Quantitative Module **E**

Learning Curves

Module Outline

Learning Objectives

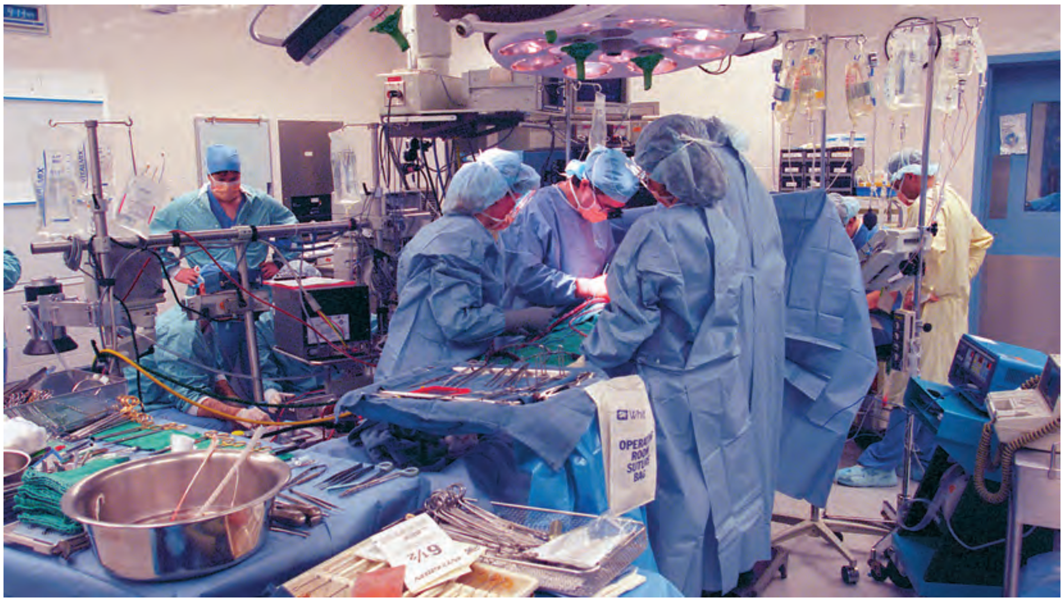
When you complete this module you should be able to

IDENTIFY OR DEFINE:

- What a learning curve is
- Example of learning curves
- The doubling concept

DESCRIBE OR EXPLAIN:

- How to compute learning curve effects
- Why learning curves are important
- The strategic implications of learning curves



Medical procedures such as heart surgery follow a learning curve. Research indicates that the death rate from heart transplants drops at a 79% learning curve, a learning rate not unlike that in many industrial settings. It appears that as doctors and medical teams improve with experience, so do your odds as a patient. If the death rate is halved every three operations, practice may indeed make perfect.

Most organizations learn and improve over time. As firms and employees perform a task over and over, they learn how to perform more efficiently. This means that task times and costs decrease.

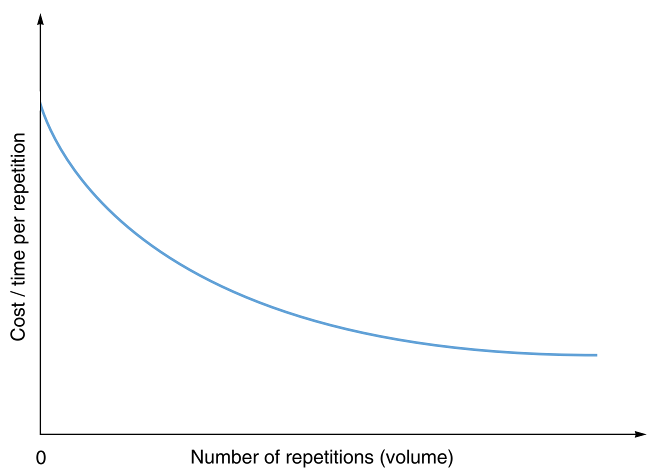
Learning curves The premise that people and organizations get better at their tasks as the tasks are repeated; sometimes called experience curves.

Learning curves are based on the premise that people and organizations become better at their tasks as the tasks are repeated. A learning curve graph (illustrated in Figure E.1) displays labor-hours per unit versus the number of units produced. From it we see that the time needed to produce a unit decreases, usually following a negative exponential curve, as the person or company produces more units. In other words, *it takes less time to complete each additional unit a firm produces*. However, we also see in Figure E.1 that the time *savings* in completing each subsequent unit *decreases*. These are the major attributes of the learning curve.

Learning curves were first applied to industry in a report by T. P. Wright of Curtis-Wright Corp. in 1936.[1] Wright described how direct labor costs of making a particular airplane decreased with learning, a theory since confirmed by other aircraft manufacturers. Regardless of the time needed to produce the first plane, learning curves are found to apply to various categories of air frames (e.g.,

FIGURE E.1 ■

The Learning-Curve Effect States That Time per Repetition Decreases as the Number of Repetitions Increases



[1]T. P. Wright, "Factors Affecting the Cost of Airplanes," *Journal of the Aeronautical Sciences* (February 1936).

jet fighters versus passenger planes versus bombers). Learning curves have since been applied not only to labor but also to a wide variety of other costs, including material and purchased components. The power of the learning curve is so significant that it plays a major role in many strategic decisions related to employment levels, costs, capacity, and pricing.

