Improvement Curves: Beyond The Basics

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Agenda

- Do They Even Exist?
- What Can Impact Them?

- Theory Selection
- Slope Selection

Objective

Background

- **A Learning Curve is a expression of how the time or cost of a task changes as the task is done repetitively.**

- **Individuals performing repetitive tasks exhibit a rate of improvement due to increased manual and/or mental dexterity. These mental and/or physical adjustments made by an individual as a task is repeated result in a reduction of the time required for each repetition.**

‘Learning’ Curves: Do They Even Exist?

- **Production of sizeable and complex end items that require large numbers of direct labor hours**
- **Non-mechanized and machine-paced operations remain constant**
- **No major technical changes**
- **No major engineering changes**
- **No changes to make/buy plan**
- **Continuous manufacturing process**
- **Ongoing pressure from management to improve costs in all areas**

‘Learning’ Curves – Do They Even Exist? (Continued)

- **Improvement Curves**
- **Cost Curves**
- **Progress Curves**
- **Cost Improvement Curves (CICs)**
- **Cost/Quantity Curve**
- **Cost Reduction Curves (CRCs)**
- **Etc.**

Improvement Curves – What Can Impact Them?

- Traditional individual learning
- Workers' environment and morale (incentives, workforce stability)
- Flow processes (tooling, methods, equipment, line move, lot sizes, work station layout)
- Management's organization and control methods
- Engineering changes
- Production History (previous quantities, breaks in production, make/buy changes)
- Other product lines
- Fixed ("staffed" LOEs) versus unfixed cost ratios
- Contract Type
- Corporate Heritage

Improvement Curves – What Can Impact Them? (Continued)

- Many concerns can't be quantified
- These are practical applications to assist in modeling

- **Use the theory and slope associated with the best log-linear fit to historical data (i.e., perform regression analysis, analyze results – Best coefficients of correlation and fit)**
  - **Look at previous similar programs**
  - **Industry standards**
  - **Company standards**
  - **Compare results of each theory to determine if delta is significant relative to other areas of uncertainty**
  - **Consider how the data was normalized?**
- **BOTTOM LINE: <u>MUST DO SOME ANALYSIS</u>! – No universal answer!**

- Is there one best theory to use?
  - Cumulative Average or
  - Unit Theory?
- What should I use?

- **Comparison of Unit and Cum curves derived from the same known data:**

Given		
Lot Start	**Lot End**	**Avg/Unit**
26	50	100
51	100	90
101	200	81
201	400	72.9
Then		
	Unit Theory	**Cum Theory**
T1	173.6	203.9
Slope	90.0%	90.0%
R-sq	100.0%	100.0%

- **Comparison of Unit and Cum curves derived from the same T1 and same slope**

Given		
T1	=	100
Slope	=	90%
Then Units 100 - 200		
	Unit Theory	**Cum Theory**
Avg/Unit	46.85	39.75
Total	4731.96	4,014.82

- If regressing from data
  - Slopes will be the same
  - T1 will be greater using Cum theory
  - (With data closer to T1 slopes will have some difference)
- If using the same given T1 and given slope
  - Values will be greater using the unit theory
- There is no superior theory
  - Both are equally productive
  - Cumulative, Unit, and Average data can be calculated using either theory
- Be consistent in derivation and application!

- Selection of the Improvement Curve slope is critical
- The Improvement Curve slope undergoes much scrutiny in government (and contractor) reviews
- The derivation and application of the slope should be consistent
- Actual program history is the best indicator
- Analogous history is also acceptable
- Frequently the slope is established by non-empirical methods
  - Need to win business
  - Goals
  - Politics
- The slope will cause a much greater variation in program costs than uncertainty associated with the T1 cost

- **Criteria to consider in slope selection:**

Item	'Steeper' Slope	'Flatter' Slope
Technology	New	Standard
Complexity	High	Low
Process	Manual	Automated
Quantity	Low	High
Non-Recurring	Included	Excluded
Components	Custom (Application Specific)	COTS (Commercial Off The Shelf)
Procurement	Make	Buy
Tooling	"Soft"	"Hard"
Contract Type	Incentive Fee, Competitive	Cost Plus, Sole Source
Program Stage	Prototype, LRIP	Full Rate Production
Platform	Adverse Environment	Benign Environment

