimated when linear regression is used to fit a curve to the data.

- The nth Unit of interest. This is up to the analyst. Once the two previous parameters are identified, the unit resource estimates can be calculated over a range of Units. Just plug in sequential unit numbers and calculate target estimates. This can also easily be done using a spreadsheet. For the following examples, Archer Tools' ***Target Generator Tool*** will be used.

4. "How can we use Learning Curve Theory in our Lean and/or Six Sigma Projects?"

Consider the status of a process before applying Lean or Six Sigma tools. It will usually have its own inherent Learning Curve similar to that presented in Table 1, because the effects of learning and improvement are, to some degree, inherent in all human activities. Consider what the goals of Lean and/or Six Sigma projects are. The main goal is to eradicate non-value added activities and speed up cycle times (Lean), eliminate variability (Six Sigma), and create an environment of Continuous Improvement.

From the point of view of Learning Curve Theory, these improvement methodologies can be interpreted as systematic means to shift a process's inherent learning curve, which may be sub-optimal, to an optimal learning curve. Suppose a process exhibits an inherent Learning Curve of 90%. By applying our Lean and Six Sigma methodologies (and Dr. Deming's Improvement Cycle) we should move the process to an 85% Learning Curve as shown below.



Improvement Methodologies Affect Process Learning Curve

Table 2 shows guidelines for improvement goals based on the inherent Learning Curve of the process under study. This can either be assessed based on the guidelines of Table 1 or by using a Learning Curve based on actual data. The latter is preferred.

Table 2. LC Goals for Improvement Projects

Project Type	**LC Rate Factor Goal***
Aggressive Improvement Goal	Minus 5-10%
Moderate Improvement Goal	Minus 2-5%
Modest Improvement Goal	Minus 0-2%
* This is deducted from either the appropriate LC Rate in the table above or from your LC Rate calculated from actual data.	

The methodology for establishing the goals for the new "optimized" learning curve is summarized as:

1. Determine the inherent Learning Curve of the process under study:
    a. Use guidelines of Table 1, or
    b. Fit a Learning Curve to actual data (preferred)
2. Select a Learning Curve Rate Factor Goal from Table 2 based on your overall goal for your project type
3. Subtract the % goal from step 2 from your inherent goal. This is the target for your "optimized" Learning Curve.
4. Before this new learning curve can be used, the #1 Unit's Resource parameter must be normalize so the curve passes through the last known unit value at Unit N. This is done by solving the equation:

$$K = Y_N / N^{(\ln C / \ln 2)}$$

Where **K = (optimized Learning Curve #1 Unit parameter)**
Y_N = (last known unit value at Unit N)
N = (the cumulative number of the last production unit)
C = (optimized Learning Curve rate factor as decimal)

5. Using the new parameters **K** and **C**, generate new targets for your Continuous Improvement project starting at, or near, **N** (last production unit) and continue on for all units of interest.

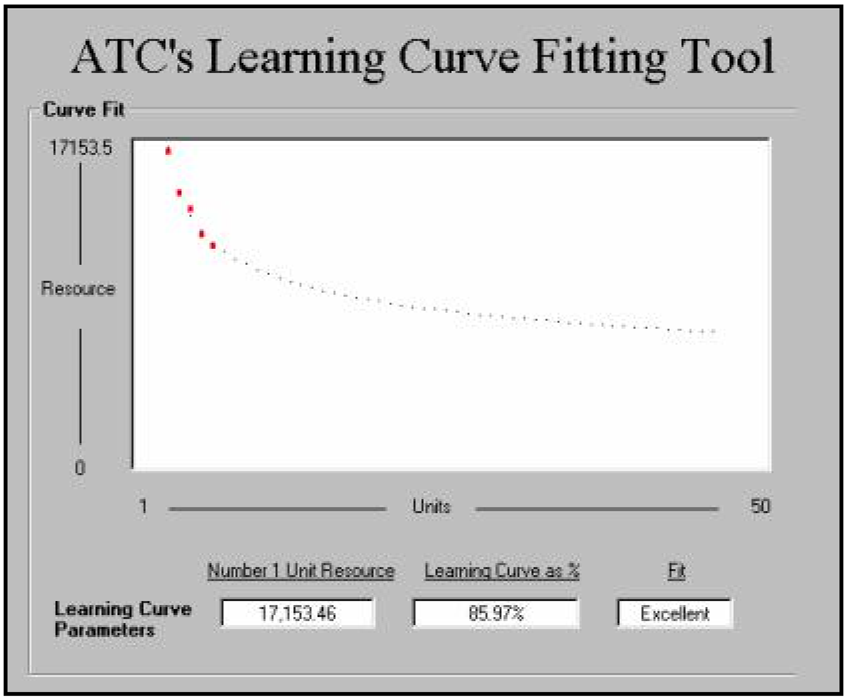
So there you have it - only five steps, three parameters, and two teeny tables. You now have some reasonable targets to measure your project's progress by! Let the process run for a while and fit a new curve to the new data. If the process is on track, the new calculated curve should be close to your target. If not, re-assess, take corrective action, if necessary, and try again. Another advantage of fitting a curve to the data is that anomalies often show up as points far away from the calculated curve indicating a spot to perform additional analysis.

