

# **Handout for three day Learning Curve Workshop**

## **Treatment of Breaks in Production**

### **DAUMW**

*(Credits to Professors Steve Malashevitz, Bob Williams, and prior faculty. Blame to Dr. Roland Kankey, roland.kankey@dau.mil)*

#### **Introduction to Learning or Cost Improvement Curves**

The general learning curve theory is that people and organizations learn to do things better and more efficiently when performing repetitive tasks, and that under certain conditions there is a usable pattern to the learning

One of the conditions that allow the continuation of a learning curve pattern is continuity of production. This handout addresses a general method used to deal with a break in production. The flip side of much of the discussion in the “Unit and Cumulative Average” handout is that a break in production causes these gains in efficiency to be lost. If the break is long enough, you would virtually have to start over with new facilities, equipment, and personnel. Generally the break in production is not of that duration and ways have been developed to address the impact of such breaks.

#### **Production Breaks**

A topic of considerable interest in the cost estimating area has been how to handle the impact of a break in production when applying learning curve theory. Production breaks may occur due to program delays (budget or technical related), time elapsed between initial and spare or follow on orders, labor disputes, etc. The method of examining a production break can be divided into two questions:

1. How much of the learning achieved has been lost (forgotten) due to the break in production?

And

2. How will this learning lost impact the costs of future production items?

The analyst can answer the first question by using the Anderlohr Method for estimating the learning lost. The analyst can then determine the impact of the learning lost (Question 2) by using the Retrograde Method.

#### **Anderlohr Method**

When assessing the impact of a production break on costs, it is first necessary to quantify how much learning was achieved prior to the break and then quantify how much of that learning was lost due to the break. George Anderlohr, a former Defense Contract Administration Services

(DCAS) employee, first published an article in *Industrial Engineering* in 1969 in which he divided all learning lost, by an organization, due to a break in production, into five categories:

1. Personnel Learning: In this area, the physical loss of personnel, either through regular movement or layoff, must be determined. The company's personnel records can usually furnish evidence on which to establish this learning loss. The percentage of learning lost by the personnel retained on other plant projects must also be ascertained. These people will lose their physical dexterity and familiarity with the product and the momentum of repetition.

2. Supervisory Learning: Once again, a percentage of supervisory personnel will be lost as a result of regular movement. Management will make a greater effort to retain this higher caliber personnel, so the physical loss, in the majority of cases, will be far less than in the area of production personnel. However the supervisory personnel retained will lose the overall familiarity with the job so that the guidance they can furnish will be reduced. In addition, because of the loss of production personnel, the supervisor will have no knowledge, so necessary in effective supervision, of the new hires and their individual personalities and capabilities.

3. Continuity of Productivity: This relates to the physical positioning of the production line, the relationship of one work station to another, and the location of lighting, bins, parts, and tools within the work station. It also includes position adjustment to optimize the individual needs. In addition, a major factor affecting this area is the balance line or the work in process build-up. Of all the elements of learning, the greatest initial loss is suffered in this area.

4. Methods: This area is least affected by a production break. As long as method sheets are kept on file, learning can never be completely lost. However, drastic revisions to the method sheets may be required as a result of a change from soft to hard tooling.

5. Special Tooling: New and better tooling is a major contributor to learning. In relating loss in the tooling area, the major factors are wear, physical misplacement and breakage. An additional consideration must be the comparison of the short run or so called soft tooling to long run or hard tooling and the effect of the transition from soft to hard tooling.[4]

The definitions presented by Anderlohr have been modified and expanded, since 1969, to accommodate today's manufacturing environment. For example, some of today's modern factories operate in a "paperless environment" where method sheets are no longer used. However, these factories normally produce all of their shop instructions on computer files, these computer files sometimes have the same "ability" to get lost as their paper counterparts. Therefore the Methods portion of learning may deal with these computer files (i.e. lost files, changes to files due to new equipment, etc.).