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• Improvement Curve selection chart:

Curve Slope and Number of Units Required to Meet the Standard Hour Estimate

	Newness of Product - Opportunity for Innovation <------------Large Small----------->							
Complexity of Production by Fabrication/ Assembly Standard Hour Content	New Product New Manufacturing Methods Standard Hours Based on 1 - 1,000 Quantity		New Product Standard Manufacturing Methods Standard Hours Based on 1 - 1,000 Quantity		Variation of Basic Product Standard Manufacturing Methods Standard Hours Based on 1 - 1,000 Quantity		Mass-Produced Product Standard Manufacturing Methods Standard Hours Based on 1,000 - 10,000 Quantity	
Type Unit/ Avg Job Cycle/ Total Hour/Unit	Recurring Work only	Total Program: Start-up; Recurring; & All Variances	Recurring Work only	Total Program: Start-up; Recurring; & All Variances	Recurring Work only	Total Program: Start-up; Recurring; & All Variances	Recurring Work only	Total Program: Start-up; Recurring; & All Variances
Components 0-0.05 0-1.0	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	95% (1000 qty)	90% (1000 qty)
Subassemblies .06-0.20 1.1-10.0	80% (100 qty)	75% (100 qty)	85% (100 qty)	80% (100 qty)	90% (100 qty)	85% (100 qty)	95% (10000 qty)	90% (10000 qty)
Rack Chassis 0.21-0.50 11-100	80% (300 qty)	75% (300 qty)	85% (300 qty)	80% (300 qty)	90% (300 qty)	85% (300 qty)	N/A	N/A
Full Racks 0.51-2.00 101-1000	80% (1000 qty)	75% (1000 qty)	85% (1000 qty)	80% (1000 qty)	90% (1000 qty)	85% (1000 qty)	N/A	N/A

Reference: "Handbook of Electronics Industry Cost Estimating Data" by Theodore Taylor; 1985

- **Improvement Curve Calculation using subsystem data (could be done with assembly, test, & material, etc.)**
- **Known Subsystem and Total System Improvement Curves**

Subsystem	Known SV Program				Projected SV Program			
	Weight		Cum Average Curve Slope		Weight		Cum Average Curve Slope	
	Pounds	%	By Subsystem*	Weighted*	Pounds	%	By Subsystem*	Weighted
AKM	200	10.0%	74.0%	7.4%	0	0.0%	74.0%	0.0%
EPS	600	30.0%	87.0%	26.1%	850	28.3%	87.0%	24.7%
ACS	150	7.5%	96.0%	7.2%	150	5.0%	96.0%	4.8%
Comm	350	17.5%	87.0%	15.2%	600	20.0%	87.0%	17.4%
Thermal	200	10.0%	93.0%	9.3%	200	6.7%	93.0%	6.2%
TT&C	50	2.5%	81.0%	2.0%	150	5.0%	81.0%	4.1%
Structure	450	22.5%	99.0%	22.3%	750	25.0%	99.0%	24.8%
Other (Incl Propulsion)	0	0.0%	93.0%	0.0%	300	10.0%	93.0%	9.3%
Subtotal	2000	100.0%	93.0%	89.5%	3000	100.0%	N/A	91.2%
Correction Factor	N/A	N/A	N/A	3.5%	N/A	N/A	N/A	3.5%
Total System	**2000**	100.0%	**93%**	**93%**	3000	**100%**	**95%**	**95%**

** AKM (Apogee Kick Motor) is dissimilar to New propulsion system

- **Correction factor adjusts for error in using a linear model to determine a logarithmic function IF quantities and work content is fairly consistent between projects**

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- **Examples of Improvement Curves actually experienced:**

Item	Description	Slope	Comments
Purchased Part	Standard Component	98% - 99%	(Cost/Quantity Relationship; Little or No Improvement)
Subcontract Assembly	Application Specific	95% - 97%	(Total Cost: Labor and Material Included)
Circuit Card Assembly	Primarily Automated	95%	(Labor Only)
Satellite System	Space System	90% - 95%	(Total Cost: Labor and Material Included)
Circuit Card Assembly	Primarily Manual	90%	(Labor Only)
Electronic Modules	Airborne System	86% - 87%	(Assembly & Test)
Electronic Racks	Shipboard or Ground System	83% - 84%	(Assembly & Test)
Fuselage Assembly	Commercial Aircraft	80%	(Assembly)