The learning curve is based on a *doubling* of production: That is, when production doubles, the decrease in time per unit affects the rate of the learning curve. So, if the learning curve is an 80% rate, the second unit takes 80% of the time of the first unit, the fourth unit takes 80% of the time of the second unit, the eighth unit takes 80% of the time of the fourth unit, and so forth. This principle is shown as

$$T \times L^n = \text{Time required for the } n\text{th unit} \tag{E-1}$$

where T = unit cost or unit time of the first unit
L = learning curve rate
n = number of times T is doubled

If the first unit of a particular product took 10 labor-hours, and if a 70% learning curve is present, the hours the fourth unit will take require doubling twice—from 1 to 2 to 4. Therefore, the formula is

$$\text{Hours required for unit 4} = 10 \times (.7)^2 = 4.9 \text{ hours}$$

LEARNING CURVES IN SERVICES AND MANUFACTURING

Try testing the learning-curve effect on some activity you may be performing. For example, if you need to assemble four bookshelves, time your work on each and note the rate of improvement.

Different organizations—indeed, different products—have different learning curves. The rate of learning varies depending on the quality of management and the potential of the process and product. *Any change in process, product, or personnel disrupts the learning curve*. Therefore, caution should be exercised in assuming that a learning curve is continuing and permanent.

As you can see in Table E.1, industry learning curves vary widely. The lower the number (say 70% compared to 90%), the steeper the slope and the faster the drop in costs. By tradition, learning curves are defined in terms of the *complements* of their improvement rates. For example, a 70% learning curve implies a 30% decrease in time each time the number of repetitions is doubled. A 90% curve means there is a corresponding 10% rate of improvement.

Stable, standardized products and processes tend to have costs that decline more steeply than others. Between 1920 and 1955, for instance, the steel industry was able to reduce labor-hours per unit to 79% each time cumulative production doubled.

Learning curves have application in services as well as industry. As was noted in the caption for the opening photograph, 1-year death rates of heart transplant patients at Temple University Hospital follow a 79% learning curve. The results of that hospital's 3-year study of 62 patients

TABLE E.1 ■ Examples of Learning-Curve Effects

Example	Improving Parameter	Cumulative Parameter	Learning-Curve Slope (%)
1. Model-T Ford production	Price	Units produced	86
2. Aircraft assembly	Direct labor-hours per unit	Units produced	80
3. Equipment maintenance at GE	Average time to replace a group of parts	Number of replacements	76
4. Steel production	Production worker labor-hours per unit produced	Units produced	79
5. Integrated circuits	Average price per unit	Units produced	72[a]
6. Hand-held calculator	Average factory selling price	Units produced	74
7. Disk memory drives	Average price per bit	Number of bits	76
8. Heart transplants	1-year death rates	Transplants completed	79

[a]Constant dollars.

Sources: James A. Cunningham, "Using the Learning Curve as a Management Tool," *IEEE Spectrum* (June 1980): 45. © 1980 IEEE; and David B. Smith and Jan L. Larsson, "The Impact of Learning on Cost: The Case of Heart Transplantation," *Hospital and Health Services Administration* (spring 1989): 85–97.

receiving transplants found that every three operations resulted in a halving of the 1-year death rate. As more hospitals face pressure from both insurance companies and the government to enter fixed-price negotiations for their services, their ability to learn from experience becomes increasingly critical. In addition to having applications in both services and industry, learning curves are useful for a variety of purposes. These include:

Failure to consider the effects of learning can lead to *overestimates* of labor needs and *underestimates* of material needs.

1. Internal: labor forecasting, scheduling, establishing costs and budgets.
2. External: supply-chain negotiations (see the SMT case study at the end of this module).
3. Strategic: evaluation of company and industry performance, including costs and pricing.

APPLYING THE LEARNING CURVE

A mathematical relationship enables us to express the time required to produce a certain unit. This relationship is a function of how many units have been produced before the unit in question and how long it took to produce them. Although this procedure determines how long it takes to produce a given unit, the consequences of this analysis are more far reaching. Costs drop and efficiency goes up for individual firms and the industry. Therefore, severe problems in scheduling occur if operations are not adjusted for implications of the learning curve. For instance, if learning-curve improvement is not considered when scheduling, the result may be labor and productive facilities being idle a portion of the time. Furthermore, firms may refuse additional work because they do not consider the improvement in their own efficiency that results from learning. From a supply-chain perspective, our interest is in negotiating what our suppliers' costs should be for further production of units based on the size of an order. The foregoing are only a few of the ramifications of the effect of learning curves.

Trade journals publish industrywide data on specific operations' learning rates.

With this in mind, let us look at three ways to approach the mathematics of learning curves: arithmetic analysis, logarithmic analysis, and learning-curve coefficients.

Arithmetic Approach

The arithmetic approach is the simplest approach to learning-curve problems. As we noted at the beginning of this module, each time that production doubles, labor per unit declines by a constant factor, known as the learning rate. So, if we know that the learning rate is 80% and that the first unit produced took 100 hours, the hours required to produce the second, fourth, eighth, and sixteenth units are as follows:

*N*TH UNIT PRODUCED	HOURS FOR *N*TH UNIT
1	100.0
2	$80.0 = (.8 \times 100)$
4	$64.0 = (.8 \times 80)$
8	$51.2 = (.8 \times 64)$
16	$41.0 = (.8 \times 51.2)$

As long as we wish to find the hours required to produce N units and N is one of the doubled values, then this approach works. Arithmetic analysis does not tell us how many hours will be needed to produce other units. For this flexibility, we must turn to the logarithmic approach.

TABLE E.2 ■ Learning Curve Values of b

LEARNING RATE (%)	b
70	−.515
75	−.415
80	−.322
85	−.234
90	−.152

Logarithmic Approach

The logarithmic approach allows us to determine labor for *any* unit, T_N, by the formula

$$T_N = T_1(N^b) \tag{E-2}$$

where T_N = time for the Nth unit
T_1 = hours to produce the first unit
b = (log of the learning rate)/(log 2) = slope of the learning curve

Some of the values for b are presented in Table E.2. Example E1 shows how this formula works.

