Improvement Curves: An Early Production Methodology

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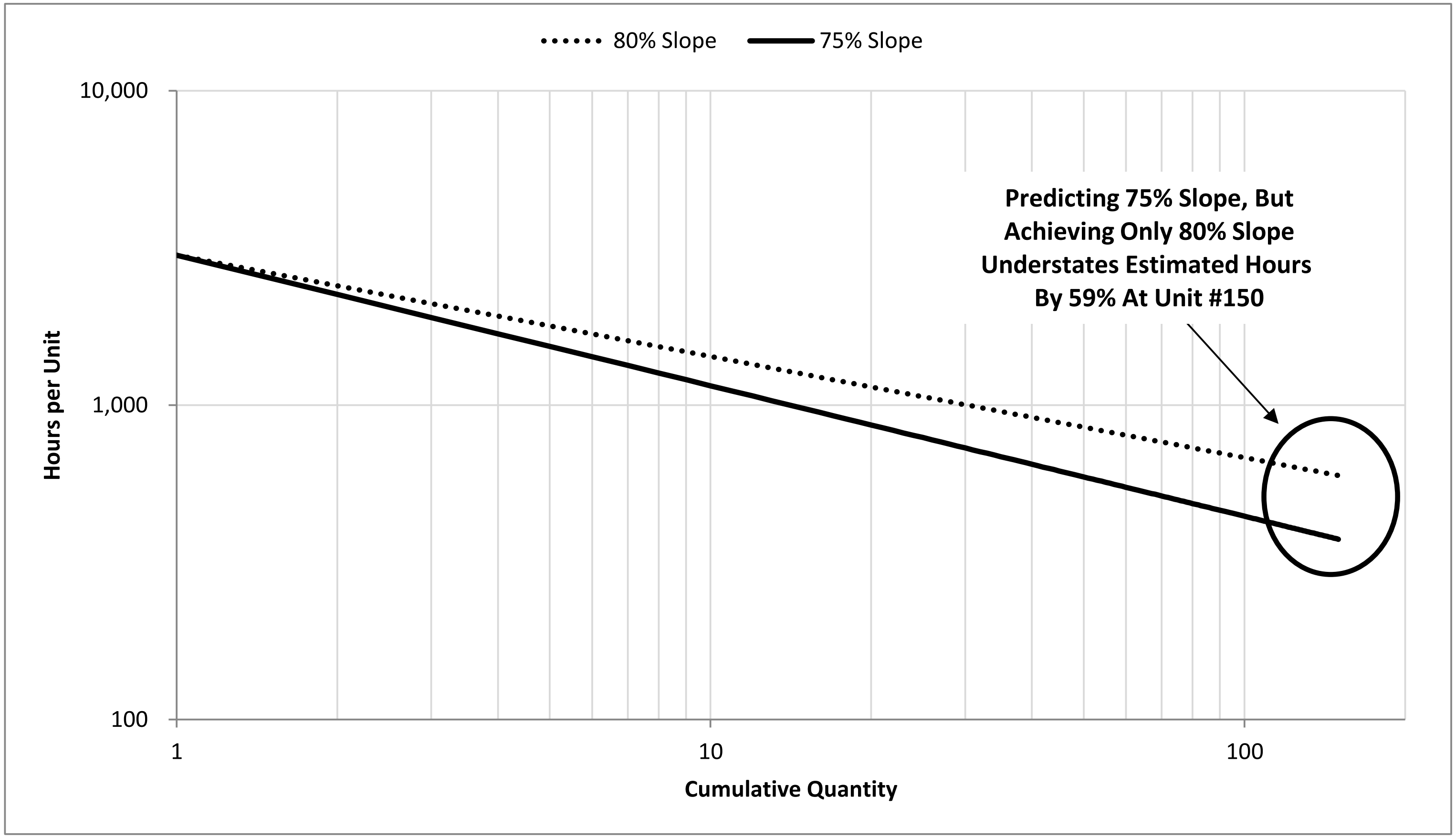
Misspecification of Slopes



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

A Simple Projection of Actual Experience To Date Is No Guarantee of Success…

"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."