According to Anderlohr, all (or 100%) of a companies learning can be placed into one of these categories. Each production situation must be examined and a weight assigned to each category, with the total of all weights equaling 100%. An example of these weights for a assembly of a particular Navy helicopter (XH-99) might look like:

<u>Category</u>	<u>Weight</u>
Personnel Learning	30%
Supervisory Learning	20%
Continuity of Production	20%
Tooling	15%
Methods	15%
<b>Total</b>	<b>100%</b>

To find the percentage of learning lost (known as the Learning Lost Factor or LLF) an estimator must find the learning lost in each category, and then calculate a weighted average based upon the above weights. Lets look at an example of how to apply the Anderlohr Method to find the amount of learning lost due to a production break.

### **Example**

A contractor who assembles XH-99 helicopters for a Naval contract experiences a six month break in production due to the delayed issuance of a follow-on production contract. The resident Defense Contract Management Command office (DCMC) conducted a survey of the contractor and provided the following information:

During the break in production, the contractor transferred many of his resources to commercial and other defense programs. As a result, the following can be expected when production resumes on the XH-99 program:

- 75% of the production personnel are expected to return to this program, the remaining 25% will be made up from new hires and transfers from other programs.
- 90% of the supervisors are expected to return to this program, the remaining 10% will be made up of recent promotes and transfers.
- during the break in production, two of the four assembly lines were torn down and converted to other uses. These lines will have to be reassembled for the follow-on contract.
- an inventory of the tools revealed that 5% of the tooling will have to be replaced due to loss, wear, and breakage
- during the break, the contractor upgraded some capital equipment on the assembly lines, due to this upgrade it is estimated that 7% of the shop instructions will need to be modified to account for this upgrade.
- the contractor estimates that during the break, the assembly worker lost 35% of their skill and dexterity, and that the supervisors lost 10% of the skills necessary for the program. DCMC concurs with this estimate based on past programs.

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**Category**

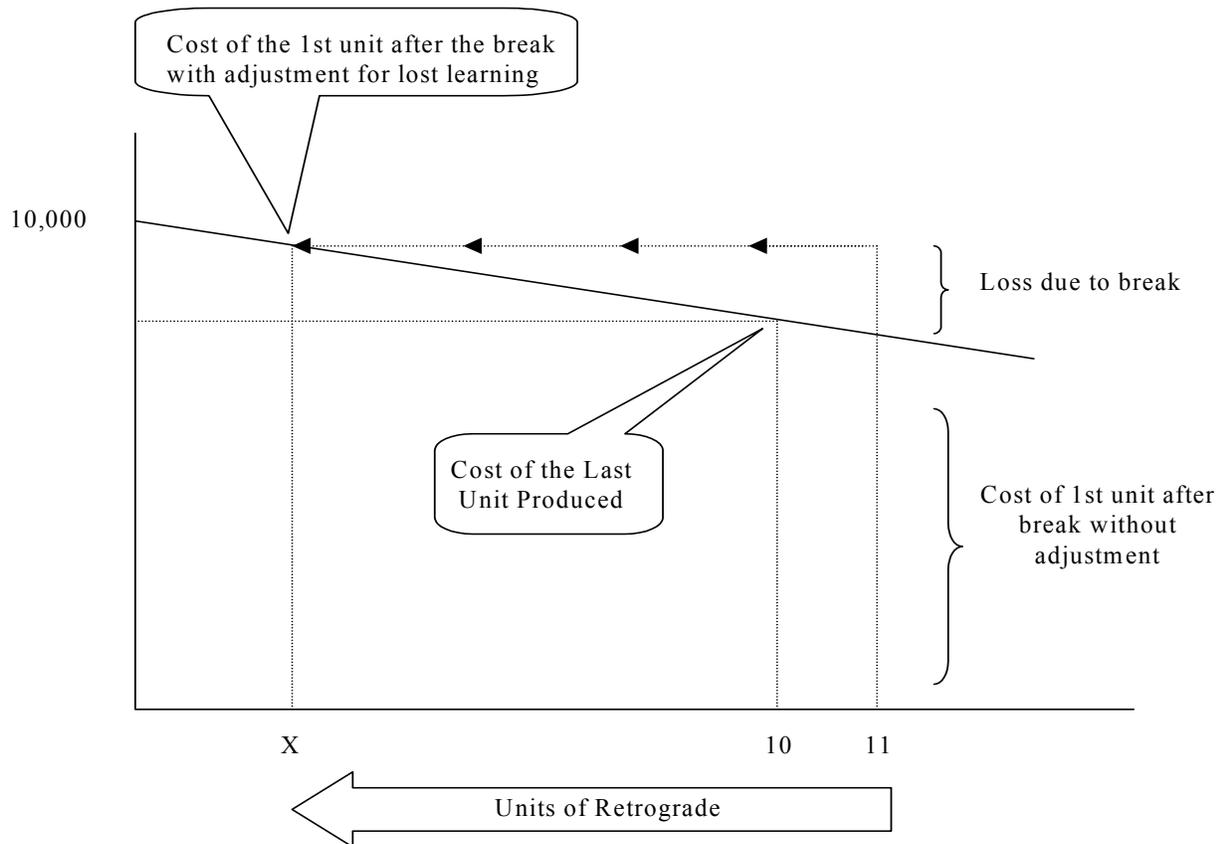
Personnel	75% returned x 65% skill retained =	48.75% learning retained	
		= 51.25% learning lost	
Supervisory	90% returned x 90% skill retained =	81% learning retained	
		= 19% learning lost	
Continuity of Production	2 of 4 assembly lines torn down =	50% learning lost	
Tooling	5% lost, worn, or broken =	5% learning lost	
Methods	7% of shop instructions need modification =	7% learning lost	