Example E1

Using logs to compute learning curves

Excel OM Data File ModEExE1.xla

The learning rate for a particular operation is 80%, and the first unit of production took 100 hours. The hours required to produce the third unit may be computed as follows:

$$
\begin{aligned}
T_N &= T_1(N^b) \\
T_3 &= (100 \text{ hours})(3^b) \\
&= (100)(3^{\log .8/\log 2}) \\
&= (100)(3^{-.322}) = 70.2 \text{ labor-hours}
\end{aligned}
$$

The logarithmic approach allows us to determine the hours required for *any* unit produced, but there *is* a simpler method.

Learning-Curve Coefficient Approach

The learning-curve coefficient technique is embodied in Table E.3 and the following equation:

$$T_N = T_1 C \tag{E-3}$$

where T_N = number of labor-hours required to produce the Nth unit
T_1 = number of labor-hours required to produce the first unit
C = learning-curve coefficient found in Table E.3

The learning-curve coefficient, C, depends on both the learning rate (70%, 75%, 80%, and so on) and the unit of interest.

TABLE E.3 ■ Learning-Curve Coefficients, Where Coefficient, $C = N^{(\text{log of learning rate/log 2})}$

	70%		75%		80%		85%		90%	
Unit Number (N) Time	Unit Time	Total Time	Unit Time	Total Time	Unit Time	Total Time	Unit Time	Total Time	Unit Time	Total Time
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	.700	1.700	.750	1.750	.800	1.800	.850	1.850	.900	1.900
3	.568	2.268	.634	2.384	.702	2.502	.773	2.623	.846	2.746
4	.490	2.758	.562	2.946	.640	3.142	.723	3.345	.810	3.556
5	.437	3.195	.513	3.459	.596	3.738	.686	4.031	.783	4.339
6	.398	3.593	.475	3.934	.562	4.299	.657	4.688	.762	5.101
7	.367	3.960	.446	4.380	.534	4.834	.634	5.322	.744	5.845
8	.343	4.303	.422	4.802	.512	5.346	.614	5.936	.729	6.574
9	.323	4.626	.402	5.204	.493	5.839	.597	6.533	.716	7.290
10	.306	4.932	.385	5.589	.477	6.315	.583	7.116	.705	7.994
11	.291	5.223	.370	5.958	.462	6.777	.570	7.686	.695	8.689
12	.278	5.501	.357	6.315	.449	7.227	.558	8.244	.685	9.374
13	.267	5.769	.345	6.660	.438	7.665	.548	8.792	.677	10.052
14	.257	6.026	.334	6.994	.428	8.092	.539	9.331	.670	10.721
15	.248	6.274	.325	7.319	.418	8.511	.530	9.861	.663	11.384
16	.240	6.514	.316	7.635	.410	8.920	.522	10.383	.656	12.040
17	.233	6.747	.309	7.944	.402	9.322	.515	10.898	.650	12.690
18	.226	6.973	.301	8.245	.394	9.716	.508	11.405	.644	13.334
19	.220	7.192	.295	8.540	.388	10.104	.501	11.907	.639	13.974
20	.214	7.407	.288	8.828	.381	10.485	.495	12.402	.634	14.608
25	.191	8.404	.263	10.191	.355	12.309	.470	14.801	.613	17.713
30	.174	9.305	.244	11.446	.335	14.020	.450	17.091	.596	20.727
35	.160	10.133	.229	12.618	.318	15.643	.434	19.294	.583	23.666
40	.150	10.902	.216	13.723	.305	17.193	.421	21.425	.571	26.543
45	.141	11.625	.206	14.773	.294	18.684	.410	23.500	.561	29.366
50	.134	12.307	.197	15.776	.284	20.122	.400	25.513	.552	32.142

Example E2 uses the preceding equation and Table E.3 to calculate learning-curve effects.

Example E2

Using learning-curve coefficients

Excel OM Data File ModEExE2.xla

Active Model E.1

Examples E2 and E3 are further illustrated in Active Model E.1 on the CD-ROM and in the Exercise on page 780.

It took a Korean shipyard 125,000 labor-hours to produce the first of several tugboats that you expect to purchase for your shipping company, Great Lakes, Inc. Boats 2 and 3 have been produced by the Koreans with a learning factor of 85%. At $40 per hour, what should you, as purchasing agent, expect to pay for the fourth unit?

First, search Table E.3 for the fourth unit and a learning factor of 85%. The learning-curve coefficient, C, is .723. To produce the fourth unit, then, takes

$$T_N = T_1 C$$
$$T_4 = (125{,}000 \text{ hours})(.723)$$
$$= 90{,}375 \text{ hours}$$

To find the cost, multiply by $40:

$$90{,}375 \text{ hours} \times \$40 \text{ per hour} = \$3{,}615{,}000$$

Table E.3 also shows *cumulative values*. These allow us to compute the total number of hours needed to complete a specified number of units. Again, the computation is straightforward. Just multiply the table value times the time required for the first unit. Example E3 illustrates this concept.

Example E3

Using cumulative coefficients

Example E2 computed the time to complete the fourth tugboat that Great Lakes plans to buy. How long will *all four* boats require?

Looking this time at the "total time" column in Table E.3, we find that the cumulative coefficient is 3.345. Thus, the time required is

$$T_N = T_1 C$$
$$T_4 = (125{,}000)(3.345) = 418{,}125 \text{ hours in total for all 4 boats}$$

For an illustration of how Excel OM can be used to solve Examples E2 and E3, see Program E.1 at the end of this module.