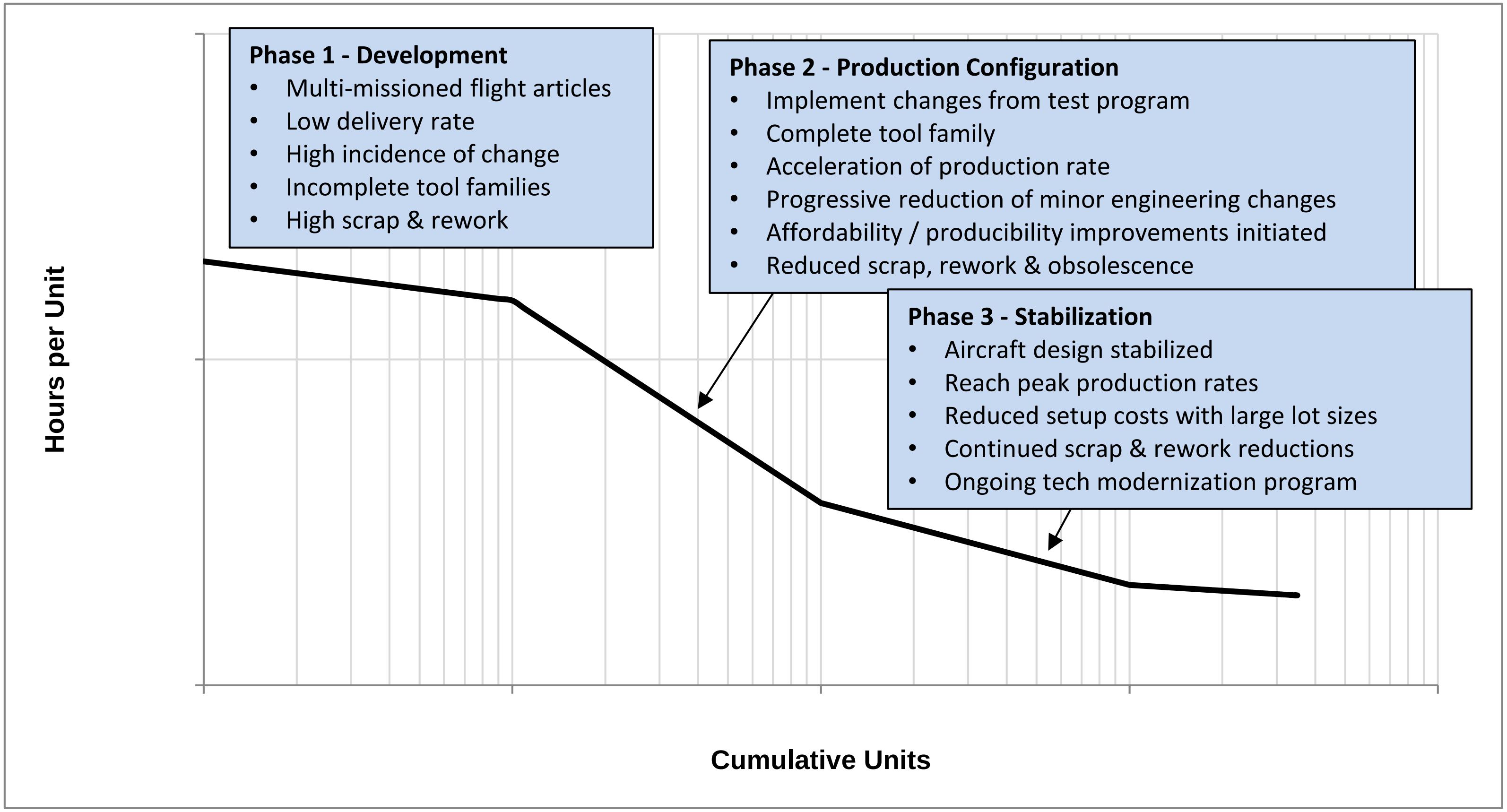
"…[E]ven projections based on producing an almost identical product over all lots, in a single facility, with large lot sizes, and no production break or design changes, do not necessarily yield reliable forecasts of labor hours. *Out-of-sample forecasting using early lots to predict later lots has shown 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**

