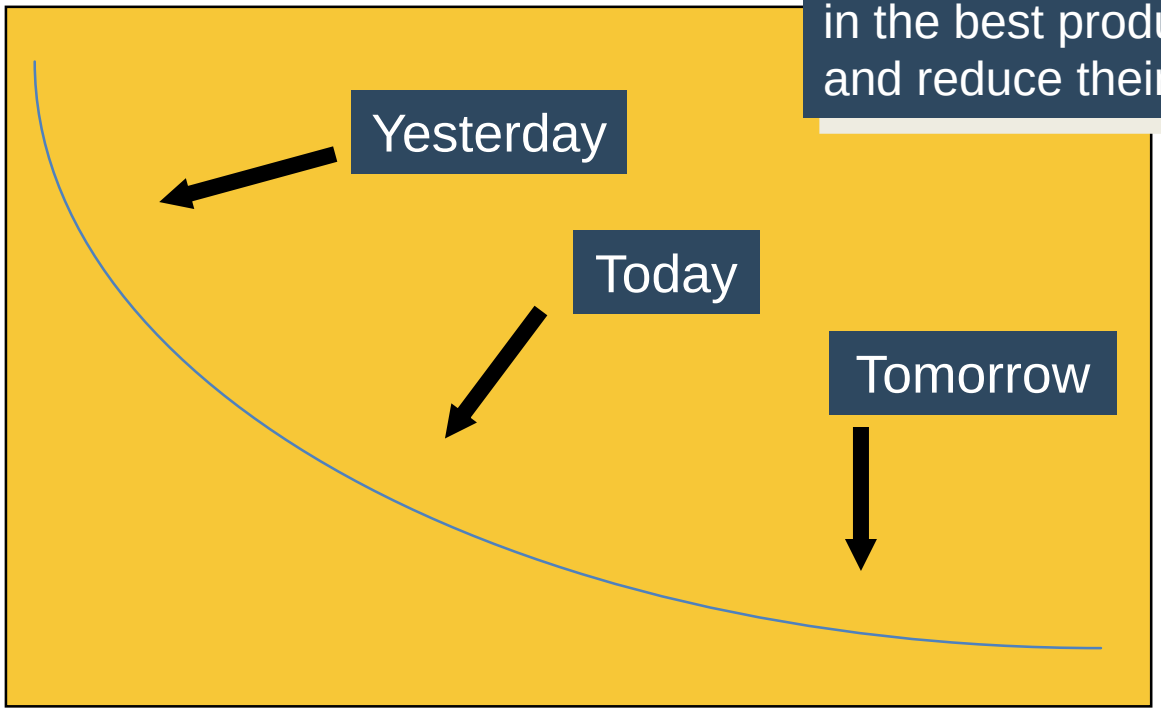
生產與作業管理

” Chapter 4A: LEARNING CURVES

The Experience Curve

As plants produce more products, they gain experience in the best production methods and reduce their costs per unit

Cost or price per unit



Total accumulated production of units

學習曲線__基本介紹

- 學習曲線理論的基本概念是在1936年由經濟學家Wright在飛機製造時所確定
- 產品每翻新一次，每架飛機的成本便有一定程度的下降
- 愈是經常地執行一項任務，每次所需的時間就越少

Application of Learning Curves

- A line displaying the relationship between unit production time and the cumulative number of units produced
- Wide range of applications
- Can be used to estimate time and cost
- One of the trade-offs in JIT