Using Table E.3 requires that we know how long it takes to complete the first unit. Yet, what happens if our most recent or most reliable information available pertains to some other unit? The answer is that we must use these data to find a revised estimate for the first unit and then apply the table to that number. Example E4 illustrates this concept.

Example E4

Revising learning-curve estimates

Great Lakes, Inc., believes that unusual circumstances in producing the first boat (see Example E2) imply that the time estimate of 125,000 hours is not as valid a base as the time required to produce the third boat. Boat number 3 was completed in 100,000 hours.

To solve for the revised estimate for boat number 1, we return to Table E.3, with a unit value of $N = 3$ and a learning-curve coefficient of $C = .773$ in the 85% column. To find the revised estimate, we divide the actual time for boat number 3, 100,000 hours, by $C = .773$

$$\frac{100{,}000}{.773} = 129{,}366 \text{ hours}$$

So, 129,366 hours is the new (revised) estimate for boat 1.

STRATEGIC IMPLICATIONS OF LEARNING CURVES

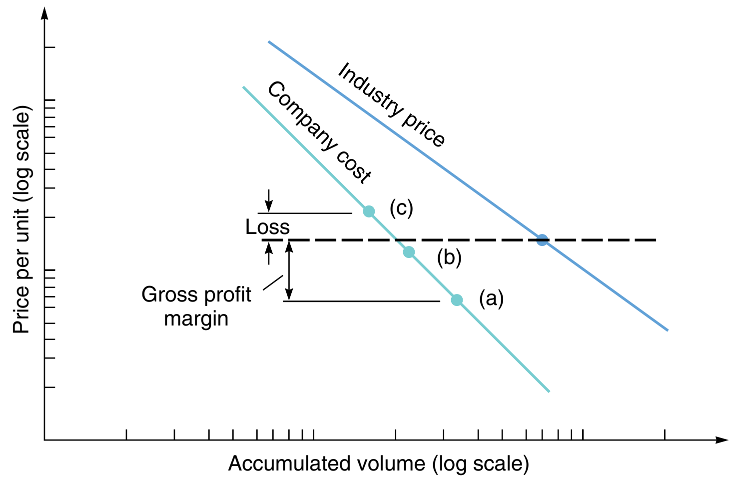
So far, we have shown how operations managers can forecast labor-hour requirements for a product. We have also shown how purchasing agents can determine a supplier's cost, knowledge that can help in price negotiations. Another important application of learning curves concerns strategic planning.

An example of a company cost line and industry price line are so labeled in Figure E.2. These learning curves are straight because both scales are log scales. When the *rate* of change is constant, a log-log graph yields a straight line. If an organization believes its cost line to be the "company cost" line, and the industry price is indicated by the dashed horizontal line, then the company must have costs at the points below the dotted line (for example, point *a* or *b*) or else operate at a loss (point *c*).

FIGURE E.2 ■

Industry Learning Curve for Price Compared with Company Learning Curve for Cost

Note: Both the vertical and horizontal axes of this figure are log scales. This is known as a log-log graph.



Applications of the learning curve:
1. Internal → determine labor standards and rates of material supply required.
2. External → determine purchase costs.
3. Strategic → determine volume-cost changes.

Lower costs are not automatic; they must be managed down. When a firm's strategy is to pursue a curve steeper than the industry average (the company cost line in Figure E.2), it does this by

1. Following an aggressive pricing policy.
2. Focusing on continuing cost reduction and productivity improvement.
3. Building on shared experience.
4. Keeping capacity growing ahead of demand.

Costs may drop as a firm pursues the learning curve, but volume must increase for the learning curve to exist. Moreover, managers must understand competitors before embarking on a learning-curve strategy. Weak competitors are undercapitalized, stuck with high costs, or do not understand the logic of learning curves. However, strong and dangerous competitors control their costs, have solid financial positions for the large investments needed, and have a track record of using an aggressive learning-curve strategy. Taking on such a competitor in a price war may help only the consumer.

LIMITATIONS OF LEARNING CURVES

Before using learning curves, some cautions are in order:

- Because learning curves differ from company to company, as well as industry to industry, estimates for each organization should be developed rather than applying someone else's.
- Learning curves are often based on the time necessary to complete the early units; therefore, those times must be accurate. As current information becomes available, reevaluation is appropriate.
- Any changes in personnel, design, or procedure can be expected to alter the learning curve, causing the curve to spike up for a short time, even if it is going to drop in the long run.
- While workers and process may improve, the same learning curves do not always apply to indirect labor and material.
- The culture of the workplace, as well as resource availability and changes in the process, may alter the learning curve. For instance, as a project nears its end, worker interest and effort may drop, curtailing progress down the curve.

SUMMARY

The learning curve is a powerful tool for the operations manager. This tool can assist operations managers in determining future cost standards for items produced as well as purchased. In addition, the learning curve can provide understanding about company and industry performance. We saw three approaches to learning curves: arithmetic analysis, logarithmic analysis, and learning-curve coefficients found in tables. Software can also help analyze learning curves.