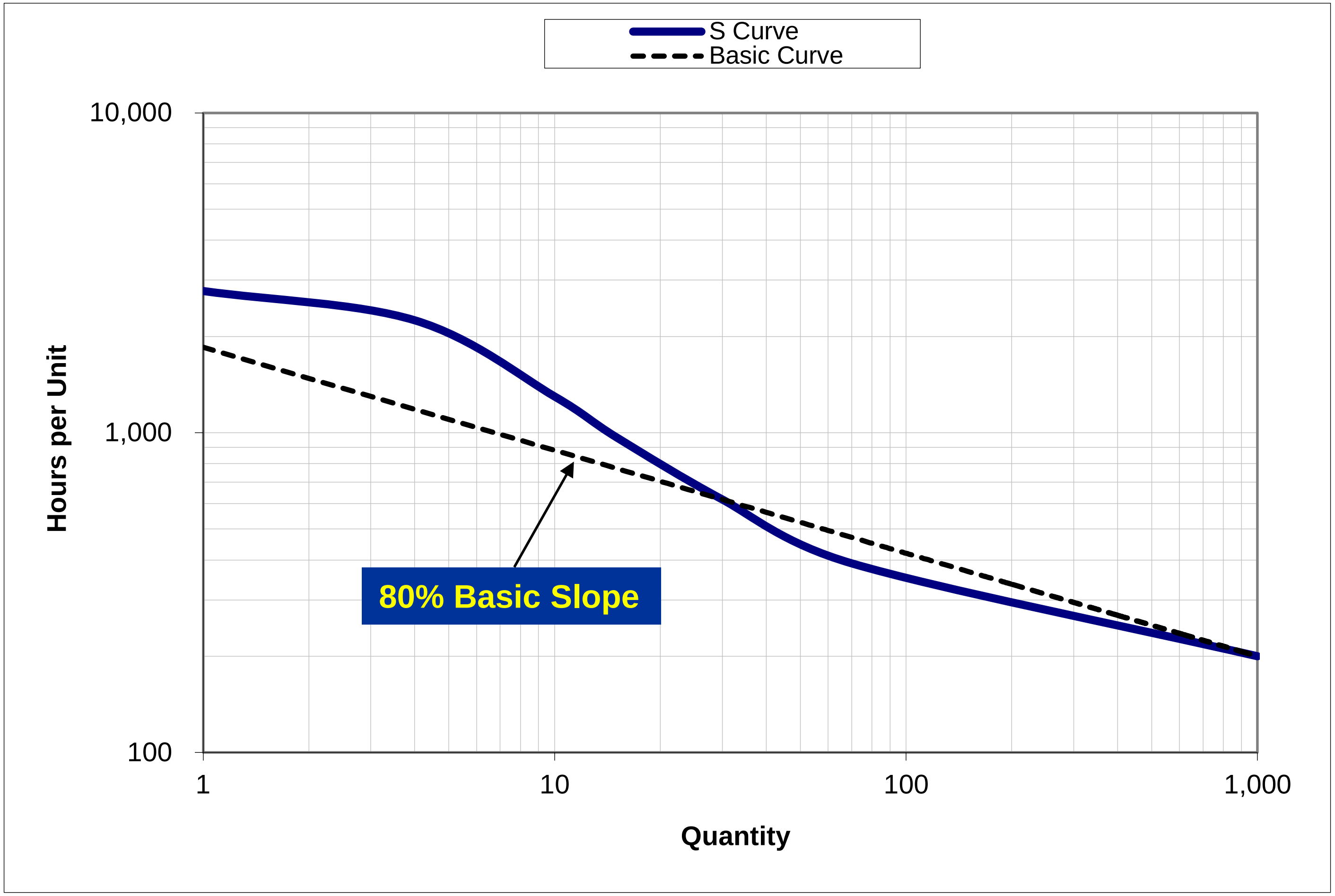
- **Development Actuals Are High & Observed Slopes Usually Very Flat**

- **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

Processes	Typical Slope %
Job Machine Shop[1]	95%
Sheet Metal Stamp[1]	92%
Composite Automated Layup[3]	92%
Electrical Fabrication[2]	90%
Job Machining – Large Parts[1]	88%
Electrical Subassembly[2]	85%
Composite Handlay[3]	85%
General Subassembly[1]	83%
Major Aircraft Assembly[1]	80%