- Summary
  - No one ‘right’ choice
  - Many signposts
  - Be consistent
  - Depends on information
  - Requires analysis

Technology Insertions

Quantities		
Block 1	8	Units
Block 2	10	Units
Block 3	12	Units

Data			
Weight (Lbs.)			
	Block 1	Block 2	Block 3
New	2000	150	300
Block 1 Common	N/A	2000	2000
Block 2 Common	N/A	N/A	150
Total	2000	2150	2450

I.C. Calculations (Assume 90% Cum Avg. I.C.)					
Type	**Weight**	**T Position**	**Ta (Factor)**	**% Weight**	**Weighted Ta**
Block 1	**2000**	**T1 - T8**	**0.7290**	**100%**	**0.7290**
Block 2 (Block 1 Common)	2000	T9 - T18	0.5768	93%	0.5366
Block 2 New	150	T1 - T10	0.7047	7%	0.0492
Block 2 Composite	**2150**	**Tu12**	**0.5857**	**100%**	**0.5857**
Block 3 (Block 1 Common)	2000	T19 - T30	0.5241	82%	0.4278
Block 3 (Block 2 Common)	150	T11 - T22	0.5588	6%	0.0342
Block 3 (New)	300	T1 - T12	0.6854	12%	0.0839
Block 3 Composite	**2450**	**Tu19**	**0.5460**	**100%**	**0.5460**
All Blocks Composite	**N/A**	**Tu9**	**0.6080**	**100%**	**0.6080**
Derived Points					

Breaks In Production

- Employee learning
- Supervisory learning
- Continuity of production (Work station layout)
- Methods
- Tooling

Breaks In Production (Continued)

Table

Loss of Learning			Break Time				
			Days		Months		
Weight	**Element**	**Description**	**10 to 30**	**30 to 90**	**3 to 6**	**6 to 12**	**12 or More**
30%	Employee Learning	Loss of Personnel	10%	20%	40%	50%	100%
	Retained Personnel	Loss of Talent	10%	25%	45%	70%	100%
20%	Supervisory Learning	Loss of Personnel	0%	10%	25%	40%	65%
	Retained Personnel	Loss of Talent	5%	10%	20%	30%	40%
20%	Continuity of Production	Work Station Layout	50%	75%	100%	100%	100%
15%	Tooling	Hard Tooling	0%	0%	10%	20%	30%
		Soft Tooling	10%	20%	35%	50%	75%
		From Hard to Soft	50%	50%	50%	50%	50%
15%	Methods	Hard Tooling	0%	5%	10%	20%	20%
		Soft Tooling	10%	10%	20%	25%	25%
		From Hard to Soft	50%	50%	50%	50%	50%

Calculation Example - 12 Month or More Production Break

Employee Learning	Loss of Personnel	Weight	30%	x	100%	=	30.0%
Retained Personnel	Loss of Talent	Retained Wt	0.0%	x	100%	=	0.0%
Supervisory Learning	Loss of Personnel	Weight	20%	x	65%	=	13.0%
Retained Personnel	Loss of Talent	Retained Wt	7.0%	x	40%	=	2.8%
Continuity of Production	Work Station Layout	Weight	20%	x	100%	=	20.0%
Tooling	Hard Tooling	Weight	15%	x	30%	=	4.5%
Methods	Hard Tooling	Weight	15%	x	20%	=	3.0%
Total "Loss of Learning" Impact						=	**73.3%**

- **Requires Calibration and Validation**

Calculation Example: 12 Month or More Production Break After 202 Units of Production (Starting at T1)

Item	Unit	95% Cum Average I.C. Factor	Source	Hours/ Unit
First Unit of Block	T1	1.0000	Unit Factor	150.0
Last Unit of Block	T202	0.6253	Unit Factor	93.8
Block "Learning"		0.3747	Delta	56.2
LOL Factor		73.3%	Anderlohrs	0.7
"Learning" Lost		0.2747	Unit Factor	41.2
Old End		0.6253	Unit Factor	93.8
New Start	**T2**	**0.9000**	**Unit Factor**	**135.0**