KEY TERM

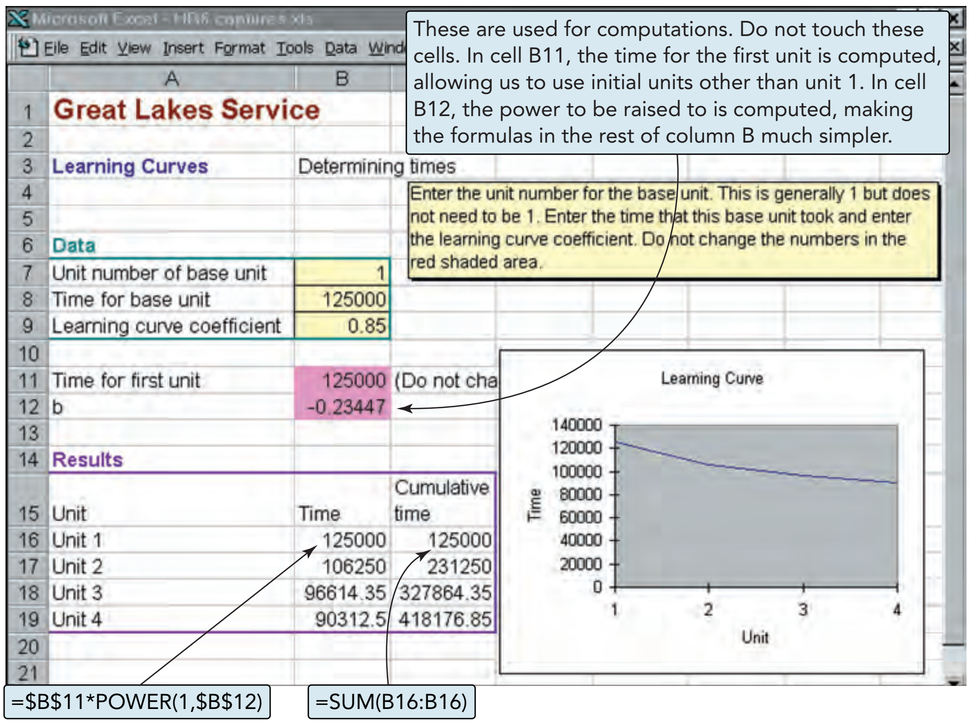
Learning curves *(p. 772)*

USING SOFTWARE FOR LEARNING CURVES

Excel, Excel OM, and POM for Windows may all be used in analyzing learning curves. You can use the ideas in the following section on Excel OM to build your own Excel spreadsheet if you wish.

Using Excel OM

Program E.1 shows how Excel OM develops a spreadsheet for learning-curve calculations. The input data come from Examples E2 and E3. In cell B7, we enter the unit number for the base unit (which does not have to be 1), and in B8 we enter the time for this unit.



PROGRAM E.1 ■ Excel OM's Learning-Curve Module, Using Data from Examples E2 and E3

Using POM for Windows

POM for Windows' Learning Curve module computes the length of time that future units will take, given the time required for the base unit and the learning rate (expressed as a number between 0 and 1). As an option, if the times required for the first and *N*th units are already known, the learning *rate* can be computed. See Appendix IV for further details.

SOLVED PROBLEMS

Solved Problem E.1

Digicomp produces a new telephone system with built-in TV screens. Its learning rate is 80%.

(a) If the first one took 56 hours, how long will it take Digicomp to make the eleventh system?

(b) How long will the first 11 systems take in total?

(c) As a purchasing agent, you expect to buy units 12 through 15 of the new phone system. What would be your expected cost for the units if Digicomp charges $30 for each labor-hour?

SOLUTION

from Table E.3—80% unit time

(a) $T_N = T_1 C$

T_{11} = (56 hours)(.462) = 25.9 hours

(b) Total time for the first 11 units = (56 hours)(6.777) = 379.5 hours

from Table E.3—80% total time

(c) To find the time for units 12 through 15, we take the total cumulative time for units 1 to 15 and subtract the total time for units 1 to 11, which was computed in part (b). Total time for the first 15 units = (56 hours)(8.511) = 476.6 hours. So, the time for units 12 through 15 is 476.6 − 379.5 = 97.1 hours. (This figure could also be confirmed by computing the times for units 12, 13, 14, and 15 separately using the unit-time column and then adding them.) Expected cost for units 12 through 15 = (97.1 hours) ($30 per hour) = $2,913.

Solved Problem E.2

If the first time you performed a job took 60 minutes, how long will the eighth job take if you are on an 80% learning curve?

SOLUTION

Three doublings from 1 to 2 to 4 to 8 implies $.8^3$. Therefore, we have

$$60 \times (.8)^3 = 60 \times .512 = 30.72 \text{ minutes}$$

or, using Table E.3, we have C = .512. Therefore:

$$60 \times .512 = 30.72 \text{ minutes}$$

INTERNET AND STUDENT CD-ROM EXERCISES

Visit our Companion Web site or use your student CD-ROM to help with material in this module.

On Our Companion Web site, www.prenhall.com/heizer

- Self-Study Quizzes
- Practice Problems
- Internet Exercises
- Internet Homework Problems

On Your Student CD-ROM

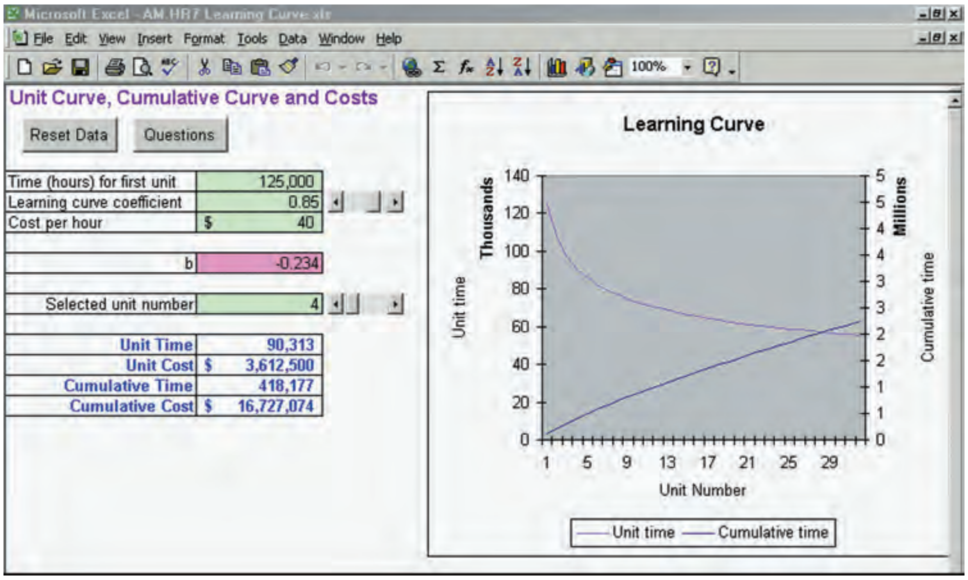
- PowerPoint Lecture
- Practice Problems
- Active Mode Exercises
- Excel OM
- Excel OM Example Data Files
- POM for Windows

