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Learning Curves Redux : A New Use for Familiar Tool

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June 2007

Introduction

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- ■ **Major Topics Addressed in This Paper:**
  - ☐ Handling of possible production concurrency
  - ☐ Three planning modes of production scheduling : constant effort, uniform rate, and ramp-up
  - ☐ Use of learning curves in the scheduling of multiple-lot production operations where learning can be transferred between production lots fully or partially
  - ☐ Demonstration that when learning curves are appropriately applied along with planning, the result is an automated scheduling process that predicts the cost, start and finish dates for production of an item, and a spread of labor hours and material costs by month or week
  - ☐ Examples of applying learning curves to production planning

Production Concurrency

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- ## SEER-H v.7.1 Approach in Handling Production Concurrency

  - ☐ Use of empirical equation : $D = \dfrac{M\ Q^{1+B}}{N}$

    - D = approximate duration of production
    - Q = user defined production quantity
    - N = user estimated average number of units in production at one time
    - M = user defined estimated time in months to produce first unit
    - B = learning curve natural slope

  Therefore, the number of units produced concurrently $N = \dfrac{MQ^{1+B}}{D}$

  - ☐ Example

    - Suppose that you want to build Q = 20 units of an item in D = 6.6 months, and the learning slope is assumed to be 87% (B = -0.2 by the usual formula) You estimate the time required to build the first unit as M = 1.5 months. Thus:

  $$N = \frac{(1.5)(20^{0.8})}{6.6} = 2.5 \text{ units in production concurrently}$$

Uniform Rate Mode

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- **We want units to finish production at equal intervals of time. Specific inputs required of the model user for each lot are:**
  - ☐ Start date, TS
  - ☐ Finish date, TF
  - ☐ Production quantity, Q
  - ☐ Labor learning slope, S%
  - ☐ Average unit makespan, UM (average months required to build each unit)

- **Step 1: SEER-H calculates first unit labor hours, H_1, based on user input parameters.**

- **Step 2: Calculate the production overall duration in calendar days:**

$$DD = TF - TS$$

- **Step 3: Convert unit makespan from months to calendar days.**

$$UM = UM * 30.4375$$

- **Step 4: Calculate the natural learning slope,**

$$B = \frac{\log(S\%/100)}{\log(2)}$$

Uniform Rate Mode (cont.)

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- **Step 5: Calculate the labor hours for each unit produced, H_q, from q = 1 to Q**

$$H_q = H_1 q^B$$

- **Step 6: Calculate the total labor hours for all units to be produced, HT:**

$$HT = \sum_{q=1}^{Q} H_q$$

- **Step 7: Calculate the finish time of each unit, Tq, also the beginning time, tq, and the labor hours spread by months.**
  - ☐ Finish time of each unit: $T_1 = TS + UM$

$$T_q = T_{q-1} + \frac{DD - UM}{Q - 1} \quad (q \neq 1)$$

  - ☐ Start time of each unit: $t_1 = TS$

$$t_q = T_q - UM \quad (q \neq 1)$$

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Uniform Rate Example

Unit	Start	Finish
1	11/15/2006	12/31/2006
2	12/13/2006	1/28/2007
3	1/10/2007	2/25/2007
4	2/7/2007	3/25/2007
5	3/7/2007	4/22/2007
6	4/4/2007	5/20/207

Unit	Nov	Dec	Jan	Feb	Mar	Apr	May	Totals
1	1296	2679						3975
2		1429	2031					3460
3			1526	1665				3191
4				1441	1571			3012
5					1566	1315		2881
6						1631	1147	2778
Totals	1296	4108	3557	3106	3137	2946	1147	19797

Constant Effort Mode

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- **Specific inputs required of the model user for each lot are:**
  - ☐ Start date, TS
  - ☐ Finish date, TF
  - ☐ Production quantity, Q
  - ☐ Labor learning slope, S%

- **Step 1: SEER-H calculates first unit labor hours, H1, based on user input parameters.**

- **Step 2: Calculate the production overall duration in calendar days, DD.**

$$DD = TF - TS$$

- **Step 3: Calculate the number of months production will run, to the nearest tenth of a month,**

$$DM = \frac{DD}{30.4375}$$

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Constant Effort Mode (cont)

- **Step 4: Calculate the natural learning slope, B.**

$$B = \frac{\log(S\%/100)}{\log(2)}$$

- **Step 5: Calculate the labor hours for each unit produced, H_q, from q = 1 to Q.**

$$H_q = H_1 q^B$$

- **Step 6: Calculate the total labor hours for all units to be produced, HT:**

$$HT = \sum_{q=1}^{Q} H_q$$

- **Step 7: Using the "Hungry Algorithm," allocate hours for production of each unit. From the result determine the begin and completion times of each unit, t_q and T_q.**