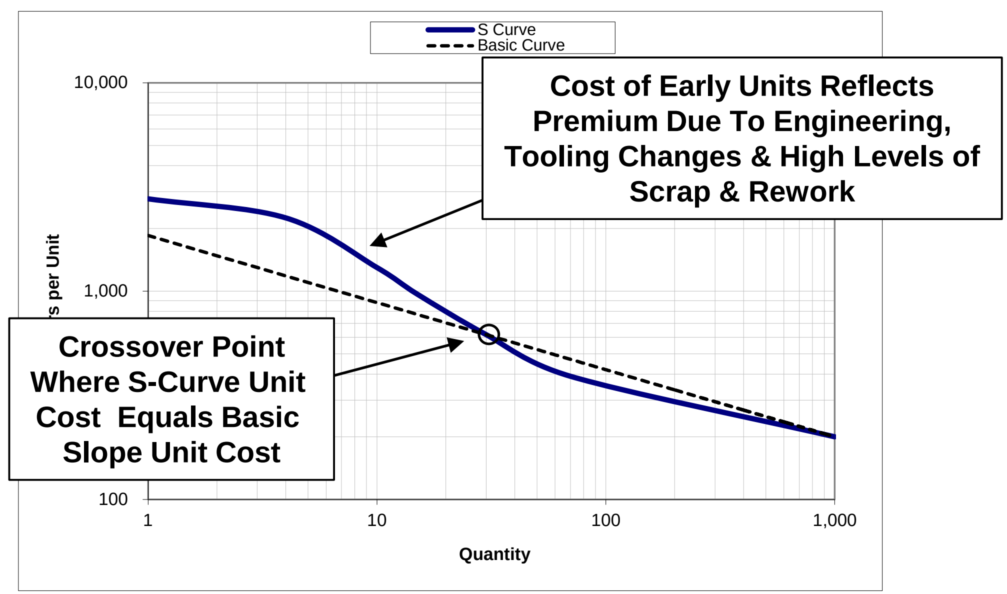
Sources:
[1]Cochran (1968)
[2]Delionback (1975)
[3]Kassapoglou (2013)

Basic Slopes Vary With Manufacturing Processes

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**

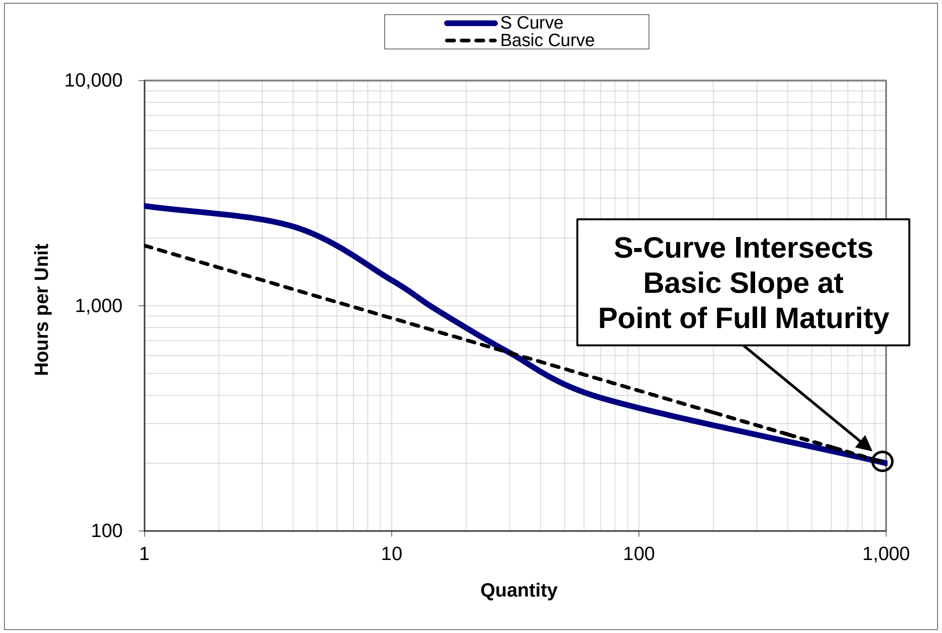
- **S-Curve Recovers To ‘Basic Slope’ After Initial Engineering, Tooling Issues Are Resolved**
  - **Cochran Suggested Crossover Point Occurred Around 30th Unit**
  - **Empirical Analysis Shows Recovery Between 30th And 100th Unit**