5. "May we see an example?"

Suppose we have a Lean project where we want to improve a tail cone assembly in an aircraft production facility. There have been 5 units built to date, and we are lucky enough to have some raw data on costs as shown below.

Production Unit	Unit Cost
1	$17,008
2	$14,791
3	$13,874
4	$12,507
5	$11,976

We use our ***Learning Curve Fitting Tool***, input the data, press a button, and …



.... we have the Learning Curve parameters for this activity.

We want to set a moderate improvement goal for this activity so we choose a 5% improvement on the 85.97% current Learning Curve. This becomes our 80.97% goal. Assuming it will take several more units for us to analyze the process and implement our lean tools, what should costs look like from Unit 8 and on if we actually move this process onto an 80.97% improvement curve? Let's assume Unit 7's costs are $11,345.

First we have to solve for the Number 1 Unit's resource of our new curve based on the last production unit's cost. This is needed to normalize the new curve so it passes through the last unit's cost. The original Number 1 Unit's cost (**K**) cannot be used, because the resulting curve would not pass through the correct starting value of the new sequence. If calculated by hand, this is just:

$$\begin{aligned} \mathbf{K} &= \mathbf{Y_N/N^{(lnC/ln2)}} \\ &= \mathbf{11{,}345/7^{(ln(.8097)/ln(2))}} \\ &= \mathbf{11{,}345/7^{-.3045}} \\ &= \mathbf{\underline{20{,}518}} \end{aligned}$$

Now we use our handy ***Target Generator Tool*** to input these parameters and…

Targets	Main Target
% of Master	**100**
Number 1 Unit Resource	20519
Learning Curve as %	80.97
Unit Prefix	Unit
Starting Unit	8
Ending Unit	15
Generate Targets	Clear Targets
Unit Heading	Main Heading
Units	Tailcone
Unit - 8	10,892.53
Unit - 9	10,508.74
Unit - 10	10,176.90
Unit - 11	9,885.75
Unit - 12	9,627.24
Unit - 13	9,395.40
Unit - 14	9,185.73
Unit - 15	8,994.74

… we have the Continuous Improvement goals for our project.

If we meet these goals, we have successfully moved our process to a steeper path of Continuous Improvement. If not, we look for anomalous points, re-assess our improvement projects, take corrective action and try again.

I have used Learning Curves to assess many activities and have found that, for a minimal investment in time and only a small data set, the results are surprisingly accurate and provide good information about your process. I've even used it with unit production that is customized from unit to unit using a simple model where the costs consist of two elements: an element that is indeed on an improvement curve that corresponds to the similarities of the units and an element that corresponds to a custom package that does not exhibit an improvement curve because each unit is different.

An example is a car with different special order interiors and paint. All the frames, engines, doors, gas tanks, trunks are made the same, but the upholstery and paint vary from unit to unit. Learning curves can be used on the standard part and then add in estimates for the options based on whatever estimation technique is applicable. In my applications, I would use a simple categorization of complexity like Low, Medium, and High. Then, I would assign option types based on statistical data. This worked much better than trying to estimate each item separately from scratch and was surprisingly close to actual results. I'm sure you can come up with your own creative ways to incorporate Learning Curves with your project goals.

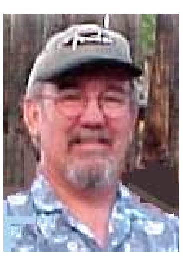
6. "So what are the key points to remember?"

The basic points to remember are:

- Learning Curve Theory can be used to assess progress and set goals for Continuous Improvement projects
- The mathematics is simple: There are only 3 variables! You can do-it-yourself or use handy tools like the ***Learning Curve Fitting Tool w/ Target Generator.*** [http://www.theindustrialanalyst.com/analysis_software/learning_curve_software.htm]
- Data collection is easy: You can use a simple guideline or actual production information.
- The methodology is simple: There are only 5 easy steps.
- The assessment of improvement in a process is easily quantified with one simple statistic – The Learning Rate (**C**).
- The goals generated are based on a rational approach based on real life data and are much better than arbitrary goals and guesses.

Learning Curve Theory, with the methodology presented in this paper, is really a nifty way to assess and set goals for Continuous Improvement programs. It is quantitative, based on facts, and inexpensive to implement. Try it!

Any questions or comments on this paper can be addressed to the author.



About the author: Mr. Tim Archer is the current Managing Member of The Archer Tool Company, LLC. He holds a B.S. in Systems Engineering from the University of Arizona and an M.S. in Industrial Engineering from New Mexico State University. He has over 20 years of experience in Systems and Industrial Engineering and has been a staff engineer for a number of high-tech organizations including Learjet, National Semiconductor, and White Sands Missile Range. He makes his home in Las Cruces, New Mexico in the beautiful Mesilla Valley.

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