Hungry Algorithm Example

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Hungry Algorithm		Months & Month Fractions						
		January	February	March	April	May	June	
Unit	Hours	0.8407	1	1	1	1	0.46	Totals
1	1150	1150						1150
2	1001	212	789					1001
3	923		831	92				923
4	872			872				872
5	833			656	177			833
6	804				804			804
7	779				639	140		779
8	759					759		759
9	741					721	20	741
10	726						726	726
Totals	8588	1362	1620	1620	1620	1620	746	8588

- $$DM = DD / 30.4375 = 161 / 30.4375 = 5.3 \text{ months}$$
- **The constant burn rate is 8,588 hours / 5.3 months = 1,620 labor hours per month.**
- **We build the table shown above, appropriately accounting for fractional months.**

Linear Ramp-up Mode

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- **The production rate increases linearly from zero at t = 0 to some Rmax at t = D**

- **The user also specifies Q, the total quantity to be produced in the period D**

- **R = at, and** $Q = \int_0^D R\,dt = \int_0^D at\,dt = \dfrac{aD^2}{2}$

- **At any intermediate time t, the quantity produced q can be derived as following:** $q = \int_0^t \dfrac{2Qt}{D^2}\,dt = \dfrac{Qt^2}{D^2}$

- **The cumulative time to produce the qth unit is:** $t_q = D\sqrt{\dfrac{q}{Q}}$

- **Hours to build any subsequent unit q are:** $H_q = H_1 q^B$

Treatment of Production Material Costs

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- **Changes proposed in SEER-H estimation of production material cost**
  - ☐ **Two possible types of material for a work element**
    - ■ **"just in time" bought material**
    - ■ **long lead-time material**
- **Assume that the material cost as calculated by SEER-H is M, and that the amount allocated to long-lead is m. Then the total concurrent material for production quantity Q is C_Q = M-m.**

  According to the cumulative average theory, the cumulative material

  cost at any intermediate quantity q is given by:

$$C_q = C_Q \left(\frac{q}{Q} \right)^{1+B}$$

- **The timing rule for cost flow of concurrent material is as follows: For each work element built, its concurrent material cost is charged in the same month the unit starts production**

Loss of Learning

- **If the user states that some of the learning is lost between the predecessor and the successor, then the Anderlohr process is invoked to determine just how large the loss is.**

- **The Anderlohr method begins with an analysis of the learning content of the predecessor lot. It continues with analysis of how that affects the successor lot.**

- **Anderlohr uses five loss factors, expressed as *subjectively* assigned percentages :**
  - ☐ **Personnel loss of learning**
  - ☐ **Supervisory loss of learning**
  - ☐ **Continuity loss of learning**
  - ☐ **Methods loss of learning**
  - ☐ **Tooling loss of learning**

Unit Theory Anderlohr Method Example

- **Suppose that the predecessor lot had production quantity Q = 20 units, first unit hours H_1 = 1000, and learning slope S% = 90%. Using the usual equation, we find that B = -0.152.**

- **Assume**
  - ☐ Personnel loss of learning – 14%
  - ☐ Supervisory loss of learning – 20%
  - ☐ Continuity loss of learning – 18%
  - ☐ Methods loss of learning – 1%
  - ☐ Tooling loss of learning – 1%

  We average these subjectively assigned percentages to obtain 10.8%.

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Unit Theory Anderlohr Method Example (cont)

- **If we calculate the hours for the 20th (final) unit of the predecessor lot, we find:**

$$H_{20} = 1000(20)^{-0.152} = 634$$

$$LA = 1000 - 634 = 366 \text{ hours}$$

- **Since LA = 366 hours and 10.8% of that has been deemed lost, the loss amount is (10.8%)(366) = 40 hours. Had no loss occurred, the hours for the next unit would have been**

$$H_{21} = H_{20}(21/20)^{-0.152} = 634(21/20)^{-0.152} = 629.3 \text{ hours}$$

- **With no loss of learning, 629.3 hours would be the first unit hours for the successor lot. But due to the loss of learning, we add the lost 40 hours to this to obtain a starting position of 629.3 + 40 = 669.3 hours.**

Unit Theory Anderlohr Method Example (cont)

- **Find a hypothetical "unit" that required 669.3 hours in a predecessor lot . This almost certainly is not an integer (whole) numbered unit. It is most likely a fractionally numbered unit with a unit number like 3.85.**

- **The reason why we want to find this unit number is because Anderlohr's method starts the learning in the successor lot all over again from that point.**

Unit Theory Anderlohr Method Example (cont)

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- **How do we find this unit number? Designate the unknown unit number as k. We know that:**

$$H_k = H_1(k/1)^B$$

- **Solving this equation for k:**

$$k = \left(\frac{H_k}{H_1}\right)^{1/B} = \left(\frac{669}{1000}\right)^{1/-0.152} = 14.07$$