DISCUSSION QUESTIONS

1. What are some of the limitations to the use of learning curves?
2. Identify three applications of the learning curve.
3. What are the approaches to solving learning-curve problems?
4. Refer to Example E2: What are the implications for Great Lakes, Inc., if the engineering department wants to change the engine in the third and subsequent tugboats that the firm purchases?
5. Why isn't the learning-curve concept as applicable in a high-volume assembly line as it is in most other human activities?
6. What are the elements that can disrupt the learning curve?
7. Explain the concept of the "doubling" effect in learning curves.
8. What techniques can a firm use to move to a steeper learning curve?

ACTIVE MODEL EXERCISE

This Active Model, found on your CD-ROM, allows you to evaluate important elements in the learning curve model described in Examples E2 and E3. You may change any input parameter in a green colored cell.



ACTIVE MODEL E.2 ■

Great Lakes, Inc. Learning Curve Analysis of Boats, Using Example E2 and E3 Data

Questions

1. If the learning is not as good as expected and rises to 90%, how much will the 4th boat cost?
2. What should the learning coefficient be to keep the total cost of the first 4 boats below $16,000,000?
3. How many boats need to be produced before the cost of an individual boat is below $4,000,000?
4. How many boats need to be produced before the *average* cost of each boat is below $4,000,000?

PROBLEMS*

• **E.1** Amand Heinl, an IRS auditor, took 45 minutes to process her first tax return. The IRS uses an 85% learning curve. How long will the
a) second return take?
b) fourth return take?
c) eighth return take?

• **E.2** Seton Hall Trucking Co. just hired Sally Kissel to verify daily invoices and accounts payable. She took 9 hours and 23 minutes to complete her task on the first day. Prior employees in this job have tended to follow a 90% learning curve. How long will the task take at the end of
a) the second day?
b) the fourth day?
c) the eighth day?
d) the sixteenth day?

• **E.3** If Professor Tacy Quinn takes 15 minutes to grade the first exam, and follows an 80% learning curve, how long will it take her
a) to grade the 25th exam?
b) to grade the first 10 exams?

Note:* **P means the problem may be solved with POM for Windows; means the problem may be solved with Excel OM; and **P** means the problem may be solved with POM for Windows and/or Excel OM.

• **E.4** If it took 563 minutes to complete a hospital's first cornea transplant, and the hospital uses a 90% learning rate, what is the cumulative time to complete

a) the first 3 transplants?
b) the first 6 transplants?
c) the first 8 transplants?
d) the first 16 transplants?

: **E.5** Beth Zion Hospital has received initial certification from the state of California to become a center for liver transplants. The hospital, however, must complete its first 18 transplants under great scrutiny and at no cost to the patients. The very first transplant, just completed, required 30 hours. On the basis of research at the hospital, Beth Zion estimates that it will have an 80% learning curve. Estimate the time it will take to complete

a) the fifth liver transplant.
b) all of the first 5 transplants.
c) the eighteenth transplant.
d) all 18 transplants.

: **E.6** Refer to Problem E.5. Beth Zion Hospital has just been informed that only the first 10 transplants must be performed at the hospital's expense. The cost per hour of surgery is estimated to be $5,000. Again, the learning rate is 80% and the first surgery took 30 hours.

a) How long will the tenth surgery take?
b) How much will the tenth surgery cost?
c) How much will all 10 cost the hospital?

• **E.7** Manceville Air has just produced the first unit of a large industrial compressor that incorporated new technology in the control circuits and a new internal venting system. The first unit took 112 hours of labor to manufacture. The company knows from past experience that this labor content will decrease significantly as more units are produced. In reviewing past production data, it appears that the company has experienced a 90% learning curve when producing similar designs. The company is interested in estimating the total time to complete the next 7 units. Your job as the production cost estimator is to prepare the estimate.

• **E.8** Candice Cotton, a student at San Diego State University, bought six bookcases for her dorm room. Each required unpacking of parts and assembly, which included some nailing and bolting. Candice completed the first bookcase in 5 hours and the second in 4 hours.

a) What is her learning rate?
b) Assuming the same rate continues, how long will the third bookcase take?
c) The fourth, fifth, and sixth cases?
d) All six cases?

: **E.9** Professor Mary Beth Marrs took 6 hours to prepare the first lecture in a new course. Traditionally, she has experienced a 90% learning factor. How much time should it take her to prepare the fifteenth lecture?

