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The Impact of Learning Curve Model Selection and Criteria for Cost Estimation Accuracy in the DoD

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Background

- Learning Curve Theory Conception
  - T.P. Wright (1936)
  - J.R. Crawford (1944)

- Learning Curve Theory Evolution
  - S-Model (1946)
  - Stanford-B Model (1956)
  - DeJong Model (1957)
  - Plateau Model (1965)
  - Anderlohr Production Break Theory (1969)
- Learning/Forgetting/Relearning
- Additional Work Theory

Research Questions

1. Is there an impact to the learning curve slope when a configuration change is introduced to the production line? Specifically:
   a. What is the learning curve slope for each new configuration?
   b. Are the production segments for each configuration significantly different?
   c. What is the difference between predicted and actual hours for each adjacent segment?
2. How many units of the newly configured aircraft are produced before the contractor regains the stable learning rate?

Methodology

- Segment “stable” production units
  - Visual Analysis
  - Based on identified configuration changes
- Nonparametric Tests
  - Compare actuals between segments to determine statistical similarity
- Regression Analysis
  - Calculate learning curve slope for each segment
  - Compare predicted versus actual hours for adjacent segments
  - Determine number of production units to stabilize rate

Data Analysis

- Regression Analysis
  - Compare predicted versus actuals for each segment pair
  - Negative difference indicates under-estimation

Program A				
	Predicted Hours	Actual Hours	Difference	% Difference
A predicting B	11,336,756.40	11,371,252.00	(34,495.60)	-0.30%
Program B				
	Predicted Hours	Actual Hours	Difference	% Difference
A predicting B*	229,114.62	295,348.35	(66,233.73)	-22.43%
Program D				
	Predicted Hours	Actual Hours	Difference	% Difference
A predicting B	1,014,525.48	986,331.30	28,194.18	2.86%
B predicting C	490,909.41	531,988.54	(41,079.13)	-7.72%
C predicting D	339,726.00	368,921.32	(29,195.31)	-7.91%
D predicting E	678,070.58	698,789.63	(20,719.06)	-2.96%
D predicting F	397,530.17	542,429.97	(144,899.80)	-26.71%
*Configuration B not considered a statistically significant change from configuration A				

Findings: Research Question 1

1. Is there a significant impact to the learning curve slope when a configuration change is introduced to the production line? Specifically:
   a. What is the learning curve slope for each new configuration?

		Configuration					
		A	B	C	D	E	F
Program	A	63.26%	49.84%	-	-	-	-
	B	87.02%	84.33%	-	-	-	-
	D	91.96%	73.15%	59.04%	68.56%	75.24%	82.49%

   b. Are the segments of each configuration significantly different?
      - Each segment statistically different aside from Program B between configurations A and B
   c. What is the difference between predicted and actual hours for each adjacent segment?
      - At least 20 thousand hours (usually under-estimated)

Findings: Research Question 2
Program A

2. How many units of the newly configured aircraft are produced before the contractor regains the stable learning rate?

- Large sample size
  - In total
  - In each segment
- One configuration change
  - Isolated impact
- Stable slope: 63.26%
  - Configuration A
- Stabilized after 19 newly configured units

First Unit	Slope	Units to Stabilize
72	49.84%	
73	50.69%	1
74	51.34%	2
75	51.95%	3
76	52.48%	4
77	52.85%	5
78	52.83%	6
79	52.81%	7
80	53.21%	8
81	53.44%	9
82	53.80%	10
83	54.36%	11
84	54.85%	12
85	55.25%	13
86	56.33%	14
87	57.39%	15
88	59.18%	16
89	60.52%	17
90	62.03%	18
91	63.60%	19
92	64.36%	
93	64.30%	
94	64.52%	
95	63.51%	
96	62.06%	
97	60.54%	