- **Hence, whatever planning mode the user has applied to the successor lot, it is applied not to the original lot numbers 1, 2, 3, etc., but to the pseudo lot numbers 14.07, 15.07, 16.07, etc.**
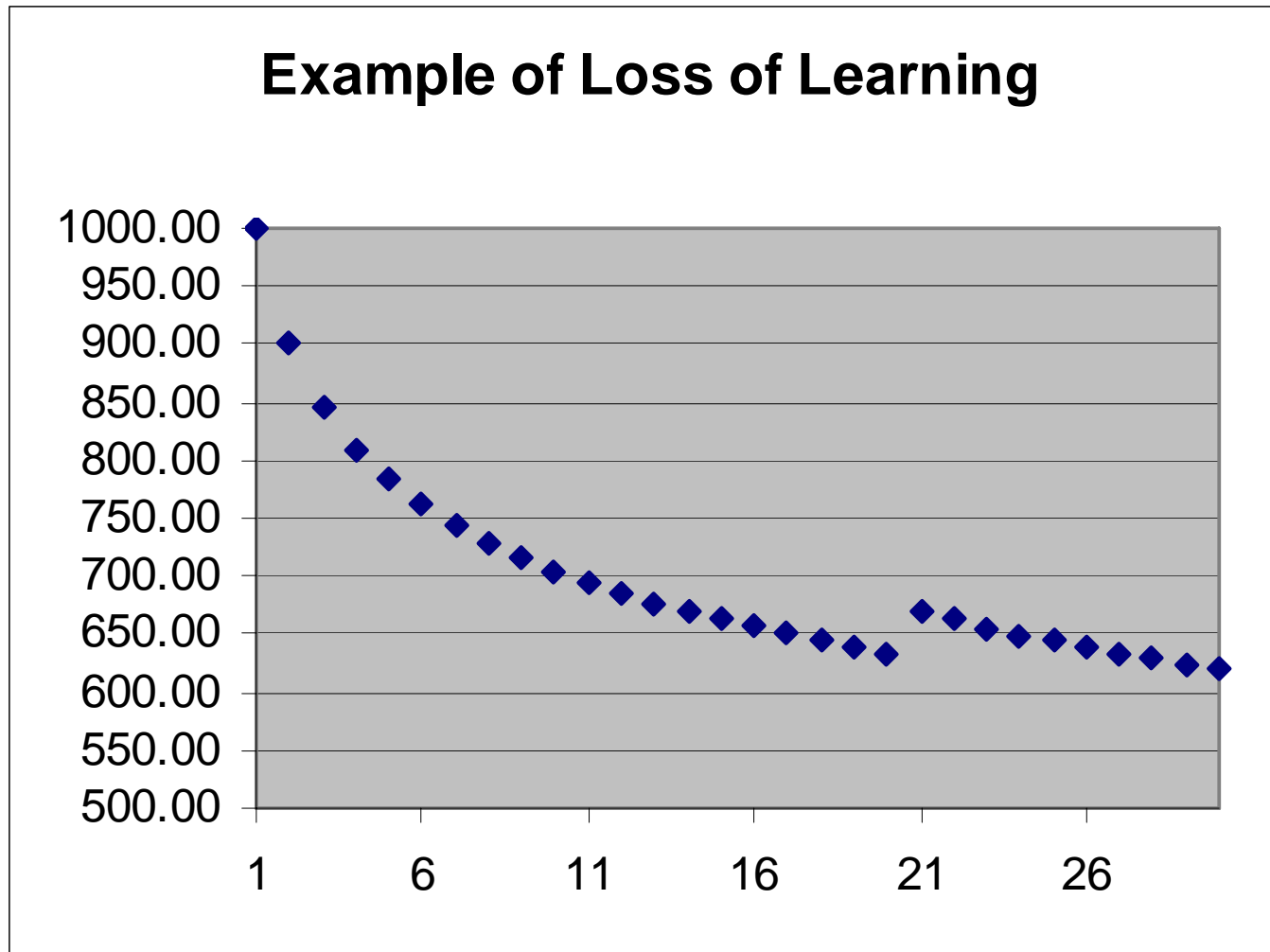
Unit Theory Anderlohr Method Example (cont)

Actual Unit Number	Pseudo Unit Number	Units Hours
1	N/A	1000
. . . . .	. . . . .	. . . . .
20	N/A	634.22
21	14.07114	669.04
22	15.07114	662.09
23	16.07144	655.66
24	17.07114	649.67
25	18.07114	644.07
26	19.07114	638.82
. . . . . .	. . . . .	. . . . .

Unit Theory Anderlohr Method Example (cont)

Example of Loss of Learning

Cumulative Average Theory Anderlohr Example

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- **The cumulative average theory replaces**

  $$H_q = H_1(q\text{\textasciicircum}B) \text{ with}$$

  $$H_q = H_1[q\text{\textasciicircum}(1+b) - (q-1)\text{\textasciicircum}(1+B)]$$

- **The calculation for k is messier. It requires an iterative solution of:**

  $$k = [\frac{H_k}{H_1} + (k-1)^{1+B}]^{1/1+B}$$

- **A good initial guess for k is the number of units in the predecessor lot divided by 2.**