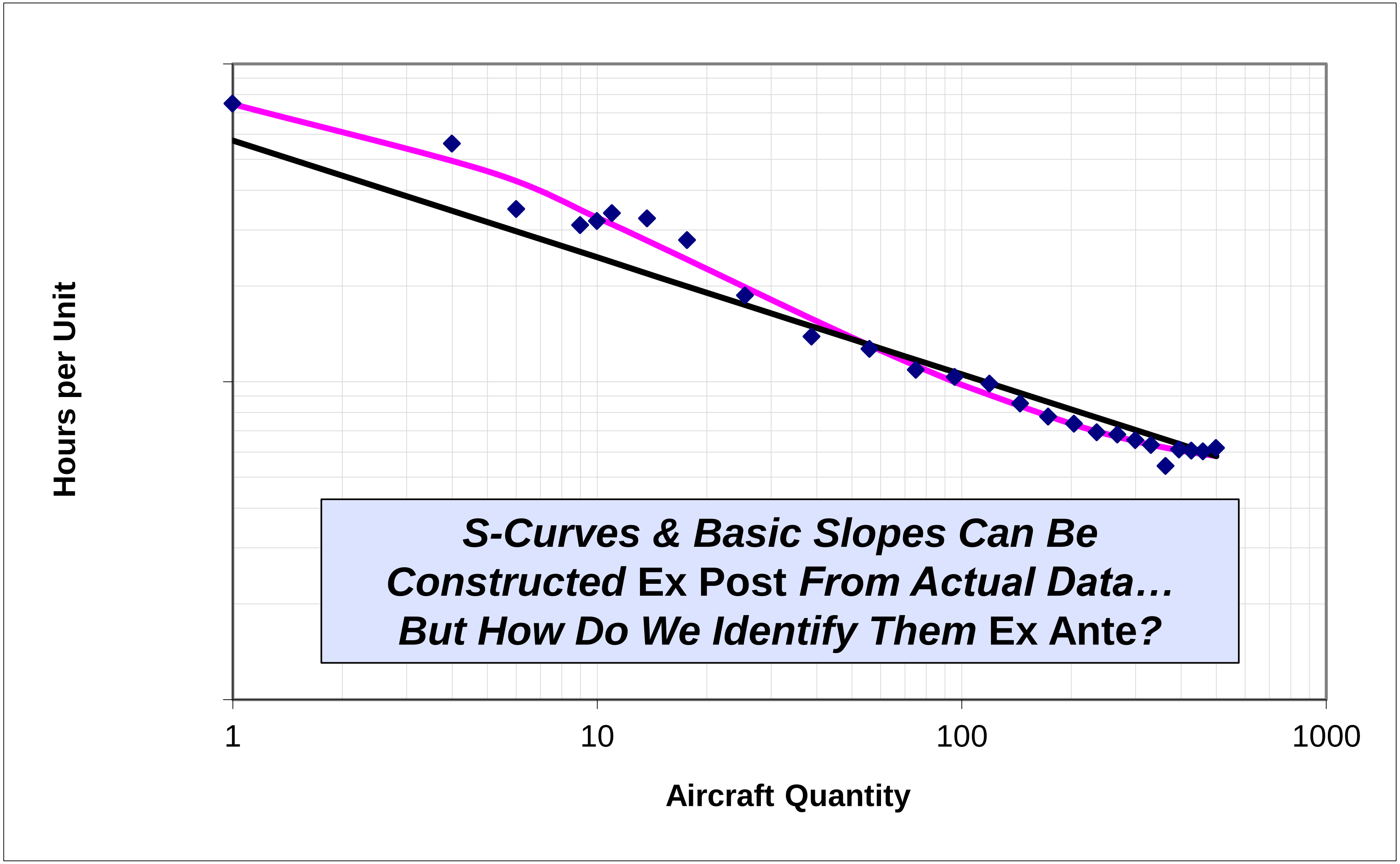
S-Curve vs Basic Slope (Cont'd)