Significance of Findings

- Configuration changes introduced during production may cause a statistically significant impact to the unit production learning rate and production hours
- After most of the configuration changes analyzed, the contractor achieved a steeper rate of learning than the stable rate
  - Analysis of Program A indicated the contractor's learning decreased with each subsequent production unit until eventually stabilizing
- In reality, a contractor will submit a tech-refresh proposal to program office to account for configuration change
  - Estimated based on extrapolation of stable learning curve
- In every program in this analysis (and in most segments), a newly configured aircraft initially experienced a higher rate of learning
  - An extrapolation of the stable curve will result in a higher per unit cost than the contractor would actually experience

The Impact of Learning Curve Model Selection and Criteria for Cost Estimation Accuracy in the DoD - Part 2

Background/Research Question

- Learning curves are commonly used in production estimates
  - Production accounts for the majority of total Acquisition Costs
- Mr. Thomas Henry (OSD CAPE) on modernization
  - "Manufacturing and depots are becoming as automated as possible. Learning curves could get much different in the future due to machines"
- Heightened scrutiny of cost estimates
  - Budget Control Act of 2011 seeks to reduce federal deficit
- Is the current DoD methodology is outdated? Are alternative models are more accurate?
  - Wright's original learning curve theory (CUMAV) was formulated in 1936.

Learning Theory

- T. P. Wright (1936) theorized that as a worker performs a task multiple times, the time required to complete that task will decrease at a *constant rate*.
  - Constant percentage decrease for doubling quantity
  - Wright's Learning Curve (WLC) Model:

$$y = ax^b$$

- Learning is a human phenomenon occurring in manual labor, so we should expect the most learning to occur when the production process involves a great deal of touch labor and little automation
- DeJong's Learning Formula
  - Incorporates percentage of process that is automated into learning models
- S-Curve Model
  - Incorporates prior experience units (prototypes) and percentage of process that is automated into learning curves.

Analytical Tests

- Use Historical data to determine CUMAV vs. Unit Theory
  - Use Regression statistics to determine validity of regression models
- Compare all sample means to determine if any models are different
  - Use skewness, kurtosis, and standard deviation to determine normality
- Compare sample means to determine which models are different from WLC status quo
- Compare means of S-Curve and DeJong if they are more accurate than WLC to determine the most accurate model

Data Table Example (WLC)

Unit (x)	Actual	Predicted	Error	Absolute Value Error	Absolute Value Percent Error
20	17336.81	17871.04	-534.22	534.22	0.03
21	17221.82	17721.17	-499.35	499.35	0.03
22	17041.33	17579.45	-538.12	538.12	0.03
23	16916.11	17445.09	-528.99	528.99	0.03
24	16854.60	17317.41	-462.81	462.81	0.03
25	16797.48	17195.83	-398.35	398.35	0.02
26	16710.27	17079.81	-369.54	369.54	0.02
27	16606.65	16968.92	-362.27	362.27	0.02

- MAPE is the average of the Absolute Percent Error
- MAPES at M of 0.05
  - WLC = 4.11%
  - DeJong = 3.00%
  - S-Curve = 2.64%