<u>Category</u>	<u>Weight</u>	<u>% lost</u>	<u>Weighted loss</u>
Personnel Learning	30%	51.25	.15375
Supervisory Learning	20%	19	.038
Continuity of Production	20%	50	.10
Tooling	15%	5	.0075
Methods	15%	7	.0105
<b>Total (LLF)</b>			.30975 $\cong$ 31.0%

Conclusion: As a result of the six month break in production, this contractor has lost 31.0% of the learning previously achieved on the XH-99 helicopter program.

Now that the Lost Learning Factor (LLF) has been estimated, we are going to apply this factor by a method described by Anderlohr in his paper known as the Retrograde Method.

**Retrograde Method**



The *true* cost of the first unit produced after the production break equals the cost of the 11<sup>th</sup> unit (assuming there had been no production break) plus the penalty due to the lost learning (31%). The retrograde method then has us back up the learning curve to the unit (X) where that cost occurred. The number of units we back up the curve are our units of retrograde or units of lost learning. We are essentially restarting production at unit “X” rather than unit 11. (See figure above)

In order to illustrate how to apply the Retrograde Method let's continue with the previous example.

Ten XH-99 helicopters were produced prior to the six month production break. The first helicopter required 10,000 man-hours to complete the assembly and the slope is estimated to be an 88% **unit curve**. Using the lost learning factor from the previous example, estimate the cost of the next 10 units which are to be produced in the next fiscal year.

**Step 1** - Find the amount of learning achieved to date.

In order to find the learning achieved (L.A.) we must subtract the cost of the last unit produced from the cost of the first unit. Since 10 units were produced before the break, our equation becomes:

$$L.A. = Y_1 - Y_{10}$$

$$L.A. = 10,000 - Y_{10}$$

where,  $Y_{10}$  is the cost of unit 10, and can be found using actual data or using the Unit Cost equation as follows:

$$Y_{10} = A(X)^b$$

$$Y_{10} = 10,000(10)^{-0.184425}$$

$$Y_{10} = 6539.97 \approx 6540$$

therefore,

$$L.A. = 10,000 - 6540 = 3460$$

**Step 2** - Estimate the number of hours of learning lost.

The number of hours of learning lost is found by applying the Learning Lost Factor to the learning achieved. In this case, we achieved 3460 hours of learning, but we lost 31% of that due to the break in production. So our hours of learning lost can be found by:

$$\text{Learning Lost} = LA * LLF$$

$$\text{Learning Lost} = 3460 * .31 = 1072.6$$

**Step 3** - Estimate the cost of the first unit after the break.

The cost of the first unit after the break in this case is unit 11. Its estimated cost can be found by adding the cost of unit 11 on the original curve to the hours of learning lost found in the previous step. We can denote the cost of unit 11 after the break as  $Y'_{11}$ .