- **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-Curve History

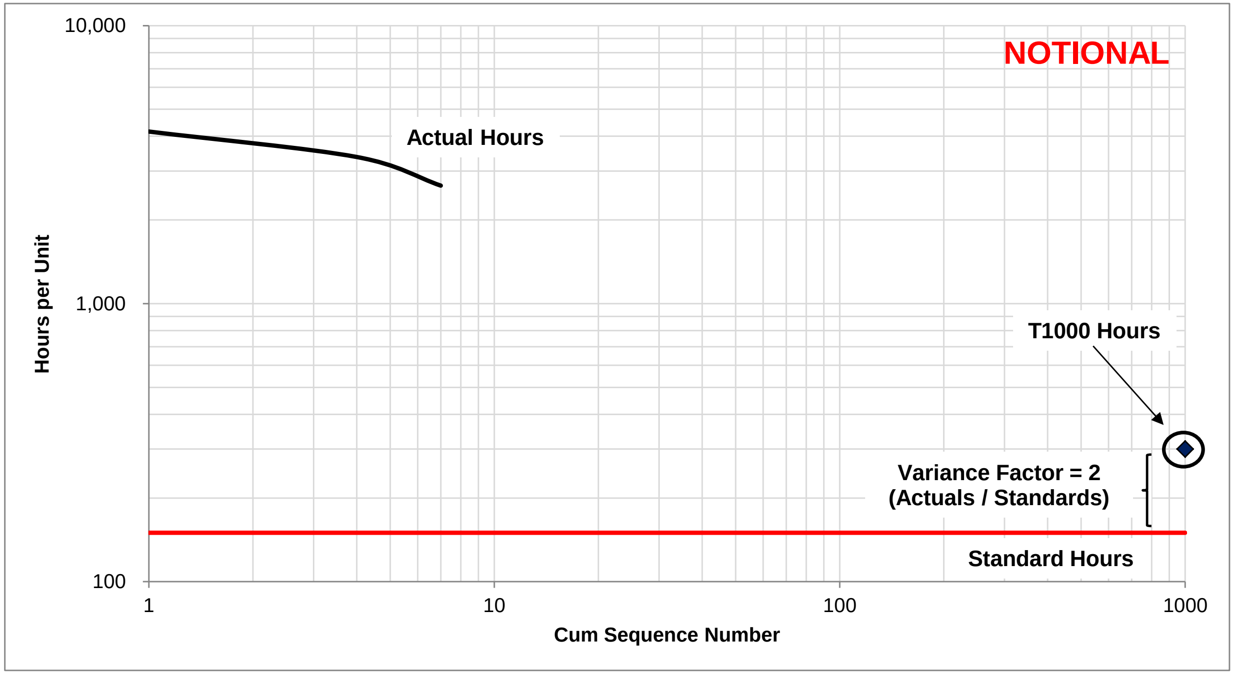


Using Standards

- 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

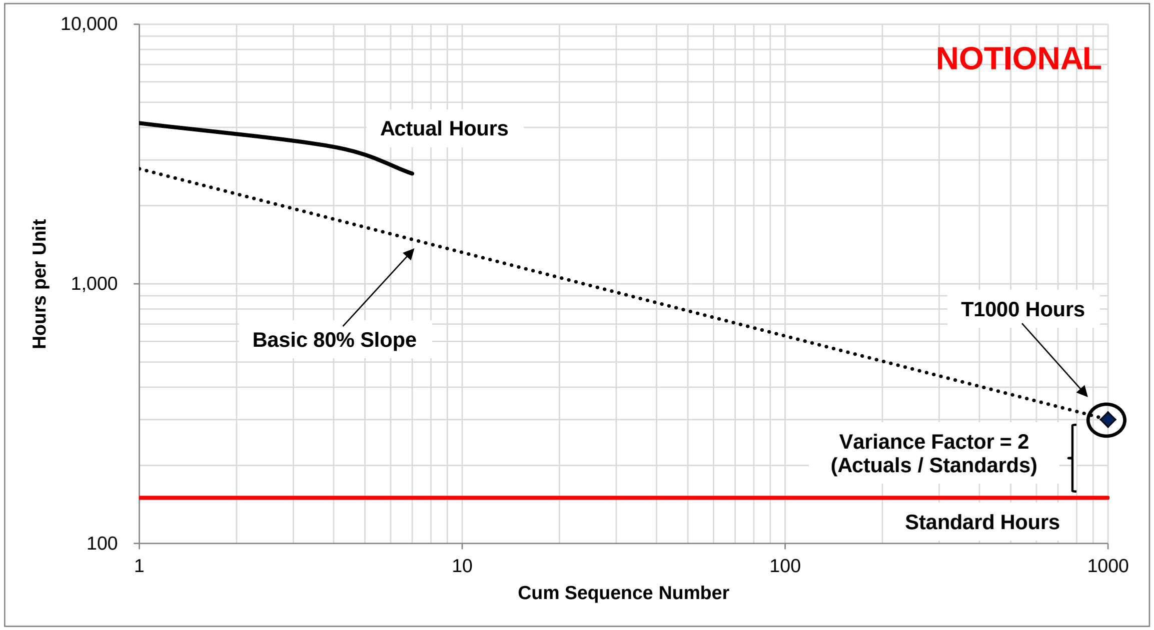
- **Determine Standard Hours For a Task and Draw This As the "Floor" Below Which the Estimate Cannot Go**
  - **Type I Standards Are Better For This Approach Than Type II**