Types of Learning

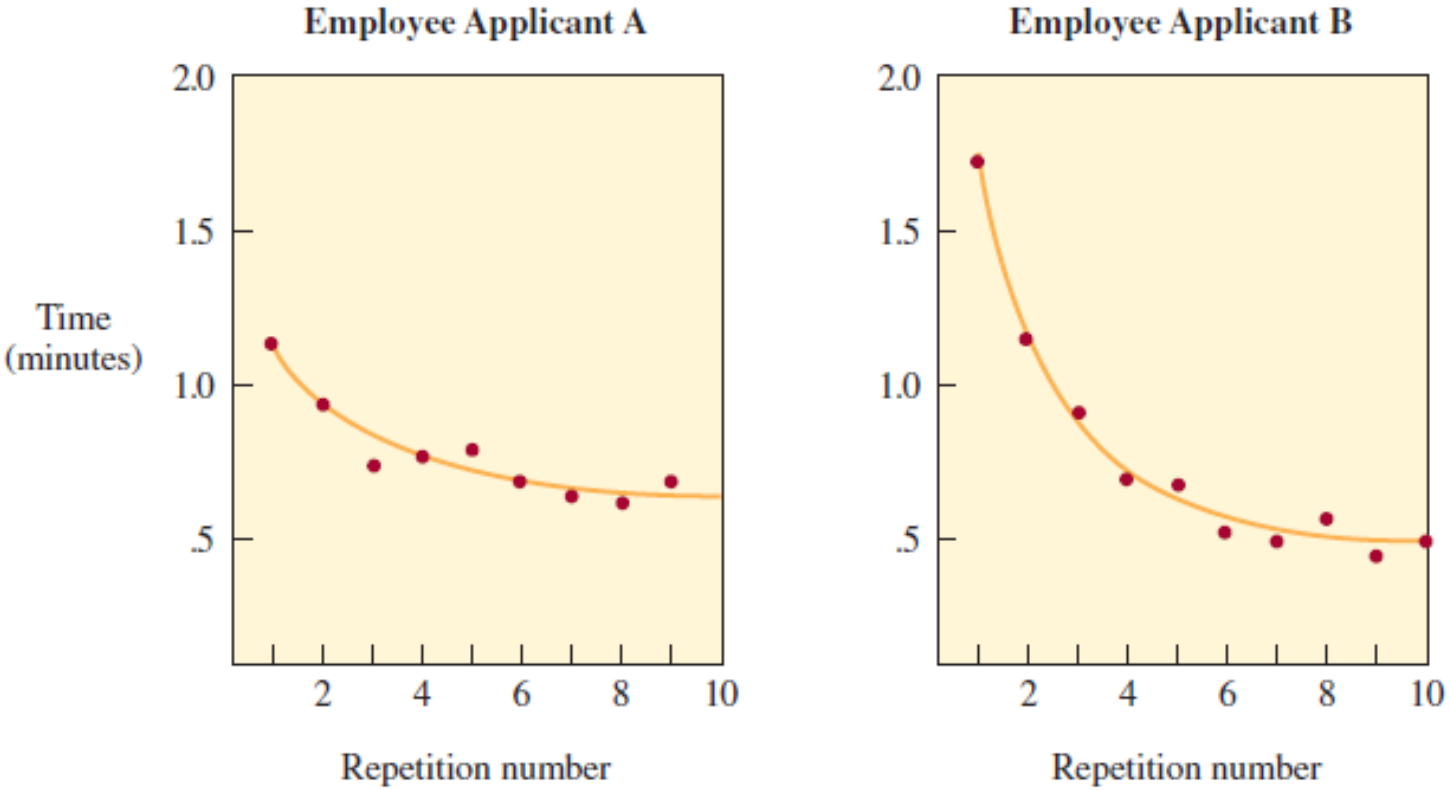
1. **Individual learning**: improvement that results when people repeat a process and gain skill or efficiency from their own experience
   - Practice makes perfect
2. **Organizational learning**: also comes from changes in administration, equipment, and product design

Expect to see both simultaneously

Individual Learning

1. Proper selection of workers
2. Proper training
3. Motivation
4. Work specialization
5. Do one or very few jobs at a time
6. Use tools that support performance
7. Provide quick and easy access for help
8. Allow workers to help redesign tasks