And the equation for  $Y'_{11}$  can be written as;

$$Y'_{11} = Y_{11} + \text{Learning Lost}$$

where,

$$Y_{11} = AX^b$$

$$Y_{11} = (10,000)(11)^{-0.184425}$$

$$Y_{11} = 6426$$

therefore,

$$Y'_{11} = 6426 + 1072.6 = 7498.6$$

**Step 4** - Find the unit whose cost is equal to  $Y'_{11}$  .

Find the unit on the original curve that is approximately the same as the estimated cost of the unit after the break. This can be done using actual data, however since the actual data contains some random error, it is best to use the unit cost equation to solve for  $x$ . The unit cost equation:

$$Y_x = A(X)^b$$

can be rearranged to solve for  $x$  as:

$$X = \left( \frac{Y_x}{A} \right)^{\frac{1}{b}}$$

Substituting our numbers in, we get:

$$X = 4.76 \approx 5$$

**Step 5-** Find the number of units of retrograde (#).

The number of units of retrograde is how many units you need to back up the curve to reach the unit found in the previous step. In this example, since your estimated cost of unit 11 is approximately the same as unit 5 on the original curve you need to back up the curve 6 units to estimate the cost of unit 11 and all subsequent units. This can be described mathematically as:

$$\# = \text{first unit after the break} - X \text{ (from previous step)}$$

$$\# = 11 - 5 = 6$$

**Step 6** - Estimate any lot costs after the break.

This can be done by modifying our standard lot cost equation to:

$$TC_{F,L} = A \left[ \sum_{x=1}^{L-\#} x^b - \sum_{x=1}^{F-1-\#} x^b \right]$$

so for the next 10 units of production,

$$TC_{11,20} = 10,000 \left[ \sum_{x=1}^{20-6} x^b - \sum_{x=1}^{11-1-6} x^b \right]$$

$$TC_{11,20} = 10,000 \left[ \sum_{x=1}^{14} x^b - \sum_{x=1}^4 x^b \right]$$

88%		CUMULATIVE PROGRESS CURVE TABLE										88%
	0	1	2	3	4	5	6	7	8	9		
		1.000000	1.880000	2.696596	3.470996	4.214174	4.932778	5.631241	6.312713	6.979541		
1	7.633538	8.276139	8.908511	9.531616	10.146263	10.753139	11.352834	11.945862	12.532671	13.113658		
2	13.689175	14.259537	14.825026	15.385898	15.942385	16.494699	17.043031	17.587561	18.128450	18.665850		
3	19.199901	19.730732	20.258464	20.783210	21.305074	21.824156	22.340548	22.854337	23.365606	23.874431		
4	24.380886	24.885040	25.386958	25.886703	26.384333	26.879905	27.373473	27.865087	28.354796	28.842646		
5	29.328681	29.812945	30.295478	30.776319	31.255504	31.733072	32.209054	32.683486	33.156398	33.627822		

$$TC_{11,20} = 10,000[10.146263 - 3.470996]$$

$$TC_{11,20} = 66,752.67$$

Our estimated cost for the assembly of the next 10 helicopters is 66,752.67 man-hours.

**Conclusion**

The general learning curve theory is that people and organizations learn (become more efficient) when performing repetitive tasks. Under certain conditions there is a usable pattern to this learning. This pattern is perturbed when there is a break in production. Anderlohr proposed a logical approach for determining the amount of learning lost during a production break, and the retrograde method provides a logical methodology for estimating the cost of units or lots following the break. Other approaches have been proposed, including treating the learning lost as a simple addition to the product, and the consideration of accelerated learning after the break. The Anderlohr approach for learning lost coupled with the retrograde method seems to be a solid alternative for handling the costs of production breaks.