- **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**

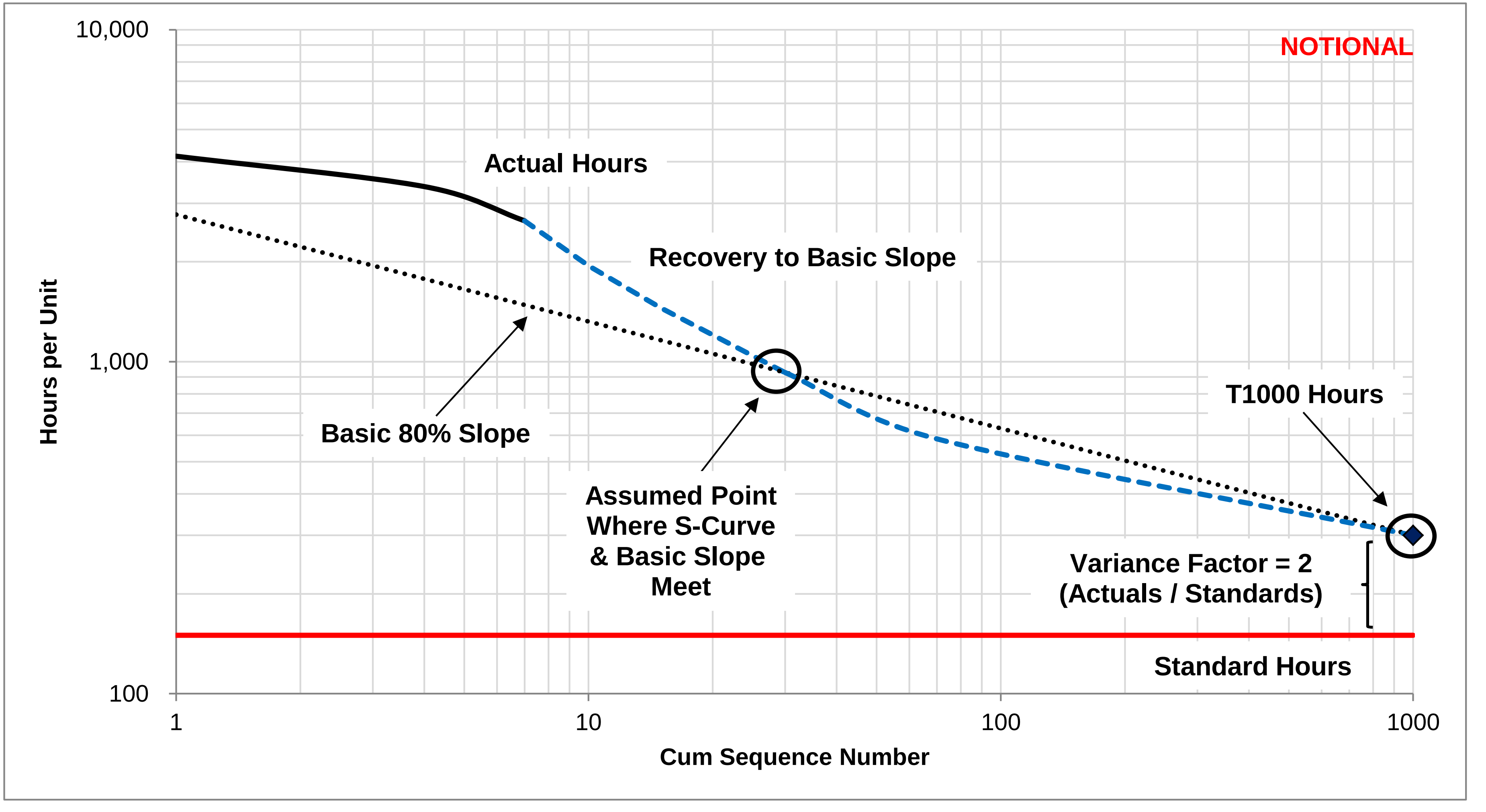
Standards-Based Approach

- 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



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**

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