Results: APE Graphs

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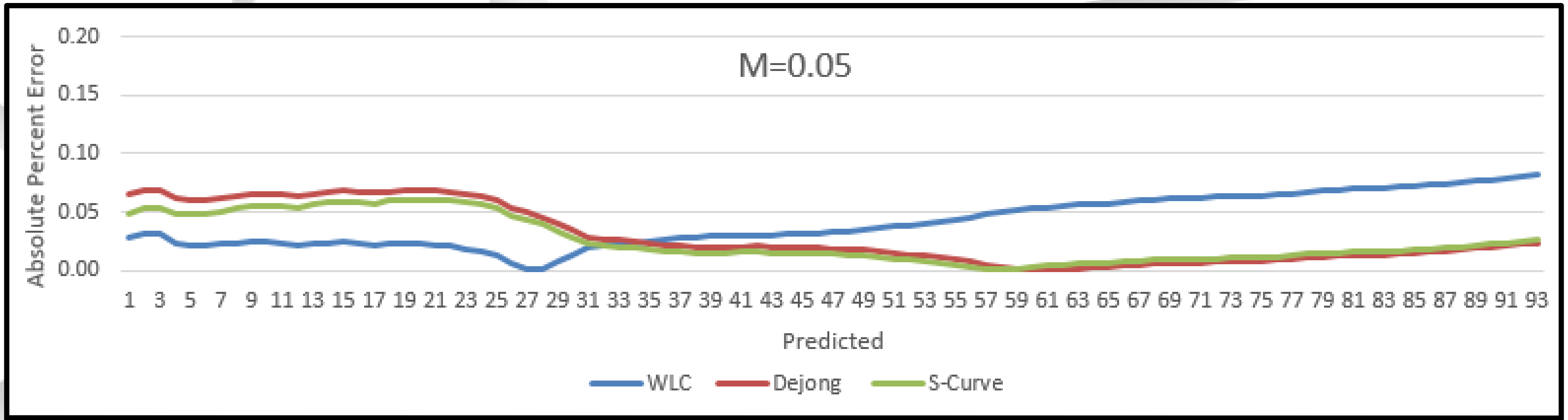

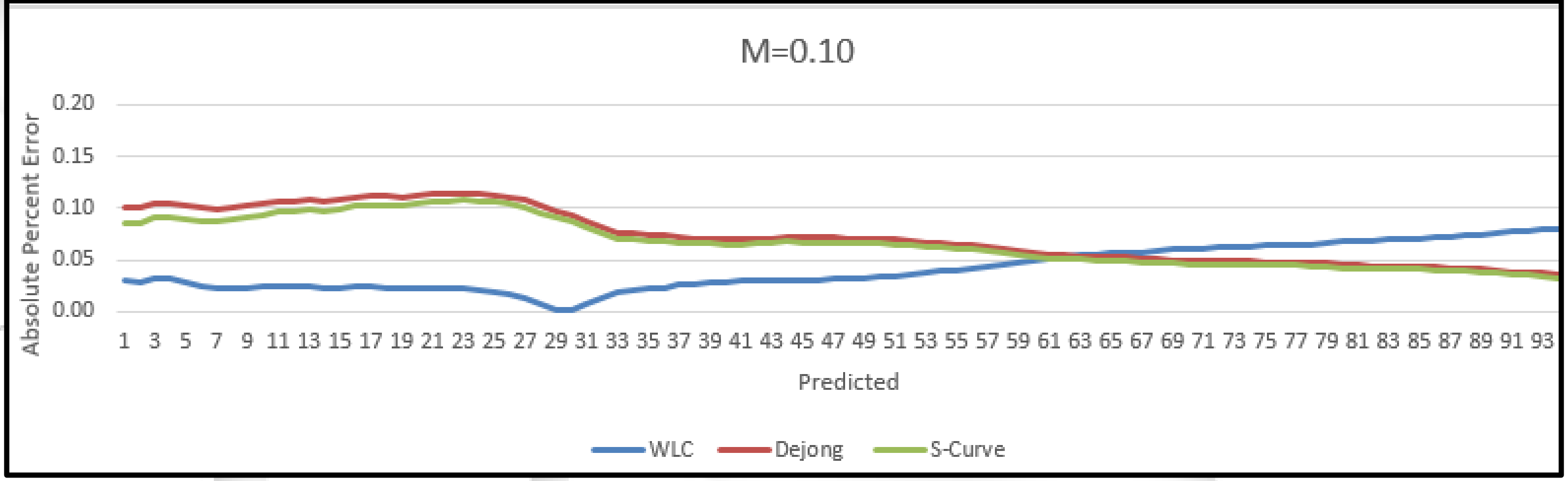

Significance of Findings

- There is *potential* for a more accurate model in predicting the effects of learning within DoD acquisitions
  - S-Curve and DeJong models
- Sensitivity of results and uncertainty of incompressibility factor make it difficult to simplify the results
- Findings provide a proxy to future research and open a dialogue for change within DoD learning methodology
- The influence of machinery potentially displayed with long production cycle