An Example Involving Two Job Applicants



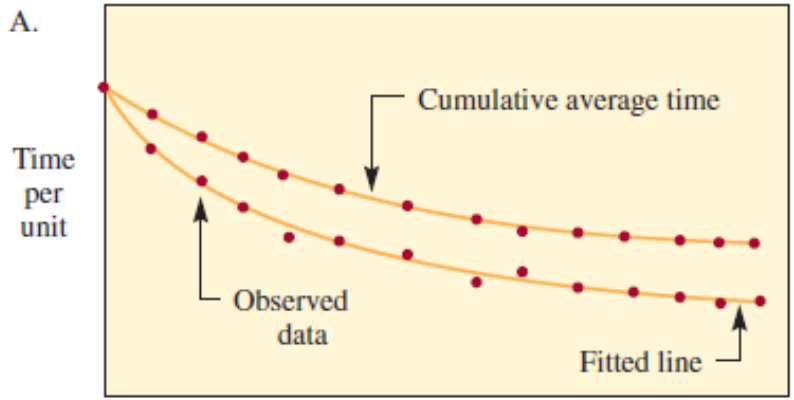
Organizational Learning

- Organizations learn as well.
  - A main source is individual learning.
- An organization also acquires knowledge in its technology, its structure, documents it retains, and standard operating procedures.
- Knowledge can also be embedded in the organizational structure.
- Knowledge can depreciate if individuals leave the organization.
- Knowledge can depreciate if technologies become inaccessible or difficult to use.

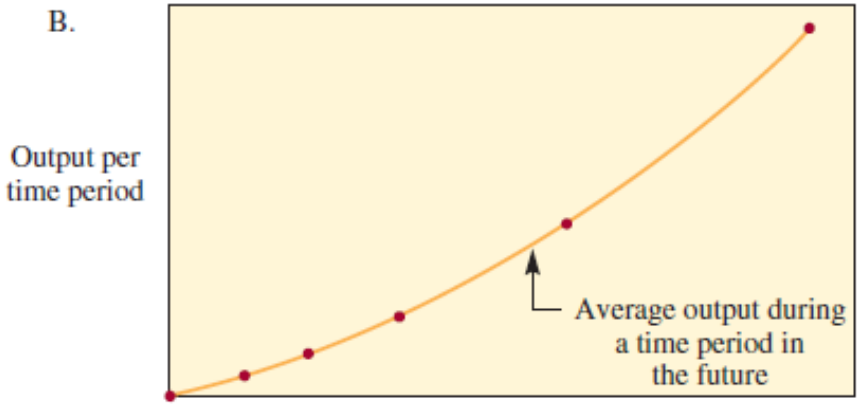
Learning Curve Assumptions

1. The amount of time required to complete a given task or unit of a product will be less each time the task is undertaken.
2. The unit time will decrease at a decreasing rate.
3. The reduction in time will follow a predictable pattern.

Learning Curves Plotted as Times and Numbers of Units



A Progress Curve



Industrial Learning

How are learning curves modeled?

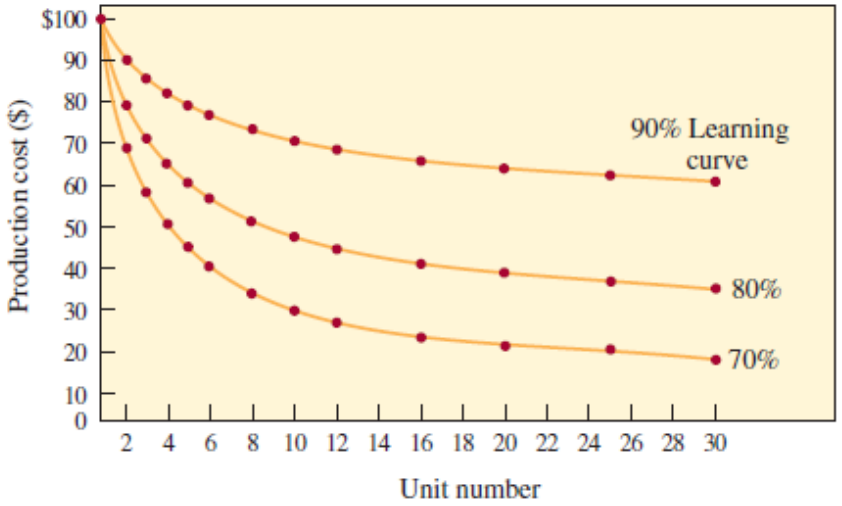
- To analyze past data to fit a useful trend line
- In practice, learning curves are plotted using a graph with logarithmic scales.
- The unit curves become linear throughout their entire range.
- The cumulative curve becomes linear after the first few unit.
- Direct logarithmic analysis is more efficient because it does not require a complete enumeration of successive time–output combinations.