• **E.10** The first vending machine that M. D'Allessandro, Inc., assembled took 80 labor-hours. Estimate how long the fourth machine will require for each of the following learning rates:

a) 95%
b) 87%
c) 72%

• **E.11** Kara-Smith Systems is installing networks for Advantage Insurance. The first installation took 46 labor-hours to complete. Estimate how long the fourth and the eighth installations will take for each of the following learning rates:

a) 92%
b) 84%
c) 77%

⁝ **E.12** Baltimore Assessment Center screens and trains employees for a computer assembly firm in Towson, Maryland. The progress of all trainees is tracked and those not showing the proper progress are moved to less demanding programs. By the tenth repetition trainees must be able to complete the assembly task in 1 hour or less. Torri Olson-Alves has just spent 5 hours on the fourth unit and 4 hours completing her eighth unit, while another trainee, Julie Burgmeier, took 4 hours on the third and 3 hours on the sixth unit. Should you encourage either or both of the trainees to continue? Why?

: **E.13** The better students at Baltimore Assessment Center (see Problem E.12) have an 80% learning curve and can do a task in 20 minutes after just six times. You would like to weed out the weak students sooner and decide to evaluate them after the third unit. How long should the third unit take?

E.14 Collette Siever, the purchasing agent for Northeast Airlines, is interested in determining what she can expect to pay for airplane number 4 if the third plane took 20,000 hours to produce. What would Siever expect to pay for plane number 5? Number 6? Use an 85% learning curve and a $40-per-hour labor charge.

E.15 Using the data from Problem E.14, how long will it take to complete the twelfth plane? The fifteenth plane? How long will it take to complete planes 12 through 15 inclusive? At $40 per hour, what can Davis, as purchasing agent, expect to pay for all 4 planes?

E.16 Dynamic RAM Corp. produces semiconductors and has a learning curve of .7. The price per bit is 100 millicents when the volume is $.7 \times 10^{12}$ bits. What is the expected price at 1.4×10^{12} bits? What is the expected price at 89.6×10^{12} bits?

E.17 Central Power owns 25 small power generating plants. It has contracted with Genco Services to overhaul the power turbines of each of the plants. The number of hours that Genco billed Central to complete the third turbine was 460. Central pays Genco $60 per hour for its services. As the maintenance manager for Central, you are trying to estimate the cost of overhauling the fourth turbine. How much would you expect to pay for the overhaul of number 5 and number 6? All the turbines are similar and an 80% learning curve is appropriate.

E.18 It takes 28,718 hours to produce the eighth locomotive at a large French manufacturing firm. If the learning factor is 80%, how long does it take to produce the tenth locomotive?

E.19 Eric Krassow's firm is about to bid on a new radar system. Although the product uses new technology, Krassow believes that a learning rate of 75% is appropriate. The first unit is expected to take 700 hours, and the contract is for 40 units.

a) What is the total amount of hours to build the 40 units?
b) What is the average time to build each of the 40 units?
c) Assume that a worker works 2,080 hours per year. How many workers should be assigned to this contract to complete it in a year?

E.20 As the estimator for Peter Ancona Enterprises, your job is to prepare an estimate for a potential customer service contract. The contract is for the service of diesel locomotive cylinder heads. The shop has done some of these in the past on a sporadic basis. The time required to service each cylinder head has been exactly 4 hours, and similar work has been accomplished at an 85% learning curve. The customer wants you to quote in batches of 12 and 20.

a) Prepare the quote.
b) After preparing the quote, you find a labor ticket for this customer for five locomotive cylinder heads. From the notations on the labor ticket, you conclude that the fifth unit took 2.5 hours. What do you conclude about the learning curve and your quote?

E.21 Sara Bredbenner and Blake DeYoung are teammates at a discount store; their new job is assembling swing sets for customers. Assembly of a swing set has a learning rate of 90%. They forgot to time their effort on the first swing set, but spent 4 hours on the second set. They have six more sets to do. Determine approximately how much time will be (was) required for

a) the first unit.
b) the eighth unit.
c) all eight units.

E.22 Kelly-Lambing, Inc., a builder of government-contracted small ships, has a steady work force of 10 very skilled craftspeople. These workers can supply 2,500 labor-hours each per year. Kelly-Lambing is about to undertake a new contract, building a new style of boat. The first boat is expected to take 6,000 hours to complete. The firm thinks that 90% is the expected learning rate.

a) What is the firm's "capacity" to make these boats—that is, how many units can the firm make in 1 year?
b) If the operations manager can increase the learning rate to 85% instead of 90%, how many units can the firm make?

E.23 Fargo Production has contracted with Johnson Services to overhaul the 25 robots at its plant. All the robots are similar and an 80% learning curve is appropriate. The number of hours that Johnson billed Fargo to complete the third robot overhaul was 460. Fargo pays $60 per hour for its services. Fargo wants to estimate the following:

a) How many hours will it take to overhaul the 13th robot?
b) The fifteenth robot?
c) How long will it take to complete robots 10 through 15 inclusive?
d) As the person who manages the costs for overhauling all equipment, what is your estimate of the cost of the entire contract for overhauling all 25 robots?

E.24 You are considering building a plane for training pilots. You believe there is a market for 50 of these planes, which will have a top speed of 400 kn and an empty weight of 10,000 lb. You will need one test plane. Use the NASA Web site (**www.jsc.nasa.gov/bu2/airframe.html**) to determine the total cost and engineering cost of building all 50 planes.