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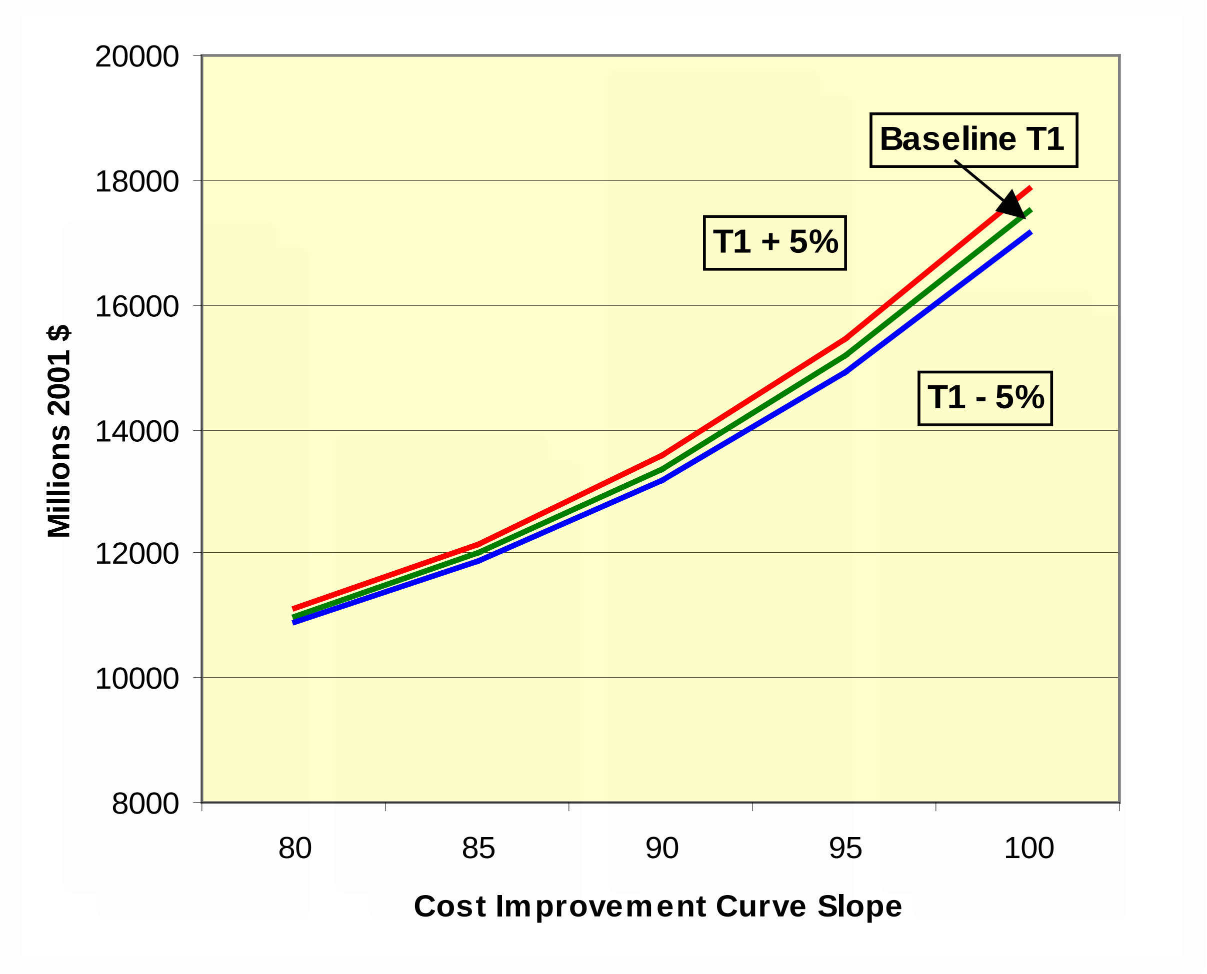
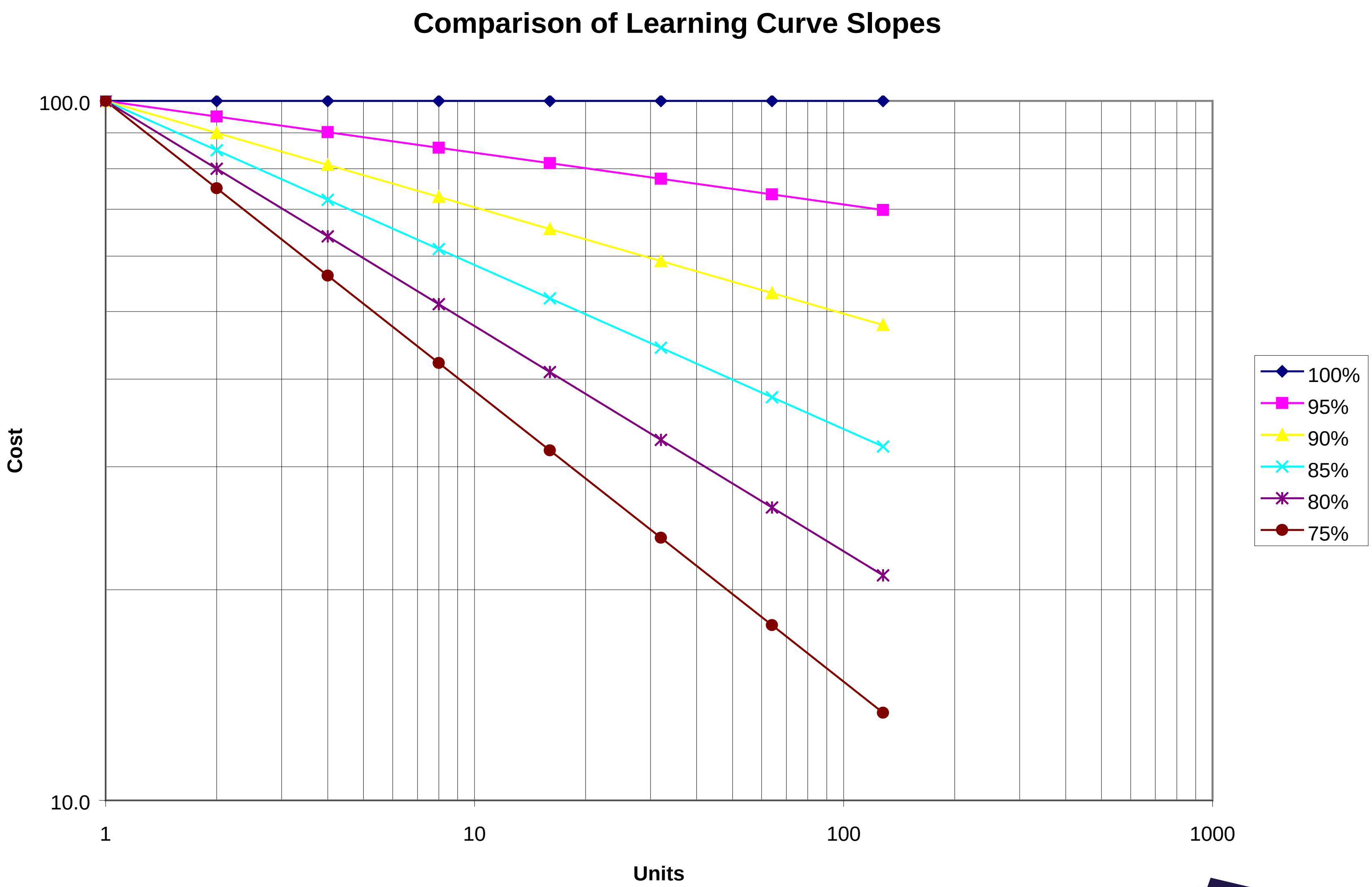
- **Impact of the Improvement Curve slope relative to T1**





Comparison of Learning Curve Slopes
100.0
10.0
Cost
1
10
100
1000
Units
100%
95%
90%
85%
80%
75%

Uncertainty Ranges On Improvement Curves (Continued)

- We seldom consider the unknown nature of the slope

Summary

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