Data for an 80 Percent Learning Curve

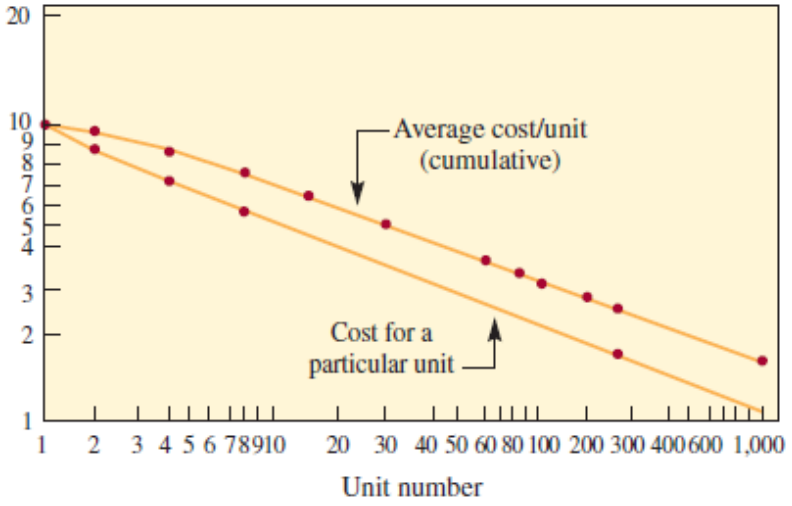
(1) UNIT NUMBER	(2) UNIT DIRECT LABOR HOURS	(3) CUMULATIVE DIRECT LABOR HOURS	(4) CUMULATIVE AVERAGE DIRECT LABOR HOURS
1	100,000	100,000	100,000
2	80,000	180,000	90,000
4	64,000	314,210	78,553
8	51,200	534,591	66,824
16	40,960	892,014	55,751
32	32,768	1,467,862	45,871
64	26,214	2,392,447	37,382
128	20,972	3,874,384	30,269
256	16,777	6,247,572	24,405

Resulting Learning Curve Plots

A. Arithmetic Plot of 70, 80, and 90 Percent Learning Curves



B. Logarithmic Plot of an 80 Percent Learning Curve



Logarithmic Analysis

$$Y_x = Kx^n$$

$$x = Unit\ number$$

$$Y_x = Number\ of\ direct\ labor\ hours\ required\ to\ produce\ the\ x^{th}\ unit$$

$$K = Number\ of\ direct\ labor\ hours\ required\ to\ produce\ the\ first\ unit$$

$$n = \frac{\log b}{\log 2} \quad \Rightarrow \log_2 b$$

$$b = Learning\ percentage$$

Example

- First unit takes 100,000 hours
- 80 percent learning curve
- Find hours for eighth unit

