Improvement Curves: An Early Production Methodology

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Choice Of Learning Slope Selection Is Critical Parameter In Manufacturing Labor Estimates. Incorrect Ex Ante Predictions Lead to Over or Understatements of Projected Hours.
Issues With Choosing Slopes

“[In general, the empirical findings caution against simplistic uses of either industry experience curves or a firm’s own progress curves. Predicting future progress rates from past historical patterns has proved unreliable.”](pg. 237) - Dutton, Thomas (1984)

“Even with both an excellent fit to historical data (as measured by metrics like $R^2$), and meeting almost all of the theoretical requirements of cost improvement, there is no guarantee of accurate prediction of future costs.”

“...[E]ven projections based on producing an almost identical product over all lots, in a single facility, with large lot sizes, and no production break or design changes, do not necessarily yield reliable forecasts of labor hours. Out-of-sample forecasting using early lots to predict later lots has shown that, even under optimal conditions, labor improvement curve analyses have error rates of about +/- 25 percent.” (pg. 94)

- RAND (2008)

Existing Literature Provides Little Guidance On Ex Ante Selection
S-Curves

• Observed Learning Curves Are Rarely Straight Logarithmic Functions But Exhibit “S” Shape Depending On Maturity Of Product

Initially Observed Based On World War II Experience (Carr, 1946)
Early Production Issues

- Choice of Learning Curve Slope Is Particularly Difficult In Early Production When There Is Limited Actual Cost History

- Development Actuals Are High & Observed Slopes Usually Very Flat

- Early Production Actuals Begin Sharp Decrease As Initial Problems Are Being Worked In the Build
  - Engineering Changes / Corrections
  - Tooling Changes / Improvements
  - Reduction In Nonconformances (Scrap, Rework & Repair)
  - Supply Chain Disruptions Overcome

- Problem For Estimating:
  - What Kind Of Learning Curve Slope Can We Expect To See?
  - How Long Will This Steep Phase Last?
  - If We Are On A ‘Recovery’ Slope, What Are We Are Recovering To and How Quickly?
S-Curve & Basic Slopes

- Cochran (1960) Suggested A Straight-Line ‘Basic’ or ‘Characteristic Slope’ Whose Total Cost Equals Total Cost For S-Curve
## Basic Slopes

<table>
<thead>
<tr>
<th>Processes</th>
<th>Typical Slope %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job Machine Shop¹</td>
<td>95%</td>
</tr>
<tr>
<td>Sheet Metal Stamp¹</td>
<td>92%</td>
</tr>
<tr>
<td>Composite Automated Layup³</td>
<td>92%</td>
</tr>
<tr>
<td>Electrical Fabrication²</td>
<td>90%</td>
</tr>
<tr>
<td>Job Machining – Large Parts¹</td>
<td>88%</td>
</tr>
<tr>
<td>Electrical Subassembly²</td>
<td>85%</td>
</tr>
<tr>
<td>Composite Handlay³</td>
<td>85%</td>
</tr>
<tr>
<td>General Subassembly¹</td>
<td>83%</td>
</tr>
<tr>
<td>Major Aircraft Assembly¹</td>
<td>80%</td>
</tr>
</tbody>
</table>

Sources:

¹Cochran (1968)
²Delionback (1975)
³Kassapoglou (2013)
S-Curve vs Basic Slope

• Unit Cost On S-Curve Is Initially Larger Than ‘Basic Slope’
  – Extensive Changes To Engineering, Tooling As Well As High Nonconformance Drive Cost Of Early Units

• S-Curve Recovers To ‘Basic Slope’ After Initial Engineering, Tooling Issues Are Resolved
  – Cochran Suggested Crossover Point Occurred Around 30th Unit
  – Empirical Analysis Shows Recovery Between 30th And 100th Unit

Cost of Early Units Reflects Premium Due To Engineering, Tooling Changes & High Levels of Scrap & Rework

Crossover Point Where S-Curve Unit Cost Equals Basic Slope Unit Cost
S-Curve vs Basic Slope (Cont’d)

- S-Curve Continues Underneath ‘Basic Slope’ Until Two Lines Intersect Again At Some Future Point (Unit # 1000 For Aircraft Assembly)
  - T-1000 Chosen As Point Of Full Product & Process Maturity

- **Total Cost For Basic Curve = Total Cost For S-Curve Over 1,000 Units**
S-Curves & Basic Slopes Can Be Constructed Ex Post From Actual Data… But How Do We Identify Them Ex Ante?
Using Standards

• One Possible Answer Is Use Of Industrial Engineering Standards

• Standard – Time Necessary For A Qualified Workman, Working At An Efficient Pace and Experiencing Normal Durability & Delay, To Do A Defined Amount Of Work of Specified Quality Using Standardized Processes & Procedures

• Types of Standards Defined By MIL-STD-1567A
  – Type I – Defined by Engineering Time Study (4M) or Work Sampling
  – Type II – All Other Kinds of Standards

• New Automated Tools To Apply Standards Allow Earlier Introduction Of Type I Standards Into Program
  – At Much Lower Cost Than 1980s-Style MIL-STD-1567A Implementation
Standards-Based Approach

• Determine Standard Hours For a Task and Draw This As the “Floor” Below Which the Estimate Cannot Go
  – Type I Standards Are Better For This Approach Than Type II

• Determine Assumed Realization at T-1000 (Aircraft Assembly)
  – Realization Is Expected or Observed Actual Variation To Standard
  – This Value Is Usually Known From Prior Programs
Standards-Based Approach

• Draw a Line From T-1000 Back To T-1 Using the Appropriate “Basic Slope” Suggested By Cochran Or By Empirical Study
  – I.e., Major Aircraft Assembly – 80%

• This Is The “Basic Slope” To Which You Tend To Recover Over Time
  – At Any Given Time, The Actual Hours May Be Higher or Lower…Especially Early In The Program, When The Actual Hours Will Tend To Be Higher
Example Curve Projection

- Actual Hours
- Recovery to Basic Slope
- Basic 80% Slope
- Assumed Point Where S-Curve & Basic Slope Meet
- Variance Factor = 2 (Actuals / Standards)
- T1000 Hours
- Standard Hours

NOTIONAL
Conclusions

• Use Of I.E. Standards As Floor To Establish Basic Slope Provides Empirical Basis For Choosing “And-On” Learning Curves

• Basic Slopes Can Be Derived From Industry Experience Or Prior Program Data

• Approach Can Be Used As “Cross-Check” To Verify Projected Learning Curve Slopes
References

References (cont’d)