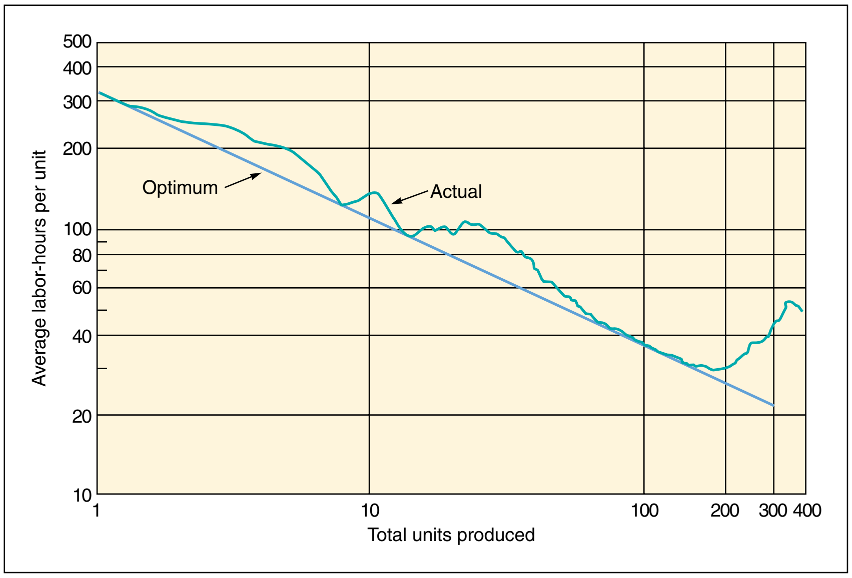
E.25 Using the accompanying log-log graph, answer the following questions:

a) What are the implications for management if it has forecast its cost on the optimum line?

b) What could be causing the fluctuations above the optimum line?

c) If management forecast the tenth unit on the optimum line, what was that forecast in hours?

d) If management built the tenth unit as indicated by the actual line, how many hours did it take?



INTERNET HOMEWORK PROBLEMS

See our Companion Web site at **www.prenhall.com/heizer** for these additional homework problems: E.26 through E.33.

CASE STUDY

SMT's Negotiation with IBM

SMT and one other, much larger company were asked by IBM to bid on 80 more units of a particular computer product. The RFQ (request for quote) asked that the overall bid be broken down to show the hourly rate, the parts and materials component in the price, and any charges for subcontracted services. SMT quoted $1.62 million and supplied the cost breakdown as requested. The second company submitted only one total figure, $5 million, with no cost breakdown. The decision was made to negotiate with SMT.

The IBM negotiating team included two purchasing managers and two cost engineers. One cost engineer had developed manufacturing cost estimates for every component, working from engineering drawings and cost-data books that he had built up from previous experience and that contained time factors, both setup and run times, for a large variety of operations. He estimated materials costs by working both from data supplied by the IBM corporate purchasing staff and from purchasing journals. He visited SMT facilities to see the tooling available so that he would know what processes were being used. He assumed that there would be perfect conditions and trained operators, and he developed cost estimates for the 158th unit (previous orders were for 25, 15, and 38 units). He added 5% for scrap-and-flow loss; 2% for the use of temporary tools, jigs, and fixtures; 5% for quality control; and 9% for purchasing burden. Then, using an 85% learning curve, he backed up his costs to get an estimate for the first unit. He next checked the data on hours and materials for the 25, 15, and 38 units already made and found that his estimate for the first unit was within 4% of actual cost. His check, however, had indicated a 90% learning-curve effect on hours per unit.

In the negotiations, SMT was represented by one of the two owners of the business, two engineers, and one cost estimator. The sessions opened with a discussion of learning curves. The IBM cost estimator demonstrated that SMT had in fact been operating on a 90% learning curve. But, he argued, it should be possible to move to an 85% curve, given the longer runs, reduced setup time, and increased continuity of workers on the job that would be possible with an order for 80 units. The owner agreed with this analysis and was willing to reduce his price by 4%.

However, as each operation in the manufacturing process was discussed, it became clear that some IBM cost estimates were too low because certain crating and shipping expenses had been overlooked. These oversights were minor, however, and in the following discussions, the two parties arrived at a common understanding of specifications and reached agreements on the costs of each manufacturing operation.

(continued)

At this point, SMT representatives expressed great concern about the possibility of inflation in material costs. The IBM negotiators volunteered to include a form of price escalation in the contract, as previously agreed among themselves. IBM representatives suggested that if overall material costs changed by more than 10%, the price could be adjusted accordingly. However, if one party took the initiative to have the price revised, the other could require an analysis of *all* parts and materials invoices in arriving at the new price.

Another concern of the SMT representatives was that a large amount of overtime and subcontracting would be required to meet IBM's specified delivery schedule. IBM negotiators thought that a relaxation in the delivery schedule might be possible if a price concession could be obtained. In response, the SMT team offered a 5% discount, and this was accepted. As a result of these negotiations, the SMT price was reduced almost 20% below its original bid price.

In a subsequent meeting called to negotiate the prices of certain pipes to be used in the system, it became apparent to an IBM cost estimator that SMT representatives had seriously underestimated their costs. He pointed out this apparent error because he could not understand why SMT had quoted such a low figure. He wanted to be sure that SMT was using the correct manufacturing process. In any case, if SMT estimators had made a mistake, it should be noted. It was IBM's policy to seek a fair price both for itself and for its suppliers. IBM procurement managers believed that if a vendor was losing money on a job, there would be a tendency to cut corners. In addition, the IBM negotiator felt that by pointing out the error, he generated some goodwill that would help in future sessions.

Discussion Questions

1. What are the advantages and disadvantages to IBM and SMT from this approach?
2. How does SMT's proposed learning rate compare with that of other companies?
3. What are the limitations of the learning curve in this case?

Source: Adapted from E. Raymond Corey, *Procurement Management: Strategy, Organization, and Decision Making* (New York: Van Nostrand Reinhold).

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INTERNET RESOURCES

Bailey, Charles (University of Central Florida):
www.bus.ucf.edu/bailey

NASA:
www.jsc.nasa.gov/bu2/learn.html

Production technology, Tampa, Florida:
www.protech-ie.com/software.htm