$$Y_8 = (100{,}000)(8)^n$$

$$Y_8 = 100{,}000(8)^{\log 0.8/\log 2}$$

$$= 100{,}000(8)^{-0.322} = \frac{100{,}000}{(8)^{0.322}}$$

$$= \frac{100{,}000}{1.9535} = 51{,}192$$

Improvement Curves: Table of Unit Values

Unit Improvement Factor								
Unit	60%	65%	70%	75%	80%	85%	90%	95%
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	.6000	.6500	.7000	.7500	.8000	.8500	.9000	.9500
3	.4450	.5052	.5682	.6338	.7021	.7729	.8462	.9219
4	.3600	.4225	.4900	.5625	.6400	.7225	.8100	.9025
5	.3054	.3678	.4368	.5127	.5956	.6857	.7830	.8877
6	.2670	.3284	.3977	.4754	.5617	.6570	.7616	.8758
7	.2383	.2984	.3674	.4459	.5345	.6337	.7439	.8659
8	.2160	.2746	.3430	.4219	.5120	.6141	.7290	.8574
9	.1980	.2552	.3228	.4017	.4930	.5974	.7161	.8499
10	.1832	.2391	.3058	.3846	.4765	.5828	.7047	.8433
12	.1602	.2135	.2784	.3565	.4493	.5584	.6854	.8320
14	.1430	.1940	.2572	.3344	.4276	.5386	.6696	.8226
16	.1290	.1785	.2401	.3164	.4096	.5220	.6561	.8145
18	.1188	.1659	.2260	.3013	.3944	.5078	.6445	.8074
20	.1099	.1554	.2141	.2884	.3812	.4954	.6342	.8012
22	.1025	.1465	.2038	.2772	.3697	.4844	.6251	.7955
24	.0961	.1387	.1949	.2674	.3595	.4747	.6169	.7904
25	.0933	.1353	.1908	.2629	.3548	.4701	.6131	.7880
30	.0815	.1208	.1737	.2437	.3346	.4505	.5963	.7775
35	.0728	.1097	.1605	.2286	.3184	.4345	.5825	.7687
40	.0660	.1010	.1498	.2163	.3050	.4211	.5708	.7611

Improvement Curves: Table of Cumulative Values

Cumulative Improvement Factor								
Unit	60%	65%	70%	75%	80%	85%	90%	95%
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.600	1.650	1.700	1.750	1.800	1.850	1.900	1.950
3	2.045	2.155	2.268	2.384	2.502	2.623	2.746	2.872
4	2.405	2.578	2.758	2.946	3.142	3.345	3.556	3.774
5	2.710	2.946	3.195	3.459	3.738	4.031	4.339	4.662
6	2.977	3.274	3.593	3.934	4.299	4.688	5.101	5.538
7	3.216	3.572	3.960	4.380	4.834	5.322	5.845	6.404
8	3.432	3.847	4.303	4.802	5.346	5.936	6.574	7.261
9	3.630	4.102	4.626	5.204	5.839	6.533	7.290	8.111
10	3.813	4.341	4.931	5.589	6.315	7.116	7.994	8.955
12	4.144	4.780	5.501	6.315	7.227	8.244	9.374	10.62
14	4.438	5.177	6.026	6.994	8.092	9.331	10.72	12.27
16	4.704	5.541	6.514	7.635	8.920	10.38	12.04	13.91
18	4.946	5.879	6.972	8.245	9.716	11.41	13.33	15.52

Example 4.1: The Data

- Contract for 11 boats, has completed 4 of them.
- Production manager has been reassigning people to torpedo assembly.
- The first boat required 225 workers, each working a 40-hour week, while 45 fewer workers were required for the second boat.
- Manager has told them that “this is just the beginning” and he will complete the last boat with only 100 workers!

Example: The Solution

- 180 / 225 = 0.80
- Look up unit 11 for an 80 percent improvement ratio in Exhibit 6.4 approximately equal to the average of .4765 (corresponding to 10) and .4493 (corresponding to 12)
  - 0.4629
- 0.4269 x 225 = 104

Example 4.2: The Data

- SUB Company has produced the first unit of a new line of mini-subs at a cost of $500,000.
  - $200,000 for materials and $300,000 for labor
- It has agreed to accept a 10 percent profit and is willing to contract on the basis of a 70 percent learning curve.
- What will be the contract price for three mini-subs?

Example 4.2: The Solution

Cost of first sub		$ 500,000
Cost of second sub		
Materials	$200,000	
Labor: $300,000 × .70	210,000	410,000
Cost of third sub		
Materials	200,000	
Labor: $300,000 × .5682	170,460	370,460
Total cost		1,280,460
Markup: $1,280,460 × .10		128,046
Selling price		$1,408,506

Estimating the Learning Percentage

- If production has been under way for some time, the learning percentage is easily obtained from production records.
- The longer the production history, the more accurate the estimate.

Estimating the Learning Percentage

- **If production has not started …**

1. Previous applications within the same industry.
2. Same or similar products.
3. analyze the similarities and differences between the proposed start-up and previous start-ups and develop a revised learning percentage that appears to best fit the situation.

Solution & HW